ANA 99

"THIRD CONFERENCE ON NUCLEAR SCIENCE & ENGINEERING IN AUSTRALIA"

RYDGES CANBERRA HOTEL
CANBERRA, ACT, AUSTRALIA
27 - 28 OCTOBER 1999

CONFERENCE HANDBOOK

THEME: "A NUCLEAR RENAISSANCE"

ANA

HOSTED BY THE
AUSTRALIAN NUCLEAR ASSOCIATION INC.

ISBN 0 949188 12 3

ANA 99

"THIRD CONFERENCE ON NUCLEAR SCIENCE & ENGINEERING IN AUSTRALIA"

RYDGES CANBERRA HOTEL
CANBERRA, ACT, AUSTRALIA
27 - 28 OCTOBER 1999

CONFERENCE HANDBOOK

THEME: "A NUCLEAR RENAISSANCE"

ANA

HOSTED BY THE
AUSTRALIAN NUCLEAR ASSOCIATION INC.

ISBN 0 949188 12 3

First published in Australia in 1999 by
The Australian Nuclear Association Inc.
PO Box 445, Sutherland, NSW 1499
Australia

Responsibility for the content of the papers rests upon the authors and not the Australian Nuclear Association Inc.

Cataloguing-in-Publication entry
Australian Nuclear Association Inc.
Conference Handbook of the Third Conference on
Nuclear Science & Engineering in Australia
Canberra, ACT, 27-28 October 1999

Includes titles and authors of papers
and index of authors
ISBN 0 949188 12 3

1. Nuclear Research
2. Uranium Resources
3. Radiation Regulation & Safeguards
4. Radioactive Waste Management
5. Medical Applications of Nuclear Science
6. Nuclear Technology
7. Sustainable Energy and the Environment
8. Public Perceptions on Nuclear Issues

Cover design and page layout by C. J. Hardy
Typeface 18/12/10 pt Times New Roman
Printed in Australia by J. Lyons Printer
84 Harris Street Pyrmont NSW 2009

FOREWORD

The Australian Nuclear Association (ANA) inaugurated a series of biennial national conferences in 1995 to be held in alternate years to the series of international Pacific Basin Nuclear Conferences, of which the Ninth in the series was hosted by the ANA in Sydney in May 1994. The main objective of these national conferences is to present information on all aspects of the peaceful uses of nuclear science and engineering in Australia and to place this information in a world context and in a readily understood form.

These conferences have the general title of "Nuclear Science and Engineering in Australia" and consist mainly of papers invited from leading experts in areas of topical interest in nuclear science and technology supported by contributed poster papers. This third conference in 1999 has the special theme "A Nuclear Renaissance" and again consists mainly of invited papers on the topics:

(1) Nuclear Research;
(2) Uranium Resources;
(3) Radiation Regulation and Safeguards in Australia;
(4) Radioactive Waste Management;
(5) Medical Applications of Nuclear Science;
(6) Nuclear Technology Developments;
(7) Sustainable Energy and the Environment; and
(8) Public Perceptions on Nuclear Issues, including a Discussion Forum.

The Opening Address by Emeritus Professor Max Brennan, AO, expands on this theme of a nuclear renaissance. The Keynote Address by Professor Helen Garnett, Executive Director of ANSTO, on "The Priorities for ANSTO", is particularly appropriate in view of the recent announcement by the government that funding will be provided to ANSTO to build a replacement research reactor for HIFAR at Lucas Heights. Additional information on this major project is also provided.

The texts of the majority of the papers presented orally and as posters are included in this Handbook. The posters include two from the winners of the David Culley Award in 1997 and 1998. This Award was instituted by the ANA in 1993 to encourage work in nuclear science and technology in schools and colleges in recognition of the interests in education of Mr David Culley, a former Treasurer of the ANA, who died in 1992.

The ANA is pleased that the early registrations received for this conference as this Handbook went to the printers have confirmed its expectations that a broad spectrum of persons would attend from government, industry, the universities and the public.

The assistance of the members of the Conference Advisory Committee is gratefully acknowledged as also is the work of Mrs Margaret Lanigan as Conference Manager.

Dr Clarence J. Hardy
Executive Chairman and Editor

CONTENTS

CONFERENCE ADVISORY COMMITTEE

Dr Clarence J. Hardy, Executive Chairman ANA 99; President, ANA
Mr Roger J. Alsop, Vice-President, ANA
Dr Peter L. Airey, ANSTO; Honorary Secretary, ANA
Mr John T. Rodd, Treasurer, ANA
Dr Neil R. McDonald, ANSTO, Past-President ANA
Mr Douglas R. Ebeling, Chairman, Nuclear Engineering Panel, The Institution of Engineers, Australia
Dr Dennis Mather, Scientific Secretary, AINSE
Mr John Mulcair, ANSTO Communications
Mr J. (Jim) C. E. Button, Consultant; Chairman, NSW Branch, ARPS
Mr Stame George, St George Hospital Nuclear Medicine, Member ANZSNM
Mr Ian Hore-Lacy, General Manager, Uranium Information Centre, Melbourne
Mrs Margaret Lanigan, Conference Manager, Conference Overload Australia Pty Ltd

CONFERENCE MANAGER

Mrs Margaret Lanigan
Conference Overload Australia Pty Ltd
(ACN 071 932 146)
PO Box 327 Mosman NSW 2088
Australia

FINAL PROGRAM

ANA 99

"THIRD CONFERENCE ON NUCLEAR SCIENCE & ENGINEERING IN AUSTRALIA"
CANBERRA, ACT, 27-28 OCTOBER 1999

Hosted by the Australian Nuclear Association Inc.

Technical Co-Sponsors

Australian Nuclear Science & Technology Organisation (ANSTO)
Australian Institute of Nuclear Science & Engineering (AINSE)
Nuclear Engineering Panel, The Institution of Engineers, Australia
The Australia and New Zealand Society of Nuclear Medicine (ANZSNM)
The Australasian Radiation Protection Society (ARPS)

Conference Venue

The Lake Michigan Room
Rydges Canberra Hotel
Canberra, ACT
Australia

FINAL TECHNICAL PROGRAM
Wednesday, 27 October 1999

10.30	**Opening of Conference** Welcome by Dr Clarence Hardy, President, ANA **Welcome and Opening Address** General Chairman, Emeritus Professor Max Brennan, AO
Session 1.	**Nuclear Research**
10.55	**Keynote Address:** "The Priorities for ANSTO" Professor Helen Garnett, Executive Director, ANSTO
11.20	"AINSE's Future Role" Professor Ron MacDonald, President, AINSE
11.45	"International & Local Trends in Nuclear Physics" Professor George Dracoulis, Dept of Nuclear Physics, ANU
12.10	"Fusion Energy for the 21st Century" Professor Jeffrey Harris, Plasma Research Laboratory, ANU
12.35	"The Replacement Research Reactor Project" Dr Ron Cameron, ANSTO
13.00-14.00	**Buffet Lunch and Viewing of Posters and Exhibition**
Session 2.	**Uranium Resources**
14.00	"Opportunities for Ranger and Jabiluka", Ms K. M. Oxnam, Energy Resources of Australia Ltd
14.20	"Olympic Dam Expansion Completed", Computer graphics presentation, Olympic Dam Operations, WMC
14.50	"The Future of Solution Mining" Mr M. C. Ackland, Dr P. D. Bush & Mr T. C. Hunter, Southern Cross Resources Australia Pty Ltd.
15.10	"Environmental Protection Issues in Uranium Mining" Dr Arthur Johnston, Alligator Rivers Environmental Research Institute
15.30-16.00	Tea/Coffee Break
Session 3.	**Radiation Regulation and Safeguards in Australia**
16.00	"The New Look for Radiation Regulation" Dr John Loy, ARPANSA
16.20	"Nuclear Safeguards - A System in Transition" Mr John Carlson, Australian Safeguards & Nonproliferation Office
16.40	"An Epidemiological Study of Cancer Incidence and Mortality among Nuclear Industry Workers at Lucas Heights Science & Technology Centre in Collaboration with IARC" Ms Rima Habib and Professor John Kaldor, University of NSW
Session 4.	**"Radioactive Waste Management"**
17.00	"Progress on the National Low Level Waste Repository Project" Dr Caroline Perkins, Department of Industry, Science & Resources, and Dr Simon Veitch,Bureau of Rural Sciences, Agriculture, Forests & Fisheries Australia
17.20	"Synroc for Plutonium Disposal" Dr Adam Jostsons and Dr Lou Vance, ANSTO
17.40	"The Pangea Concept for an International Radioactive Waste Repository" Dr Marcis Kurzeme, Pangea Resources Australia
18.00	Close of Technical Sessions, Day 1.
18.15-20.15	**Reception and Viewing of Posters and Exhibition**

FINAL TECHNICAL PROGRAM
Thursday, 28 October 1999

Session 5.	**Medical Applications of Nuclear Science**
09.00	**Keynote Address:** "The State of the Art in Nuclear Medicine", Dr Andrew Scott, Austin & Repatriation Hospital, Heidelberg, Vic.
09.30	"Nuclear Medicine in Oncology", Professor Jim Bishop, Sydney Cancer Centre, University of Sydney
10.00	"Medical Radioisotopes for the Next Century" Dr Stuart Carr, ANSTO
10.30-11.00	Tea/Coffee Break
Session 6.	**Nuclear Technology Developments**
11.00	"The Uranium Enrichment Industry and the SILEX Process" Dr Michael Goldsworthy, SILEX Systems Ltd
11.20	"Accelerator Driven Nuclear Energy Production and Transmutation Systems" Dr John Boldeman, ANSTO
11.40	"A Decade of Industrial Tracer Applications" Dr Stuart Charlton, TRU-TEC Services
Session 7.	**Sustainable Energy and the Environment**
12.00	"The Institution's Position on Sustainable Energy" Dr Michael Sargent, M. A. Sargent & Associates Pty Ltd
12.20	"Accelerators for the Australian Environment & Heritage" Dr Claudio Tuniz, ANSTO
12.40	"Implications of International Protocols on Energy Markets", Mr Vivek Tulpule, Australian Bureau of Agriculture and Resource Economics, Canberra
13.00-14.00	**Buffet Lunch and Viewing of Posters and Exhibition**
Session 8.	**Public Perceptions on Nuclear Issues**
14.00	"Factors in Public Perception of Nuclear Energy" Mr Ian Hore-Lacy, Uranium Information Centre
14.20	"Nuclear Reaction and Interaction" Mr John Mulcair, ANSTO
14.40	"Nuclear Issues in the Print Media" Mr Frank Devine, The Australian
15.00	"The Young Generation Network" Dr Urs Meyer, The Young Generation Network, European Nuclear Society
15.20-16.30	Discussion with the Panel of Speakers
16.30	**Closing Remarks** Dr Clarence Hardy, President, ANA

Friday, 29 October

9.30-12.30	Optional Visit to ANU's Nuclear Research Laboratories.

LIST OF POSTER PRESENTATIONS
18.00 - 20.00, 27 OCTOBER

1. Amorphization of Ge and InP studied using nuclear hyperfine methods
A. P. Byrne and F. Bezakova, Dept of Nuclear Physics, ANU; C. J. Glover and M. C. Ridgway Dept. of Electronic Materials Engineering, ANU

2. A direct measurement of the thermal-spike lifetime after ion implantation
A. E. Stuchbery and E. Berzakova, Dept of Nuclear Physics, ANU

3. Elastic recoil detection using heavy ion beams
H. Timmers, R. G. Elliman, T. R. Ophel and T. D. M. Weijers, Depts of Nuclear Physics and Electronic Materials Engineering, AN

4. Calibration of ARI QC ionisation chambers using the Australian secondary standards for activity
Li Mo, H. A. van der Gaast, D. Alexiev, K. S. A. Butcher and J. Davies, ANSTO

5. The standardisation of Sm-153
J. Davies, H. A. van der Gaast, Li Mo, H. A. Wyllie and D. Alexiev, ANSTO

6. Recent progress in digital coincidence counting
K. S. A. Butcher, G. C. Watt and D. Alexiev, ANSTO

7. Tracing discharges of plutonium and technetium from nuclear processing plants by ultra-sensitive accelerator mass spectrometry (summary only)
L. K. Fifield, P. A. Hausladen, R. G. Creswell and M. L. di Tada, Dept of Nuclear Physics, ANU; J. F. Day and R. S. Carling, Dept. of Chemistry, University of Manchester; and D. H. Oughton Agricultural University of Norway, Oslo

8. Barriers to Fusion
A. C. Berriman, R. D. Butt, M. Dasgupta, D. J. Hinde, C. R. Morton and J. O. Newton, Dept of Nuclear Physics, ANU

9. A charcoal canister survey of radon emanation at the rehabilitated uranium mine site at Nabarlek
J. R. Storm and J. R. Patterson, Dept of Physics and Mathematical Physics, University of Adelaide

10. The Internationalisation of Research Facilities (summary only)
Emeritus Professor T. M. Sabine, Glebe, NSW

11. Application of radiotracer technology to the study of coastal processes
P. Airey, R. Szymczak, M. Zaw, J. Tu, T. Kluss and J. Barry, ANSTO

POSTERS BY
DAVID CULLEY AWARD WINNERS

1997-8 Trinity Grammar School, Kew, Victoria

An application of neutron activation analysis to determine the pathways of undergound streams using bark from eucalyptus trees (Ironbark) within an afforested region near Rushworth, Central Victoria (summary only)
K. Nelms and students in association with D. Garnett, ANSTO

1998-9 Lake Ginninderra College, Canberra, ACT

Historical rates of erosion of the Australian landscape as measured with Beryllium-10
S. Rymers, E. Mancini and L. Harman, in association with L. K. Fifield, M. L. di Tada, P. A.Hausladen and G. dos Santos, Dept. of Nuclear Physics, ANU; and R. J. Wasson, Centre for Research and Environmental Studies, ANU

technicatome

CENTRE D'ETUDES DE SACLAY - BP 17 - 91 192 GIF-SUR YVETTE CEDEX - FRANCE
TEL. 33 1 69 33 80 38 - FAX 33 1 69 33 80 12

AN ENGINEERING AND TECHNOLOGICAL DEVELOPMENT COMPANY

TECHNICATOME, when created in 1972 by the French Atomic Energy commission (CEA) and Electricité De France (EDF- the French Electricity Generating Board), incorporated CEA teams specialised in the Research and Test Reactor field, and related experimental facilities.

Today TECHNICATOME, with the Fench CEA, the French Navy Construction Division, FRAMATOME and EDF as shareholders, is the French lead engineering Company for the delivery of Research and Test Reactors.

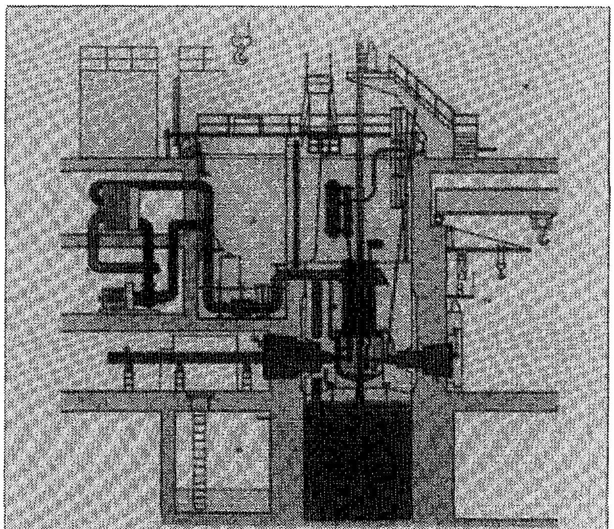
TECHNICATOME combines, in an original way, its industrial experience as nuclear operator (two reactors operated) with its trade of engineering and technological development ; it holds a key position between the CEA Research and the industrial development of equipment and processes.

Today, TECHNICATOME's staff is about 950 employees, mainly engineers and senior technicians (1900 for the whole TECHNICATOME Group) working to offer the best answer to the requirements of the market.

Thanks to them, TECHNICATOME offers to its customers a full range of skills and techniques allied with a certain attitude and approach, which has been the hallmark of TECHNICATOME from the very beginning : enthusiasm, the ability to listen, adaptability, creativity, scientific thoroughness, a passion for researching new technologies and the capability for a successful completion of the projects with a satisfactory operation on time in the budget.

TECHNICATOME teams with the impressive record of 33 reactors commissioning are now conducting three major projects in the Research and Test Reactor field:

- The JULES HOROWITZ REACTOR (RJH), a 100MW irradiation reactor for the CEA,
- The RES reactor, a test reactor for the Navy,
- The delivery of a Nuclear Research Centre to Marroco.


Orphée Reactor

TECHNICATOME with FRAMATOME, backed by the CEA is prequalified as Reactor Vendor for the ANSTO Replacement Research Reactor Project.

ANA 99 SPONSORS

Major Sponsor - AECL, Canada and Thiess Contractors Pty Ltd

Satchel Sponsor - Technicatome, France

Reception Sponsor - Siemens Ltd

Advertising Sponsor - Roger Alsop Consulting

TECHNICAL EXHIBITION

The Technical Exhibition will be held on 27 - 28 October
in the Lake Superior Room on the First Floor of Rydges Canberra Hotel

EXHIBITORS

ARPANSA

Australian Nuclear Association Inc

Australian Nuclear Science & Technology Organisation (ANSTO)

Nuclear Fields (Aust.) Pty Ltd

Nucletron Pty Ltd / BNFL

Southern Cross Resources Australia Pty Ltd

THE AUSTRALIAN NUCLEAR ASSOCIATION INC.

The Australian Nuclear Association Inc (ANA) is an independent voluntary incorporated organisation of persons with an interest in nuclear topics drawn from the professions, business, government and universities. The principal aim of the ANA is to provide opportunities for members to meet on a regular basis. A second aim is to publish a bi-monthly newsletter "Nuclear Australia" to report mainly on events in the nuclear field in Australia, and this is sent to members and subscribers worldwide. Other aims are to make awards to recognise outstanding contributions to nuclear science and technology, and to support education and training.

Meetings are usually held bi-monthly at the Australian Museum, Sydney, on the third Thursday in the month, and usually include a technical lecture by a leading expert in the field. A joint program of meetings is arranged with the Nuclear Panel of The Institution of Engineers, Australia, with the Panel hosting meetings on the second Tuesday in each alternate month at Engineering House, Milson's Point, Sydney.

The ANA hosts international and national conferences, eg. the 9th Pacific Basin Nuclear Conference in Sydney, 1994, the First Conference on Nuclear Science & Engineering in Australia, 1995, and the Second International Conference on Isotopes held in conjunction with the Second Conference on Nuclear Science & Engineering in Australia, in October 1997. The ANA is a Member of the International Nuclear Societies Council and the Pacific Nuclear Council and has bilateral cooperation agreements with a number of overseas Nuclear Societies.

Persons interested in obtaining further information on the ANA should contact:

The Honorary Secretary, Australian Nuclear Association Inc.
PO Box 85 Peakhurst NSW 2210 Australia.
Tel.61.2.9579.6193; Fax 61.2.9570.6473;
Email: cjhardy@ozemail.com.au

AUSTRALASIAN RADIATION PROTECTION SOCIETY

Incorporated in South Australia

The Australasian Associate Society of the International Radiation Protection Association

The Australasian Radiation Protection Society Inc (ARPS) is a professional society of members engaged in one or more aspects of radiation protection.

The primary objective of the Society is to promote the principles and practice of radiation protection, and to this end it seeks to:

- establish and maintain professional standards of radiation protection practice
- encourage co-operation among persons engaged in radiation protection activities
- provide for and give support to scientific meetings on topics related to radiation protection
- encourage publications in the field of radiation protection.

The Australasian Radiation Protection Society was founded in 1975 and has more than 230 members. Members are engaged in a variety of activities designed to ensure the safe use of both ionizing and non-ionizing radiation for a wide variety of applications, in medicine, pure and applied science, industry and mining. ARPS is the Australasian associate society of the International Radiation Protection Association (IRPA).

The Society publishes its own journal "*Radiation Protection in Australasia*" four times a year. The journal is circulated to members and to a number of libraries in Australia, New Zealand and overseas. A Newsletter is published quarterly informing members of ARPS activities.

ARPS holds an annual scientific meeting and the State Branches hold local meetings on a more frequent basis. The annual scientific meetings for the next 2 years will be held in in Margaret River, WA, in 1999 and in Sydney in 2000.

Anyone with an interest in radiation protection is welcome to enquire about membership of the Society or about participation in the annual scientific meetings. All enquiries should be addressed to:

The ARPS Secretariat,
P.O. Box 27,
Parkville,
Victoria, 3052,
Australia

Telephone: (61 3) 9347 9633
Facsimile: (61 3) 9347 4547
email: arps@vicnet.net.au

A Nuclear Renaissance

OPENING ADDRESS BY

EMERITUS PROFESSOR MAX BRENNAN, AO

The Australian Nuclear Association has organised this third Conference in a biennial series with the theme: "A Nuclear Renaissance". The conference aims to review all of the major nuclear issues of importance to Australia as we enter the 21st Century. These include:

- uranium mining and upgrading;
- the management of nuclear waste;
- the plans for the future by the government's major nuclear research laboratory, operated by ANSTO, including plans for constructing a major Replacement Research Reactor at Lucas Heights,
- the status of safeguards and nuclear regulation in Australia now that the government has set up the Australian Radiation Protection and Nuclear Safety Agency,
- and the many and varied applications of nuclear science in Australia.

The conference also presents the plans for nuclear research by the universities through the Australian Insitute of Nuclear Science & Engineering, and features in particular the work at the Australian National University in Canberra.

I want to refer now to a little of the history of nuclear science and technology before explaining what is underpinning this renaissance in Australia.

A little over 200 years ago, in 1789, uranium was discovered in the mineral pitchblende by Martin Klaproth, a German chemist, and it was named after the planet Uranus, which had been discovered only eight years before in 1781. The pure element uranium was not isolated until 1841 by the Frenchman Peligot. A little over 100 years ago, in 1897, uranium was discovered in Australia at Carcoar, a small village in New South Wales. Uranium was somewhat of a scientific and geological curiosity until Becquerel discovered radioactivity in uranium compounds in 1897. The intense research in nuclear physics and chemistry in the following 40 years led to a better understanding of the structure of atoms and eventually in 1939 to the realisation that uranium could be the source of enormous amounts of energy. The world became vividly aware of this energy in the atomic bombs at the end of the Second World War and in the development of the early nuclear power stations and nuclear-powered ships in the 10 years after the war.

The first man-made nuclear fission reactor was constructed by Enrico Fermi in Chicago in 1943. The first nuclear power station to be connected to an electricity grid system was the Calder Hall reactor in Britain in 1955. Today there are 429 nuclear power reactors operating in 32 countries and a large number of nuclear powered ships in service in the defence forces of many countries. Whilst nuclear power only contributes about 17% of world electricity production, some countries rely on it for a very significant part of their electricity supply, eg. France for 80%, Belgium for 60%. The total installed nuclear capacity is expected to be about 360 GWe by 2000, and the way in which this will change in the first 10 or 20 years of the next century is very difficult to predict. Suffice to say that Australia has no nuclear power and is unlikely to have any in this time frame largely because of its abundant resources of good quality cheap coal and gas. The situation is very different in other parts of the world and the most likely region to continue installing nuclear power plants is the Asia-Pacific Region, spearheaded by China, which has an ambitious program.

Turning now to the applications of nuclear science and technology other than nuclear power, there have been applications over the last 100 years in many fields including medicine and health, primary and secondary industries, the environment, and research. The development of research and power reactors in many countries after the Second World War provided a large number of radioisotopes and made available powerful sources of gamma radiation for medical, industrial and research applications. The IAEA listed in 1998 a total of 265 research reactors operating in 59 countries with a further 12 under construction. Australia has operated successfully a relatively large research reactor, HIFAR, for over 40 years and also a smaller research reactor, MOATA, which was recently decommissioned.

The papers to be presented by leading experts over the next two days will give the latest information on the following issues which contribute to this renaissance:

- A keynote address by Professor Helen Garnett, Executive Director of ANSTO, on the priorities for ANSTO as it enters the next century, followed by a paper by Dr Ron Cameron on the major new project for the Replacement Research Reactor.
- The role of AINSE in the future will be presented by its President, Professor Ron MacDonald and nuclear physics and nuclear fusion research at ANU will be discussed by Professors Dracoulis and Harris.
- The session on uranium resources will discuss the expansion of the uranium industry in the Northern Territory and in South Australia, with an increased investment of over $1 billion in conventional mining and processing. The start being made on the in-situ leaching process, and environmental issues in the industry, will also be discussed;
- The new look for radiation regulation will be presented by Dr John Loy, Chief Executive of the new ARPANSA, and a nuclear safeguards system in transition will be discussed by Mr John Calson, Director of the Australian Safeguards and Non-Proliferation Office. A progress report will be given by the University of Sydney on a major international epidemiological study on radiation in which Australia is cooperating.
- Progress on the national low level radioactive waste repository will be discussed by staff of the Department of Industry Science and Resources, and ANSTO will present a report on its major application of Synroc to the disposal of unwanted plutonium. Finally, in that session, Pangea will outline its work on a Concept for an International Radioactive Waste Repository, a concept which has been subject to a degree of controversy this year.
- The very important medical applications of nuclear medicine will be the topic of the first session on Thursday, when the state of the art in nuclear medicine in the study of cancer and in isotope production will be discussed by three of Australia's leading experts.
- A session is being devoted to nuclear technology developments and we are very pleased to have a presentation of the new SILEX Process invented in Australia for enrichment of uranium and other isotopes. This process is being evaluated very seriously by the US Enrichment Corporation as the next generation replacement for the aging US diffusion enrichment plants and for their own laser process.
- Also in this session we will have a review of the novel Rubbia Concept for Energy Production and Transmutation of Isotopes, and an overview of a decade of industrial tracer applications by the former ANSTO-ICI Joint Venture which has been so successful that it has now been taken over by a major US organisation.
- The very important areas of sustainable energy and the environment will be addressed in three papers. The first will be a paper presenting the Position on Sustainable Energy developed by The Institution of Engineers Australia. The second will be a paper outlining

the way in which accelerators are contributing to a better understanding of the environment. The third paper will discuss the implications of the new international agreements on the climate on energy markets and future use of nuclear power.

- The final session on Thursday will discuss the equally important issue of public perceptions on nuclear issues with papers from ANSTO, the Uranium Information Centre, a well-known journalist and a member of The Young Generation Network. This Network was set up in Europe a few years ago and is receiving strong support. This session will end with a discussion period with the Panel of Speakers in which audience participation is strongly requested.

The Theme "A Nuclear Renaissance" is based on our perception that nuclear science and technology is on the threshold of a major expansion after a period which many thought was the onset of the Dark Ages after the old Australian Atomic Energy Commission was abolished in 1987. Fortunately, nuclear science and technology was not abolished and the AAEC was replaced by the government with ANSTO, which the government has continued to support strongly. The most recent expression of this support has been the approval of nearly $300M in investment in a major Replacement Research Reactor to be operational in about 2005, and the establishment of the new regulatory body ARPANSA.

It gives me great pleasure to declare open the Third Conference on Nuclear Science and Engineering in Australia.

*****

KEYNOTE ADDRESS ON 27 OCTOBER 1999

The Priorities for ANSTO

PROFESSOR HELEN M. GARNETT
ANSTO, PMB 1, Menai 2234.

As Australia's major centre of expertise in nuclear science, technology and its applications, ANSTO's priorities take account of the stated strategic and tactical needs of its various stakeholders, which in turn are considered as the Government (as owner), industry – including the health sector, the academic and research community and the public at large. Its priorities also take account of the opportunities perceived by its own staff in the light of the organisation's strengths, the activities of the international scientific, technology and industry community and a rapidly changing socioeconomic environment where environmental management and social accountability are becoming as important as fiscal responsibility and accountability.

4. INTRODUCTION.

ANSTO's activities range from the provision of products, such as radioisotopes and radiopharmaceuticals, to services, including advice to Government, irradiation services to industry, including the resource, health and agricultural sectors, provision of functional neutron scattering beamlines and instrumentation to researchers from industry, universities and other state and national research institutions, provision of isotopic analyses of biological, archaeological, environmental and industrial samples using its reactor and accelerators to a wide range of national and international clients, industrial training in radiation protection and radiological safety nationally and regionally and research, development and technology transfer, particularly in areas which benefit the environmental sector, the resource and resource processing industries, the manufacturing and the health sector. ANSTO's future capacity to benefit Australia is a function of its facilities, its people and its processes.

2. THE FABRIC OF THE ORGANISATION

3.1 Facilities.

The core of ANSTO's facilities is a research reactor. The current reactor HIFAR will operate to around the end of 2005. The project to replace this facility by a modern research reactor, a high priority for ANSTO and the scientific and technology community at large, is now well underway. The priorities for this facility are to meet the predicted

- range, quantity and specific activity of radioisotopes both for medical and industrial procedures and for research to understand environmental, biological and industrial processes
- irradiation requirements of samples to enable fission track analysis, as used in petroleum exploration, neutron activation analysis for the resource, environmental and manufacturing industries and for forensic and occupational medicine
- fields of research endeavour where neutron studies will be an essential component of leading edge studies and from which Australia has the potential to benefit.

Further details on the replacement research reactor and its many uses are covered in a separate paper.

Other complementary facilities which are priorities now and for the future are accelerators and accelerator-based instrumentation. These include provision of

- a small modern accelerator to replace the 40 year old van de Graaff which will service the need for ion beam analysis, particularly of surfaces - a growing research field, and provide a routine facility for the burgeoning applications of C-14 dating.
- continued availability of synchrotron radiation for world class X-ray studies to complement other accelerator-based analyses (ion beam etc) as well as to complement neutron studies of industrial materials such as polymers,
- additional cyclotron capability in the longer term to complement the existing production facility, particularly for research and development project.

3.1 People

A priority for ANSTO is the availability of versatile committed staff, staff who qualify as knowledge workers. Such knowledge workers will not just create or access knowledge, they will harness information and knowledge to produce useful action which will benefit ANSTO and Australia at large. Knowledge workers respond to and cope with unstructured and, uncertain environments. Further, addressing significant questions and producing useful actions almost invariably requires interdependent teams and the capacity to work across units within the Organisation, with staff from other research organisations, from universities and from industry in interdependent teams – teams established to undertake a particular project, which subsequently dissolve. These requirements mean that priorities for ANSTO are

- recruitment of adequately educated staff, with their own discipline knowledge and professional networks who are prepared to share information and knowledge
- retention and development of staff who are flexible and agile and committed to ongoing learning; staff prepared to spend the time to develop shared understandings with the members of their current team regardless of the culture of those members' parent organisations and staff committed to serving our clients
- reward of staff in a merit based system.

3.1 Processes

ANSTO has developed and implemented new processes for capturing ideas, scoping and evaluating possible projects, costing and pricing its products, services and research activities and monitoring progress, outputs and outcomes.

A priority for the Organisation is consistent implementation of these processes and. as appropriate, improvement thereof. A further priority is the development of more effective systems to enable sharing of information and the capturing of relevant data to answer the increasing demands for external reporting against a host of parameters.

3. ACTIVITIES

ANSTO's vision is for nuclear science and technology to be valued as benefiting all Australians through the innovative endeavours of ANSTO, one of the world's leading nuclear science and technology organisations. In addressing this vision, five core science 'business' areas have been identified as the most appropriate for focussing our effort. Within these, the medium term priorities for business development, services and research and development projects have been scoped through stakeholder and client consultation, the activities being chosen for their potential impact.

3.1 International Strategic Relevance of Nuclear Science and Technology

The major priorities of this area are to

- apply knowledge by the provision of quality scientific and technical advice on the nuclear fuel cycle, including reactor operations, reactor safety and the safeguarding or nuclear materials
- contribute to IAEA Cooperative Research Programs, particularly those directed to improving fuel storage, reactor safety, management of uranium tailings and management of nuclear waste
- lead projects in the Asia/Pacific region to understand coastal and marine pollution pathways, which require isotope applications
- develop and apply sensitive analytical procedures in support of wide area monitoring for safeguard purposes, that is for independent monitoring of the presence and type of nuclear activities
- develop and test a model to effectively predict the radiological consequences for any incident in tropical and subtropical regions, noting that existing models have been developed for northern hemisphere temperate climates
- develop methods for assessing and improving safety culture at nuclear installations and test these within ANSTO and in the Asian region, the focus being on non-power installations

3.1 Core Nuclear Facilities, Operation and Development

The major priorities in this area are to

- operate HIFAR and ANSTO's accelerators, and their associated instrumentation safely and efficiently, so that they are available for the maximum time to produce product and deliver required services for business and research purposes
- develop leading edge instrumentation for these facilities to enable innovative research on materials of a biological, environmental, geological or industrial nature
- provide expertise in the interpretation of data from these various facilities

Associated with this area is the Replacement Research Reactor Project, the objectives of which are discussed elsewhere in this meeting, and the development of other infrastructure as mentioned above.

3.1 Applications of Nuclear Science and Technology to the understanding of Natural Processes

The objective of this area of endeavour is to apply nuclear-based techniques to research projects in support of national and international programs,such as investigations of global climate change, environmental pathway analysis and to applied studies driven by industry and government. The major priorities over the next few years are to

- quantify and evaluate annual and seasonal variations in fine particle elemental concentrations in air masses at particular locations as a basis for quantifying the major factors in the atmosphere likely to be responsible for present and future climate change
- apply a range of nuclear techniques to studies addressing natural climate variability in the past
- improve the understanding of the biogeochemical processes at solid/liquid interfaces relevant to radionuclide migration in unsaturated soils and aquatic environments focussing on processes that will contribute to solving identified environmental issues or are important for refining the assessment of impact of nuclear facilities, particularly in Australia and the Asia/Pacific, including repositories, uranium mines and sites contaminated with radioactivity

3.4 Treatment and Management of Man-Made and Naturally Occurring Radioactive Substances

The priorities in this core business area are

- development and application of cleaner production techniques for the resources industry-reducing the radioactivity in flue gases, tailings and finished product
- application of specific titanate waste formulations and ANSTO processing technologies for managing radioactive wastes, arising from previous overseas defence programs
- provision of quality assured procedures for handling, characterising and packaging radioactive waste suitable for acceptance by the national repository
- effective management of a program to ship and reprocess HIFAR spent fuel

3.5 Competitive and Ecological Sustainability of Industry

The objective is to develop and apply critical technologies, based on ANSTO's nuclear and associated technical capabilities, which will enhance the competitiveness of selected industry sectors.

In pursuing this objective ANSTO aims to be involved in appropriate CRC's, which are effectively networked with end users. To this end ANSTO has enhanced its participation, the Organisation now being a full member of three CRCs and a potential associate of at least two additional centres. Through these centres its priority activities are

- increasing the reliability and durability of welded structures, such as gas pipelines
- contribution to the cost effective production of improved polymer products that can compete effectively in local and export markets
- commercialisation of a process developed to remove and immobilise metal contaminants from industrial process effluents and groundwater

Other major priorities are

- the provision of quality services, including training - nationally and regionally, based on radiation standards, radiation safety, radiation sterilisation and plant assessment technologies
- strategic research and development inmaterials science - particularly the engineering of oxide ceramic interfaces by controlled manipulation at the molecular level and understanding the microstructure of selected materials using nuclear science and technology
- strategic and tactical research aimed at reducing the impact of mine waste effluents
- the supply of quality radiopharmaceuticals and radioisotopes for industry and environmental studies, contributing to the international development of new products, particularly those for the management of cancer and movement disorders – problems manifested in Australia's aging population.

4. CONCLUSION

ANSTO, like any effective science and technology Organisation aims to focus and at the same time balance its endeavours. It must continue to develop and enhance its infrastructure , its people and its processes so that it can deliver competitive solutions to current and future problems of those sectors of national and international endeavour where nuclear science and technology can clearly contribute, among which are environment, health, archaeology, resources, process industry and manufacturing. All of these are important to the future of Australia.

AINSE'S Future Role

PROFESSOR R.J. MACDONALD
PRESIDENT
Australian Institute for Nuclear Science and Engineering

SUMMARY

AINSE (Australian Institute for Nuclear Science and Engineering) was created in 1958 as a consortium of nine universities and the then Australian Atomic Energy Commission (AAEC) to develop research projects associated with the use of atomic energy. In 1999 AINSE remains strong, but has increased its membership to include 35 Australian universities and 1 New Zealand university. AINSE's role has been to facilitate access by researchers in universities to the facilities of the ANSTO Laboratories. Over the years the emphasis of the research projects themselves has shifted from those related to nuclear physics and the solution of problems associated with the development of nuclear energy, to projects where the emphasis is on the application of nuclear and nuclear related techniques to problems in a wide range of areas, including biomedical science and the environment.

AINSE has reached a 40-year milestone and is about to enter the next millennium (and the next 40 years) at a time when ANSTO will host a new and modern reactor and the application of basic sciences to the biological areas is tipped to become the major focus of scientific discovery. Increasingly the environment becomes a source of major concern for everyone and the subject of a large component of research. The challenge for AINSE is to retain existing interests and expertise, but to also develop new ways in which nuclear science can be applied to these exciting and expanding areas of research.

1. INTRODUCTION

The Australian Institute of Nuclear Science and Engineering (AINSE) was created as a consortium of nine universities and the then Australian Atomic Energy Commission in 1958. The initial universities involved were the Universities of Queensland, New England, New South Wales, Melbourne, Tasmania, Adelaide, Sydney, Western Australia and the Australian National University. At the time this would have represented 100% of the then established universities. There were a few fledgling colleges in other areas established by a couple of these universities, but the growth of the second wave of new universities of the Menzies era was still to come.

In some universities there were schools or departments of Nuclear Science or Engineering. The Lueas Heights laboratories had a newly-commissioned reactor and had one of the few accelerators in the country. The mission of AINSE then is the same as that today - to provide an organised mechanism for access of university researchers in the universities and what is now the Australian Nuclear Science and Technology Organisation (ANSTO).

Today, however, the membership of the consortium has grown with the growth of the university system in Australia; 36 of the 38 universities in Australia are currently members, with negotiations initiated with the 37th university to join. The 38th university does not have faculties of science, engineering or related biomedical sciences. In addition, the University of Auckland in New Zealand is a member.

AINSE as an organisation involving the universities in Australia is therefore almost unique. The only other organisation of any similarity in scope would be the Australian Vice-Chancellors' Committee (AVCC). It would be apparent to observers of both consortia that AINSE is probably a more cohesive unit, with goals more common to all its members than the AVCC.

2.1 AINSE FINANCES

AINSE is not a high budget organisation. AINSE's main resource is the subscription income from its members. The basic underlying formula is a subscription of $2 from ANSTO for each $1 of university fee income. There are 13 levels of fees which universities pay, related to the level of benefit the university receives and ranging in value from approximately $6,000pa to $60,000pa. The total income from subscriptions for 1998 was just under $2M.

In the current research funding operation AINSE has been able to provide a valuable input as the managing agent for a series of infrastructure and equipment grants obtained from the Australian Research Council. In 1998, for example, AINSE managed approximately $625,000 of dedicated grant funding from the ARC and DSIR. Over the last few years AINSE has successfully managed grants for Accelerator Mass Spectrometry (AMS), neutron scattering, support for the ANSTO Secondary Ion Mass Spectrometry system, subscription for access to the ISIS neutron scattering facility in England, and has been a major player in the Major National Facility grant for the Plasma Fusion project at ANU.

Australian Government research policy is currently under intense discussion as a result of the issuing of the DETYA Green Paper, *"New Knowledge, New Opportunities"*, on research in the university sector. The Discussion Paper is strongly oriented towards even greater cooperation involving all research providers and users. In the climate initiated by such major policy statements one would expect an organisation such as AINSE to be even more important.

The benefit to AINSE members accrues mainly from the substantial in-kind contribution of ANSTO facilities to the collaborative projects. AINSE aims to provide an estimated 3:1 return to AINSE members in terms of the ratio of benefits retained to subscription paid. The subscription level of any university is determined by maintenance of at least this level of return over a three year period.

2.2 AINSE GRANTS

The research areas supported by AINSE are those in which there is opportunity for collaboration with ANSTO and a need for the use of ANSTO facilities. Grants of access to AINSE facilities and travel and accommodation to allow the researchers from the university to participate in research projects are made as a result of an assessment of a research proposal by a Specialist Committee made up of approximately 50% university researchers and 50% ANSTO research staff.

The current Specialist groups are Accelerator Science, Accelerator Mass Spectrometry, Radiopharmaceuticals and Neutron Irradiation, Engineering, Materials and Nuclear Technology, Environmental Science, Neutron Scattering, Plasma Fusion and Radiation Science. The Specialist Committees assess applications in their respective areas and allocate funding which is primarily used to purchase facility time on ANSTO equipment at heavily discounted rates. Currently approximately half of submitted applications are funded.

2.3 POSTGRADUATE STUDENT SUPPORT

AINSE offers a number of supplements to scholarships already held by postgraduate research students where the student's project involves the use of ANSTO facilities. The stipend supplement is $7,500pa for the duration of the other scholarship held by the candidate. The student is funded for travel and accommodation to work at ANSTO for two periods each year. In addition, the student is awarded the equivalent of $5,500 in facility time on the appropriate ANSTO facility.

A member of ANSTO research staff becomes a co-supervisor of the candidate's project, and the candidate gains experience working in a non-university research environment. In practice there is significant commitment to the project from the candidate, the university and ANSTO, and a project developing well will often attract facility support in excess of the $5,500 allowance.

2.4 AINSE CONFERENCES

A major activity of AINSE is the organisation and management of a number of workshop/conference activities which coincide with the areas represented by the Specialist Committees. Currently AINSE organises the following:

AINSE Nuclear and Particle Physics Conference
Conference on Nuclear Techniques of Analysis
Symposia on Advances in Radiopharmaceuticals
Nuclear Techniques Environmental Science Conference
Plasma Physics Symposia
Workshops on Quaternary Science
Radiation Science Conference

as well as a variety of topical workshops on such areas as Small Angle Neutron Scattering, SIMS Analysis, and so on.

In 1998 a major effort went into the organisation of the 40th AINSE Anniversary Conference. This was very topical in that it provided a review of AINSE activities up to the time of the announcement of the building of the new reactor.

In recent years AINSE has cooperated with other organisations, particularly the Australian Institute of Physics, in respect of its Congress, and the Australian Vacuum Society, to ensure topical conferences can attract both good contributions and good attendance. Also AINSE has been involved in the organisation of major international conferences; e.g. the International Conference on Radiation Research which will be held in Australia in 2003.

2.5 AINSE WINTER SCHOOL

A few years ago AINSE turned its concern at the relatively low representation of nuclear science and technology in undergraduate curricula into the AINSE Winter School. Several schools have now been successfully organised. Each school involves one senior undergraduate from each member university attending at ANSTO for a four-day intensive experience. This involves the attendees conducting a substantial experiment on four major ANSTO facilities, analysing the results and preparing a report. The attendees work in groups in a team situation and are instructed and supervised predominantly by ANSTO staff members. The latter donate their time in preparation and delivery, including a weekend of experiments.

Feedback from attendees has been very positive with reflections of enjoyment of the social and scientific experience. A major outcome has been the number of attendees who have expressed surprise at the range of facilities available at Lucas Heights and particularly at the range of non-nuclear areas of research in which the techniques associated with nuclear science and technology have application.

3. THE AINSE OF THE NEXT MILLENNIUM

The future role of AINSE is, of course, one of speculation, but developments entering the year 2000 point to a solid future for the collaboration with ANSTO. The main basis for this is, of course, the decision to build a new reactor. This will be a more energetic source than HIFAR and as such will provide a more extensive range of experimental facilities supported by more intensive neutron beams and irradiation facilities.

Coupled with this will be a more intense effort worldwide in a range of cross-disciplinary scientific research areas. The study of underlying effects of environmental problems will be essential as our world struggles with possible global warming, coupled with the effects of overindulgence in chemical control of agriculture. There will be an increasing emphasis on our wish to understand the future, particularly in climatological terms, by studying our past. Similar techniques will be applied to attempts to understand the history of mankind - in both instances techniques such as AMS and neutron activation analysis will provide the isotope ratio sensitivities important in the dating of scientific material.

More importantly, there will be an increase in the use of nuclear oriented techniques in biomedical and molecular biochemical research. Medical science at the molecular level is becoming more and more sophisticated in its application and isotope tracers and their detection will be increasingly important in mapping biomolecular reactions and in the highly localised delivery of possible radiotherapy.

In the last 20 years there have been incredible changes in visualisation technology. These advances have yet to be applied to aspects of autoradiography. Cell reactions and gene technology will benefit from such studies over the next 20 years.

We can get some idea of what is likely to be the areas of major development by looking at some of the work being done today. The examples to follow are all taken from the 1998 AINSE Annual Report. Perhaps a topic for the 2010 ANA conference might be to compare some of what I will briefly describe now with entries in the Annual Report of AINSE for that year.

Applications involving the use of Accelerators

3.1 Aerosol Characterisation

A major source of the irritants associated with atmospheric pollution is the incidence ofaerosols. Many of these particles with diameters of less than 2.5 microns can penetrate into the lungs. They are readily dispersed from their source by atmospheric action and they are of sizes which can react with and scatter solar radiation.

A group at UNSW led by Dr Gail Box is using accelerator techniques such as PIXE and PIGME to characterise the constituent aerosols in Sydney's atmosphere and relating these to the spectral absorbance and scattering of solar radiation.

3.2 Nitrogen in Biological Material

In a unique and unusual application of accelerator analysis to biological materials, a group at the University of Western Australia is measuring isotope ratios for nitrogen in a reaction associated with the protein content of animals. This is related to the well-being of free ranging animals and to the resources needed for reproduction and hence conservation of the species.

3.3 Accelerator Based Mass Spectrometry

Radiocarbon dating using AMS has been used in a variety of environmental applications. A question being considered is the extent to which parts of the coastal regions of the Antarctic became ice-free in the recent past. A University of Newcastle group led by Professor Eric Colhoun is using fossil oil regurgitations from the stomachs of snow petrels in an attempt to date some of the ice-free events. The regurgitated oil accumulates at the entrance to the birds' nest and dating using carbon isotope ratios of the accumulations will indicate when the region was ice-free.

Current results indicate the region was ice-free only about 3500 years ago. This is a much younger age than anticipated and have really only opened the questions, not answered them.

3.4 Neutron Activation Analysis

Stalagmites preserve excellent records of climate change. Another group at The University of Newcastle led by Dr Russell Drysdale is studying stalagmites from caves in central NSW from which continuous paleo-environmental records extending over tens of thousands of years can be obtained. Neutron activation is used to establish uranium-thorium dates for the growth of the stalagmite. Current indications give a growth period preserving the paleo-environmental record in excess of 100,000 years. More detailed studies of the climate change plus other indications of hydrological soil and biological conditions will follow.

3.5 Materials Science

Superconducting materials have been around for some time, but the problems of low temperature requirements and materials themselves have limited their application to highly specialised situations. The high temperature ceramic superconductors have the potential to relieve some of the problems of the low temperature environment, but their current capabilities and material properties are also limiting.

Neutron irradiation can introduce defects into a ceramic superconductor in a way which contributes to the pinning of the magnetic flux and an increase in the current carrying capacity. Professor S. Dou and his group at The University of Wollongong are conducting extensive studies of this effect using ANSTO facilities and AINSE support.

3.6 Neutron Scattering

The current facilities for neutron scattering allow a range of structural studies. Current planning for the new reactor envisages a possible large expansion in the range of facilities available.

Through AINSE, Australian researchers can gain access to major facilities overseas as a prelude to some of the studies which the new facility might provide. Neutron scattering will be a major source of experimental observation of structural changes, including phase changes and stoichiometry for a variety of materials which respond better to neutron than to x-rays or electrons.

3.7 Radiation Science

Free radicals are important components of the role of antioxidants in foods and chemical reactions in the atmosphere. Dr Karl Cornelius of The University of Adelaide is concentrating on the latter, developing one of the first comprehensive studies of the reaction of the types of free radicals generated photochemically in the atmosphere with a group of peptides indicative of the range of products commercially used in Australian agriculture. AINSE's role has been to provide access to pulsed electron accelerators for pulse radiolysis experiments. These allow the chemical changes produced by the free radicals to be followed at short time scales. From the initial reaction rates deduced it is possible to untangle the highly complex range of reactions occurring in atmospheric processes.

3.8 Radiopharmaceuticals

This represents an area in which we can expect major developments over the next decade. Typical of studies to come are the types of experiment developed by Dr Suzanne Smith and coworkers at ANSTO and several researchers in universities (Associate Professor Jim Camakaris of The University of Melbourne and Professor Alan Sargeson of ANU). ^{64}Cu has a role to play in a number of cancers and other diseases such as Alzheimers and Parkinsons disease. By labelling proteins with ^{64}Cu and following reactions, pathways for copper metabolism can be followed.

^{64}Cu can also be attached to certain cage structures which themselves attach to antibodies which recognise, for example, colon cancer. This then delivers therapeutic radiation right to the cancer source.

CONCLUSION

AINSE is alive and well and its future looks bright. Given the current climate for research in Australia, plus the development of a new reactor, we can expect continuous development over the next decade.

ACKNOWLEDGEMENT

This paper has drawn heavily on the 1998 AINSE Annual Report. Examples of work supported by AINSE are drawn from this report. Readers may access full details of these projects using the list of publications contained in that report.

International and Local Trends in Nuclear Physics

PROFESSOR GEORGE DRACOULIS
Department of Nuclear Physics, RSPhysSE,
Australian National University Canberra ACT, 0200, Australia

SUMMARY Examples of basic Nuclear Physics research carried out at the Australian National University are outlined in the context of international trends, including the study of neutron-rich nuclei, nuclear isomers and heavy elements.

1 Introduction

The major accelerator-based nuclear research facility in Australia is operated by the Department of Nuclear Physics within the Research School of Physical Sciences and Engineering, in the Institute of Advanced Studies at the Australian National University.

The Department sees its primary roles as the conduct of research in Nuclear Physics which is competitive at an international level, the provision of postgraduate and postdoctoral training in experimental nuclear physics, the pursuit of innovative developments in application, and the maintenance and development of accelerator facilities and instrumentation for current and future research.

As such it supports a balanced programme which extends from studies of basic nuclear structure to the development and application of experimental technique to other scientific fields. It provides a major venue for research training for postgraduates and postdoctoral fellows, as well as facilities which are available to National and International users.

2 Research and Facilities

The accelerator capabilities are currently and forthe medium-term future squarely aimed at synthesis and reaction studies with heavy ions and heavy nuclei, at energies in proximity to the Coulomb barrier, from 4-10 MeV/nucleon.

The current research programme has as its main components:

- Fusion and fission dynamics with heavy ions
- Nuclear spectroscopy of exotic states
- Heavy ion reaction studies and nuclear clusters
- Nuclear moments and hyperfine fields
- Perturbed angular correlations and hyperfine interactions in materials
- Accelerator Mass Spectrometry - developments and applications
- Heavy ion elastic recoil detection for elemental analysis

Of the above, the study of cluster structures in nuclei is carried out largely by UK groups who have access under the auspices of an ANUEPSRC agreement. Most of the projects are to some extent collaborative, and also link in to experimental studies on overseas facilities. They involve colleagues from overseas, other Australian universities and institutions, other Research Schools within this institution, and other Departments.

Figure 1 shows the layout of the present laboratories which deliver a wide range of heavy ion beams to the experimental areas. The 14UD Pelletron, the centrepiece of the

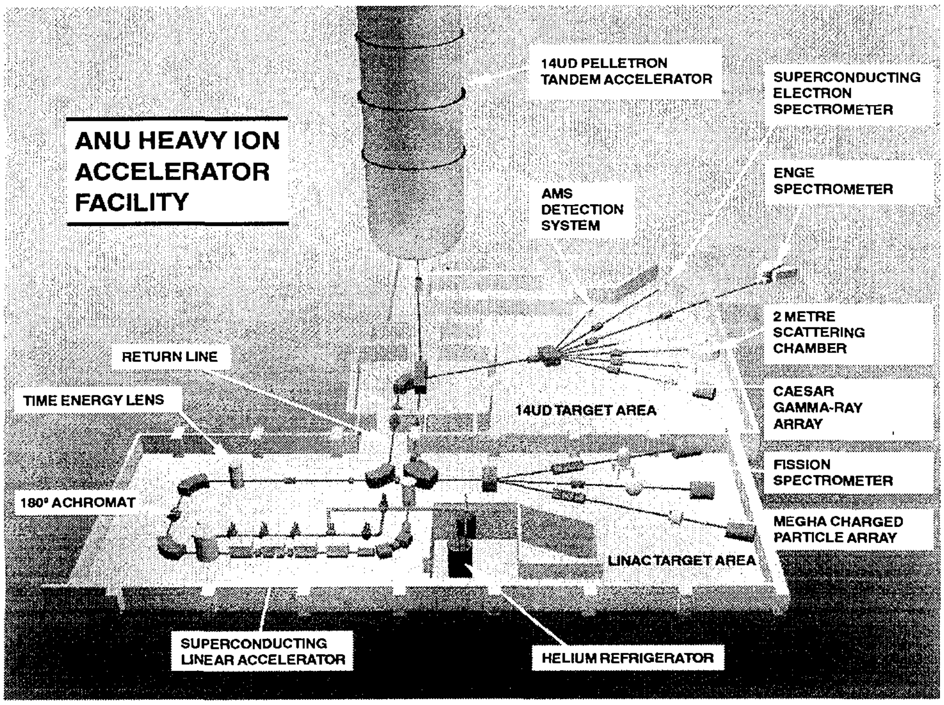


Figure 1: Layout of accelerators and beam-lines.

facility is coupled to a recently commissioned Superconducting Linear accelerator. Several other accelerators (some originally used for Nuclear Physics) are operated within the precincts by the Department of Electronic Materials Engineering, whose main research is in materials modification and characterisation.

3 Neutron-Rich Nuclei

A major direction in international research is the study of nuclei close to, and on the neutron-rich side of stability. This emphasis has emerged both because of the dearth of information on the neutron-rich side of the nuclear chart and because of predictions that new regimes of nuclear behaviour can be expected in the regions of the neutron drip-lines. One means of producing neutron-rich heavy nuclei which is currently being pursued, despite its non-selectivity, is inelastic and deep-inelastic scattering using very heavy beams such as ^{208}Pb and ^{238}U, at energies of about 6.5 MeV/nucleon, about 20% above the Coulomb barrier, on heavy targets. These reactions induce energy and mass transfer in both directions, resulting in the production and excitation of many nuclei. Only the increase in sensitivity provided by new γ-ray arrays such as *GAMMASPHERE* makes most of these feasible since channel selection is required. Therefore ANU efforts in this area mainly involve collaborations at Argonne National Laboratory and the Lawrence Berkeley Laboratory. Reaction studies with medium-weight beams such as ^{76}Ge aimed at both spectroscopy of isomers, where timing gives increased sensitivity, and the study of the reaction process itself, are planned for the ANU-LINAC. Similar developments in instrumentation have made the study of very neutron-rich, medium-weight nuclei produced in fission, feasible, despite the hundreds of species produced in these processes. (A local development in neutron-induced fission related to this area is outlined below.)

3.1 Rare Isotope Accelerators

The last decade has also seen a push towards producing accelerated beams of unstable nuclei (both neutron-deficient and neutron-rich). The focus is now shifting from a scenario where exotic light nuclei, such as ^{9}Li and ^{11}Li were produced in high-energy fragmentation reactions and studied for their intrinsic (and unusual) nuclear structure properties, to one where these products themselves can be produced with sufficient intensity to induce nuclear reactions. The *SPIRAL* facility at GANIL in France, for example, is at an advanced stage, with initial experiments later this year. It is the first of several European facilities mooted [1]. Beams from the Radioactive Ion Beam Factory are one component of extensive developments at RIKEN in Japan. In the USA, the National Research Council Commission on Physical Sciences, reiterated the role of Radioactive Ion Beams as a central component of future research [2]. The preferred technology identified by an NSAC task force is for multi-beam driver accelerators capable of accelerating ions from protons to uranium, at up to 400 MeV/nucleon. Depending on the application, rare beams will be produced by in-flight fragmentation, or by spallation in a thick target coupled to an ISOL-type source, and a post accelerator. This will be the basis for a large US national facility, to be constructed by about 2005. Australian involvement is at present, and probably for the foreseeable future, as users of the new capabilities. The ANU group for example, is involved in the first approved experiments at SPIRAL.

These will aim initially to use neutron-rich beams for fusion-evaporation reactions for the spectroscopy of nuclei in the mass-180 and trans-lead regions. These are areas of local expertise and they are also practicable, because of the high cross-sections – an important consideration given the low beam fluxes of $\sim 10^{9}$ particles/second, at best.

3.2 Incomplete Fusion Reactions

While the advent of such beams is likely to eventually change the face of such spectroscopy, *incomplete* fusion reactions already provide a window into some relatively neutron-rich nuclei at medium spins. These reactions can be viewed as break-up of the beam, say ^{9}Be, into an α-particle and ^{5}He in the Coulomb field. This fleetingly results in a ^{5}He beam which can proceed to fuse with the target. Detection of the α-particle can be used to select this reaction channel. Figure 2 shows the compact particle-detector system installed in the γ-ray array *CAESAR* developed to exploit these reactions.

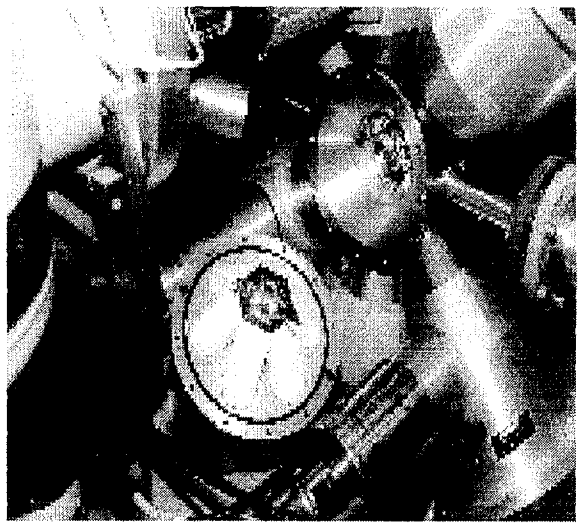


Figure 2: View of the Particle-Detector-Ball, inside CAESAR, the γ-ray array .

A recent example of our application of this technique was the identification [3] of the rotational band based on the 31 year, 16^{+} isomer in ^{178}Hf. A substantial part of the current local research program is aimed at using such reactions with relatively light projectiles to study medium to high spin states in deformed nuclei including nuclei of astrophysical interest, such as ^{180}Ta [4].

3.3 Neutron Beams and Fission

Up to now detailed spectroscopic studies of nuclei such as the neutron-rich krypton isotopes have been made solely on products of the spontaneous fission of ^{252}Cf and ^{248}Cm, and on products from the fission of ^{235}U induced by slow neutrons. However, fission of ^{238}U by neutrons with energies of a few MeV is expected to allow studies to be made on fragments with a higher neutron to proton ratio. In a recent development [5] we have demon-

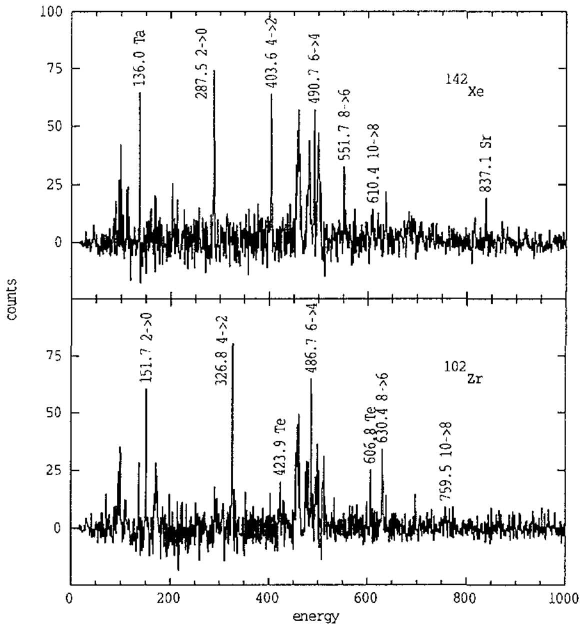


Figure 3: Summed coincidence spectra of γ-rays for ^{102}Zr and ^{142}Xe obtained in the first study of fast-neutron induced fission.

strated a new technique for the efficient production of a directed flux of neutrons capable of inducing fission, and for using that system to observe fission products. The arrangement uses high energy ^{7}Li beams from the 14UD to bombard a high pressure hydrogen gas target, producing an intense beam of neutrons, kinematically-confined within a narrow forward cone. The flux corresponds to more than 10^7 neutrons/second and is in the energy range (about 2.5 MeV) where the cross-sections for inducing fission on a ^{238}U foil situated in the centre of the CAESAR array, are large.

The first γ-γ-coincidence spectra obtained with such a technique are shown in figure 3 . These data were sufficient to establish the independent yields of secondary fragments from the fission of ^{238}U, confirming the predicted mass distribution, but not sufficient to define the spectroscopy of the more neutron-rich products. Higher sensitivity and channel selection through the use of *triple* γ-ray coincidences is one aim of a proposed enhancement of the γ-ray array.

3.4 Triple Concidences

The principal technique employed for nuclear spectroscopy is the measurement of two-fold γ-ray coincidences with the CAESAR detector array. This array consists of eight high-resolution detectors - six Ge detectors and two Low-Energy Photon (LEP) detectors for γ-ray detection. However, it has insufficient granularity and efficiency to measure γ-ray coincidences of fold higher than two. A proposal has been to developed to augment the array by incorporating four Compton-suppressed dual-detectors in the horizontal plane with the existing CAESAR detectors remaining in the vertical plane, as shown in figure 4.

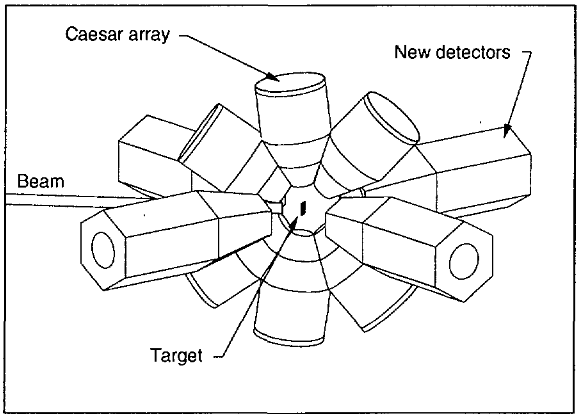


Figure 4: Schematic of the proposed layout

Calculated rates and sensitivities for typical cases with the CAESAR array with the additional detectors are such that the expected rates for *triple* coincidences match those previously obtained for dual coincidences, and there is an order of magnitude increase in sensitivity, allowing channels with yields as low as 10^{-4} of the main channel, to be identified.

3.5 Electron Spectroscopy

Parallel developments in an electron-detector system which will enable electron-electron coincidence studies are in progress. This system is to be installed in the superconducting solenoidal spectrometer (*SUPER-e*), which is used for the measurement of electron spectra, and is usually operated in Lens mode [6] . The measurement of conversion co-efficients is a powerful tool in the assignment of spins and parities to nuclear states. Furthermore, the conversion process dominates over low-energy γ-ray emission in very heavy nuclei.

4 Spectroscopy of Isomers

An area which is having a continuing impact is the discovery and characterisation of high-spin metastable states (isomers) in heavy nuclei. Those found include some of the highest-spin cases so far identified [7, 8].

Such states have well-defined orbital configurations which make them a strict test of nuclear models. The approach we have pursued is to identify the collective bands associated with the intrinsic (and often isomeric) states, as a way of probing the collective motion and particularly its relationship to the pairing which is the major short-range interaction controlling nuclear structure [9] .

The large suite of multiquasiparticle states now identified has resulted in improvements in model calculations (see [10]) so that the reliable prediction of favoured configurations in nuclei near stability is possible.

As well as providing a test of mean-field calculations and the potentials used to describe nuclear structure in detail, isomers may provide a means of energy storage, and if a fortuitous juxtaposition of nuclear states can be found, possibilities for controlled energy release or even γ-ray lasers [11].

4.1 Isomers and Energy Storage

In principle, low-energy ($\sim$eV) photons should be able to initiate isomer decay, either by stimulated emission to a nearby lower-energy state, or by stimulated absorption to a nearby higher-energy state. In either case, if the stimulated transition is to a short-lived energy level, a cascade of gamma-rays could be released, with a total energy of several MeV, a substantial nuclear reservoir with a photon "switch".

Such an idealised scenario (and possibly fanciful) has not yet been realised. In the search for stimulated transitions, the isomers studied to date have mostly been at low energies (on the nuclear scale). The 45 hour isomer in ^{229}Th, at an excitation energy of 3.5 eV is a special case since it is a nuclear excitation on an energy scale similar to that of atomic transitions, however stimulation of the 3.5 eV transition would release no additional energy.

Isomers at excitation energies of keV or MeV occur usually when a favoured nuclear configuration falls at lower energy than states of similar spin, (or K-projection), hence their decay path is severely limited. At face value, the use of eV photons to stimulate nuclear transitions requires one or more nuclear states to lie within a few eV of the isomer. For low-lying isomers, where the density of states is low, this presents a general problem. For highly excited isomers with energies of several MeV, the isomers can become embedded in a high "statistical" density of excited states so the "chance" of a near-degeneracy becomes a certainty. Notwithstanding this certainty, the isomer would most likely have very different angular-momentum quantum numbers from the background states, otherwise it would not be an isomer in the first place. Hence both the recent interest in stimulated de-excitation of specific cases [12, 13] and the search for new cases in neutron-rich deformed nuclei where many isomers are predicted to occur, for nuclear structure reasons.

5 Fission and Fusion studies

The synthesis of new nuclei is a central element of current and future research but it depends increasingly on a detailed understanding of the process of fusion of heavy nuclei and the subsequent probability for survival against competing processes such as fission. A major effort in this laboratory is the study of fission and fusion. The ANU studies have led to a significant change in the understanding of the fusion process and specifically the unexpected sensitivity near the Coulomb barrier to the structure of the projectile and target nucleus [14].

5.1 Fusion Barrier Distributions

The new understanding has come by treating fusion in the context of barrier distributions [15]. To fuse, nuclei have to tunnel through the fusion barrier, the residue of the sum of the long-range repulsive electrostatic and short-range attractive nuclear forces. However, excitation of other nuclear degrees of freedom (e.g. rotation, vibration) of the target or projectile, results effectively in a distribution of fusion barrier heights.

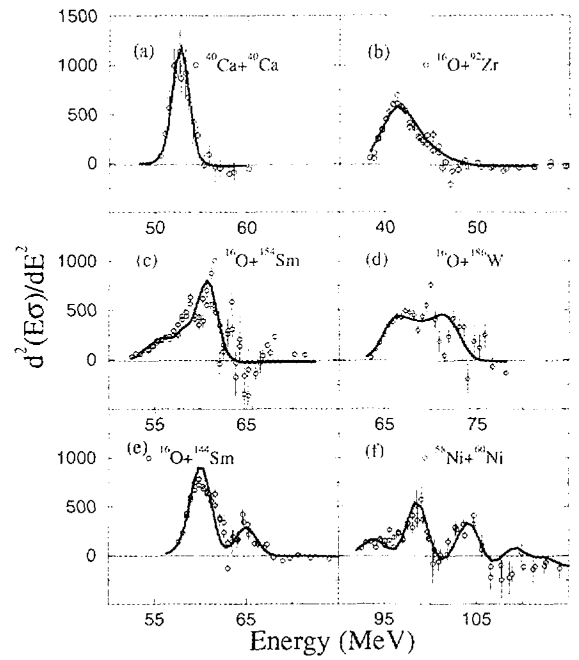


Figure 5: Barrier distributions for a number of systems compared to calculations [16].

To see these effects, reduction of a cross-section/energy product through the second differential is carried out, hence measurements of unprecedented accuracy are required. Some of the results are shown in figure 5 [16] which compares data with calculations which use quantal tunnelling.

The structure in the barrier distributions is a fingerprint of the underlying nuclear structure of the fusing nuclei. The phenomena range from a single peak for the spherical-spherical case, ^{40}Ca on ^{40}Ca; through complex distributions characteristic of deformed rotors, to a two-barrier structure for ^{16}O on ^{144}Sm which involves 2^+ and 3^- phonon couplings.

Depending on the *nuclear* structure, the effective barriers can be moved down in energy substantially compared to the nominal barrier position. This has clear implications for optimising fusion leading to a particular compound nucleus given that even small shifts in the barriers can have order of magnitude effects on the cross-section – a proposition which may be particularly significant for the production of exotic nuclei such as superheavies. The recent synthesis of very heavy elements (e.g. [17]) has stimulated this pursuit which is one of the areas projected for study with a new superconducting solenoid to be commissioned for use with the LINAC.

References

[1] *Nuclear Physics in Europe: Highlights and Opportunities* NuPECC Report, Dec. 1997

[2] *Nuclear Physics, The Core of Matter, The Fuel of Stars* National Academy Press (Washington) 1999

[3] S.M.Mullins *et al* Phys. Lett. B **393**(1997)279

[4] G.D.Dracoulis *et al* Phys. Rev. C. **58**(1998)1444

[5] W.R.Phillips *et al*, Euro. J. **A3**(1998)205

[6] T.Kibédi, G.D.Dracoulis and A.P.Byrne Nucl. Instr. Meth. in Phys. Res. **A294**(1990)523

[7] G.D.Dracoulis *et al* Phys. Lett. **B246**(1990)31

[8] A.P.Byrne *et al* Phys. Rev. C **42**(1990)R6

[9] G.D.Dracoulis, F.G.Kondev and P.M.Walker Phys. Lett. **B419**(1998)7

[10] Kirain Jain *et al* Nucl. Phys. **A 591**(1995)61

[11] *Energy traps in atomic nuclei*
P.M.Walker and G.D.Dracoulis
Nature **399**(1999)35

[12] *Accelerated Emission of Gamma Rays from the 31-yr Isomer of ^{178}Hf Induced by X-Ray Irradiation*
C.B. Collins *et al* Phys. Rev. Lett. **82**(1999)695

[13] *Photoactivation of $^{180}Ta^m$ and its Implications...*
D. Belic *et al* to be published

[14] M. Dasgupta *et al* Annu. Rev. Nucl. and Part. Sci. **48**(1998)401

[15] N. Rowley, G.R. Satchler and P.H. Stelson Phys. Lett. B **245**(1991)25

[16] N. Rowley in Sub-Barrier Fusion of Heavy Ions; Proc. Int. Conf. on Low-Energy Nuclear Dynamics, St. Petersburg, Russia, 18-22 April 1995

[17] V. Ninov *et al* Phys. Rev. Lett. **83**(1999)1104

Fusion Energy for the 21st Century

PROFESSOR J. H. HARRIS
Plasma Research Laboratory, RSPhys SE
Institute of Advanced Studies
The Australian National University, Canberra, ACT, 0200

SUMMARY. Fusion reactions like those that power the stars have the potential of providing bulk electricity generation with reduced emissions and low radioactive hazard, but pose many challenges in physics and technology. The H-1 Heliac Major National Research Facility now being developed offers Australian scientists and engineers an opportunity to participate in the collaborative international fusion research program. Work on H- INF contributes not only to the realisation of fusion power, but offers the stimulus and opportunity for advanced training and the development of spin-off technology.

1. Introduction.

Nuclear fusion, in which light elements in an ionised plasma combine to form heavier elements, is the ultimate source of energy in the universe, as it powers stars. Research to develop a terrestrial fusion reactor has been pursued since the 1950s in laboratories all over the world, including Australia. Fusion is attractive as a means to generate bulk electricity with low greenhouse gas emissions and low radioactive waste hazards, as its fuel cycle is based on hydrogen isotopes found in water, and fusion confinement devices have intrinsically lower stored fuel in the reacting core.

Conditions for fusion-temperatures of 10 keV (100 million degrees C), densities of 10^{14} particles/cm3, and energy confinement times of the order of 1 second-are difficult to achieve. Nevertheless, recent experiments on large toroidal magnetic fusion devices in the US, Europe, and Japan have demonstrated plasma conditions like those in a reactor. But much further work is needed to develop toroidal magnetic confinement schemes that are attractive for commercial reactor applications, and fusion power reactors could become available sometime toward the middle of the 21st century. This is the time scale over which for climate effects and electricity supply problems are expected to become serious. In this situation, the present carbon-dominated production of electricity (Fig. 1) cannot be sustained. Australia has participated in fusion research with small, and Australian scientists have longfundamental experiments in universities for many years, worked on large fusion experiments all over the world.

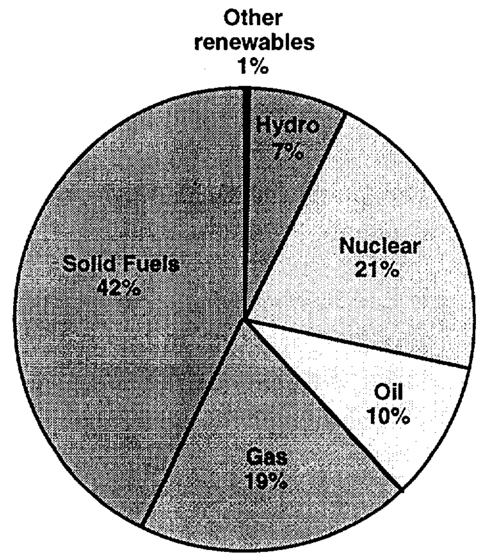


Fig. 1. Primary fuel consumption required to generate the world's electricity supply. Data for 1995 from International Energy Agency, available at *http://www.iea.org/*.

In the 1995 Major National Research Facility funding round, the ANU and the Australian Fusion Research Group (AFRG) won $8.7M to develop the H-1 toroidal heliac experiment at the ANU Research School of Physical Sciences and Engineering into the National Plasma Fusion Research Facility. This funding is being used to build up the capabilities of H- 1 to allow Australian researchers to make world-lcass contributions to fusion research.

The AFRG is an organisation of six university research groups from around Australia acting under the umbrella of the Australian Institute for Nuclear Science and Engineering (AINSE). The Group was formed in late 1994 with the specific aim of consolidating fusion research in Australia on the large Heliac device at the ANU. The AFRG acts with AINSE to coordinate national collaboration on the Heliac, now recognised as an AINSE facility for the purpose of AINSE Research Grants. At present the AFRG has participating members from the Australian National University, Central Queensland University, Flinders University, University of Canberra, University of New England and University of Sydney.

2. The H-1NF Device.

The H-1NF Heliac (shown with the vacuum tank removed in Fig. 2) is a medium sized device from the Stellarator family of toroidal confinement devices. These devices use external conductors to produce the helically-twisted toroidal field needed to confine plasma particles. They are closely related to widely studied Tokamak, in which part of the helical field is produced by an induced plasma current, but have the advantage of steady-state operation without current-driven plasma instabilities that can disrupt the plasma column.

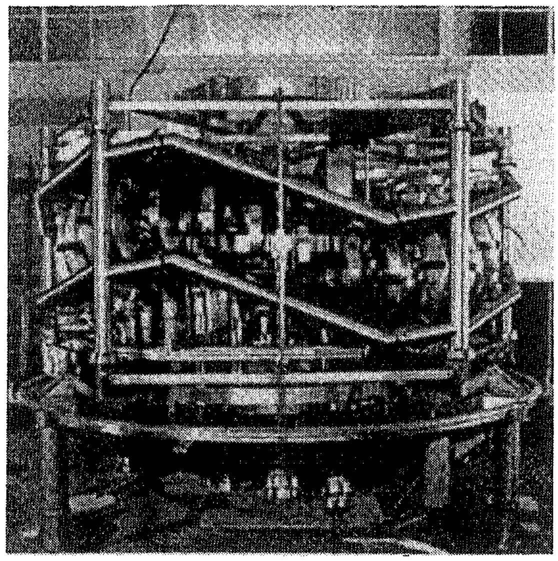


Fig. 2. H-1NF with the vacuum vessel removed.

There are many specific configurations which use variations on these helical fields. These include a number of *heliotron* and *torsatron* systems developed in Japan (and sometimes referred to together as *helical systems*), *advanced stellarators* developed in Germany, and helical-axis systems called *heliacs* which have been studied in Australia, Spain, the US, and Japan.

The H-1NF device[1] has been operational at low powers for some three years and has already produced some notable papers.[2,3] The MNRF funding is being used to upgrade the machine systems to higher power levels to allow access to higher plasma temperatures and densities enabling research into the stability and confinement of fusion relevant plasmas.

The Heliac design has a helical toroidal axis, motivated by theoretical studies indicating that such plasmas will have good stability properties at high values of plasma pressure. The strong breaking of axisymmetry, combined with a highly non-circular plasma cross section, means that designing a heliac requires a theoretical effort combining the development of new analytical tools and advanced computational methods. The H–1NF device parameters are shown in Table 1.

Major Radius:	$R = 1.0$ m
Avg. Minor radius:	$\langle a \rangle = 0.2$ m
Toroidal Field:	$B_T < 1.0$ T (< 0.2 T DC)
RF Heating:	4-26 MHz 500 kW
Microwave Heating:	28 GHz, 200 kW
Vacuum Vessel:	Diameter = 4 m Height = 4 m
Gas Feed:	Ar, H, He and Ne < 300 Torr-l/s

Table 1. Parameters of the H-1NF device.

The resulting plasma has a bean-shaped cross section and a helical axis with 3 periods about the major axis as shown in Fig. 3. Although this geometry seems rather complicated and difficult to model; most of the coils can be circular, which greatly simplifies construction. There is a central conducting ring coil, and simple circular toroidal field coils arranged, offset, around the ring to generate the plasma shape shown in Fig. 3. An additional helical winding is wrapped around the central ring coil. The major constructional difficulty in this geometry is the threading of the central current conductor through all the toroidal coils and the accurate positioning of the components.

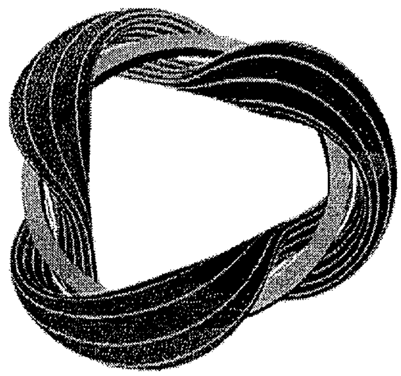


Fig. 3. The H-1NF helical-axis plasma.

The main advantage of this geometry is that it offers good physics properties with relative ease in construction. It is flexible[4] in that changing the relative currents in the various coil sets can vary the magnetic geometry. From a physics point of view, the geometry has an inherent "magnetic well" that has a stabilising influence on the plasma. Theoretical studies of a linear Heliac model have shown that high normalised plasma pressures $\beta = p/(B^2/2\mu_0) \approx 30\%$ can be stably confined. Values of $\beta \geq 5\%$ are needed for an attractive fusion reactor, and the pressure limit in a toroidal heliac is expected to be set by pressure-driven "ballooning" instabilities which cause the plasma energy to leak across the magnetic field to the wall.

The H-1NF device was designed using state-of-the-art, three-dimensional, computer design tools, and the magnets and supporting structure were constructed and assembled with component location tolerances of ±1 mm using the facilities available in the Research School of Physical Sciences and Engineering at the Australian National University.

3. Research Program.

The facility objectives are fourfold:

- To provide a high temperature plasma National Facility of international standing on a scale appropriate to Australia's research budget.
- To provide a focus for national and international collaborative research, to make significant contributions to the global fusion research effort and to increase Australia's presence in the field of plasma fusion power into the next century.
- To gain detailed understanding of the basic plasma physics of hot plasma confined in the helical axis Stellarator configuration.
- To develop advanced plasma and fusion measurement systems, integrating real-time processing and multi-dimensional visualisation of data.

The first two of these objectives emphasise national and international collaboration. Such collaboration is already well under way in the form of the AFRG nationally and in the formal agreement between H-1NF and the Japanese National Institute for Fusion Science (NIFS), which operates the very large LHD fusion experiment.

Connection to larger research programs abroad is important because H-1NF itself is designed for fundamental physics experiments and not for "parameter pushing" to temperatures and densities where fusion power is actually produced. H-1NF will be used to gain understanding of the fundamental physics of plasma (particle and energy) transport and confinement in the Heliac geometry as well as a test bed for the development of advanced diagnostics for which Australian plasma physicists are justifiably renowned. Collaboration with large programs outside Australia gives Australian researchers opportunities to apply their ideas and equipment on large machines with reactor-grade plasma parameters.

The facility has three regimes of operation that depend broadly on the plasma heating used. Scheduling of experimental work in these different regimes depends therefore on the installation program of the different heating systems:

- High-temperature plasma heated by Electron Cyclotron Heating (ECH). Only fixed frequencies are available (28 GHz) which restricts operation to high field (0.5 to 1.0T)and hence moderate plasma pressure.
- High-pressure plasma heated by high power RF in the MHz range giving moderate temperatures and high densities and thus higher beta.
- Low-temperature plasmas in the edge of the discharge, an important region where probes can be used. Experiments carried out in this regime link well to studies of the plasma processing of materials that are carried out in Australia.

These different operating regimes will support investigations in the following research areas:

- Finite pressure equilibrium and stability
- Transport in high temperature plasmas (~500 eV)
- Plasma heating and formation
- Instabilities and turbulence
- Edge plasma physics
- Advanced diagnostic development.

4. International Collaboration

The most developed international collaboration for H-1NF is with the Japanese fusion research program. The National Institute for Fusion Science (NIFS) in Toki operates the medium-sized (R = 0.9 m), the CHS (Compact Helical System) experiment, and is constructing a large (R = 4 m) experiment, the LHD (Large Helical System), which is the largest magnetic fusion experiment in the world. Kyoto University operates the Heliotron-E experiment (R = 2.2 m) and is designing a new device that is related to H-1NF by virtue of having a strongly helical magnetic axis.

NIFS and Kyoto University have joined together to collaborate with the Australian fusion program by loaning a 28 GHz gyrotron for use in electron-cyclotron heating experiments on H-1NF. This system, which is worth about A$1 M, has been installed and tested at the ANU, and awaits the upgrade of the H-1NF magnetic field system to be used in plasma experiments. Japanese researchers will also contribute to the planning and analysis of heating experiments on H-1NF.

NIFS and Australian fusion researchers are also collaborating on diagnostics for LHD and H-1NF, low frequency plasma heating, equilibrium, stability, and transport theory, and 3-D computation. Australian researchers also collaborate on the theory and design of new stellarator configurations and plasma diagnostic development with scientists at the Princeton Plasma Physics Laboratory in the US.

5. Recent experimental results

During the low-temperature phase of operation before the magnetic field and heating power, the temperature and energy content of the H-1NF plasma are low enough that small metal probes can be inserted into the plasma. By measuring the current-voltage characteristics of these probes, the plasma density, temperature and electric field can be determined.

Experiments on H-1NF in this regime have already revealed interesting plasma confinement phenomena. For discharges in which the magnetic field exceeds a critical value that depends on the pressure and the magnetic configuration, the density suddenly increases by a factor ~2, the profiles of density and electric field change (Fig. 4), and the energy of the ions increases. The outward transport of particles due to plasma turbulence decreases. This is evidence of a transition to an improved mode of plasma confinement; one model for this transition involves reduction of turbulence and transport due to shear in the plasma drift induced by the radial electric field. Such transitions are of critical interest in magnetic fusion research because improvements in confinement directly affect the overall size (and therefore cost) of a magnetic fusion reactor that produces electric power. Typically, the transitions to improved confinement occur in large devices with megawatts of heating power.[5] In H-1NF, qualitatively similar regimes can be attained at low powers ~50 kW and low temperatures, which permits detailed measurements with relatively simple diagnostics.

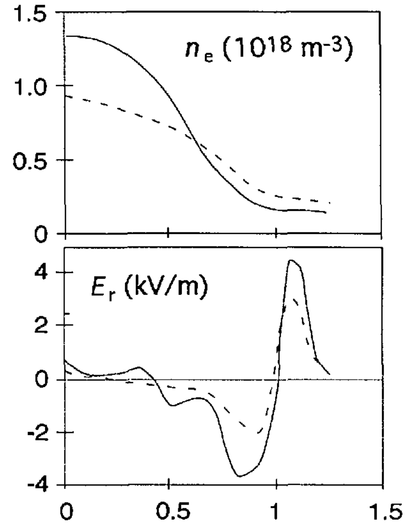


Fig. 4. Radial profiles of plasma density (n_e) and radial electric field (E_r) in an H-1NF plasma. Profiles taken before (dotted) and after (solid) transition to improved confinement.

6. Industrial connections and spin-offs.

The many technical problems that must be solved in doing fusion experiments provide a stimulus to develop new techniques and instruments that can be applied in other fields. Historically, the most important spin-offs have been in the areas of computation and the plasma processing of semiconductors, but fusion experiments also offer opportunities in the areas of high vacuum technology, power engineering, communications, and instrumentation and remote sensing.

The capital program to improve the capabilities of H-1NF has resulted in considerable R & D contracting with Australian industry. The new magnetic field power supply, a 14 MW unit using the latest in computer controlled switching technology, was built by an industrial consortium consisting of ABB-Australia, Transformer Mfg. Co, Ltd, CEGELEC, ACTEW, and several smaller companies, and has a net contract value of over $2M. Installation of new plasma heating equipment was carried out by the Australian subsidiary of British Aerospace for ~$300,000. Smaller contracts for modifications to the vacuum vessel and to the experimental hall were executed by Cowan Engineering, Ltd. and Pierson & Sullivan, Ltd, respectively.

In 1998, two spin-off activities developed as a result of research on H-1NF. A new electro-optically modulated solid-state spectrometer (MOSS) was developed for the measurement of line emissions from excited species in plasma discharges. This device is much smaller, more rugged, and less expensive than the spectrometers typically used for these measurements, and has potential commercial applications in semiconductor materials processing, plasma chemistry, and related fields. An industrial version of the MOSS is being developed and marketed by Australian Scientific Instruments Pty Ltd.

Members of the H-1NF team worked with the Defence Science and Technology Organisation (DSTO) in Salisbury to develop schemes for using plasma tubes (Fig. 5) as antennas in the HF through UHF frequency ranges. These antennas have the advantage of low radar cross section when not in operation, and may make possible the development of novel directional arrays for communications and radar use. Under the aegis the Rapid Engineering Development Centre (REDcentre), we are exploring possibilities for commercial development of this concept in collaborative efforts with three companies from the Canberra-Sydney area.

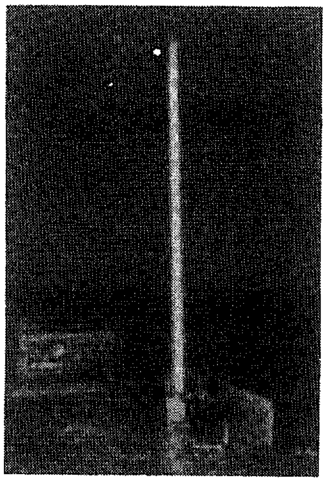


Fig.5 Prototype plasma antenna constructed with fluorescent tube.

7. Conclusions.

The Australian fusion program is centred around the H-1NF heliac, an innovative and flexible experimental facility located at the ANU. Promising experimental results are being obtained in low-power operation, work to increase the heating power and magnetic field is under way, and a network of research collaborations involving Australian and overseas scientists is being developed. Work on H-1NF has already produced several inventions whose commercial exploitation is being pursued.

Further information concerning the H-1 National Facility and the AFRG collaborative research can be found on the World-Wide Web at:

http://rsphysse.anu.edu.au/prl/

References

1. S. M. Hamberger *et al*, Fusion Technol. **17** (1990) 123.
2. M. G. Shats *et al*, Phys. Rev. Lett. **77**, 4190 (1996).
3. M. G. Shats *et al*, Physics of Plasmas **6,** 2390 (1998).
4. J. H. Harris *et al*, Nucl. Fusion **25**, 623 (1985).
5. F. Wagner *et al,* Phys. Rev. Lett., **49** 1408 (1982).

AU0019545

The Replacement Research Reactor

RON CAMERON, Australian Nuclear Science and Technology Organisation
PMB 1 Menai, NSW 2234

Summary : As a consequences of the government decision in September 1997, ANSTO established a replacement research reactor project to manage the procurement of the replacement reactor through the necessary approval, tendering and contract management stages. This paper provides an update of the status of the project including the completion of the Environmental Impact Statement, Prequalification and Public Works Committee processes. The aims of the project, management organisation, reactor type and expected capabilities are also described.

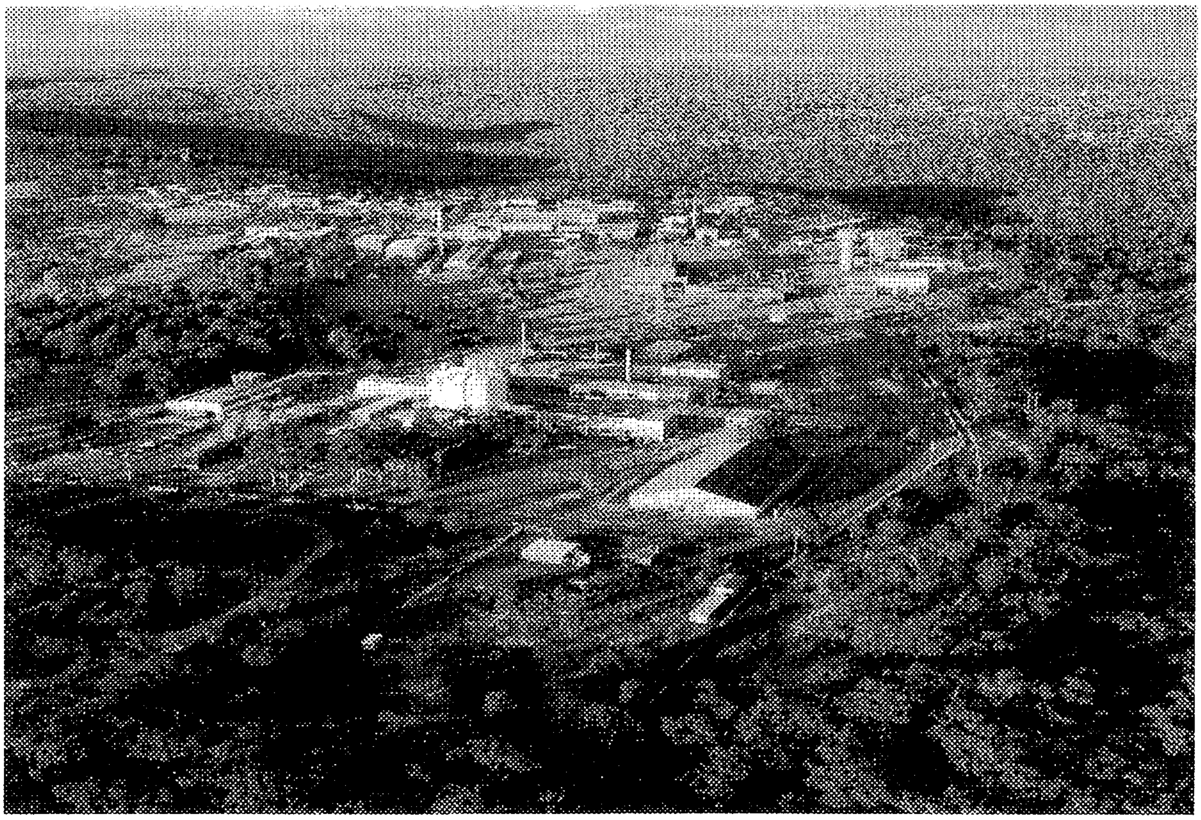
1. INTRODUCTION

On 3 September 1997 the then Minister for Science and Technology announced the proposal to fund ANSTO to construct a replacement research reactor at Lucas Heights. This reactor is to replace the 40 year old, technologically obsolete HIFAR which is expected to reach the end of its operational life around 2005. The Minister stated that the proposal will meet the strictest international nuclear safety standards and its construction would be subject to a stringent environmental assessment process under the Environment Protection (Impact of Proposals) Act 1974, which will be open to public comment (McGauran, Hon. P. 1997 (1)). At the same time, the government announced the intention to establish the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and to provide funding for removing spent fuel from Lucas Heights for reprocessing overseas.

The purpose of the replacement research reactor is to replace the technologically obsolete HIFAR and to provide the Australian medical and science community and industry with access to a modern, multi-purpose reactor with the performance and facilities necessary to maintain and enhance Australia's nuclear science and technology capabilities across the range of defined needs. The specific objectives of the proposal are to:

- maintain and enhance health care benefits provided to the community and ensure security of supply through the local production of the quantities and the known likely range of diagnostic and therapeutic radiopharmaceuticals needed to satisfy Australia's requirements over the next 40 to 50 years;
- maintain Australia's nuclear technical expertise in order to provide sound advice to Government in support of nuclear policy issues of strategic national interest and its international obligations in this area;
- provide a neutron beam research facility which would not only meet Australia's own scientific and industrial research needs, but would also be a regional centre of excellence. Research undertaken using this facility will have broad applications to investigations in a wide spectrum of scientific and industrial fields, including the life sciences and medicine, environmental science, chemistry, materials science and engineering science;
- provide research and research training facilities and programs to enhance the educational opportunities available to Australian scientists and engineers;
- provide industrial isotopes and facilities for neutron activation analysis, irradiation of materials, and neutron radiography to service the needs of agriculture and industry, particularly in the electronics, environmental, resource and minerals processing industries; and
- achieve the construction and operation of the facility in a manner that meets all health, safety, environmental and quality standards. This includes meeting community expectations as well as all legal and regulatory requirements and applicable standards.

To meet these objectives it is proposed to construct and operate a replacement research reactor at the Lucas Heights Science and Technology Centre site in Lucas Heights, located 30 kilometres south-west of Sydney's central business district. The replacement reactor would be located near the existing HIFAR as shown on Figure 1.



To achieve these objectives. ANSTO established the Replacement Research Reactor Project (RRRP) to manage the procurement process. to liaise with users of the facility and to oversee the required approval stages. The project was split into three phases.

2. PHASE 1

Phase 1 is the approvals stage. including the EIS development. the site licence application. the Public Works Committee process. the prequalification of reactor vendors and the development of the tender documents.

2.1 The EIS

The Draft EIS was produced and submitted to Environment Australia on 18 August 1998. There followed a 12 week public exhibition period. during which EA commissioned three independent reviews of the EIS from the IAEA. CH2M Hill and Parkman of the UK. Major conclusions of the technical reviews include:

"*On the basis of the available written information, discussion with key parties as well as the brief site visit, it can be concluded that the site for the proposed reactor has no negative characteristics which would make it unacceptable from a nuclear or radiological safety point of view.*" (International Atomic Energy Agency 1998 (2))

"*The report concludes that the Risks and Hazards assessment for the EIS has been carried out using currently accepted methodologies and internationally verified computer codes. The Reference Accident has been selected and analysed in detail, and is judged to be appropriate for bounding any fault that can occur on a well designed reactor system.*" (Parkman Safety Management 1998 (3))

"*In Summary, CH2M HILL concludes that radiological impacts of the proposal, as described in the DEIS, are minimal and of no significance to the public. All discharges are well below regulatory limits, as would be expected for a modern pool reactor.*" (CH2M HILL 1998 (4))

Nine hundred and thirty-five submissions were received by Environment Australia during and immediately following the 12-week Draft EIS exhibition period. Of these. some 776 submissions were pro-forma submissions. A further 50 submissions were either pro-forma based or repeated issues contained in pro-formas. Substantive submissions included technical submissions from Sutherland Shire Council. from Greenpeace Australia. from the three Peer Review Consultants and from the NSW Government (via the Department of Urban Affairs and Planning). *Figure 2* shows submissions by area and type.

A Supplement to the Draft EIS was produced, taking into account all submissions, and lodged with Environment Australia in January 1999. Environment Australia evaluated the EIS and the Minister for Environment and Heritage gave approval in April 1999 with 29 recommendations, which were accepted by the Minister for Industry, Science and Resources.

2.2 Site Licence Application

Before any work can commence on the site, it is necessary to obtain a Facility Licence, Site Authorisation from the CEO of the Australian Radiation Protection and Nuclear Safety Agency. This licence application was based on a detailed characterisation of the features of the proposed site and an evaluation of a reference accident, as a bounding case to all credible accidents with a pool type reactor. The application was submitted in April 1999 and a response is expected shortly.

2.3 Parliamentary Public Works Committee

All major government funded capital programs are required to gain the approval of the Public Works Committee (PWC). The ANSTO project was referred to the PWC in February and public hearings were held in May. The report from the PWC was tabled in parliament in late August (5). The report concluded that, *"provided all recommendations and commitments contained in the Environment Assessment Report are implemented during construction and commissioning and for the expected life of the research reactor, the Committee believes, based on the evidence, that all known risks have been identified and their impact on public safety will be as low as technically possible"*. On that basis, "The Committee recommends the construction of a replacement research reactor at Lucas Heights at an estimated cost of $286.4 million at 1997 prices".

2.4 Prequalification

As part of the tendering process, a prequalification of reactor vendors took place in 1998. This was designed to prequalify experienced reactor vendors with capabilities in delivering an integrated pool type reactor facility. As a result of this process, four reactor vendors were prequalified. These were:

- AECL from Canada
- INVAP from Argentina
- Siemens from Germany
- Technicatome from France.

These companies will take part in the main tendering stage.

2.5 Tender Documentation

The specification of the requirements for the replacement reactor was an iterative process involving extensive discussions with reactor users and study of the capabilities of reactors overseas. A Beam Facilities Consultative Group was formed involving major neutron beam users to identify their requirements. Discussions were also held with medical and industrial radioisotope users and other industrial users to understand their product needs now and in the future. This resulted in a set of requirements for beams and irradiation facilities.

Staff from ANSTO and a range of consultants, both from Australia and overseas, worked to translate these requirements in specifications that could become part of the tender documents.

The process has been designed to provide transparency and probity throughout and the Australian Government Solicitor has performed probity audits at all significant stages.

The tender documents were finalised after the completion of the approval stages, taking into account the findings and recommendations from the Minister for Environment and Heritage and the PWC.

3. PHASES 2 AND 3

Phase 2 of the project relates to the tender issue, evaluation and award of the contract. It is expected that this process will take approximately 10 months.

Phase 3 is the design, construction and commissioning of the reactor. The contract will be let as a turn-key contract so that the successful tenderer will be required to deliver against the specifications and ANSTO will manage the contract against the agreed milestones. The commissioning process, after fuel loading, will be performed by ANSTO with assistance from the Contractor, as this requires a separate licensing authorisation.

Following successful commissioning there will be a requirement to operate both reactors for a period long enough to allow transfer of the isotope production to the replacement reactor. Following this, HIFAR will be shut down and eventually decommissioned.

During phases 2 and 3, there will be a separate project to develop and eventually install a suite of neutron beam instruments in both the Reactor Hall and the Neutron Guide Hall.

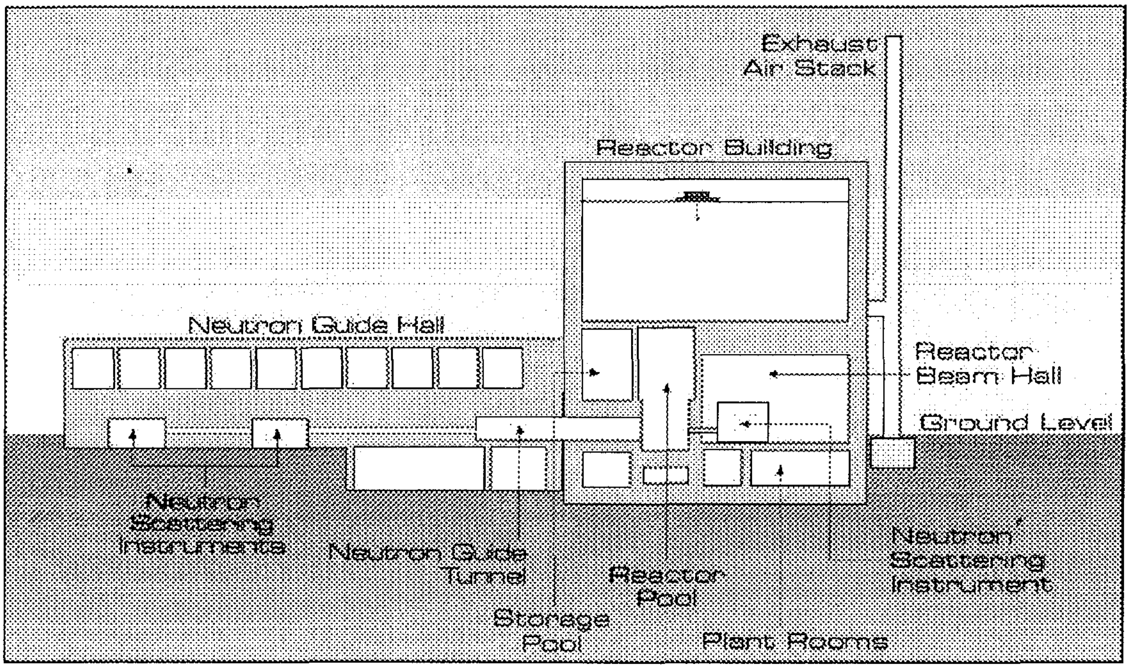


Figure 3 Typical vertical section of reactor building and neutron guide hall

4. TYPE AND CAPABILITIES OF THE REPLACEMENT REACTOR

The reactor will be a pool reactor, in contrast to HIFAR which is a tank type reactor. This maximises the inherent safety features, since the core is contained in a large pool of water and operations with fuel are more accessible and visible. Some comparisons between the reactors are shown in Table 1.

	HIFAR	RR
Type	tank	pool
Power	10-15 MW	Up to 20MW
Core	Loose array	Compact
Fuel	High enriched	Low enriched
Coolant	Heavy water	Light water
Reflector	Heavy water	Probably heavy water
Neutron beams	Thermal	Thermal, cold and provision for hot
Peak neutron flux ($ncm^{-2}s^{-1}$)	1×10^{14}	3×10^{14}
Guide hall	No	Yes

The main uses for the reactor are in neutron beam research, radioisotope production and irradiation services.

4.1 Neutron Beams

The reactor will have a separate guide hall to allow experimenters access to the beam guides without needing access to the reactor area. Figure 3 shows a schematic of the type of design possible and Figure 4 shows a possible arrangement for the instruments in the guide hall. HIFAR has only thermal neutron beams but the replacement will allow thermal and cold neutron beams and have provision for a hot source. This significantly widens the type of research possible and allows research into polymers and biological molecules.

Eight neutron beam instruments are planned for the replacement reactor when it is commissioned in 2005. ANSTO expects to add more within 5 years. These instruments comprise diffractometers, small angle scattering instruments, reflectometers, spectrometers and neutron radiography.

4.2 Irradiation facilities

The two main applications of radioisotopes are in production of nuclear medicine and in industrial services. A steady increase in demand for nuclear medicine is predicted. The Commonwealth Department of Health and Aged Care has estimated growth at around 14% per year over the next 10 years. The replacement reactor will provide a

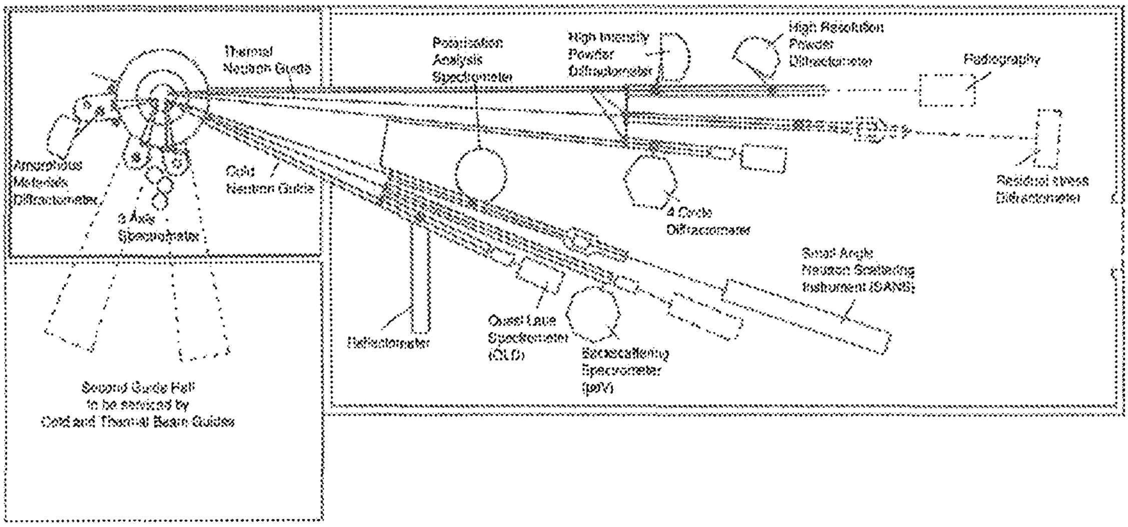


Figure 4 Typical arrangement of neutron beams in the guide hall

significantly larger volume for irradiations, including the capability to expand molybdenum production by a factor of up to four over current production. Additional benefits would also be derived from the development of new radiopharmaceuticals, including the emerging therapeutics, and drug delivery systems. New radiopharmaceuticals designed to provide a greater understanding of, and improvements to, the diagnosis of neurological disease and cancers are being produced.

Industrial isotopes are widely used in, for example, measuring flow rates in power stations, monitoring sewage and pollution movements offshore, measuring wear in engines and groundwater flow detection. In addition, they are used in radiography and sterilisation . Neutron activation analysis is also growing as a non-destructive technique for measuring trace element concentrations of a wide range of industrial, geological, biological and environmental samples. The replacement reactor will provide greater capacity for production of such isotopes.

5. CONCLUSIONS

The replacement reactor offers a greatly enhanced capability for a wide range of applications of neutron beams and irradiation facilities. The pool type reactor will have many inherent safety features such that there will be no need for any intervention, even in the event of a severe accident, outside the buffer zone.

The project has received approval from the Minister for Environment and Heritage and from the Public Works Committee. It has now entered phase 2.

6. REFERENCES

1. McGauran, Hon P (1997) *Nuclear Reactor Replaced*, Media release, Minister for Science and Technology, September 1997
2. IAEA, *Review of the Draft Environmental Impact Statement for the Replacement Research Reactor*, September, 1998
3. Parkman Safety Management, *ANSTO Replacement Nuclear Research Reactor EIS: Peer Review of Hazards and Risks*, September 1998
4. CH2M Hill, *Report to Environment Australia: Replacement Reactor Draft EIS Technical Review*, September 1998
5. Parliamentary Standing Committee on Public Works, *Report on the Replacement Nuclear Research Reactor, Lucas Heights, NSW*, August 1999.

AU0019546

Opportunities for Ranger and Jabiluka

K.M. OXNAM – Director Jabiluka, Energy Resources of Australia Ltd

SUMMARY

The processing of ore from ERA's Ranger mine will be completed before 2009, so the development of the Company's Jabiluka project is vital to its future. In order to achieve the Company's aim of utilising the Ranger mill to process the Jabiluka ore ERA is looking at innovative ways of furthering community relationships and responding to the needs of its major stakeholders, particularly the local Aboriginal landowners. The Jabiluka development has been a trigger for ERA to reconsider the way it does business in order to meet expectations of the community while maintaining financial viability.

1. INTRODUCTION

Jabiluka has been an issue of media and public interest since the late 1960's and more recently since the preparation of an EIS for the development of the mine by ERA in 1996.

The adjoining Ranger mine was also the focus of attention in the 70s and was brought on-line in 1980. With nineteen years of successful operation, independently scrutinised for environmental impact, Ranger has won the right for public acceptance.

It is what lies ahead for Jabiluka and the long term future of ERA which is perhaps of most interest and is the focus of this paper.

Energy Resources of Australia (ERA) has recently been reviewing what is required to bring Jabiluka successfully into production. What ERA means by successful production is having an operation which meets, and if possible exceeds, the expectations of local Aboriginal communities, the Government, shareholders, concerned community groups, employees and our customers.

2. HISTORY

ERA commenced operations at Ranger in the Northern Territory in 1980 (See Figure 1 - Location Map). The Ranger operation consists of two open pits, Ranger #1 (mined out in 1994) and Ranger #3 (mining commenced in 1997) and a processing plant capable of producing 6,000 tonnes of U_3O_8.

In 1991 ERA purchased the Jabiluka deposit from Pancontinental for $125 million. Pancontinental had been denied the opportunity to develop the Jabiluka deposits following the election of the ALP Government in 1983 and the implementation of the "Three mines Policy".

Following the election of the Coalition Government in March 1996, ERA prepared an EIS for the Jabiluka development which was subsequently approved by the Government subject to ERA complying with 75 stringent conditions designed to protect the World Heritage Values of the adjacent Kakadu National Park.

Stage 1 of the development, a 1,150 m decline, 720 m of lateral development for further mine planning studies and surface facilities has been completed. The Jabiluka project has now entered a 12 month design phase that will enable the completion of further environmental and cultural studies as well as further negotiations with the Aboriginal people. Figure 2 shows the current Jabiluka site.

3. OUTLOOK

It is expected mining will be completed at Ranger by 2006 and production will be completed before 2009. The Company's plans are to commence limited production at Jabiluka in 2001, phasing in to full production as the last of the Ranger ore is depleted.

In the short-term ERA plans to produce to match its sales, currently around 4,000 tonnes at Ranger, however the mill capacity is 6,000 tonnes and the Company is in a strong position to increase production to this rate in response to any upturn in the market.

4. WORLD HERITAGE DECISION – A TURNING POINT

Followers of the fortunes of Jabiluka would be aware of the July 1999 decision by the World Heritage Committee not to list Kakadu "in danger" as a result of the Jabiluka mine. The Company believes that the recent World Heritage decision has been a real turning point in the debate about this project. And in many respects a turning point for ERA as it was a sharp reminder of the ever increasing expectations of operating a mine immediately adjacent to the World Heritage listed Kakadu National Park.

The message of this paper is that the community expectations on this project continue to increase and ERA is putting particular effort into finding innovative ways of meeting these expectations.

First, a little about an ongoing discussion that has been taking place between ERA, and within groups which oversee Jabiluka at North Limited, the parent company of ERA. It is a discussion about what ERA perceives as the facts of the Jabiluka issue versus the emotion of the issue.

On one hand there are the range of emotional arguments, often used by opponents of projects and often with success, which focus on the rights and wrongs, the what if's and maybe's of proposed activities. Such emotional arguments are often played out in stereotypes and often at the expense of the facts of the matter. And it is this point which causes some discussion within ERA and North. Our people frustratingly ask "Why is it we can't get the facts of the matter across?", or more commonly "If only they knew the facts then their concerns would dissipate".

Indeed at no time in the past have the facts surrounding the Jabiluka development seemed more remote and lost. The emotion surrounding Jabiluka is everywhere.

So first a few of the facts about the Jabiluka development which we see as important in this debate.

- Jabiluka for all intent and purposes is a small underground mining operation in a dedicated lease on the eastern side of Kakadu National Park. The project covers an area of less than 20 hectares. The existing Ranger mine is 620 hectares and is 22 km to the south of Jabiluka while the adjacent Kakadu National Park covers two million hectares.
- It will also operate under even more stringent conditions than those at the adjacent Ranger mine, which has successfully operated for the past 19 years without causing detriment to Kakadu.
- Ultimately Jabiluka and Ranger will be completely rehabilitated to world's best practice to blend in with the Park. Indeed this rehabilitation process is guaranteed by cash funds and bonds held by the Federal Government.

- The project will generate nearly $4 billion in economic wealth for Australia and over $200 million in royalties for Aboriginal groups.

These facts as we see them stand in contrast to the emotional side of the debate where the statements are all too familiar to ERA. These being:

- ERA should not be in Kakadu National Park
- the world heritage values of the area are being endangered, and
- the Company is not respecting the cultural values and wishes of the Traditional Owners.

ERA has spent countless hours attempting to address these claims. No more recently than with World Heritage deliberations on Jabiluka and whether Kakadu should be listed as "in danger" from the current Jabiluka development.

The initial delegation from UNESCO arrived at Kakadu in late October last year to gather information. ERA proudly stated its impressive environmental record of operating the Ranger uranium mine for the past 18 years - a record backed by the Federal Government's Supervising Scientist Group of over forty five scientists and technicians.

The Company's proposal to develop Jabiluka had also been through a thorough environmental assessment and passed with a range of stringent consent conditions. ERA's proposal to develop Jabiluka submitted to the Federal Government for review in 1996 represented a unique opportunity to use the existing mill at Ranger, 20 km to the south. There was no open cut - it was an underground operation without the need for all of the infrastructure required by a new mill. It was remote from the public eye and required minimal surface facilities. It could be operated as a contained site - all run off could be collected. It posed a straight forward rehabilitation solution. Tailings could be stored at the existing Ranger project in the used pits. In simple terms it was, and indeed remains, a near perfect development scenario.

In addition the Company believed it had, since exploration days, respected and listened to the wishes of traditional owners of the area - ERA had placed some uranium deposits out of development limits due to Traditional Owners' concerns about their closeness to important sites. Overall the Company believed that good intent had been displayed with Aboriginal groups of the region and ERA had the scientific data to back the claim that the Company had not impacted Kakadu National Park as a result of 18 years of operation at Ranger.

The World Heritage Committee expressed concern about a number of issues that they believed posed a threat to Kakadu National Park's world heritage values.

The cultural concerns ranged from social impacts to impacts on the land and important sites, while the scientific uncertainty related to what was an acceptable degree of risk to the Kakadu environment. Indeed the very royalty payments that were imposed on ERA to compensate Aboriginal people were blamed for some of the social problems.

And so the debate was played out. There were claims and counter claims. More facts and more emotion. Different sets of experts from all points of view. There was a tremendous amount of documentation produced, significant media comment and heavy political interest.

It became clear that the Australian Government wished to understand and either address the concerns of UNESCO's World Heritage group or show that their concerns had already been addressed, an approach supported by ERA.

In discussing this issue it is important to note that ERA's place in this process was pushed very much from the sidelines.

The key to the resolution of the World Heritage issue rested not so much on a debate of the facts of the matter, but in gaining of a clear understanding of the expectations many World Heritage delegates had of additional development in the area. In short, the view from a majority of delegates to the World Heritage Committee was that an additional new mine in the region would at the end of the day bring too much environmental and cultural pressure to the area. The expectation was one of no significant additional impact.

Most of you would have read or seen that as a result of the concerns of the World Heritage group that ERA has agreed to phase in production at Jabiluka as production at Ranger is phased out. This places limitations around ERA's production capacity and therefore effectively limits the company's ability to respond to a strong market. It does however address prime concerns of the World Heritage Committee relating to the impacts that an additional mine in the area would bring.

The decision to change the Company's development expectations for Jabiluka and bring it in line with the expectations of the World Heritage group was not an easy one, but as I said at the beginning of this address, the events of the World Heritage decision were a turning point in the debate for Jabiluka and significantly a turning point for ERA.

I would however like to stress that ERA believes it has in the past always responded to reasonable expectations placed on the Company. The turning point in the world heritage debate was the scale of expectations that ERA was prepared to respond to. It was the first time that the production plans of the company had been questioned, not for commercial reasons, but from the broader community expectations on that operation.

This is an interesting precedent, but one which has given ERA confidence to face some of the more intangible issues still facing the project.

With the world heritage deliberations behind us, there are now even more important expectations to be faced.

A key expectation comes from the Traditional Owners of the Ranger and Jabiluka leases. This group, represented by the Mirrar Gundjehmi Aboriginal clan, has consistently opposed the development of Jabiluka. Along with other Aboriginal people in the region affected by the project, the Mirrar Gundjehmi have a right to refuse the transfer of ore from Jabiluka for processing at the existing Ranger Mill.

As we all know communication is the first step in understanding expectations of key stakeholders and ERA is the first to admit there it still has a long way to go to understand the views of some Traditional Owners.

Indeed with respect to the Mirrar Gundjehmi, the fact is that ERA and North do not fully understand why the Mirrar Gundjehmi are opposed to the development of Jabiluka, although it may be due to the perceived or real social and cultural impacts of the initial Ranger developments. The Company's conversations with the Mirrar Gundjehmi on their concerns have been extremely limited.

ERA's relationship with the representative body for all negotiations with Aboriginal groups in the area, the Northern Land Council, has also been a tense, legal type of relationship - where trust has been scarce and communication difficult.

In an effort to improve these relationships, ERA is at this moment agreeing a protocol with the Northern Land Council on how to conduct communication with the Council and other Aboriginal groups. It is a commitment beyond previously set conditions.

In a further recent initiative ERA has also begun to examine the future benefits from Ranger and Jabiluka to Aboriginal groups in the region. It involves an analysis of mine plans, project life and royalty streams, asset ownership and partnerships. It is a comprehensive review of the future of Jabiluka which involves examining the Company's responsibilities of operating in the Kakadu region. The review is at its infancy and is firmly based around a renewed effort to identify expectations on ERA's future in the Kakadu region.

The issue ERA is currently facing is not based on the facts or merits of Jabiluka but rather a better appreciation of the community's expectations of us.

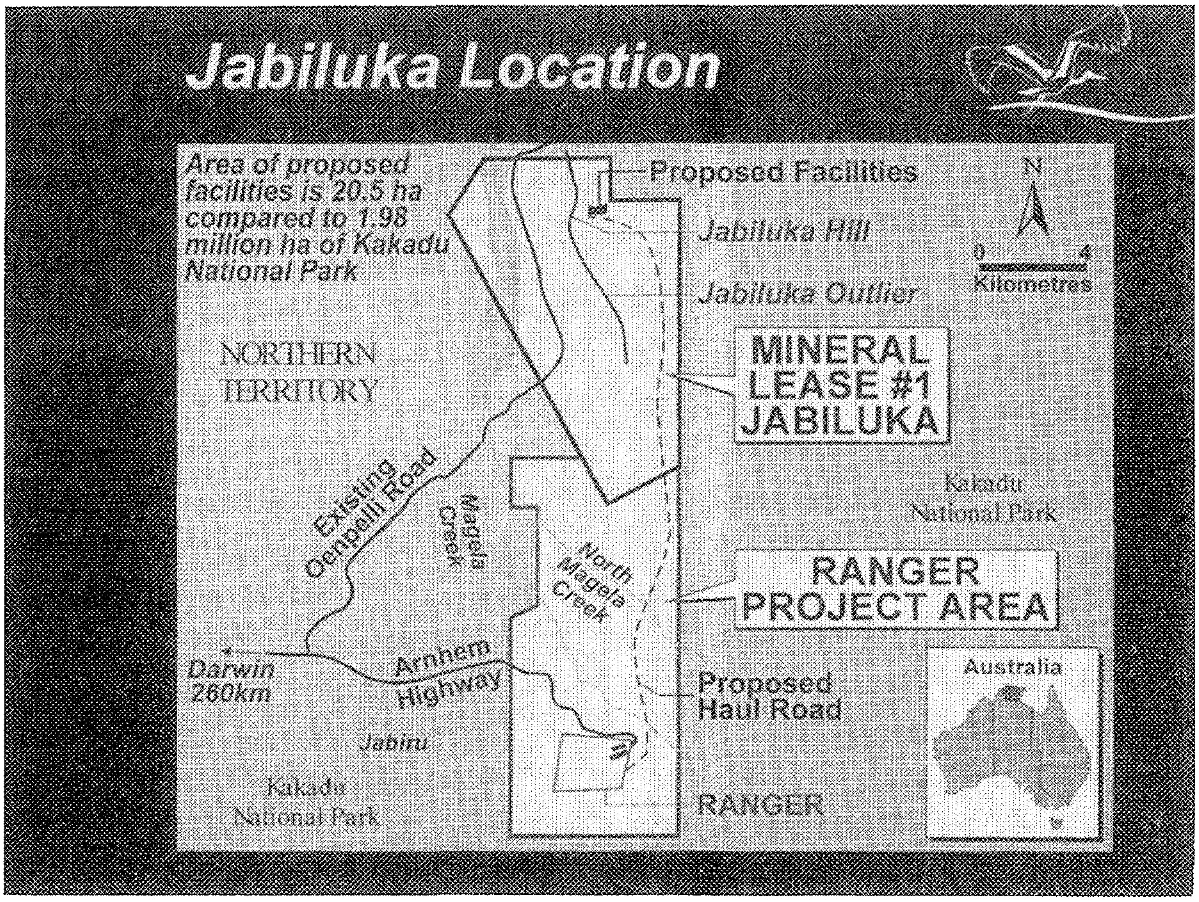
Just as the Company needed to respond to the expectations of the World Heritage group, it now needs to respond in a new way to the expectations of the Traditional Owners which, to be frank, ERA does not fully know or necessarily appreciate.
There is, of course, one final expectation that is the most difficult to address and one which I would like to briefly discuss. This is the expectation that many people would prefer not to have mining in a World Heritage area such as Kakadu National Park, no matter how safe.

Although ERA firmly believes in its short to medium term future in the region we are endeavouring to come to grips with this expectation. ERA has significant investment in the area with many groups dependent on our ongoing presence. Nevertheless in an effort to move beyond the facts of the matter, we are refocussing our efforts to plan our eventual departure from the Kakadu region.

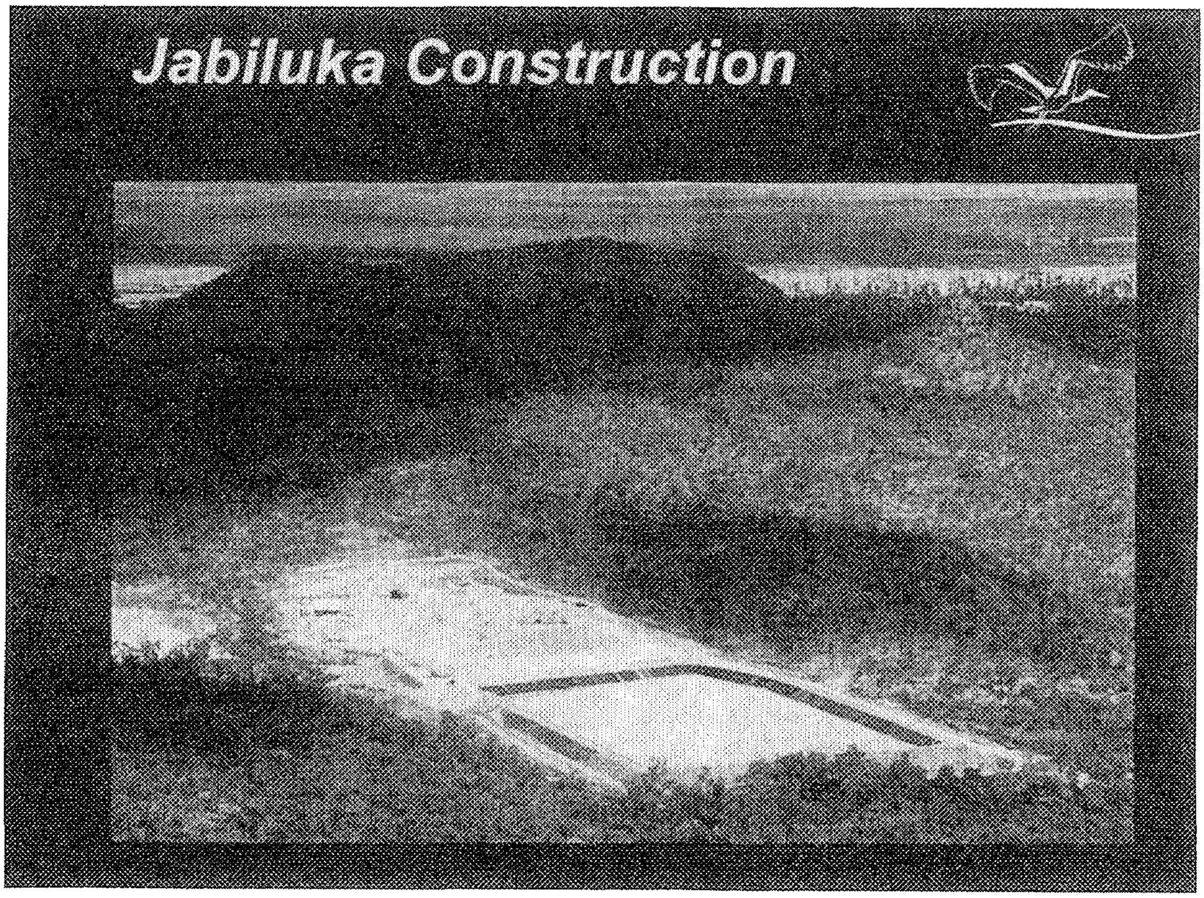
As you can see the expectations ERA faces are not the normal set of expectations on a mineral development; they are expectations that in some instances go to the heart of whether development should take place in an area or not.

Over the next 12 months we will pursue discussions with key Aboriginal groups over our preferred development scenario of trucking Jabiluka ore to Ranger. It is the development concept which minimises environmental impact and which provides a platform for a financially sound business for ERA. No further development is expected to take place at the project over this time during which every endeavour will be made to establish a new level of consultation and one which provides the opportunity for a more thorough understanding of the expectations of key stakeholder groups.

ERA never would have known what the other side's expectations were if the Company had not tried to understand where they are coming from. And this has been the case for many of the issues facing Jabiluka. Most often the first thing we see is people trying to stop us, and our own assumptions are often too easily made. As with many of the challenges ERA has faced in this region, important precedents are again being established which will have wide-reaching implications for resources development projects in Australia.



Jabiluka Location
Area of proposed facilities is 20.5 ha compared to 1.98 million ha of Kakadu National Park
Proposed Facilities
Jabiluka Hill
Jabiluka Outlier
N
0 4
Kilometres
NORTHERN TERRITORY
MINERAL LEASE #1 JABILUKA
Kakadu National Park
Existing Oenpelli Road
Magela Creek
North Magela Creek
RANGER PROJECT AREA
Darwin 260km
Arnhem Highway
Proposed Haul Road
Australia
Jabiru
Kakadu National Park
RANGER



Jabiluka Construction

Olympic Dam Expansion Completed

Computer Graphics Presentation by
WMC Copper Uranium
PO Box 474 Marleston SA 5033

The text of this presentation is not available.

The Future of Solution Mining

M. C. ACKLAND, P. D. BUSH and T. C. HUNTER
Southern Cross Resources Australia Pty Ltd
PO Box1513 Toowong Qld 4066

This paper reviews the history of In-Situ Leaching (ISL) mining in relation to uranium production and focusses on recent developments in Australia and the USA.

Differences between the Australian and US ore bodies are discussed in general, particularly in regard to the parameters that are required for an ISL uranium operation to be technically, commercially and environmentally viable.

Recent developments at the Honeymoon Project are compared with the latest US project to commence commercial production. Particular emphasis is placed upon process and wellfield operations.

In the immediate future, uranium prices are expected to continue at or slightly above present levels placing emphasis upon operating and development costs. Overall, the paper concludes that there is a future for ISL uranium production to be commercially competitive with conventional uranium mining and processing operations.

*****

Environmental Protection Issues In Uranium Mining

A JOHNSTON, Environmental Research Institute of the Supervising Scientist
Jabiru, NT 0886, Australia

SUMMARY The extent to which the environment in the vicinity of the Ranger uranium mine has been protected throughout the past twenty years has been assessed on the basis of radiological, chemical and biological minitoring. Based on this experience, a risk assessment of the proposed development of the Jabiluka mine has been carried out. It is concluded that mining of uranium at Ranger has not given rise to adverse effects on the people or the ecosystems of Kakadu National Park and the natural values of the Park are not threatened by the development of the Jabiluka mine.

1. INTRODUCTION

Uranium mining has been a significant political issue in Australia since the mid – 1970s, not least because of community concerns about the impact, or the potential impact, of mining on the environment. While these environmental concerns refer to all stages of the nuclear fuel cycle, an issue that has been repeatedly debated is the effect of uranium mining on the environment in the immediate vicinity of mine sites and on the health of people who live nearby.

These issues have been given significant media coverage during 1998–99 following the visit to Australia of a Mission of the World Heritage Committee. The purpose of the Mission was to assess any ascertained or potential threats to the World Heritage values, both natural and cultural, of Kakadu National Park that might arise from the proposal to mine uranium at Jabiluka. The report of the Mission concluded that the development of the Jabiluka mine poses both ascertained and potential dangers to the cultural and natural values of the World Heritage property. As a result, the World Heritage Committee requested that the Australian Government provide a detailed response to the Mission report and, in particular, that the Supervising Scientist provide an assessment of a number of scientific issues related to the likely impact of mining at Jabiluka on people and ecosystems in the World Heritage Property.

It is timely, therefore, to use the experience of the Ranger mine and the assessment of a possible mine at Jabiluka to summarise the extent to which the environment in the vicinity of uranium mines has been, and can be, protected from the effects of mining and milling.

2. ENVIRONMENT PROTECTION AT THE RANGER MINE

For almost twenty years, the mining and milling of uranium has been undertaken by Energy Resources of Australia (ERA) at the Ranger mine in Australia's Northern Territory. The Ranger Project Area has become surrounded by, but has never formed part of, Kakadu National Park. Kakadu is inscribed on the World Heritage List and its wetlands are listed under the Convention on Wetlands of International Importance. About half of the land area of Kakadu National Park, which was Crown Land, has been recognised as the traditional estate of Aboriginal people of the region and ownership of this land has been formally granted to the traditional owners.

The control regime for environmental protection at Ranger has, therefore, been designed to ensure the highest level of protection for both people living in the region and for the natural environment, particularly the aquatic ecosystems downstream from the mine. Protection of people is achieved by controls on the emission of radon from the mine site and the specification of radiological standards for the release of radionuclides into the aquatic environment. Protection of aquatic ecosystems from potential effects arising from the discharge of water from the site is ensured by the specification of chemical standards, the use of whole effluent toxicological testing and biological monitoring at the species and the community level. The analyses presented here are summarised from Johnston & Needham (1).

2.1 Protection of people

The principal pathways by which members of the public can be exposed to radiation from the mining and milling operations at Ranger are:

- surface water transport of the long-lived radionuclides of the uranium series contained in waters discharged from the mine, and
- atmospheric transport of radon and its short-lived radioactive progeny and dust containing the long-lived nuclides of the uranium series.

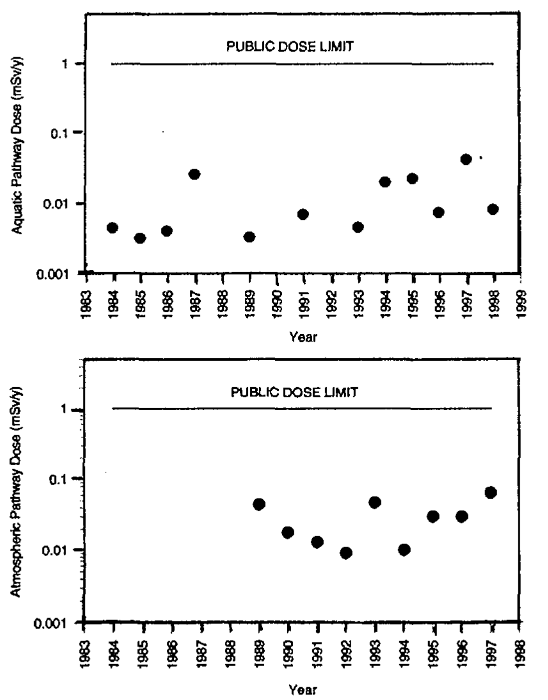


Figure 1 Radiation exposure of members of the public resulting from operation of the Ranger Mine via the aquatic pathway (upper graph) and the atmospheric pathway (lower graph).

In the case of the aquatic pathway, doses are calculated by modelling the physical transport of radionuclides in the surface water system, estimating the uptake of these radionuclides in aquatic flora and fauna, using the diet of the critical group to estimate the total intake of each radionuclide and converting this ingested intake into radiation exposure. ***eriss*** has carried out extensive research on each of these processes to enable reliable dose estimates to be made. Wherever uncertainties exist, conservative assumptions have been made to ensure that the dose is not underestimated. For example, it is assumed that 70% of all food consumed by the people concerned is derived from traditional hunting and fishing. This is certainly an overestimate.

The results obtained for the radiation exposure of people arising from the discharge of waters from Retention Ponds Nos 1 and 4 at Ranger are shown in figure 1 for each year since operation of the mine began. Those years for which no estimate is given were years of low rainfall during which no discharges of water took place. Also shown in the figure is a line representing the public dose limit recommended by the International Commission on Radiological Protection (ICRP). In all years, the estimated radiation dose to members of the public is less than the dose limit by more than a factor of 20.

Radon is a short-lived radioactive gas which, together with its radioactive progeny, is always associated with uranium. It occurs naturally in the atmosphere, arising from trace quantities of uranium found in all soils and rocks. Radon is released from a uranium mine at concentrations substantially above normal background rates and can lead to increased radiation exposure of the public. As radon can disperse over large distances from the point of emanation, its atmospheric concentration at a location several kilometres from a mine could be due both to radon sources associated with the mining project and to natural background sources. For regulatory purposes, the contribution from these two sources needs to be distinguished because the regulatory dose limits apply only to the contribution from the mine-related source. The need to make this distinction becomes important when the combined radiation dose due to both mine-related and natural sources exceeds the prescribed limit, as is the case at Ranger.

eriss has developed a method of separately identifying the mine-related and background components by measuring radon and radon progeny concentrations arising from wind sectors containing only the natural background sources, and those from wind sectors containing both background sources and mine-related sources. Following the completion of this research, ERA has used a simplified version of the method, but one that is adequate for routine monitoring at Ranger, to make public dose estimates. The results obtained in this program since 1989 are also shown in figure 1 and a comparison is drawn with the public dose limit recommended by the ICRP. These results show that radiation exposure of members of the public living in the vicinity of the Ranger Mine due to the dispersion of radon and its progeny from the mine site has always been less than 10% of the recommended dose limit.

Similar methods have been used to determine the dose due to dispersion of radionuclides in dust from the mine. The estimated dose for members of the public is about 5% of the recommended dose limit. The overall conclusion drawn has been that people living in the vicinity of the Ranger mine have not been subject to radiation exposure greater than the internationally recognised limit for members of the public.

2.2 Protection of aquatic ecosystems

The control regime established to ensure the protection of aquatic ecosystems is based on the use of both chemical and biological measures.

The chemical controls consist of a set of site – specific standards to regulate the maximum increase in the concentration of a number of constituents in the waters of the creek once the discharged water has mixed fully with natural stream water. There are also limits on the total loads of specified chemical constituents. The choice of constituents specified for control was made after careful assessment of the chemical composition of ore and waste rock, the identification of substances introduced in the milling process and examination of the US EPA list of substances that it recommends for inclusion in the development of water quality standards.

Preliminary standards were derived using a very conservative criterion based on the observed natural fluctuation of constituents in the waters of Magela Creek. For substances that could give rise to concentrations in the creek outside the range of natural concentrations, a detailed toxicological assessment was made on the basis of both international and local toxicology data.

In addition to these chemical standards, the flow of water released is controlled so that the dilution by creek water is greater than a minimum value determined by toxicological tests. These tests determine the lowest concentration of the effluent in creek water at which a change is detected for some sensitive measure of the animal's health (the LOEC) and the highest concentration at which no effect is observed (the NOEC). The geometric mean of the lowest NOEC and LOEC values for the three species tested is then divided by a safety factor of 10 to obtain the safe concentration of the effluent in Magela Creek. This value is used to specify the minimum dilution. The choice of species tested was made following an extensive period of research at ***eriss*** during which 19 different species of local aquatic animals and plants were examined to determine the most sensitive species to waters at Ranger and species that could be successfully bred and maintained in the laboratory. The large number of species examined, the use of local native species and the use of a safety factor in specifying the dilution are factors that make the testing program for release of water to the Magela system the most rigorous anywhere in Australia.

The actual minimum dilution required would be the larger of the values determined by the above chemical and biological procedures.

Chemical and biological monitoring programs are in place to determine the extent to which downstream ecosystems are protected as a result of the enforcement of the above control measures. For example, the data in figure 2 provide a comparison of uranium concentrations downstream from the Ranger mine with the receiving water standard recommended by the Supervising Scientist on the basis of site – specific toxicological tests using local native species of aquatic biota. The maximum and mean annual values are shown for each year of operation of the mine. The mean value has always been lower than the standard by more than a factor of ten and the maximum value observed throughout the period of operation of the mine is lower than the standard by a factor of three. Similar data can be shown for all of the chemical constituents of concern at the Ranger mine.

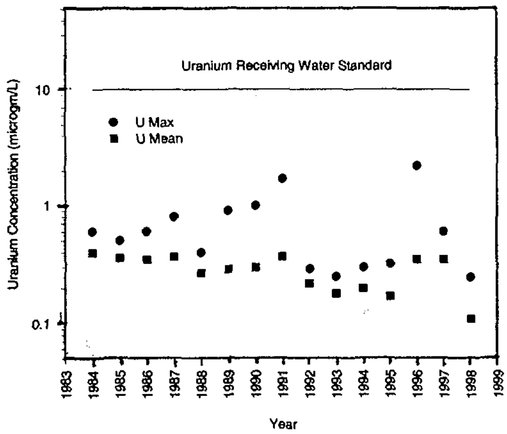


Figure 2 Comparison of uranium concentrations downstream from the Ranger Mine with the receiving water standard recommended by ***eriss***.

An example of biological monitoring is shown in Figure 3. In this example, freshwater snails were exposed to waters collected from sites upstream and downstream of the Ranger mine over a number of years. The endpoint of the tests was the egg production rate for each pair of snails. The data show that there is quite a significant natural variation in the egg production rate. Nevertheless, the variation at the downstream site is matched very well to that at the upstream site and the difference in response between the two sites is not statistically significant. The discharge of water from Retention Pond No 4 (at the times indicated on the figure) had no detectable effect on the reproductive rate of freshwater snails. Similar data are available both for creekside tests on fish and for community structure measurements on fish and macroinvertebrates.

The conclusion drawn from both the chemical and the biological monitoring programs is that, while increases have been observed in the concentrations of a number of chemical constituents in the waters downstream from the Ranger mine, the changes are well within conservative chemical standards and have not given rise to adverse effects on the aquatic fauna of Kakadu National Park.

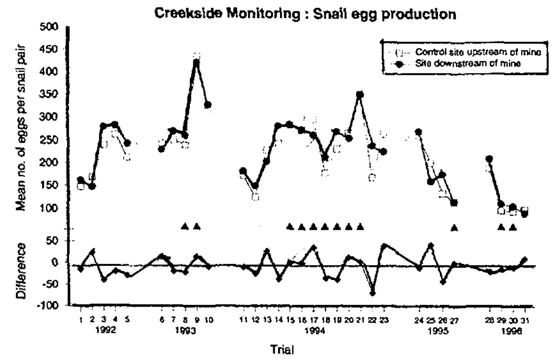


Figure 3 Biological monitoring of the impact of mining at Ranger using fish larval survival (upper graph) and freshwater snail reproduction (lower graph). Data are shown for animals exposed to water from sites upstream and downstream of the Ranger Mine. Differences between upstream and downstream responses are also shown. Periods of release of RP4 water are indicated.

3. RISK ASSESSMENT FOR THE JABILUKA MINE

As stated above, the Ranger mine has been operating for almost twenty years. The information gained from research and monitoring associated with the Ranger mine has enabled a thorough risk assessment to be carried out for a proposed new mine at Jabiluka, about 20 km north of Ranger. The assessment provided here, which is described in detail in Johnston & Prendergast (2), refers to ERA's Jabiluka Mill Alternative, under which all ore would be milled at Jabiluka.

3.1 Risks associated with surface water dispersal of contaminants

Unlike the Ranger mine which is open cut, the Jabiluka mine is an underground development and it has been designed for the total containment of all waters that come in contact with uranium ore in a suitably designed retention pond. As part of the environmental assessment of the proposed development, the Supervising Scientist has assessed the risks to people and the environment arising from a contingency situation in which the accumulated runoff from the catchment of the water storage pond at Jabiluka exceeds the capacity of the pond and the excess water from the Total Containment Zone is diverted and allowed to flow freely to surface waters. Also assessed was the risk to the environment associated with structural failure of the water storage pond arising from overtopping of the pond, static failure of the constructed embankment, or the occurrence of a severe earthquake.

As an example of the results obtained, the risk assessment for exposure of members of the public resulting from the occurrence of a severe earthquake are shown in figure 4. The assessment is based upon a review of all hydrological data for the region (3), climate change modelling (4) and Monte Carlo analyses (5) of the proposed water management system at Jabiluka. From these data it can be seen that the risk of radiation exposure of members of the public would be extremely low. At the 1 in 10,000 level of probability, the estimated radiation exposure is about 30 μSv. The highest calculated exposure, which is less than one tenth of the internationally accepted limit, has an extremely small exceedence probability.

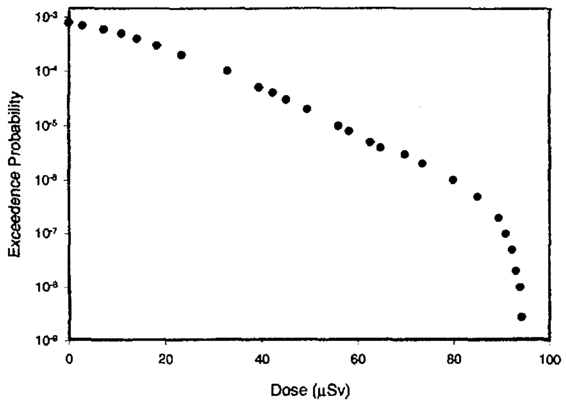


Figure 4. Probability versus radiation exposure of members of the public resulting from the discharge of water from the Jabiluka mine site as a result of a severe earthquake

The site specific information on the toxicity of uranium to aquatic animals has also been used to estimate the risk to aquatic ecosystems arising from an earthquake of sufficient magnitude to cause failure of the retention pond structure.

Water from the pond would flow to the downstream floodplain where it would be diluted in floodplain waters until concentrations of uranium become lower than the lowest LOEC observed in toxicological tests. The known hydrological features of the floodplain enable an estimate of the area of the floodplain required to provide this dilution. The resulting area has been termed the "effects area" inside which adverse effects on some biota would be expected to occur. Similarly, the "safe area", beyond which no adverse effects would be expected to occur, can be estimated using the geometric mean of the lowest LOEC and NOEC values and applying a safety factor of ten. The probability versus area is shown in figure 5 for both the "effects area" and the "safe area".

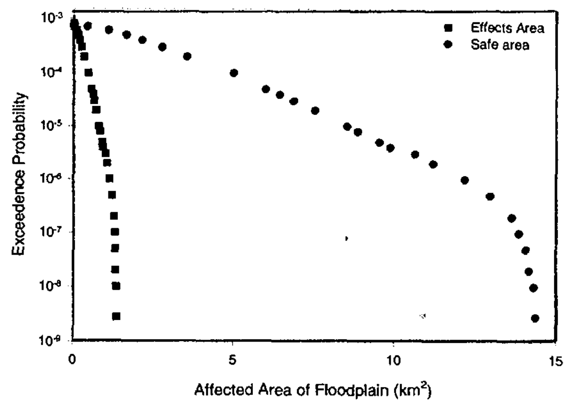


Figure 5. Probability versus the affected area of Magela floodplain for a severe earthquake. Beyond the safe area no adverse toxicological effects are expected. Adverse effects on invertebrates are expected inside the effects area. Between the two areas, some residual effects may occur.

Hence the maximum area within which effects would be expected to occur is about 1.5 km^2 but the probability of this occurring is extremely small. The "effects area" at the 1 in 10,000 level of probability is less than 0.5 km^2 which is less than 0.3% of the floodplain area. At the same level of probability, residual effects may occur for some aquatic animals out to an area of about 5 km^2. Even within these areas the impact would be very small (for example, fish should not be affected) and the system would fully recover following flushing by the natural waters of the Magela system.

3.2 Risks associated with ground water dispersal of contaminants

Under the Jabiluka Mill Alternative proposal submitted by ERA for environmental assessment, tailings produced at the mill would be returned to the mine void in the form of a concrete paste and also to specially excavated pits in the Kombolgie sandstone near the mill. This proposal was not accepted by the Commonwealth Government when it granted approval for the Jabiluka Mill Alternative to proceed. Rather, the Government required ERA to place all tailings in the mine void and in specially excavated stopes or silos in the vicinity of the orebody, some 100m below ground level.

A detailed study of the hydrogeology of the Jabiluka area and modelling of groundwater contaminant dispersion has been carried out (6) as part of the Supervising Scientist's assessment of the Jabiluka proposal. A two dimensional finite element model was used to determine flow directions, head distributions and the range of Darcy velocities. A three dimensional solute transport model was used to determine the concentrations of solutes leached from the tailings paste material for use as the source concentrations in an analytical dispersion model. The analytical contaminant transport model was used to determine concentrations of solutes at locations in the groundwater aquifer far from from the tailings repositories. Monte Carlo calculations using the analytical model were carried out to determine concentration profiles for a large number of different parameter values within selected ranges.

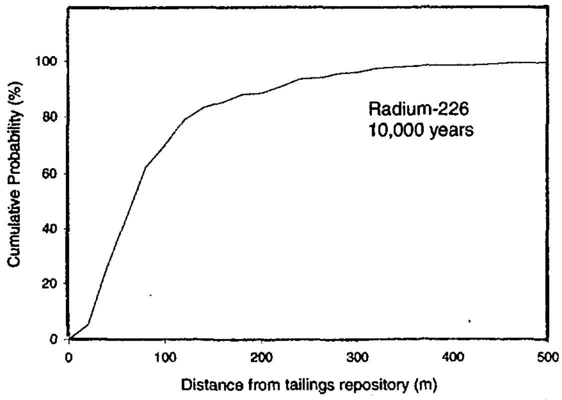


Figure 6. Cumulative probability distribution for dispersion of radium from tailings repositories at Jabiluka in a westerly direction over 10,000 years

An example of the results obtained is shown in figure 6 which shows the predictions for the movement of radium from the tailings repositories over a period of 10,000 years. These data show that there is a 90% probability that radium will move less than 200 metres from the repositories over this period. The conclusion of this work was that the wetlands of Kakadu would not be harmed as a result of the dispersal of tailings constituents in groundwater.

4. CONCLUSIONS

The overall conclusions of the review of past performance at Ranger (1) and the assessment of the Jabiluka proposal (2) are that:

- Mining of uranium at Ranger has not given rise to adverse effects on the people or the ecosystems of Kakadu National Park, and
- The natural values of Kakadu National Park are not threatened by the development of the Jabiluka uranium mine

REFERENCES

(1) Johnston A & Needham S 1999. *Protection of the environment near the Ranger uranium mine,* Supervising Scientist Report 139, Supervising Scientist for the Alligator Rivers Region, AGPS Canberra.

(2) Johnston A & Prendergast JB 1999. *Assessment of the Jabiluka Project: Report of the Supervising Scientist to the World Heritage Committee.* Supervising Scientist Report 138, Supervising Scientist, Canberra.

(3) Bureau of Meteorology 1999. *Hydrometeorological analysis relevant to Jabiluka.* Supervising Scientist Report 140, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra.

(4) Jones RN, Abbs DJ & Hennessy KJ 1999. *Climate change analysis relevant to Jabiluka.* Supervising Scientist Report 141, Supervising Scientist for the Alligator Rivers Region, AGPS Canberra.

(5) Chiew F & Wang QJ 1999. *Hydrological analysis relevant to surface water storage at Jabiluka,* Supervising Scientist Report 142, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra

(6) Kalf F & Dudgeon C 1999. *Analysis of long-term groundwater dispersal of contaminants from proposed Jabiluka mine tailings repositories.* Supervising Scientist Report 143, Supervising Scientist for the Alligator Rivers Region, AGPS, Canberra.

The New Look For Radiation Regulation

J LOY, Australian Radiation Protection and Nuclear Safety Agency
PO Box 655 Miranda 1490 NSW Australia

SUMMARY The *Australian Radiation Protection and Nuclear Safety Act (1998)* provides the CEO of the Australian Radiation Protection and Nuclear Safety Agency with responsibilities related to researching and advising on radiation protection and nuclear safety, and powers to regulate the Commonwealth's use of radiation and nuclear facilities. This regulation is new to Commonwealth departments and agencies. To support the CEO in meeting these responsibilities and exercising the regulatory powers, the Act also establishes a new advisory council and two advisory committees. Other novel aspects of the Act include a public consultation process for applications for licence related to nuclear facilities, and a regime of quarterly reporting by the CEO to Parliament, in addition to the usual requirements for annual reports.

1. INTRODUCTION

The object of the *Australian Radiation Protection and Nuclear Safety Act (1998)* is to protect the health and safety of people, and to protect the environment, from the harmful effects of radiation. For this purpose, the Act establishes a statutory officer, to be known as the Chief Executive Officer (CEO) of the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), for the purposes of performing functions and exercising powers under the Act. The functions of the CEO, as specified in the Act, include:

- to promote national uniformity of radiation protection and nuclear safety policy and practices;
- to provide advice, research and services related to radiation protection and nuclear safety;
- to report to Parliament; and
- to monitor compliance with the regulatory requirements of the Act.

To advise the CEO in meeting the above functions, the Act establishes a Radiation Health and Safety Advisory Council and two supporting advisory committees, the Radiation Health Committee and the Nuclear Safety Committee. Membership of the Council and Committees includes State/Territory radiation control officers, relevant scientific and technical experts and people representing the interests of the public.

The Act also establishes a licensing scheme for the regulation of nuclear installations and prescribed radiation facilities, called controlled facilities, and ionizing radiation sources and certain non-ionizing radiation sources, called controlled sources, operated by the Commonwealth or Commonwealth entities. The requirements for licensing include public notification of applications for licence involving prescribed radiation facilities and nuclear installations, and, in the case of nuclear installations, submissions from the public on the applications. The CEO is required to take these submissions into account when making a decision on an application.

In addition to the requirement for the CEO to report annually to the responsible Minister, the Act requires the CEO to report to the Minister every quarter on the operations of the CEO. The annual and quarterly reports are required to be tabled in both Houses of Parliament.

The Act came into affect on 5 February 1999. Commonwealth entities subject to the licensing requirements of the Act were allowed six months from that date to submit to ARPANSA appropriate applications for licence for their existing sources and facilities. Staff of the agency is assessing these applications.

2. COUNCIL AND COMMITTEES

The Radiation Health and Safety Advisory Council is a new body that will provide high level policy advice to the CEO on:

- emerging issues in radiation protection and nuclear safety;
- matters of major concern to the community;
- the adoption of recommendations, policies and codes of practice; and
- any other matters identified by the CEO

The Act specifies that the Council shall comprise the CEO, two radiation control officers (that is, persons holding senior positions in a State or Territory regulatory body responsible for radiation protection and/or nuclear safety matters), a person to represent the interests of the general public and up to 8 other members. It is intended that the Council be an expert body comprising experts and/or people with a strong knowledge of radiation protection and/or nuclear safety.

Members of the Council are appointed by the Minister, in consultation with the CEO and such consumer and environmental groups as the Minister considers appropriate. The inclusion of community and environmental representatives as members of such a body is an innovation in Australia, and is a reflection of current community expectations and international practice. The deliberations of the Council on nuclear safety policy will involve a far greater cross-section of views than those of any previous advisory bodies.

Advisory committees will provide advice on the implementation of the policies covered by the Council to the CEO. The Act establishes two of these committees – the Radiation Health Committee (RHC) and the Nuclear Safety Committee (NSC).

The RHC will advise the CEO and the Council on radiation protection and will develop policies and prepare draft publications for the promotion of uniform national standards of radiation protection. It is intended that the Committee will present its advice, which may include draft Codes and policies to the CEO and/or the Council for consideration. The Committee will also draft national policies, codes and standards for consideration by all jurisdictions. The Committee's functions are to be performed only on the request of the CEO or the Council.

Membership of the RHC consists of a radiation control officer from each State and Territory, the CEO, a representative of the Nuclear Safety Committee, a person to represent the interests of the public and up to 2 other members. It is intended that this Committee be similar to the Radiation Health Committee that was originally established to advise the National Health and Medical Research Council, and be predominantly a forum for regulators from all jurisdictions to develop codes and standards for national application and examine national uniformity of radiation controls.

The NSC has similar functions to those of the RHC, but related to the safety of controlled facilities. The membership of this Committee comprises the CEO, a person to represent the interests of the general public, a representative of the Radiation Health Committee, a person to represent the local government or the local administration of an area affected by a matter related to the safety of a controlled facility and up to 8 other members.

The CEO, in consultation with the Council appoints the members of both committees. For all members, the CEO must be satisfied that the person has expertise or knowledge relevant to the functions of the committee to which they are appointed. Both committees include members to represent the interests of the public, with the NSC including a person to represent a local government. This requirement provides for a continuance of input from the local council in whose jurisdiction the ANSTO site is located to the assurance of safety of ANSTO's nuclear operations following the establishment of regulation and the consequent disbandment of the ANSTO Safety Review Committee.

It should be noted that the advisory committees will not contribute directly to the assessments of individual applications for licence or the regulation of licensed organisations. However, the advice of the committees, in the form of standards, codes or practice, recommendations and reports will form a major component of the ARPANSA regulatory framework and the uniform requirements for radiation protection.

3. LICENSING NUCLEAR INSTALLATIONS

The *ARPANS Act* and Regulations, together with the guidance documents developed by ARPANSA, form a regulatory framework that aims:

- to ensure that licence holders bear the prime responsibility for the safety of activities covered by a licence;
- to provide a system of regulation based on the hazard of the regulated practice;
- to be administratively efficient and flexible;
- to ensure accountability of the CEO of ARPANSA and licence holders;
- to ensure that Commonwealth entities are subject to a comparable level of regulation as that applying to non Commonwealth entities under current State/Territory laws;
- to be consistent with the guidelines for the development of uniform requirements for radiation protection and control, agreed by the States and Territories; and
- to reflect internationally agreed standards and international best practice.

In summary, a nuclear installation could be a nuclear reactor for research or production of nuclear materials for industrial or medical use, a plant for preparing or storing fuel for use in a nuclear reactor, a nuclear waste storage or disposal facility with an activity that is greater than the activity level prescribed by the ARPANS regulations or a facility for production of radioisotopes with an activity that is greater than the activity level prescribed by the ARPANS regulations.

Conducts in relation to nuclear installations and other controlled facilities are not explicitly defined in the legislation but refer to the activities that may be authorised under a facility licence. Conducts include: preparing a site for a controlled facility; constructing a controlled facility; having possession or control of a controlled facility; operating a controlled facility; and de-commissioning, disposing or abandoning a controlled facility.

The Act requires that no conduct may be undertaken at a nuclear installation without an appropriate authorisation under a licence issued by the CEO. Requirements for applications for licence are described in ARPANSA guides, and include general details of the applicant and the facility, plans and arrangements for managing the safety of the proposed conduct, and safety assessments related to the proposed conduct. An application fee, based on the proposed conduct and the type of facility, is also required.

ARPANSA officers assess the applications, and a Safety Evaluation Report (SER) is prepared for the CEO recommending a decision on the application. The legislation requires the CEO to take the following matters into account when making a decision on a licence application:

- Whether the application includes the information asked for by the CEO.
- Whether the information establishes that the controlled apparatus, material or the conduct can be dealt with without undue risk to the health and safety of people, and the environment.
- Whether the Applicant has shown that there is a net benefit from dealing with the controlled apparatus, controlled material or controlled facility.
- Whether the Applicant has shown that the magnitude of individual doses, the number of people exposed and the likelihood that potential exposures will actually occur is as low as reasonably achievable (ALARA), having regard to economic and social factors;
- Whether the Applicant has shown a capacity for complying with the Regulations and the licence conditions that would be imposed under Section 35 of the Act.
- Whether the application has been signed by the applicant.
- If the application is for a facility licence for a nuclear installation – the content of any submissions made by members of the public about the application.

Licences will be issued with attached conditions designed to ensure ongoing compliance with legislative requirements and the arrangements for safety describe in the licence application. The main conditions are specified in the Act and Regulations, while specific conditions arising from the review of the licence application will be recommended in the SER for the application. Some conditions of licence may be issued to provide additional regulatory control at significant points in the life of a facility. These will be specific to individual facilities.

Facility licences will not be subject to renewal, but will continue until surrended by the holder or cancelled by the CEO. Ongoing safety at licensed facilities will be assured through requirements for approvals and notifications of changes to the facility and regular reviews of safety by the licence holder. The licence holder will be responsible for monitoring their compliance with the regulatory requirements, but ARPANSA will also regularly audit compliance with the requirements and licence conditions.

ARPANSA inspectors will also investigate incidents, accidents and suspected breaches of legislation, as the need arises. The purpose of these inspections would be to ascertain whether enforcement action is necessary and to ensure that acceptable standards of safety are maintained.

Enforcement actions, such as directions to improve operations, restricting or suspending operations or legal action will be designed to encourage compliance and prompt reporting of non-compliance. Enforcement will take account of whether a licence holder has detected a non-compliance, undertaken actions to ensure compliance, and reported these to the CEO promptly. Actions may be escalated where detection, rectification and reporting have been inadvertently or intentionally delayed by the licence holder.

4. PUBLIC SUBMISSIONS

As noted above, the CEO is required by the Act to advise the public of applications related to controlled facilities and, in the case of nuclear installations, invite public submissions on the applications. These submission must be taken into account when the CEO makes a decision on the application.

Although public submissions and hearings are a part of the nuclear regulatory processes of many other western countries, this level of public involvement in the licensing process is a new development in Australia. It was anticipated that the first application for licence for a nuclear installation to be assessed by ARPANSA, the ANSTO application for licence to prepare a site for the Replacement Research Reactor, would attract many submissions to the CEO. In the event, some 73 submissions were received, which might be compared with the 975 submission submitted on the EIS for the project.

Many of the submissions covered the same issues raised in response to the Draft EIS, and which were responded to by ANSTO in the Supplement to the draft. Any requirements for further action by ANSTO to resolve these issues were covered in the recommendations of Environment Australia in its review of the EIS, and these were taken into account when developing the ARPANSA licence conditions for the project.

Public submissions on licence applications for installations that were not previously subject to an EIS process, such as the existing research reactors and radioisotope production facilities, may provide more challenges for ANSTO and ARPANSA.

5. REPORTS OF THE CEO

The requirements of the Act on the reporting by the CEO provide an additional level of public information on the performance of ARPANSA and Commonwealth users of radiation sources and nuclear facilities. As noted above, in addition to the usual annual reporting requirements, the CEO is required to report quarterly to the Minister on the operations of ARPANSA. This will include summaries of compliance of the regulated entities with legislative requirements and any enforcement actions necessary to ensure compliance.

A predecessor organisation of ARPANSA, the Nuclear Safety Bureau, functioned under a similar requirement. The Bureau reported to the Minister on its functions, including the monitoring and review of safety of ANSTO's nuclear plant. In the absence of a formal licensing system, the Bureau found the quarterly reports helpful in attracting the attention of operators to areas of non-compliance with the conditions of operation set by ANSTO and agreed by the Bureau. The reports were also widely read by parliamentarians and members of the public with an interest in the safety of operation of nuclear plant.

Experience to date with the issuing of quarterly reports of the CEO has confirmed the continuing interest of the public and its representatives in nuclear safety. Descriptions of ARPANSA's regulatory activities have been limited to reporting the number of licence applications received, but as assessments are completed and licences are issued, this area will certainly expand. It is expected that the reporting of the performance of both the regulator and the licence holders will be useful incentive to all organisations involved.

6. A FINAL THOUGHT

As far as practicable, and in the spirit of ensuring consistency with best international practice, the definition of terms used in drafting the Act were taken from the publications of the International Atomic Energy Agency. Consequently, the facilities defined as being nuclear installations included nuclear power plant, nuclear fuel fabrication plant, enrichment plant and reprocessing plant.

In negotiations with the minor parties holding the balance of power in the Senate at the time, it was clear that the inclusion such facilities in the Act was taken as a signal that such facilities may exist in Australia at some time. The Government was willing to demonstrate that it had no intention of expanding the nuclear industry in Australia to include these facilities, so the controversial facilities were deleted from the definition.

The Act was further amended during its passage through the Senate and emerged with the addition of Section 10, a prohibition on certain nuclear installations. This section declares that nothing in the Act is to be taken to authorise the construction or operation of any of the nuclear installations listed above. In addition, the CEO must not issue a licence in respect of any of these facilities.

Of course, the Act only controls the nuclear activities of the Commonwealth, and would not stop the construction or operation of one of these facilities by a non-Commonwealth entity. But the Government has used the Act to advertise its policy on such installations. So while our legislation describes a new look for radiation regulation, it might also define the new nuclear installations that will not be seen in Australia.

Nuclear Safeguards - A System in Transition

JOHN CARLSON,
Director General, Australian Safeguards and Non-Proliferation Office

SUMMARY "Classical" safeguards have a strong emphasis on nuclear materials accountancy, and are primarily concerned with verifying nuclear activities as declared by the State – what has been termed the correctness of States' declarations. Following the Gulf War, failure to adequately address the possibility of undeclared nuclear activities – the issue of the completeness of States' declarations – has been recognised as a major shortcoming in the classical safeguards system, and major changes are in progress to strengthen the IAEA's capabilities in this regard. Agreement has been reached on a Model Protocol substantially extending the IAEA's authority, and there has been good progress in developing the new approaches and technologies required to ensure this authority is used effectively. IAEA safeguards are undergoing a major transition, towards greater emphasis on information collection and analysis, diversity of verification methods, incorporation of more qualitative judgments, and improved efficiency. These changes present major challenges to the IAEA and to the international community, but the end result will be a more effective safeguards system.

1. INTRODUCTION

Nuclear safeguards are a key element in international action against the spread of nuclear weapons. Safeguards are directed at the verification of peaceful use commitments, given by States through international agreements to use nuclear materials and technology for exclusively peaceful purposes.

The overwhelming majority of States have renounced nuclear weapons - recognising that the possession of these weapons would threaten, rather than enhance, their national security – and have entered into various treaty commitments to use nuclear materials and technology for exclusively peaceful purposes. The most important of these treaties - because it is almost universal - is the Treaty on the Non-Proliferation of Nuclear Weapons (NPT).

For most States the political commitment against acquisition of nuclear weapons has been carefully reached and is strongly held. Their observance of treaty commitments does not depend on the deterrent effect of verification activities. Nonetheless, it is an important maxim of international arms control to "trust, but verify". The establishment of a credible verification mechanism to provide confidence that all parties are honouring their treaty commitments plays a vital part in reinforcing those commitments.

Broadly, safeguards may be described as a complex system of declarations by States, verified by technical measures such as inspections and evaluations, undertaken principally by the International Atomic Energy Agency (IAEA). It should be emphasised that the task of safeguards is not prevention, except in so far as risk of discovery may act as a deterrent to a would-be proliferator. The IAEA is not an international policeman. Rather, the political objective of safeguards is to exercise a positive influence on the behaviour of States: by providing assurance to reinforce non-proliferation commitments; and by deterring non-compliance through the risk of timely detection. Importantly, safeguards serve to assist States who recognise it is in their own interest to demonstrate their compliance to others. Thus safeguards are a vital confidence-building measure in their own right, as well as being a major complement to the broader range of international confidence-building measures.

Safeguards are complemented by other important measures such as: export controls on nuclear items; national intelligence activities; and political incentives and sanctions.

1.1. The Treaty on the Non-Proliferation of Nuclear Weapons (NPT)

The NPT is the centrepiece of the international nuclear non-proliferation regime. The Treaty was concluded in 1968 and entered into force in 1970. It is now almost universal, with only four States remaining outside the NPT or equivalent non-proliferation commitments. Of these, three (Israel, India and Pakistan) have unsafeguarded nuclear facilities (the fourth, Cuba, has safeguards on all its nuclear activities).

The NPT has been essential to establishing the conditions under which a general renunciation of nuclear weapons has been possible. It has done this by:

- providing a legal framework within which States can express their commitment to use nuclear energy for exclusively peaceful purposes; and
- providing a credible verification mechanism, IAEA safeguards.

The key provisions of the NPT can be outlined as follows:

- Nuclear-weapon States (NWS) agree not to assist any non-nuclear-weapon State (NNWS) to acquire nuclear weapons.
- NNWS agree not to acquire nuclear weapons or other nuclear explosive devices, and to accept IAEA safeguards on all their current and future holdings of nuclear material (what are termed "full-scope" safeguards).
- All Parties agree to cooperate in the peaceful uses of nuclear energy - but not to supply nuclear items to a NNWS unless under safeguards.
- All Parties agree to pursue nuclear disarmament, and complete and general disarmament.

1.2. IAEA Safeguards

The current, "classical", system of IAEA safeguards has its origins in the verification of peaceful use conditions applied by nuclear suppliers in the 1950s and 1960s. Verification activities were undertaken at supplied facilities, or facilities using supplied materials. Initially verification was undertaken on a bilateral basis, but following the establishment of the IAEA in 1957 this activity was gradually transferred to the Agency. These early safeguards measures were "facility-specific", and facility-specific safeguards agreements still apply to States outside full-scope safeguards, ie the NWS and the four non-NPT States.

Following conclusion of the NPT in 1968, a new safeguards system was developed, to give effect to the commitment by NNWS to accept full-scope safeguards, ie safeguards on all their current and future holdings of nuclear material. This is what has become known as the "classical" safeguards system.

Classical safeguards are based on the verification of nuclear materials accountancy. Nuclear facility operators are required to maintain, under the supervision of each country's national safeguards authority, detailed accounting records of all movements and other physical transactions involving nuclear material. IAEA inspectors regularly visit nuclear facilities to verify the completeness and accuracy of this documentation through activities such as checking inventories, sampling and other analytical procedures.

Nuclear material accountancy is complemented by other techniques such as *containment* (eg the placement of special seals on nuclear items), and *surveillance* (eg the operation of automatic cameras), to maintain *continuity of knowledge* between inspections. With the increasing complexity of modern nuclear facilities, especially large-scale bulk-handling facilities such as reprocessing plants, use of containment and surveillance is assuming greater importance. Containment and surveillance, in the form of remote monitoring systems, are also becoming increasingly important as a way of improving both the cost-efficiency and the effectiveness of safeguards.

Classical safeguards are directed primarily at the detection of diversion, ie the undeclared removal of nuclear material from safeguards coverage. The IAEA has not been expected to look for undeclared nuclear activities, except as these would be revealed through diversion.

Prior to the 1991 Gulf War, it was thought the establishment of a self-contained capability to produce nuclear weapons material entirely separate from a State's declared nuclear program would be too large and difficult an undertaking for most would-be proliferators. It was also thought that any attempt to establish clandestine military-capable facilities (plutonium production reactors and reprocessing plants, or enrichment plants) would be readily detected by national intelligence activities – in which event it was considered the duty of the States concerned to bring the matter to the attention of the international community. Thus diversion of nuclear material from facilities under safeguards was considered the more plausible scenario, and it was thought the existence of any clandestine nuclear activities would be revealed through detection of diversion.

The situation discovered in Iraq however indicates the more likely course for a proliferator: not only is diversion of safeguarded material unattractive because of the likelihood of detection, but in fact there are limited opportunities to divert *weapons grade* materials because these are unusual in civil programs. Accordingly, a State pursuing a weapons program would need to establish nuclear upgrading capabilities - enrichment or reprocessing. If the State is able to do this clandestinely, it is unlikely to risk detection by diverting safeguarded material.

2. STRENGTHENING OF THE SAFEGUARDS SYSTEM – THE ISSUE OF UNDECLARED NUCLEAR ACTIVITIES

Events in Iraq have shown that for safeguards to continue their key confidence-building role, it is essential to adequately address the issue of detection of undeclared nuclear activities. This is the major focus of current safeguards development. At the same time, safeguards must become more efficient, so as to manage an expanding workload within budget constraints. It can be seen that new techniques, such as remote monitoring (CCTV and other systems which transmit encrypted data to the IAEA by phone or satellite) and environmental analysis, offer both improved efficiency (through reducing inspection time) and greater effectiveness.

Efforts to strengthen safeguards have proceeded at two levels, the technical and the institutional. Technical efforts, to develop the technology and the methodology to address the risk of undeclared nuclear activities, have made good progress, though there is much more to be done. At the institutional level, in 1997 the IAEA Board of Governors agreed the text of a Model Protocol which is to be used as the basis for each State to conclude an individual Protocol additional to its existing safeguards agreement, giving the IAEA substantially increased authority.

2.1. The Model Protocol

Key elements of the strengthened safeguards regime, of which the Model Protocol is a central element, are:

- The IAEA is to receive considerably more information on nuclear and nuclear-related activities, including through an "Expanded Declaration" by each State and widened reporting requirements. This includes, *inter alia*, information on nuclear-related R&D activities, production of uranium and thorium, production of heavy water and graphite, and nuclear-related imports and exports.
- IAEA inspectors have rights of complementary access: to anywhere on a nuclear site; to various locations included in the Expanded Declaration; and to locations elsewhere in the State to carry out environmental sampling and other verification measures.
- Access on nuclear sites can be short-notice, 2 hours or less, if carried out with a routine inspection.
- The IAEA can employ environmental sampling, to look for indications of undeclared nuclear activities anywhere in the State. Initially this is to be "location-specific", but the Protocol recognises the possibility of using "wide-area" environmental sampling, looking for nuclear indications over extensive areas, once the efficacy of this technique has been established.
- Information analysis and the conduct of complementary access are to be used to establish a State Evaluation, that is, the IAEA will apply its safeguards approaches and draw its conclusions on the basis of the State as a whole.

Although the IAEA can implement some aspects of strengthened safeguards without reliance on the Additional Protocol, the Protocol is central to efforts to establish more effective safeguards, and it is imperative that it be brought into general application without delay. The Protocol, in conjunction with the basic NPT safeguards agreement, is a consolidated statement of the contemporary "Agency safeguards system", and should be seen as the standard for full-scope safeguards pursuant to the NPT. Australia is urging other States to conclude their Protocols with the IAEA as soon as possible, and it is hoped there can be a substantial number in place by the time of the NPT Review Conference in April 2000.

3. INTEGRATED SAFEGUARDS

Although implementation of strengthened safeguards is still at an early stage, attention is already focusing on merging classical safeguards and safeguards strengthening measures to yield an optimally effective and cost-efficient outcome. This is known as safeguards integration, and is recognised as a high priority.

The development of safeguards aimed at undeclared activities has obvious implications for the application of classical safeguards aimed at diversion from declared inventories: in the case of natural and low enriched uranium, and plutonium in spent fuel, diversion is plausible only if the State has the capability of upgrading diverted material by enrichment or reprocessing. If it were possible to derive an acceptable level of assurance that the State has no undeclared enrichment or reprocessing capability, diversion of these materials would largely cease to be an issue.

Of course some of the benefits of integration will be achieved only in the long-term: eg at this stage the technical means and procedures necessary to demonstrate a high degree of assurance of the absence of undeclared enrichment and reprocessing have yet to be established - and indeed absolute assurance is unlikely to be ever achieved. Thus an appropriate level of assurance of non-diversion will be required from classical safeguards for the foreseeable future. That level will be high for materials that require minimal downstream processing and so offer limited opportunity for detecting downstream activities (eg highly enriched uranium, separated plutonium). For less sensitive materials, the appropriate level can be determined in the light of progress with strengthened safeguards.

An important part of integrated safeguards will be the evaluation of the State as a whole, both in reaching conclusions about a State's performance of its treaty commitments, and in developing the safeguards approaches required to reach these conclusions. The classical safeguards system has been characterised by a uniform approach to safeguards implementation – although existing safeguards agreements provide for flexibility, taking account of factors such as the characteristics of the State's nuclear fuel cycle, its international interdependence, and the effectiveness of the national safeguards system, in practice opportunities for flexibility have not been used to advantage. Integrated safeguards are to be applied to the State as a whole, and no two States will have identical circumstances. For optimal effectiveness and cost-efficiency, differences between States will need to be taken into account. This will have to be done in a transparent way, using objective criteria, to avoid any suggestion of discrimination.

4. AUSTRALIA'S ROLE

Australia, through ASNO, has been closely involved from the outset in the development of strengthened, and now integrated, safeguards. Our involvement has taken a number of forms, including:

- development of new safeguards technology and methodologies under Australia's formal Support Program of assistance to the IAEA;
- participation in various experts groups and meetings advising the IAEA;
- field trials of new safeguards methods in Australia – one of the most recent examples being facilitation of a visit to the Ranger uranium mine as part of the development of verification techniques applicable to uranium production;
- we played a major role in the negotiation of the Model Protocol, and in September 1997 Australia became the first country to conclude a Protocol based on this model, reflecting the Australian Government's strong support for the strengthening of safeguards.

5. CHALLENGES AHEAD

The critical challenge for the safeguards community is to establish a credible capability to detect undeclared nuclear activities. Success in achieving this is much harder to measure than for verifying declared material, and the assurance derived will be less certain. While it is important to avoid over-expectation, however, we must take care not to under-estimate what can be achieved.

It is vital that the IAEA is able to present authoritative conclusions about the absence of undeclared activities in a State. If States have no clear conclusions from the IAEA they may act on unsupported suspicions about the perceived proliferation activities of others. If that were to cause some to reconsider their commitment to non-proliferation the consequences for the non-proliferation regime would be severe.

While the detection of undeclared nuclear activities will not be easy, the IAEA will be better equipped for this task than individual States. The IAEA will have at its disposal its own expertise together with substantial information resources, extensive inspector access, and increasingly sophisticated technology. It will be important however that States assist the IAEA where they can, eg by providing intelligence information.

For States to derive the necessary degree of confidence from the IAEA's new safeguards activities, they need to be satisfied that the IAEA has done all that is reasonable and prudent in each situation. Some important factors in this regard are expected to include:

- a clearly established methodology for how the IAEA collects and analyses information, the extent to which it pursues specific matters, and the way it exercises its inspection and complementary access rights;
- a quality assurance process to ensure a satisfactory standard of performance across all relevant areas;
- a rigorous process of evaluation, which would take into account not only safeguards performance as such, but would put this in a wider context, looking at all the information available to the IAEA relating to the State's non-proliferation credentials;
- all these matters should be documented in guidelines which would be available to Member States.

Some cultural change will be needed in safeguards practice. Classical safeguards have encouraged a rather mechanistic approach to safeguards. Now inspectors need encouragement to be more inquisitive, but still in a rigorous way so that the international community can have confidence in their findings. The transparency and cooperation of States are further essential elements of the strengthened regime. The international community will have to view any lack of cooperation, particularly where IAEA access is obstructed, very seriously. Overall there is room for optimism that, as strengthened safeguards develop and experience grows, they will make a major contribution to international confidence-building.

6. CONCLUSIONS

The present non-proliferation regime - based on peaceful use commitments verified by IAEA safeguards - has served the international community well. The overwhelming majority of States have renounced nuclear weapons - the existence of a credible verification system being an essential factor in their decision. The regime has thus created conditions favourable to international peace and security, under which most States have been able to benefit from peaceful applications of nuclear technology.

The IAEA's safeguards system is an evolutionary, not a static, system. Safeguards practice has undergone substantial refinement since the conclusion of the NPT. Now the evolution of safeguards is entering a period of substantial change, from a mainly quantitative system, which provides a high degree of assurance about declared nuclear activities, to a more qualitative system, which is addressing a much less tangible area - the absence of undeclared nuclear activities.

With the extension of safeguards into the area of assurance against undeclared nuclear activities, it is natural to anticipate that the safeguards system will start to evolve in new directions. Some of the themes in this transition are expected to include:

- a shift in emphasis from declared inventories and flows of nuclear material at individual facilities, towards safeguards approaches based on evaluation of the State as a whole;
- a move from mechanistic uniformity in safeguards implementation to a more flexible approach, which takes account of the differences between States' nuclear fuel cycles and other factors;
- a balance between classical and new safeguards measures, achieved by integration of the two, with the exact balance likely to vary with the circumstances of each State;
- diversification of detection methods, introducing methods based upon quite different principles, resulting in a more robust system;
- greater emphasis on transparency of national nuclear programs.

Under classical safeguards the IAEA's methods were well understood - if the IAEA was satisfied about the performance of a particular State, most States were prepared to accept the IAEA's conclusions. With the new safeguards system, which incorporates a much greater degree of judgement, however, the degree of assurance which States can derive will depend very much on their understanding of, and confidence in, the IAEA's methodologies and the verification activities actually undertaken with respect to particular States.

The IAEA faces a considerable challenge not only in establishing methodologies which are as technically effective as possible, but in reporting on its performance in a way which has necessary credibility and provides sufficient assurance to meet the political objectives of the safeguards system. It is of critical importance to the international community to have the most effective safeguards system, and States must be prepared to support, and to contribute constructively to, the process of ongoing development which this will require.

An Epidemiological Study of Cancer Incidence and Mortality among Nuclear Industry Workers at Lucas Heights Science and Technology Centre in Collaboration with IARC

RIMA R. HABIB and JOHN KALDOR

School of Community Medicine, Faculty of Medicine
University of New South Wales, NSW 2052, Australia
e-mail: r.habib@student.unsw.edu.au jkaldor@nchecr.unsw.edu.au

ABSTRACT An epidemiological study is being undertaken at Lucas Heights Science and Technology Centre (LHSTC) where the only nuclear reactor in Australia has been in operation since 1958. The study is part of an international collaborative study (1,2) coordinated by the International Agency for Research on Cancer (IARC), and has dual objectives; first to assess whether workers at LHSTC have had different levels of mortality or cancer incidence from the New South Wales and the Australian populations, and second, as part of the IARC study, to estimate as precisely as possible, through collaboration with IARC, the risk of contracting cancer from low-level, long-term exposure to ionising radiation. The research project is a retrospective cohort study based on records of employment and exposure to radiation kept at LHSTC since 1957. Electronic linkage of all the available dosimetry and employment information with national registers of cancer incidence and mortality is being undertaken for the cohort of LHSTC workers, to allow for a passive follow-up of more than 7000 workers employed from 1957 onwards.

1. BACKGROUND

Lucas Heights Science and Technology Centre (LHSTC), previously known as Lucas Heights Research Laboratories (LHRL) (1), is the site shared by the Australian Nuclear Science and Technology Organisation (previously known as the Australian Atomic Energy Commission-AAEC) (1), two CSIRO divisions, the Division of Coal and Energy Technology and the Division of Minerals, and the Australian Institute of Nuclear Science and Engineering (AINSE). Reports have been published on the health of the workers at LHSTC, and of the residents of the surrounding area, the Sutherland Shire.

1.1. Local Studies

The Ferguson Reports

In the period 1975-1976, Professor David Ferguson conducted a detailed cross-sectional survey of current AAEC employees at Lucas Heights Research Laboratories (LHRL) at that time, on behalf of the School of Public Health and Tropical Medicine at the University of Sydney (2, 3). The survey was conducted following a request by the Labor Council of New South Wales and affiliated unions for an independent medical survey of employees at the AAEC, at the end of 1973. The call for the health survey arose from the compensation claim for sarcoidosis in a technician exposed to uranium, and a series of claims for respiratory disease attributed to exposure to toxic substances (2, 3).

In his two reports published in 1978 and 1979, Professor Ferguson concluded that "employment in the establishment has been relatively safe by the highest standards" (3) and made a number of recommendations regarding the health and safety of workers at LHRL. However, the cross-sectional nature of the survey left diseases of long latency such as malignancies unexplored. As stated in the Second Report, "a prevalence study based on medical interview at work is not a good index of the occurrence of cancer because the person affected mostly moves out of the workforce, therefore, "no disease related to work with ionising radiation was revealed by the health interviews subject of the First Report" (3).

The Research Reactor Review Studies

In 1992, the Minister for Science and Technology commissioned a review of Australia's need for a new nuclear research reactor to replace the ageing High Flux Australian Reactor (HIFAR) which is operated by ANSTO at Lucas Heights in the Sutherland Shire (4).

Concerns were expressed in community submissions to the Research Reactor Review about certain health outcomes among residents of Sutherland Shire. The health outcomes claimed in these submissions included leukemia in young children of pre-school age; deaths due to cancer among elderly residents; an apparent increase in thyroid cancer; and a high prevalence of asthma in Sutherland Shire especially in Lucas Heights and Menai (5).

Several submissions sought information on the health of residents of Sutherland Shire and the health of staff working at the research reactor at Lucas Heights (5).

A study was conducted by the Australian Institute of Health and Welfare National Perinatal Statistics Unit to assess the health of residents in Sutherland Shire (5). This study analysed some specific outcomes that had previously been associated with exposure of human populations to radiation. These were spontaneous abortions, fetal deaths in the later stages of pregnancy (still births), and microcephalus (a malformation with a reduced head size). The study concluded that health outcomes among residents of Sutherland Shire were similar to those in Warringah, an area in North-Eastern Sydney that was comparable to Sutherland in its socioeconomic characteristics and that there were no major differences between the two regions in fertility, most reproductive health outcomes, congenital malformations, or asthma (5).

As part of the review, Sir Richard Doll produced a report entitled "Public Health Effects of the Operation of a Research Nuclear Reactor" (6). The report described "the extent of the risk likely to be produced in the vicinity of the research reactor in New South Wales". He concluded that "the extra risk of death from cancer from living at the boundary site for the whole of one's life (taken to be 75 years) is 0.3 per cent of that attributable to natural radioactivity, which is, itself, estimated to account for about 2.6 per cent of all fatal cancer". Natural radioactivity is background level of radiation to which everyone is exposed (6).

Another study looking at leukaemia and lymphoma among residents of Sutherland Shire, as compared to Warringah Shire and New South Wales as a whole during the period 1970-1990 was undertaken by the New South Wales Cancer Registry (7). The study concluded that there was no evidence to indicate higher incidence of leukemia or lymphoma, or all-cause mortality in population groups resident near the Lucas Heights facility compared with others more distant and the New South Wales average. However the investigators pointed out that any real adverse health effects caused by the Lucas Heights facility would be more likely to be seen in employees than in local residents (7).

Given these limitations to the studies carried out to date, the potential value became apparent of a historical cohort study of all personnel who had worked in the plant (7). Follow-up could be achieved through the national and state registries of cancer and mortality.

1.2. International Studies

Current Protection Standards of Exposure to Ionising Radiation in the Workplace

The current environmental and occupational standards for exposure to chronic low linear energy transfer (LET) ionising radiation are mainly based on estimates of radiation-induced cancer risk derived from studies of atomic bomb survivors in Hiroshima and Nagasaki, and of patients irradiated for therapeutic purposes (8, 9, 10, 11). Uncertain extrapolation methods are involved in the use of data from populations who have received comparatively high radiation doses over short periods to predict carcinogenic effects in populations receiving long-term exposures at much lower levels (8, 10, 11).

A direct assessment of the carcinogenic effect of protracted low-level radiation exposure can be made from studies of cancer among workers in the nuclear industry, many of whom have been exposed to above background levels of ionising radiation over several decades and whose exposures have been carefully monitored through the use of personal dosimeters (12).

Combined Analyses of Nuclear Workers

The International Agency for Research on Cancer (IARC) combined mortality data from seven cohort studies on 96000 nuclear industry workers monitored for external radiation in Canada, UK, and USA to directly assess the carcinogenic effects of protracted low-dose exposure to ionising radiation (11). The combined study, published in *The Lancet* in 1994, suggested that the current radiation protection recommendations based on Atomic Bomb Survivors data were not appreciably in error. However because the confidence intervals around the estimates remained wide, the investigation concluded that additional follow-up and studies of other cohorts of workers were needed to increase the precision of the estimates of radiation-related risk of cancer and to strengthen further the scientific basis for setting radiation protection standards.

ANSTO Participation in an International Collaborative Study

In 1987, the International Agency for Research on Cancer approached ANSTO and many other nuclear agencies around the world to participate in a meeting to discuss the feasibility of carrying out an international collaborative study of cancer risk among workers in the nuclear industry (13, 14).

Following a feasibility study undertaken by IARC, ANSTO, along with most of the other agencies, agreed to participate in this project, the "International Collaborative Study of Cancer Risk Among Radiation Workers in the Nuclear Industry" (13, 14, 15).

The new combined study is the largest epidemiological investigation ever conducted of workers exposed to ionising radiation (13, 14, 15). Undertaken under the auspices of IARC, it will bring together data on over half a million nuclear industry workers from Australia, Belgium, Canada, Finland, France, Germany, Hungary, Japan, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom, and the United States of America, thereby providing valuable information for determining future radiation protection standards and regulations. This international study will provide a direct test of adequacy of the current extrapolation models used for risk assessment and for the setting of radiation protection standards, and may assist in the construction of improved risk assessment models (16).

To take part in this international collaborative effort, a cohort study of workers at LHSTC is currently being undertaken.

2. STUDY OBJECTIVES

The study of workers at LHSTC has dual objectives:

1) To assess whether workers at LHSTC have different levels of cancer incidence and mortality from the New South Wales and Australian populations, and if so what factors may be involved.

2) Through collaboration with an international working group, coordinated by IARC, to estimate as precisely as possible, the risk of contracting cancer from exposure to long-term low levels of ionising radiation.

3. STUDY DESIGN AND ANALYSIS

The Australian study uses an observational retrospective cohort design based on existing records of employment and exposure to radiation kept in hard copy format by LHSTC since its establishment.

3.1. Study Cohort

The study involves data collection on two distinct study groups:

1) All workers, males and females of working age, monitored for radiation at LHSTC. The information collected on this group will also serve the purposes of the IARC study.

2) Other LHSTC workers, males and females of working age, to provide a basis for comprehensive local analyses.

3.2. Dosimetry

Unlike many occupational epidemiological studies in which surrogate measurements are used for analyses due to the difficulty in measuring exposure of workers to chemicals or other substances, this study is characterised by detailed dosimetric information on doses of ionising radiation, collected in real time on individual workers, and recorded on historical hard copy dosimetry records kept at LHSTC. Monitoring of radiation exposure has been carried out routinely at LHSTC since 1957 even before the start of operation of the nuclear reactor in 1958. This information has been documented in dosimetry records kept by the Safety Division at the Australian Nuclear Science and Technology Organisation at LHSTC. Individual annual doses from occupational exposures to ionising radiation are abstracted from dosimetry files.

3.3. Confounding

Data on smoking habits were sought from employer medical records to adjust for tobacco consumption as a potential confounder of the association between exposure levels to ionising radiation and cancer incidence and mortality.

Data on job classification and educational level were also abstracted from personnel records to derive a measure of socio-economic status and study its confounding effect (17).

3.4. Follow-up

Data collected from historical hard copy records and brought together in one computerised database will be electronically linked with records of national cancer incidence and death registers, for a passive follow-up of more than 7000 workers employed from 1957 onwards (17).

3.5. Analyses of Data

Analyses will be conducted according to the study objectives mentioned above:

For objective 1: Mortality and cancer incidence in monitored and non-monitored workers will be compared between both groups. Also comparison to the Australian population, and the New South Wales population rates will be done taking account of age, sex, and calendar period.

For objective 2: Workers monitored for radiation will be classified by exposure level, and mortality and cancer incidence will be estimated according to exposure categories taking account of age, sex, and calendar period.

Possible confounding or effect modifying variables will be taken into account when appropriate and possible, such as job category, smoking history, socio-economic status, time since first exposure, and duration of exposure.

4. PRIVACY AND CONFIDENTIALITY

Ethical issues, mainly privacy and confidentiality, were addressed in accordance with the laws and regulations governing medical research in Australia. Ethical approval was obtained from the Committee on Experimental Procedures Involving Human Subjects (the institutional ethics committee at the University of New South), the Australian Institute of Health and Welfare Ethics Committee, the NSW Cancer Council Ethics Committee, and the Anti-Cancer Council of Victoria Institutional Ethics Committee.

Rigorous data protection is being employed including the use of randomly assigned numbers to replace identifying information in the analyses of data.

5. PROGRESS-TO-DATE

Data collection on workers at LHSTC is complete. As part of quality assurance extensive checking of the data was carried out (17).

The cohort data file has been forwarded to the Australian Institute of Health and Welfare to carry out linkage with relevant cancer and death records from the National Cancer Statistics Clearing House and the National Death Index Databases.

ACKNOWLEDGEMENTS

The authors would like to thank the Australian Nuclear Science and Technology Organisation for providing funding and logistic support in collecting the data, and the International Agency for Research on Cancer for providing scientific assistance on the project.

REFEERENCES

(1) Hardy, C.J. *Atomic Rise and Fall – The Australian Atomic Energy Commission 1953-1987,* Glen Haven Publishing, Peakhurst, NSW Australia, 1999.

(2) Ferguson, D. *Survey of Health of Employees in the Research Establishment of the Australian Atomic Energy Commission at Lucas Heights, Sydney – First Report – Analysis of Medical Interview Data,* The University of Sydney and the Australian Department of Health, May 1978.

(3) Ferguson, D. *Survey of Health of Employees in the Research Establishment of the Australian Atomic Energy Commission at Lucas Heights, Sydney – Second Report – Interpretation of Hazard and Recommendations,* David Freguson, The University of Sydney and the Australian Department of Health, April 1979.

(4) Wilson, G. *Evaluation of ANSTO's Science Performance.* Appendix 1 in: Future Reaction – Appendices: Report of the Research Reactor Review, pp 1-80. University of Central Queensland. Commonwealth of Australia, 1993.

(5) Lancaster, P., Kidd, S., Liu, J., Mann, J., Pedisich, E., Shafir, E., Tun, G. *Health Outcomes among the residents of Sutherland Shire, New South Wales.* Appendix 2 in: Future Reaction – Appendices: Report of the Research Reactor Review, pp 81-122. Australian Institute of Health and Welfare National Perinatal Statistics Unit, and the University of Sydney. Commonwealth of Australia, 1993.

(6) Doll, R. *Public Health Effects of the Operation of a Research Nuclear Reactor – Produced for the Research Reactor Review.* Appendix 5 in: Future Reaction – Appendices: Report of the Research Reactor Review, pp 207-226. Imperial Cancer Research Fund, Cancer Studies Unit, Oxford. Commonwealth of Australia, 1993.

(7) Taylor, R., Coates, M., Smith, D., Hayes, L. *Investigation of Aspects of Health Status of the Population of Sutherland Shier, Lucas Heights, Research Reactor Review – Incidence of Leukaemia and Lymphoma and All-Cause Mortality in Sutherland and Warringah Shires, Aggregations of Postcodes within Sutherland Shire and NSW, 1970-1990.* Appendix 4 in: Future Reaction – Appendices: Report of the Research Reactor Review, pp 183-206. NSW Cancer Council, and the University of Sydney. Commonwealth of Australia, 1993.

(8) BEIR V (Committee on the Biological effects of Ionising Radiation). *Health Effects of Exposure to low Levels of Ionising Radiation.* National Academy of Sciences, Washington, D.C., 1990.

(9) ICRP 60 (International Commission on Radiological Protection). *Recommendations of the International Commission on Radiological Protection.* Pergamon Press, Oxford, 1991.

(10) UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation). *Sources, Effects and Risks of Ionising Radiation.* United Nations, New York, 1988.

(11) IARC Study Group on Cancer Risk Among Nuclear Industry Workers. (1994) *Direct Estimates of Cancer Mortality Due to Low Doses of Ionising Radiation: An International Study.* The Lancet, 344:1039-1043.

(12) IARC, *Combined Analyses of Cancer Mortality Among Nuclear Industry Workers in Canada, the United Kingdom and the United States of America. IARC Technical Report No. 25,* International Agency for Research on Cancer, World Health Organization, Lyon, 1995.

(13) IARC, *International Collaborative Study of Cancer Risk Among Nuclear Industry Workers - Protocol of the Feasibility Study.* IARC Internal Report 90/001A, International Agency for Research on Cancer, World Health Organization, Lyon, 1990.

(14) IARC, *International Collaborative Study of Cancer Risk Among Nuclear Industry Workers. I-Report of the Feasibility Study.* IARC Internal Report 92/001, International Agency for Research on Cancer, World Health Organization, Lyon, 1992.

(15) Martuzzi, M., Cardis, E. (1996) *Etudes epidemiologiques sur les travailleurs du nucleaire.* Revue Generale Nucleaire, 6:42-45.

(16) Cardis, E.; Martuzzi, M. (1998) *Improving the estimates of radiation induced cancer risk.* Seguridad Nuclear, 6:31-37.

(17) Habib, R.R. (1998) *Retrospective Cohort Study of Cancer Incidence and Mortality Among Nuclear Industry Workers at Lucas Heights Science and Technology Centre: Data Collection.* In Proceedings of the 6th International Symposium, Epidemiology and Occupational Risks, Graz, Austria, 22-24 April.

Progress on the National Radioactive Waste Repository Project

C PERKINS, Coal and Mineral Industries Division, Department of Industry, Science and Resources GPO Box 9839 Canberra ACT 2601
S VEITCH, Bureau of Rural Sciences, Agriculture, Forestry Fisheries Australia GPO Box 858 Canberra, ACT 2601

SUMMARY In 1992, the Commonwealth Government commenced an Australia-wide search for a suitable site for the national radioactive waste repository for Australia's low level and short lived intermediate level waste. In 1998 the central north region of South Australia was chosen as the preferred area in which to undertake detailed site investigations. An intensive public consultation process was begun in the region inl998, followed by a first stage of investigative drilling, which commenced in May 1999. Eleven sites have been drilled in the first stage, and the results will be assessed to select five sites for follow-up drilling. Of these, one preferred and two alternative sites will be chosen, and will be subject to environmental and safety assessment.

1. INTRODUCTION

Australia requires a national repository for the small quantity of low level and short lived intermediate level radioactive waste resulting from the medical, industrial and research use of radioisotopes in Australia. These wastes are in temporary storage at over 50 locations around the country, including Commonwealth and State storage facilities, hospitals, research institutions, and in industry stores. The waste comprises lightly contaminated soils, plastics, paper, laboratory equipment and clothing, industrial smoke detectors, gauges and exit signs.

Current temporary storage arrangements for radioactive waste are not ideal as many small producers of radioactive waste, such as hospitals and universities, are not equipped to manage long-term storage of the material in a satisfactory manner, and storage space is limited. A national facility for Australia's radioactive wastes is preferable to current temporary arrangements and would be more efficient than establishing separate disposal facilities in each state.

In 1992, the Commonwealth Government commenced an Australia-wide search for a suitable site for the near-surface disposal of Australia's low level and short lived intermediate level radioactive waste. The process to date has consisted of three phases, and the results from each phase have been reported in public discussion papers.

Phase 1 of the study, commenced in 1992, involved the development of the methodology for siting a national repository. The method used computer-based geographic information systems to apply internationally accepted site selection criteria on an Australia-wide basis.

Phase 2 of the study, commenced in 1994, involved the application of the site selection methodology developing Phase 1, taking into consideration public comment on Phase 1, to identify eight broad regions of Australia likely to contain suitable sites.

Phase 3 of the study commenced in 1998, with the announcement of the selection of the central-north region of South Australia as the preferred area for finther detailed investigation.

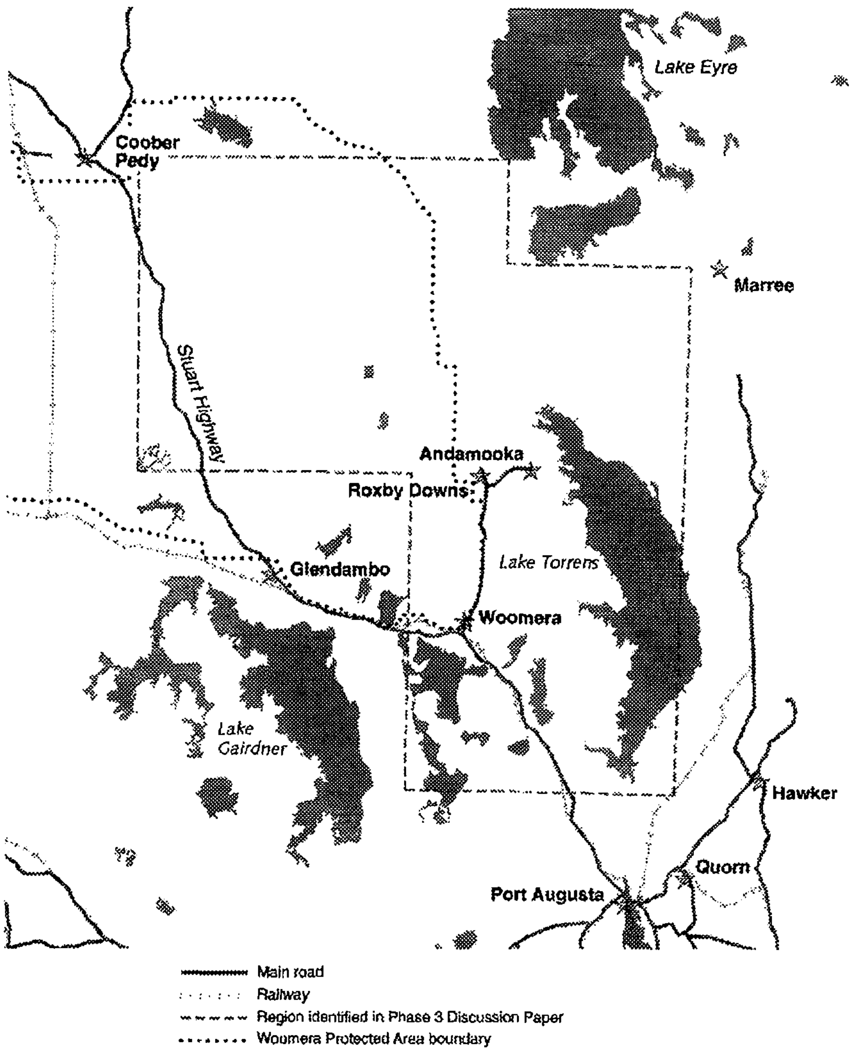
The national radioactive repository project is being managed by the Commonwealth Department of Industry, Science and Resources (previously the responsibility of the Department of Primary Industries and Energy). The Bureau of Rural Sciences (previously the Bureau of Resource Sciences) is conducting technical studies as part of the site selection study for the national radioactive waste repository.

2. PHASE 3 OF THE SITE SELECTION STUDY

The Phase 3 discussion paper, *A Radioactive Waste Repository for Australia: Site Selection Study - Phase 3 Regional Assessment,* released in February 1998, identified the central-north region of South Australia (previously called Billa Kalina) as the preferred region for location of the proposed national radioactive waste repository. The region covers approximately 67,000 square kilometres (Figure 1).

The central-north region was identified for further investigation because it offered the largest area of potentially suitable sites for the near-surface repository. The determination of this region as the most suitable of the eight regions identified in Phase 2 is based on descriptive comparisons and technical assessments using the computer based information system, ASSESS (A System for Selecting Suitable Sites). ASSESS was used to review the thirteen National Health and Medical Research Council (NHMRC) site selection criteria, which were based on internationally accepted criteria.

The central-north region of South Australia



Public Consultation

As in previous phases of the project, public consultation is an important part of the Phase 3 investigations. After the announcement of the selection of the region, intensive consultation was commenced. For example, a regional information office was opened for several weeks in Port Augusta, community information days were held in the region, a toll free information line and Internet site were established, meetings were held with community groups and other stakeholders, and a regional consultative committee, comprising key regional stakeholders, was established. Consultation has been ongoing with pastoralists and Aboriginal groups throughout the site selection process.

During 1998, public submissions on Phase 3 of the national radioactive waste repository project were requested. In July 1999, the report *National Radioactive Waste Repository Site Selection Study - Phase 3 - A Report on Public Comment* was released. The paper summaries and responds to public comment on the Phase 3 investigation. It discusses issues such as the site selection criteria, the origin and types of wastes to be accepted at the repository, packaging requirements, transport arrangements to the site, the total capacity of the facility, its operational period, the effect of the siting of the facility on the local economy, the need for continued consultation in the region, the ownership of the repository, and the cost of using the facility.

2.1 Progress of field investigations

In June 1998, 18 sites were identified for field investigation based on desktop assessment of the region against the site selection criteria. After field inspection, and consultation with pastoralists and Aboriginal groups, the location of some of the sites was changed.

The investigations are proceeding in three stages; stage 1, which involves the identification of up to 18 sites for further investigation from a range of possible sites; stage 2 which involves further investigation of 5 of these sites; and stage 3, which concludes with the selection of one preferred and two alternative sites from the five.

Drilling for stage 1 of the investigations commenced in May 1999, and it is expected that stage 2 will commence in October, with stage 3 expected to commence in late 1999.

Once a preferred site is identified late in 1999 or in early 2000, the proposal for the national radioactive waste repository will be subject to detailed environmental assessment and further public review as required under relevant statutory processes. Construction could commence in 2001.

2.2 Field investigation technique

After consultation about the areas of relative suitability indicated from the desktop by ASSESS, refinements were made to the location of potential sites. Each site was visited to mark out a 1.5 kilometre square area, the corners of which were located with a GPS and pegged. Particular attention was given to selecting sites to include homogeneous surface characteristics, and most sites are situated on gibber plains consisting of silcrete and quartzite. The vegetation is typically salt bush which supports extensive sparse grazing for sheep or cattle.

The first stage of investigative assessment begins with drilling at one corner of each potential site. Reverse circulation hammer drilling with compressed air is used so that all the drilled material passes into a sample bag which is changed after each metre, and sub-samples are then taken for geological description, chemical assay and for other compositional and performance assessments.

While drilling is under way the site geologist records the rate of drilling and the depth of groundwater intersection. Most holes are drilled to approximately 100 metres so that a good geological section is recorded and a good connection is made with the groundwater system. The groundwater is then sampled and its salinity recorded. The drill hole is fully cased with slotted PVC pressure pipe and is then logged with down-hole geophysics, recording natural gamma, induced potential and neutron, the suite being established by the mainly dry strata and because of the PVC casing. Each hole is subsequently pumped to determine the supply rate of groundwater.

For the second stage of field assessment five sites will be chosen based on the results of the first drillhole. At each of the five sites further reverse circulation drilling will be undertaken at the diagonally opposite corner of the 1.5 kilometre square. The drilling method will then change to diamond core to investigate the remaining two corners of each site, and the drill core will provide an intact sample of the potential host and deeper materials of the repository. Micro and macro textures and structures can then be determined as a basis for comparing the performance characteristics within and between the sites.

From the five sites three will be chosen for a third and final stage of assessment. The four perimeter sides of each 1.5 kilometre square site will be drilled with two more reverse circulation holes (at 500 metre in-fill spacing) to confirm that internal site variability is minimal and can be defined. Several shallow test holes, approximately 20 metres deep will be drilled at the centre of each site to confirm the nature of near-surface materials where disposal trenches would be dug. Based on this full suite of drilling information a single site will be recommended for the repository with the other two remaining as alternatives pending the outcome of environmental impact assessment.

3. NATIONAL RADIOACTIVE WASTE REPOSITORY

Design criteria for the repository will be based on the requirements of the National Health and Medical Research Council (NHMRC) *Code of practice for the near-surface disposal of radioactive waste*, the International Atomic Energy Agency (IAEA) Radioactive Waste Safety Standards (RADWASS), and recommendations and principles outlined in the *Joint Convention on the Safety of Spent Fuel and on the Safety of Radioactive Waste Management*. The design will depend on the volumes and types of radioactive waste for disposal, the climate and geology of the site, the dose constraints, regulatory controls, and the level of access control that can be imposed while the site is operational.

The site will occupy an area defined by a 1.5 kilometre square, the vast majority of which will be a buffer zone. The site will easily fit the near-surface disposal trenches, which will comprise a number of trenches less than 20 metres deep. The trenches will have different designs and levels of engineering, depending on the type of waste to be disposed. The trenches will be within a several hundred metres square area at the centre of the site. The buffer zone surrounding the area will be large enough to conduct environmental monitoring and to ensure an adequate distance between the facility and the public.

The waste acceptance criteria will include treatment, packaging and conditioning requirements, and activity concentration limits also need to be taken into account in the repository design.

3.1 Type of waste to be accepted

Australia has about 3500 cubic metres of low level and short lived intermediate level waste arising from about 40 years of the medical, industrial and research use of radioactive materials, which will be disposed of in the near surface repository, and about 45 cubic metres of annual increase.

The existing inventory of low level and short lived intermediate level waste comprises about 2000 cubic metres of soils from CSIRO's research into treatment of radioactive ores, approximately 1000 cubic metres of ANSTO waste, including compacted contaminated clothing, paper, and glassware, about 100 cubic metres of waste from the States and Territories, including industrial gauges, exit signs, smoke detectors, medical sources, and approximately 60 cubic metres of waste from the Commonwealth Department of Defence, including electron tubes, radium painted watches, compasses, and sealed sources. It is expected that about 500 cubic metres of waste will be produced from the decommissioning of the HIFAR reactor.

3.2 Facility Management

A likely option is that the facility will be Commonwealth owned, with regulation by the Commonwealth Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). Operation could be by private contractor, with oversight by ARPANSA.

The near-surface repository will be used for disposal of Australia's current inventory of low level and short lived intermediate level radioactive waste and estimated annual arisings for at least 50 years from the date of its commissioning. The 50 year operational period is an arbitrary period at the end of which it is proposed that the use of the repository be reviewed. Operations will cease at the repository when the authorised disposal space or the limit on total site radioactivity is reached, whichever comes first. Following closure of the repository, the radioactivity of the materials disposed of in the facility will decay to safe levels during a period of restricted access and monitoring which would be about 200 years. At the end of this period no further control of the near-surface repository site will be necessary.

4. CO-LOCATION OF A STORE FOR LONG-LIVED INTERMEDIATE LEVEL WASTE

A purpose-built above ground national storage facility is required for the safe management of Australia's long-lived intermediate level radioactive waste. The store will be for the waste arising from research, medical and industrial use of radioisotopes, including sealed radium sources and wastes from the production of radiophamaceuticals. It is also expected that the store will eventually accommodate the small volume of long-lived intermediate level waste to be returned to Australia from the overseas processing of Australia's research reactor spent fuel. Spent fuel would not be stored at the facility.

No site has yet been identified for the store. When a preferred site for the near-surface repository for the low level and short lived intermediate level waste has been identified, it may be considered for possible co-location with the store for long-lived intermediate level waste.

5. NO HIGH LEVEL RADIOACTIVE WASTE REPOSITORY FOR AUSTRALIA

Successive Australian Governments have agreed that Australia should not accept the radioactive waste of other countries. The Government's position is based on the clear principle that countries deriving benefits from nuclear power should expect to make their own arrangements to safely dispose of nuclear waste. As Australia does not have a nuclear power industry and does not produce high level radioactive waste, no high level radioactive waste facility is planned for Australia.

Views expressed by certain companies and individuals as to the suitability of Australia to host an international high level radioactive waste repository are totally unrelated to the site selection studies being undertaken for the national radioactive waste repository.

6. CONCLUSION

The investigation of the central north of South Australia for a low level and short lived intermediate level waste repository site is now well advanced. Locally based public consultation and investigative drilling is continuing with a view to selecting one preferred site and two alternative sites late in 1999 or early in 2000. All thirteen of the NHMRC selection criteria are being used to assess the suitability of candidate sites. Indications so far are that a highly suitable site will be identified.

Synroc for Plutonium Disposal

ADAM JOSTSONS and E. R. (LOU) VANCE

Australian Nuclear Science and Technology Organisation
PMB 1 Menai NSW 2234

SUMMARY

A pyrochlore-rich titanate ceramic has been chosen by the US DOE for excess weapons Pu immobilisation in the USA. The development of this wasteform was based on the synroc strategy which aims to immobilise radioactive waste in durable multiphase titanate ceramics with phases chosen to be similar to titanate minerals that exist in nature and have immobilised U and Th for billions of years. The evolution of the pyrochlore-rich ceramic for Pu immobilisation from earlier synroc variants is described and the choice of process steps is discussed. Leaching studies demonstrate that the release rate of Pu from the wasteforms in aqueous media is very low and similar to those of U and the neutron absorbers Gd and Hf that will ensure avoidance of nuclear criticality in repository environments.

1. INTRODUCTION

In the aftermath of the Cold War, the US and Russia have agreed to large reductions in their stockpiles of nuclear weapons. The US is pursuing a two-track strategy for the disposition of 50 metric tonnes of surplus weapons plutonium:

- as mixed-oxide fuel in existing commercial power reactors to render the material non-weapons-usable
- immobilisation and geologic disposal.

Both approaches will ensure that the overall goal of the disposition program is met by "rendering the plutonium as unattractive and inaccessible for retrieval and weapons use as residual plutonium in the spent fuel from commercial reactors", ie the US National Academy of Science's (1) "spent fuel standard". Following an extensive screening study of more than 70 technologies and waste forms previously studied for high level waste (HLW) immobilisation, a synroc-based pyrochlore-rich titanate ceramic was recommended (2) to the US Department of Energy (DOE) for the immobilisation of surplus weapons plutonium for use with can-in-canister technology. In this approach, cans with 7.5cm diameter and about 51cm long would be loaded with ceramic discs containing the immobilised plutonium. These cans in turn would be loaded into standard Defense Waste Processing Facility (DWPF) canisters for HLW glass and the molten glass would be poured around them to provide an external gamma radiation barrier.

The Australian Nuclear Science and Technology Organisation (ANSTO) has been developing titanate ceramic wasteforms since 1980 through its synroc program. ANSTO is participating with the Lawrence Livermore National Laboratory (LLNL), the lead laboratory on plutonium immobilisation for the US DOE office of Fissile Materials Disposition (MD). Other members of the team are Argonne National Laboratory, Pacific Northwest National Laboratory and the Westinghouse Savannah River Company Technology Center. The US DOE has expressed a preference for siting the immobilisation facility at the Savannah River site and current plans envisage that the facility would be fully operational by 2006/7.

ANSTO's involvement in the Pu immobilisation program commenced late in 1994. ANSTO provided LLNL access to some of the results of its synroc development program centred on the Synroc Demonstration Plant for the screening process and the subsequent Programmatic Environmental Impact Statement on Storage and Disposition of Weapons-Usable Fissile Materials (3). This screening process resulted in borosilicate glass and "titanate-based Synroc-like" ceramics being ranked first and second, respectively. This choice was reversed late in 1997 (2) following a period of intense wasteform development and formal independent evaluations.

The final choice by the DOE of a pyrochlore-rich titanate ceramic rather than a lanthanum borosilicate glass (LaBS) under development by WSRC for storage of americium and curium, was made against a number of criteria developed by DOE MD. These included: (1) resistance to Pu theft, diversion and recovery by a terrorist organisation or rogue nation; (2) resistance to recovery and reuse by a host nation; (3) technical viability, including technical maturity, development risk and acceptability for repository disposal; (4) environmental, safety and health factors; (5) cost effectiveness; and (6) timeliness.

2. SYNROC-BASED TITANATE WASTEFORMS

The synroc strategy aims to immobilise radioactive wastes in durable multiphase ceramics, with the phases chosen to be similar to titanate minerals that exist in nature and have immobilised U and Th for billions of years. Most of the early development of synroc wasteforms and process technologies focused on the Synroc-C formulation for immobilising liquid HLW from the reprocessing of commercial Light Water Reactor (LWR) spent fuel. The actinides in Synroc-C partition into zirconolite ($CaZrTi_2O_7$) and perovskite ($CaTiO_3$). Perovskite is mainly designed to immobilise Sr present in HLW. Barium hollandite ($BaAl_2Ti_6O_{16}$) is included in Synroc-C to primarily immobilise cesium although it also accepts K, Rb, and Ba. The basic Synroc-C formulation is flexible and a single precursor composition can be used to immobilise HLW loadings in the range 0 to 30 wt% without significant effects on its chemical durability in aqueous media. This flexibility is due largely to the extended solubility of the radionuclides in the titanate phases and the excess of titanium oxide as reduced rutile in the formulation. Even at 30 wt% HLW, the principal host phases, zirconolite, perovskite and hollandite, are undersaturated with respect to the key radionuclides in the HLW from LWR fuels.

The solubility of Pu in Synroc-C is extensive and 11.8 wt% PuO_2 (^{238}Pu) has been successfully incorporated (4) in solid solution in the host phases of Synroc-C, in experiments to study accelerated α-decay damage. The normal rare earth loadings were eliminated by molar substitutions with the Pu. Nevertheless, to increase the PuO_2 loadings in parallel with neutron absorbers it was necessary to look for alternative formulations to Synroc-C. Since zirconolite is the most durable phase of Synroc-C, the focus of these newer formulations was on the zirconolite family of phases, including pyrochlore which can incorporate as much as 50wt% of PuO_2 and/or UO_2.

The avoidance of nuclear criticality is essential during wasteform processing, during its storage, and over the very long term in the repository environment. Such avoidance is ensured in the Pu-rich titanate wasteforms by having high loadings of neutron absorbers such as Gd, Sm and Hf in solid solution in the Pu host phases.

3. Pu IMMOBILIZATION IN TITANATE CERAMICS

A. Zirconolite-Rich Titanates

Zirconolite-rich Synroc has been developed for actinide wastes in general (5,6) and more particularly since 1994 as a candidate ceramic host for the immobilization of excess weapons Pu (7). Kesson et al (8) found that zirconolite solid solutions can separately accept as much as 27 wt% UO_2, 20 wt% ThO_2 and 29 wt % rare earth oxides, particularly if charge coupled multiple cation substitutions are utilised.

Zirconolite-rich ceramics (7) containing about 10 wt% each of hollandite and rutile have been fabricated to contain 13.5 wt% PuO_2 as well as 10 wt% HfO_2, 4 wt% Gd_2O_3 and 4 wt% Sm_2O_3. The hollandite was included in the formulations as a host phase for radioactive cesium to provide an internal gamma radiation source in contrast to the present reference can-in-canister approach. The Gd and Sm oxides were each incorporated in a 1:2 molar ratio with respect to Pu. The HfO_2 content could have been increased to provide additional neutron absorption since it only replaced one third of the Zr in zirconolite in the above case. Full substitution of Hf for Zr is possible in zirconolites.

These ceramics were produced by two methods, either by (a) sintering of blended high-fired oxides in air for 4 hours at 1375°C or (b) by hot isostatic pressing (HIPing) at 1280°C/150 MPa of calcined alkoxide route powders in which the Pu was introduced as a nitrate solution prior to calcination at 750°C in argon. The HIPed material was fully dense (~5.1 g/cm^3) with all the Pu incorporated in the zirconolite. The sintered material had a grain size of ~ 4 µm compared with ~ 1 µm in the HIPed material and a density of ~ 93% of theoretical. Less than 2% of the Pu inventory remained atomically unincorporated in the sintered zirconolite - as a reacted oxide (Hf, REE, Pu) O_2.

B. Pyrochlore-Rich Titanates

After the preliminary compositions of actual Pu streams for immobilization became available, it was apparent that the feed streams had on average about equal amounts of uranium and plutonium. This uranium content could be incorporated in a zirconolite-rich ceramic together with the Pu but with a significant loss of rare earth neutron absorbers because of total solubility limits. Consequently, it was decided to focus on a pyrochlore-rich wasteform in which:

- the uranium to plutonium ratio would be 2 to 1. High ^{238}U loadings would ensure additional criticality control through limitation of the long term $^{235}U/^{238}U$ ratio with the decay of ^{239}Pu to ^{235}U

- the plutonium-to-gadolinium-to-hafnium mole ratio was 1:1:1.

Pyrochlore and zirconolite in titanate ceramics are closely related structurally and are derived from ordered anion-deficient fluorite structures. In the cubic pyrochlore with the empirical formula unit of $A_2Ti_2O_7$ the A site is 8-coordinated and can be occupied by Ca^{2+}, Gd^{3+}, U^{4+}, Pu^{4+} and Hf^{4+}, amongst others. The Ti^{4+} is 6-coordinated. The monoclinic zirconolite ($CaZrTi_2O_7$) has five distinct cation sites permitting incorporation of a wider variety of cations of different charge and ionic radius than pyrochlore. Moreover, a particular cation may enter more than one site in zirconolite.

The baseline pyrochlore-rich ceramic was designed to incorporate about 11.5 wt% PuO_2 and 23 wt% UO_2 to yield about 95% of pyrochlore and 5% of rutile in which some substitution of Ti by Hf was anticipated. The actual product, formed after sintering for 4 hours at 1350°C, contains some brannerite (UTi_2O_6) which also contains Pu, Gd and Hf. As for the zirconolite-rich titanates mentioned above, a small (<2%) amount of the Pu inventory remains unincorporated in the sintered pyrochlore made from high-fired oxides, as a reacted oxide (Hf,REE,Pu,U) O_2, whereas in materials made from alkoxide powders the actinides are fully dissolved in the titanate phases. The theoretical density of the baseline pyrochlore ceramic is about 6.0 gm/cm^3 and the observed density of the ceramics is about 5.6 gm/cm^3.

The mineralogy and partitioning of Pu, U and the neutron absorbers among the phases in the pyrochlore-rich ceramic have been studied extensively. The phase relationships are depicted in the simplified ternary diagram in Fig 1. The baseline ceramic has six oxide components that need to be reduced to three variables on the basis of the following simplifying assumptions:

- TiO_2 is always in excess, so the TiO_2 activity is fixed at unity.

- UO_2 and PuO_2 behave sufficiently similarly in pyrochloric-rich titanates that they can be treated as one oxide, AnO_2.

- Gd_2O_3 is distributed relatively evenly among the actinide-bearing phases, enabling it to be proportioned out of the phase diagram.

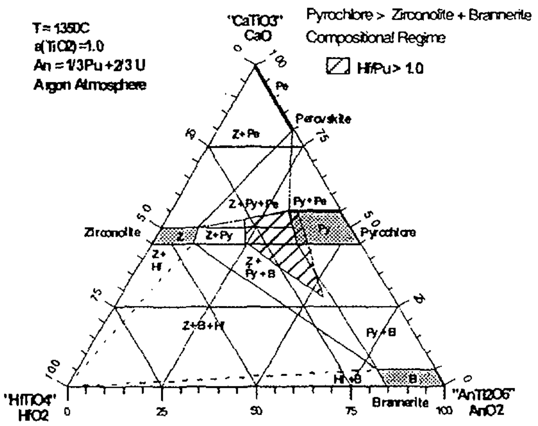


Figure 1. Depiction of the compositional regime (diagonally hatched) expected for impurity-bearing pyrochlore-rich ceramics.

The UO_2/PuO_2 ratio does show some variations amongst the phases. Pyrochlore and brannerite have UO_2/PuO_2 ratios close to 2:1 whereas it is about 1:3 in zirconolite. All primary Pu-containing phases have been found to accommodate more neutron absorbers (Gd and Hf) than plutonium on a molar basis.

The mineralogy of the pyrochlore-rich ceramic is influenced by impurities in the Pu feed stocks destined for immobilisation. The plutonium assay in the candidate feeds varies from under 10 wt% to over 99 wt%, ie from trace depleted uranium in plutonium to trace plutonium in fully enriched (93% ^{235}U) uranium. Impurities in the existing feed stock include: aluminum, carbon, calcium, chlorine, iron, fluorine, gallium, potassium, magnesium, molybdenum, sodium, silicon, tantalum, tungsten and zinc.

With the exception of carbon and the halides, fairly high levels of all the impurities in currently envisaged Pu feed stocks are tolerated by the immobilization form. Feed blending may be used to create impurity concentrations closer to the average which has been shown to be acceptable. Carbon contents and high halide element concentrations could be removed or depleted by appropriate pre-treatment of the particular Pu material prior to blending. The observed volume abundances of pyrochlore (60-90%), brannerite (0-22%), zirconolite (0-25%) and rutile (0-16%), depend on the impurity levels. Zirconolite is stabilized relative to pyrochlore by a number of divalent and trivalent metal oxides.

Silica, boron, phosphorus and the alkalis Na and K, if present at significant levels, lead to the formation of glasses. These glasses do not contain significant

Pu, U and neutron absorbers and are effectively micro-encapsulated by the resistant titanate phases.

4. TITANATE WASTEFORM FABRICATION

The Synroc-C process involves rotary calcination of a titanate precursor mixed with liquid HLW followed by uniaxial hot-pressing of the resultant calcine in bellows containers at about 1180°C/20 MPa (9). The hot-pressed disks containing about 30 kg of Synroc were about 30 cm in diameter. These disks were considered inappropriate for the preferred can-in-canister immobilisation option and could have impeded the flow of the HLW glass into the canister.

An alternative was to use HIPing rather than hot uniaxial pressing. ANSTO had demonstrated with zirconolite-rich formulations described earlier that long and slender cans could be so produced, containing up to 30 kg of ceramic. This would have eliminated the obstruction of the flow of the HLW glass and the risk of a negative impact on the quality of the glass.

The final choice of a process based on cold pressing and sintering was derived from the industrially mature technologies in glove-box plants used by the MOX fuel industry in Europe to satisfy the DOE MD criteria 3, 5 and 6 noted in the Introduction. There are substantial differences between the ceramic immobilisation product and the MOX product in terms of size and composition. The nominal size of the ceramic product (puck) is 6.3 cm in diameter by 2.5 cm high. The pyrochlore-rich ceramic sinters adequately at 1350°C whereas MOX fuel is produced by sintering at about 1700°C. Each ceramic puck contains about 58 g Pu and 20 sintered pucks are loaded in a can with 28 cans per HLW canister.

The most important steps in the fabrication process, in terms of impact on the final form, are the milling/blending and agglomeration steps. Two technologies relevant to the needs of the form processing have been established industrially. The "short binderless route" using attritor mills has been developed by British Nuclear Fuels Limited (10) whereas COGEMA, France uses ball milling (11). Both processes use dry milling to achieve sufficient micronisation of powders, homogenisation and conditioning to produce free flowing aggregates for the pressing operation.

Grinding and homogenisation are important steps because some residual actinide oxide particles (Hf, REE, Pu, U)O_2, tend to remain in ceramics fabricated from high-fired oxides whereas they are not part of the mineralogy of ceramics prepared from reactive alkoxide powders.

Sintering atmospheres ranging from reducing (Ar + 3.5% H_2), neutral (argon) and air have been examined during the development of the wasteform. Both air and argon are acceptable to produce the desired mineralogy. Under reducing conditions perovskite may form. Since perovskite is somewhat less durable in aqueous media than the other titanate phases it is less desirable.

Apart from benefiting from the proven industrial experience of MOX fuel fabrication, there are two other important factors in support of the cold press and sinter route:

i) on line non-destructive evaluation of product density, mineralogy and composition is facilitated by the absence of cans used in hot-pressing;

ii) fissile materials accountancy is more precise for bare pucks than canned material.

Nevertheless, HIPing remains a fall back option and has the benefits of a lower fabrication temperature, greater homogeneity and density, and would eliminate the need for automatic puck handling equipment.

5. WASTEFORM DURABILITY AND CRITICALITY SAFETY

Criticality safety during fabrication is ensured by limiting batch sizes of PuO_2 and by early blending with a precursor containing Gd_2O_3 and HfO_2, which are effective neutron absorbers. The safest approach to assuring criticality safety in the repository is to minimise the release of Pu, U and the neutron absorbers in the first place, i.e. to have low leach rates in aqueous media. Additionally, it is desirable for the individual release rates from the wasteform not to differ significantly and hence not generate uncertainty that the fissile materials and neutron absorbers separate after they are released. This separation may otherwise occur within a waste package, in the near-field repository environment, or in the far field.

Plutonium releases from Synroc-C (12), and zirconolite-rich and pyrochlore-rich ceramics (7) in deionised water are shown in Fig 2. These are normalised leach rates determined by α-counting and include contributions from ^{241}Am activity that could not be distinguished from Pu. The data in Fig 2 show the usual decrease of Pu leaching with time in MCC-1 tests and indicate that the Pu releases from the zirconolite-rich and pyrochlore-rich ceramics follow the long-term trend of Synroc-C. The "total" normalised release rate contains contributions from soluble Pu, colloids, and material absorbed on the leach vessel walls. The only uncertainty relates to dissolved elements that are reincorporated in very thin hydrous titania films formed on the specimen during alteration. The total normalised release rates of Pu asymptote to a long term value of $5 \times 10^{-6} g.m^{-2}.d^{-1}$ at 70 to 90°C. Such a low release rate corresponds to a long-term alteration rate of 0.001 mm/day or 0.5mm in 10^6 years. Consequently, the titanate wasteforms act as an independent immobilisation barrier.

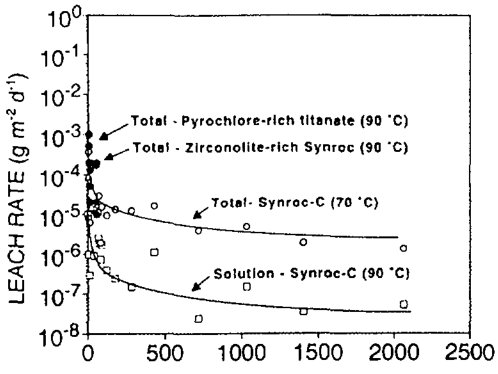


Figure 2. Normalised Pu leach rates measured in MCC-1 tests in deionised water at 70 and 90°C.

In 7 day MCC-1 leach tests at 90°C in deionised water, the Pu and U release rates varied by about a factor of 2 with impurity loadings from 1 wt% up to ~ 13 wt%. These results show that the baseline pyrochlore-rich ceramic is tolerant to the expected impurities and changes in mineralogy within the process regime adopted. In the same short term tests the total average leach rate ($g.m^{-2}.d^{-1}$) varied from ~ 2×10^{-4} for Pu, ~ 4×10^{-4} for U, ~ 5×10^{-4} for Gd and less than 4×10^{-5} for Hf. These leach rates demonstrate that the absolute differences between the releases of Pu and neutron absorbers are very small. These differences will be even smaller in the longer term.

A principal concern with crystalline wasteforms is that α-decay damage may render them amorphous and lead to significant changes in physical and chemical properties. The results of Weber et al (13), however, suggest that the Pu leach rate would increase only by a factor of about 10 from titanate ceramics in accelerated damage tests after amorphisation. The leaching behaviour of actinide doped specimens in accelerated damage tests could be influenced by α-radiolysis effects that would not be important in Pu immobilisation, given the longer half lives of ^{239}Pu and ^{235}U than that of ^{238}Pu.

Recent analysis by Gottlieb et al (14) concludes that no external criticality is possible from any Pu concentration mechanisms in the near field of Pu-containing can-in-canister packages employed in the Yucca Mountain potential repository. They also conclude that criticality is not likely in the far field.

6. DISCUSSION

The need for a high Pu loading in the wasteform was driven by economics since the Pu wasteform impacts the displacement of DWPF glass resulting in the MD program having to pay a fee for each additional HLW canister placed in the repository. Current costs for each additional HLW canister are about $US500,000. The high Pu loading combined with high density of the pyrochlore ceramics ($5.6 gm/cm^3$) versus LaBS glass ($3.85 gm/cm^3$) resulted in a life cycle cost advantage to the ceramic of as much as $US70M.

Significant public and worker health and safety benefits, as well as unquantified economic impacts, resulted from a total radiation dose field of seven to eight times higher for LaBS glass than the titanate ceramic, predominantly from (α, n) reactions on boron, a key constituent in the LaBS glass. This higher neutron dose would have necessitated additional shielding and may have prevented "hands on" maintenance of equipment in the glove boxes.

The primary resistance to diversion arises from the can-in-canister concept that provides a strong gamma radiation field. The canisters are large - 0.6m in diameter, 3m long and weigh about 2.5 metric tons. A shielded flask would be required to transport a canister containing ceramic cans and there would be no easy identification of co-located canisters with and without PuO_2. The pyrochlore ceramic is not soluble in nitric acid and hence recovery of Pu is not possible using the well established PUREX process without additional steps at the head end.

The ability to adapt the mature ceramic process technologies from MOX fuel production Pu immobilisation was helpful in meeting criteria on technical viability and timeliness.

The durability of the synroc-based pyrochlore waste form which contained Pu, U and high loadings of neutron absorbers in solid solution of the titanate phases was seen to be an advantage for avoiding nuclear criticality possibilities in a repository. The data base available from ANSTO's synroc research for over fifteen years on Pu behaviour in the relevant titanate phases was a significant factor in judgements of eventual repository acceptance of the ceramic form. Finally, the extensive data base on the durability of natural mineral analogues of the titanate phases with high U and Th contents provided assurance of long term safety.

7. CONCLUSIONS

The pyrochlore-rich titanate ceramic chosen for excess Pu immobilisation in the US has evolved from earlier Synroc wasteforms to produce an optimised ceramic to meet the various demands of the fissile materials disposition program. The pyrochlore-rich ceramics can incorporate in a multiphase microstructure high loadings of Pu, U and neutron absorbers such as Gd and Hf. The wasteform is tolerant of impurities in the Pu streams designated for immobilisation. Current leaching tests show that pyrochlore-rich ceramics have Pu releases in aqueous media that closely follow the behaviour of Synroc-C in which the total Pu release rate after 2000 days is as low as 5×10^{-6} $g.m^{-2}.d^{-1}$ at 70 to 90°C, equivalent to alteration of about 0.5mm in 10^6 years. The low Pu release and the small absolute differences in Pu release rates compared to those of U, Hf and Gd indicate that criticality is not credible in repository environments.

ANSTO continues to support the Plutonium Immobilisation Project as part of a team led by LLNL. Our activities are centred on process, envelope development including impurity tolerance as part of the process to gain regulatory acceptance. The plutonium wasteform qualification process will assist in opening up for ANSTO further opportunities for development of titanate ceramics in other radioactive waste remediation projects.

8. REFERENCES

1. National Academy of Sciences, Committee on International Security and Arms Control, *Management and Disposition of Excess Weapons Plutonium*, National Academy Press, Washington, DC (1994).

2. S G Cochran, W H Dunlop, T A Edmunds, L L MacLean and T H Gould, "Fissile Material Disposition Program Final Immobilization Form Assessment and Recommendation", UCRL-ID-128705 (1997).

3. U.S. Department of Energy "Storage and Disposition of Weapons – Usable Fissile Materials Final Programmatic Environmental Impact Statement", Washington DC, December 1996.

4. K A Boult, J T Dalton, J P Evans, A R Hall, A J Inns, J A C Marples and E L Paige, "The Preparation of Fully-Active Synroc and its Radiation Stability", UKAE Report, AERE R 13318 (1988).

5. E R Vance, P J Angel, B D Begg and R A Day, "Zirconolite-Rich Titanate Ceramics for High-Level Actinide Wastes" in *Scientific Basis for Nuclear Waste Management XVII*, Edited by R Van Konynenburg and A A Barkatt, pp 293-298, Materials Research Society, Pittsburgh, PA, USA (1994).

6. E R Vance, C J Ball, R A Day, K L Smith, M G Blackford, B D Begg and P J Angel, "Actinide and Rare Earth Incorporation in Zirconolite", *J Alloys and Compounds*, **213/214**, pp 406-409 (1994).

7. E R Vance, A Jostsons, S Moricca, M W A Stewart, R A Day, D B Begg, M J Hambley, K P Hart and B B Ebbinghaus, "Synroc Derivatives for Excess Weapons Plutonium" in *Ceramic Transactions (Environmental Issues and Waste Management Technologies IV)*, Eds. J C Marra and G T Chandler **93**, pp 323-329, American Ceramic Society, Westerville, OH (1999).

8. S E Kesson, W J Sinclair and A E Ringwood, "Solid Solution Limits in Synroc Zirconolite" Nuclear Chem Waste Management, **3**, pp 259-266 (1983).

9. A E Ringwood, S E Kesson, K D Reeve, D M Levins and E J Ramm, "Synroc" in *Radioactive Wasteforms for the Future*, Editors W Lutze and R C Ewing, pp 233-334, North-Holland, Amsterdam (1988).

10. J Edwards, J M Brennan, H M MacLeod and C Brown, "MOX Fuel at BNFL", *The Nuclear Engineer*, **37,** pp 178-181 (1996).

11. R Liberge, M H Mouliney, S Masson and J-C Thieblemount, "French Experience with Dry Milling of Nuclear-grade Ceramic Powders", presented at WM '99 Conference, Feb 28 – March 4, 1999, Tucson, AZ (1999) (on disc).

12. K L Smith, G R Lumpkin, M G Blackford, M Hambley, A E Day, K P Hart and A Jostons, "Characterisation and Leaching Behaviour of Plutonium-Bearing Synroc-C", in Scientific Basis for Nuclear Waste Management XX, Edited by W J Gray and I R Triay, pp 1267-1272, Materials Research Society, Pittsburgh, PA, USA (1997).

13. W J Weber, J W Wald and Hj Matzke, "Effects of Self-Radiation Damage in Cm-Doped Gd_2 Ti_2 O_7 and Ca Zr Ti_2 O_7", *J Nucl Materials*, **138**, pp 196-209 (1986).

14. P Gottlieb, S Goluoglu and P L Cloke, "Disposal Criticality Analysis for Immobilized Plutonium External Configurations", in Proc of Third Topical Meeting on DOE Spent Nuclear Fuel and Fissile Materials Management, Sept 8-11, 1998, Charleston, SC, American Nuclear Society, La Grange Park, IL, pp 221-225 (1998)

AU0019554

The Pangea Concept for an International Radioactive Waste Repository

DR. MARCIS KURZEME, General Manager, Operations,
Pangea Resources Australia Pty. Ltd.
PO Box Z5287, St Georges Terrace, Perth WA 6831

SUMMARY

Pangea Resources Australia Pty. Ltd. is engaged in a study to investigate the feasibility of constructing and operating an international radioactive waste repository in Australia. Western Australian in particular has a unique combination of geology, topography and climate which makes it eminently suitable for a deep geological repository for the safe and permanent disposal of radioactive waste. Australia also has the political, social, legal and financial systems, together with the technical capability to make it acceptable as a host nation for an international repository. The establishment of an international repository in Australia would benefit the whole world as well as Australia.

1. INTRODUCTION

The Pangea concept can provide an integrated global radioactive waste management service. At the core of the concept is an international radioactive waste repository that can accept spent fuel for direct disposal, appropriately conditioned high level and intermediate level waste, and appropriately conditioned nuclear materials from global disarmament activities.

The site of the repository would be selected primarily on technical grounds to provide the highest levels of safety and the greatest ease in demonstrating safety. Pangea has developed a new approach for site selection in defining a series of "high isolation" site attributes, which then enable such potential sites to be readily selected, investigated, characterised and analysed for safety.

This paper reviews the origins of the Pangea concept, describes the high isolation approach to site selection, the Pangea integrated waste management system, together with its potential economic impact on Australia.

2. THE ORIGINS OF THE PANGEA CONCEPT

At this time neither the federal government nor the state government of Western Australia has endorsed the Pangea concept for an international repository in Western Australia. Pangea is currently engaged in a feasibility study in Western Australia and is not seeking any government endorsement or approval. Rather, within the context of examining the feasibility of the concept, Pangea seeks the opportunity to engage both governments in a reasoned and objective dialogue to examine the merits and benefits of the concept. Pangea also seeks to stimulate and to engage in an open and informed discussion with the public and those groups who have a direct interest in the Pangea proposal. In addition Pangea is informing other governments on the Pangea concept and the global benefits of an international repository for the safe and permanent disposal of high level nuclear waste and spent fuel.

The Pangea concept can be traced to the SYNROC Study Group, which began its activities in late December 1988. This was a vehicle set up by the Australian government to study the commercial potential for SYNROC in a global context. This work progressed towards a conceptual plan for a reprocessing facility located in Australia with a deep geological disposal facility to take the resultant immobilised high level waste, and to provide the option of direct spent fuel disposal. Pangea with a different set of supporting organisations - has built on some components of the SYNROC Study Group conclusions and combined these with new concepts.

Pangea is currently funded by BNFL, NAGRA and EHL. These organisations bring to the Pangea project the technical skills and the experience needed for all the components of the project, such as transport of nuclear materials, site selection and characterisation, performance assessment and safety analysis, repository design and project management. The current group of supporters and Pangea are acutely aware that this project can succeed only with the support of the Australian people and the participation of Australian industry. It is a declared objective of Pangea to include Australian investors and to interact closely with Australian industry.

Recently it became obvious that a new nuclear waste disposal initiative was justified because many national waste repository programs were suffering delays, cost overruns, and, in some unfortunate cases, significant loss of investment due to failed attempts to site a geological repository. The unexpected complexity of making a safety case in highly complex geological conditions was a key factor contributing to these problems. Pangea believes that both scientific and public support would be more easily obtained if assertions of safety were based on simple and robust geological systems.

A further aspect of large and growing importance was the recognition that, with the end of the cold war, an enormous effort would be required to attain the crucial goal of total nuclear disarmament. To reach that goal there will be necessary to dispose safely and permanently of appropriately conditioned surplus nuclear materials as the world progresses towards nuclear disarmament. Most of the weapons grade material is likely to be converted to fuel for use in power reactors and an international repository for disposal of the resulting spent fuel would certainly expand the range of disarmament options available.

The Pangea concept was therefore developed with a strong focus on the long-term safety of the repository and on the security of weapons sourced nuclear materials. The safety aspect led to the development of the "high-isolation" concept for repositories which is described in the following section. The focus of the project is a deep repository located in suitable, very simple and stable geology, with flat topography with a stable arid climate. The security aspect is enhanced with a host country which has a history of strong support for non-proliferation, which has a stable democratic society, and which is trusted by the other nations of the world.

3. THE HIGH-ISOLATION APPROACH TO SITE SELECTION

The basic feasibility of geological disposal is accepted within the nuclear waste management community and the achievability of safe and permanent safe disposal has been asserted by many international experts and organisations. All states with nuclear power and related activities have active programs for repository development. No insuperable technical problems are foreseen for developing geological repositories by those directly responsible, or by the majority of the scientific and technical community. In the wider public and political circles, however, the perceptions are often different. Waste disposal programs are not widely regarded as being on a straightforward route towards successful implementation. In recent years there has been growing debate on other approaches such as long-term surface storage or advanced transmutation schemes – although neither of these can be regarded as a real alternative to deep geological disposal.

The single most important reason for this situation is the lack of public confidence in the ability of scientists to predict repository performance with sufficient reliability over the long time scales of relevance. Methodologies have been developed to at least scope the bounding behavior of disposal systems. However, safety assessments for deep geological repositories have become enormously complex. Within the technical area, the issue which has undoubtedly led to the most debate is the characterization of the geological environment at a potential repository site. The geological media being investigated and characterised are mostly complex and heterogeneous on the scales of relevance, and this has turned out to be a much more challenging task than was appreciated in early years.

Pangea, using the knowledge and experience gathered over decades of involvement in site investigation, characterisation and performance assessment in many repository programmes, has developed a new approach. Unrestricted by political boundaries, Pangea considered the necessary attributes for a repository site which would not only make it extremely safe but also so simple that the safety case could be readily demonstrated to the public as well as the experts. A set of attributes for such a site was developed, based on consideration of the features, processes and events taken into account in state of the art safety analyses of repositories. These characteristics which can be identified as essential or as favourable can be summarised as follows:

- Stable geology (needed because of the long isolation times aimed at)
- Flat topography (reduces driving forces for groundwater movement)
- Near-horizontal sedimentary strata (simpler to investigate and extrapolate)
- Stable, arid climate with negligible erosion (eases problem of extrapolation)
- Low permeability (host rock formation reduces groundwater movements)
- Old and saline groundwater (indicates extremely slow groundwater movement; non-potable)
- Stratified salinity (counteracts thermal buoyancy effects)

- Reducing geochemical conditions (reduces solubilities of radionuclides)
- Absence of complex karst systems (avoids complex hydrogeologic modelling)
- Low population density (reduces intrusion risks)
- No significant resource conflicts (reduces intrusion risks)

In principle, the safety assessment for a high-isolation site with the above attributes will not differ from safety assessments for other repository programs. In practice, the high isolation concept is aimed at easing the burden of demonstrating safety by choosing a system with as many positive safety characteristics as is feasible. The objective is to choose a site and a repository design that are of intrinsic high quality with respect to safety and are also amenable to a reliable assessment of safety. The safety case for a high-isolation site may be different from that for more conventional sites because of the low energy natural system, which has extremely low driving forces for any processes which could lead to nuclide release and transport away from the repository. This would make it easier to model groundwater flow scenarios of the types that are central to most conventional safety assessments. Direct evidence of extremely long residence times (e.g. by age dating, salinity profiling) will be an important indicator of stability. The safety case for a high isolation site may however need to focus more upon potential effects on the natural system due to disturbances introduced by the repository itself.

A survey of the world aimed at identifying large, flat, historically-arid areas with stable and simple geological formations quickly lead to a group of areas which were part of the original Pangaea super-continent. This land mass started to break apart some 200 million years ago, with Australia separating from Antarctica about 80 million years ago. Remaining in the continents of the Southern Hemisphere are areas which have not been subjected to large tectonic forces nor to the influences of repeated glaciation. The largest contiguous stretch Pangea geology is in the desert basins of Western and South Australia.

In addition to the natural attributes of high-isolation sites, further selection criteria were applied, based on the technological capabilities, the non-proliferation credentials, the societal stability, the political and legal system, and the economic status of potential host countries. As a result, the feasibility study is focused on Western Australia where extensive regions appear to satisfy the appropriate geological, climatic and environmental criteria.

4. THE PANGEA INTEGRATED SYSTEM AND ITS ECONOMIC IMPACT

The total waste management and disposal system foreseen by Pangea includes the conditioning, packaging and transport of spent fuel or wastes within the client country, international transport in a fleet of special purpose ships to a dedicated port in Australia, rail transport to the repository site, a surface buffer storage and final disposal in the repository 500 to 1000 m below the surface. The reference project provides for disposing of an inventory corresponding to around 75'000 tonnes of spent fuel, plus high level and intermediate level waste, over a 40 year operating life. However, there are no fundamental reasons for either limit. At the current feasibility study stage, designs are at the conceptual level and costs are partly by analogy with existing and planned facilities elsewhere.

Broadbrush estimates, give the following picture of costs and benefits. The total investment in the Pangea project will be about $10.5 billion. The annual costs associated with the operation of the repository, together with the transport and handling of the cargo from the waste generators to the repository will be in the order of $0.8 billion. It is estimated that about 23,000 jobs will be created during the construction of the sea terminal, rail link and repository and in the manufacture of transport casks, disposal packages and ships. The operation of the facilities is likely to provide long-term employment for about 2000 people. Many of the positions created will be in areas of high technology, engineering and science. In addition, there will be employment in the necessary service industries. The revenues generated over the 40 year operating life of the Pangea project are estimated to be about $200 billion, with about $90 billion returned to governments in royalties and taxes. Finally, the economic boost of the project to Australia will provide further opportunities for employment. The economic impulse to the Australian economy has been estimated by Access Economics to be of the order of 1% of the Gross National Product of Australia over the 40 year reference operating life.

5. CONCLUSION

The Pangea concept for an international radioactive waste repository can provide a unique Australian solution to a global problem the safe and permanent disposal of radioactive waste. Australia has a combination of geology, topography and climate which satisfy the criteria of a high isolation site and make it highly suitable for hosting a deep geological repository. In addition Australia has the political, legal, financial and social systems which would make it acceptable to other nations as a host country for such a repository.

Consequently, the establish ment of an international radioactive waste repository in Australia, with its unique combination of natural and social attributes, can benefit the whole world as well as Australia.

AU0019555

The State of the Art in Nuclear Medicine

A. M. SCOTT, Department of Nuclear Medicine and Centre for PET,
and Ludwig Institute for Cancer Research, Austin & Repatriation Medical Centre,
Heidelberg, Vic., 3084. Australia.

SUMMARY Recent improvements in the understanding of the physiologic and biologic mechanisms of health and disease have led to an expansion of nuclear medicine applications both in clinical studies and research. Advances in radiopharmaceutical development, instrumentation and computer processing have resulted in the implementation of Positron Emission Tomography for clinical studies, and improved treatments with radiopharmaceuticals particularly in cancer patients. There has also been an dramatic increase in the techniques available with nuclear medicine to detect and measure cellular biologic events *in-vivo,* which have important implications in clinical and basic science research. Nuclear medicine studies provide unique information on human physiology and remain an integral part of clinical medicine practice.

1. INTRODUCTION

Nuclear Medicine is a medical specialty that evaluates physiology and tissue metabolism *in-vivo* with tracer techniques. The tracers used for these studies are generally short-lived isotopes, and are linked to chemical compounds that permit specific physiologic processes to be imaged and/or quantitated non-invasively. Unlike more conventional imaging techniques such as x-ray, CT, ultrasound or MRI, nuclear medicine has as its basis the analysis of function of tissue and organs, rather than the anatomical structure of the area studied.

Nuclear medicine can be used for both diagnostic and therapeutic applications in patient care. It has existed as a clinical specialty in Australia for 30 years, and approximately 430,000 nuclear medicine procedures are performed in Australia each year. Almost every person in Australia will require a nuclear medicine procedure during their lifetime.

The role of nuclear medicine has changed dramatically in the last decade, due to advances in radiopharmaceuticals and imaging technology. Evolving areas of clinical utility include the increased role of nuclear medicine in therapy (particularly in oncology); the introduction of Positron Emission Tomography (PET) as a mainstream technology in oncology, neurology and cardiology; and the development of novel radiolabelled molecules for the biologic characterisation of human tissues, which has both clinical and research applications.

2. TISSUE PHYSIOLOGY AND CELL BIOLOGY

Recent advances in the understanding of physiologic processes responsible for disease have allowed a more fundamental understanding of disease etiology. The identification of unique tissue and cellular changes associated with disease are required, however, in order to implement effective treatments. Specifically, advances in genetics and cell biology have led to identification of gene expression, intracellular signalling pertubations and cell receptor expression changes that can be linked to disease and prognosis (1).

In-vivo detection, measurement and quantitation of these tissue, cellular and sub-cellular processes with nuclear medicine techniques allows the characterisation of normal and diseased body functions. This has diagnostic relevance in a range of clinical conditions. In heart disease, measurements of myocardial perfusion and viability, combined with left ventricular ejection fraction, is now possible through ^{99m}Tc-MIBI single photon emission tomography (SPECT) studies. Measurements of cerebral perfusion, and functional brain neuroreceptors, may also be performed with SPECT and PET imaging (2). Detection of tumours, and biological characterisation of antigen or receptor expression (eg EGF receptor, Her/2-neu receptor), or metabolic processes (eg glucose metabolism) is also possible with radiolabelled ligands, peptides and antibodies (3).

The therapeutic utility of this aproach relates to the ability to target specific receptors expressed on tumours (eg somatostatin receptors), which can be used to deliver radioisotopes for therapeutic effect, or to determine the effects of therapy through changes in metabolic parameters (eg glycolysis, amino acid turnover and DNA proliferation). The in-vivo imaging of gene expression, and gene therapy approaches, can also be achieved with nuclear medicine techniques (4). The development of more sophisticated therapies is ideally suited *to in-vivo* measurement of treatment efficacy with nuclear medicine.

3. RADIOPHARMACEUTICALS

The most common isotopes used in general nuclear medicine diagnostic studies are listed in Table 1. These isotopes are usually short lived, produced by generator, cyclotron or reactor, and are linked to specific ligands or chemical compounds depending on the physiologic or cellular process that is to be evaluated.

Table 1.
Isotopes Commonly Used in Nuclear Medicine

Diagnostic	Therapeutic
^{99m}Tc	^{131}I
^{201}Tl	^{89}Sr
^{111}In	^{153}Sm
^{67}Ga	^{90}Y
^{123}I	^{32}P

Advances in diagnostic radiopharmaceuticals include novel chemical compounds that permit the study of neuroreceptors with SPECT (eg bezodiazepine receptors), somatostatin receptors in tumours, and acute clot detection with peptides against gpIIb/IIIa receptors on activated platalets. The use of α and β emitting isotopes for therapy applications is an area of active development at present.

4. INSTRUMENTATION

4.1 Gamma Camera Design

Recent developments in gamma cameras include improved resolution instruments, and more advanced computers for image reconstruction. New camera developments also include the incorporation of attenuation correction (for improved quantitation and SPECT studies), and coincidence detection for PET. This latter approach has been complemented by the use of slightly thicker detector crystals, which allow higher sensitivity for ^{18}F-FDG while retaining the ability to image conventional nuclear medicine isotopes.

Image analysis methods have been improved by coregistration techniques for anatomic studies (eg CT scan) with nuclear medicine SPECT and PET. Modelling of image datasets for statistical analysis or receptor binding parameters is also performed. The use of digital data storage is routine in most Departments, and archiving and display systems (PACS) are being implemented in major Institutions.

4.2 PET Instrumentation

Modifications to scanner design have enabled the production of lower cost PET scanners for clinical PET studies (see Section 6). One new camera design incorporates NaI crystals (of one inch thickness) in the detector array with a large field of view and operation in 3D mode. This allows rapid image acquisition and potentially lower doses of ^{18}F-FDG to be used for clinical studies. Another camera design uses bismuth germanate ("BGO") crystals (used in standard PET design cameras) but installed over a 120° gantry that rotates around the patient and also acquires images in 3D mode. Both of these designs reduce the cost of the PET scanner, without sacrificing image quality and patient throughput (5).

Current research into new crystal materials (for example, leutetium) for PET scanners has indicated that higher resolution instruments will be possible, although no commercial systems currently are available. Larger field of view PET cameras, and cameras combining PET imaging and CT scanning, are the subject of continuing research overseas.

5. DIAGNOSTIC STUDIES

The most common nuclear medicine diagnostic procedures are in cardiac, neurology, skeletal, lung, liver and kidney disorders. The most recent developments in diagnostic studies relate to improved imaging and processing methods, and new imaging agents based on peptides and antibodies.

In cardiology, developments in image processing now permit routine examination of myocardial perfusion and contractility with calculation of ejection fraction in a single study (either ^{99m}Tc-MIBI or ^{201}Tl-chloride). The implementation of pharmacologic stress, and newer agents eg ^{99m}Tc-tetrofosmin, have also occured.

The development of new peptide and antibody constructs has been translated into diagnostic tests for somatostatin receptors (tumour characterisation), acute clot detection (platelet gpIIb/IIIa receptor), and detection of colon, ovarian and prostate cancer (1,2). Peptide studies in infection, inflammation and other cancers are also in Phase II/III trials at present.

6. POSITRON EMISSION TOMOGRAPHY

Positron emission tomography (PET) is an imaging technique that provides *in vivo* measurements in absolute units of a radioactive tracer. One of the attractive aspects of PET is that the radioactive tracer can be labelled with short-lived radioisotopes of the natural elements of the biochemical constituents of the body.

In clinical applications, a very small amount of a biological compound labelled with a positron-emitting radionuclide is introduced into the patient, usually by intravenous injection, and the concentration of that compound in tissue is measured by a PET scanner. During its decay process, the radionuclide emits a positron (positively-charged electron) which, after travelling a short distance, encounters a negatively-charged electron from the surrounding environment. The two particles combine and "annihilate" each other, converting their rest mass into energy and resulting in the emission in opposite directions of two gamma rays of 511 keV each (Figure 1).

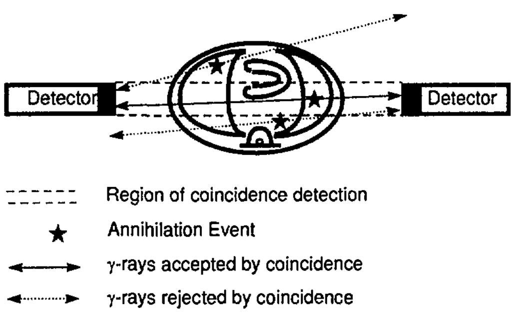


Figure 1. Basic principal of PET: coincidence detection

PET image acquisition is based on the external detection in coincidence of the simultaneously emitted 511 keV γ-rays and therefore localisation of the annihilation event inside the patient.

The most commonly used positron emitting radiopharmaceutical in clinical studies is ^{18}F-FDG (Table 2). This tracer utilises the characteristic of malignant cells of an enhanced rate of glycolysis in the presence of oxygen, and FDG enters the cell and competes for the enzyme hexokinase by the same mechanism as glucose. ^{18}F-FDG has been used in clinical studies in neurology, cardiology and in oncology. ^{13}N-ammonia has been used for measurement of blood flow, principally in cardiac PET studies.

Table 2.
Positron-Emitting Radionuclides used in Clinical Studies

Radionuclide	Half-Life
^{15}O	120 seconds
^{13}N	10 minutes
^{11}C	20.4 minutes
^{18}F	110 minutes

Research studies in PET include the use of oxygen-15 for measurement of oxygen metabolism (^{15}O-water, ^{15}O-carbon dioxide). ^{11}C has been used for labelling molecules that allow the study of a range of neuroreceptor-ligand interactions non-invasively, which has research applications in neurology and psychiatry. Labelling of a large array of other compounds including hypoxic markers, amino acids, DNA proliferation markers and chemotherapy drugs have also been studied in clinical trials (1,6).

The experience over the last decade is that the most important clinical role of ^{18}F-FDG PET is in oncology. In many cancers, ^{18}F-FDG PET has been shown to be the most accurate non-invasive method to detect and stage disease (7-9). This has major implications in terms of improving the planning of treatment and avoiding unnecessary treatment and its associated morbidity and cost.

The ability of ^{18}F-FDG PET to monitor cancer response to treatment (including radiotherapy and chemotherapy) is an area where increasing attention is now being directed and is potentially one of the most important applications of ^{18}F-FDG PET in clinical practice (10).

PET has also been used in coronary artery disease patients to detect viable myocardium, which has immediate relevance in the evaluation of patients prior to cardiac surgery or transplantation (11). ^{18}F-FDG PET has also been studied in epilepsy and neurodegenerative disorders, where it has been found to have an important diagnostic and prognostic role (2,12).

7. THERAPY

An increasingly important area in nuclear medicine practice is in therapy, particularly in oncology. The established therapy procedures in nuclear medicine are listed in Table 3.

Table 3.
Therapeutic Studies

Treatment	Isotope
Hyperthyroidism	^{131}I
Thyroid carcinoma	^{131}I
Bone pain	^{89}Sr, ^{153}Sm
Polycythemia Rubra Vera	^{32}P
Synovectomy	^{90}Y

The identification of receptors and antigens highly expressed on tumour cells that can be targeted with peptides and antibodies has led to a range of clinical trials in recent years. Promising results have been obtained with ^{131}I-B1, directed against the CD20 antigen on non-Hodgkins lymphoma, with greater than 70% response rates in Phase II/III trials (3). Similar results have also been achieved with ^{90}Y-labelled anti-CD20 antibody. Phase I/II trials with radiolabelled antibodies against colon, lung and renal cancer, and in acute myeloid leukemia, are also underway (3). ^{90}Y-peptide studies (against somatostatin receptor) are also in development. These approaches will become more widely available in the next few years.

Locoregional therapy of tumours with ^{131}I- and ^{90}Y- labelled microspheres (particularly colorectal liver metastases and hepatoma) is in Phase I/II trials at present, and the treatment of glioma with ^{131}I- and ^{90}Y- labelled antibodies, and ovarian cancer with intraperitoneal radiolabelled anti-MUC antibody have achieved impressive response rates and survival results (1,3). The application of nuclear medicine therapy continues to be one of the most active areas in oncology research at present.

8. CONCLUSIONS

The last decade has seen dramatic changes in nuclear medicine in both diagnostic and therapy applications. The inherent ability of this technology to provide insight into basic physiologic events in the body, and cellular processes in response to disease, through non-invasive techniques, is a unique and powerful tool for the clinician and researcher. The future development of this field is limited only by our understanding of the basic biologic events that occur in health and disease.

ACKNOWLEDGEMENTS

The staff of the Department of Nuclear Medicine and Centre for PET at the Austin & Repatriation Medical Centre, and the Tumour Targeting Program, Ludwig Institute for Cancer Research, are gratefully acknowledged.

REFERENCES

1. Scott, A.M., Larson, S.M. Tumor Imaging and Therapy. (1993) *In: Nuclear Medicine. Radiologic Clinics of North America.* E. Coleman (ed.) W.B. Saunders Inc. New York. 859-880.

2. Ho, S.S., Berkovic, S.F., Berlangieri, S.U., Newton, M.R., Egan, G.F., Tochon-Danguy, H.J., McKay, W.J. (1995) Comparison of ictal SPECT and interictal PET in the presurgical evaluation of temporal lobe epilepsy. *Ann Neurol* Vol 37 pp 738-745.

3. Scott, A.M., Welt, S. (1997) Antibody-Based Immunological Therapies. *Current Opinion in Immunology* Vol 9, pp 717-722.

4. Tjuvajev, J.G., Avril, N., et al. (1998) Imaging herpes virus thymidine kinase gene transfer and expression by positron emission tomography. *Cancer Res* Vol 58, pp 4333-4341.

5. Bailey, D.L., Miller, M.P., Spinks, T.J., Bloomfield, P.M., Livieratos, L., Young, H.E., Jones, T. (1998) Experience with fully 3D PET and implications for future high-resolution 3D tomographs. *Phys Med Biol* Vol 43, pp 777-786.

6. Tjuvajev, J.A., Macapinlac, H., Daghighian, F., Scott, A.M., Ginos, J.Z.,

Finn, R.D., Kothari, P., Desai, R., Zhang, J., Beattie, B., Graham, M., Larson, S.M., Blasberg, R.G. (1994) Imaging of Brain Tumor Proliferative Activity with I-131-Iododeoxyuridine. *J Nucl Med* Vol 35, pp 1407-1417.

7. Scott, A.M., Berlangieri, S.U. (1995) Positron Emission Tomography in Colorectal Carcinoma. *Diagnostic Oncology* Vol 4, pp 123-129.

8. Damian, D.L., Fulham, M.J., Thompson, E., Thompson, J.F. (1996) Positron emission tomography in the detection and management of metastatic melanoma. *Melanoma Res* Vol 6, pp 325-329.

9. Bury, T., Dowlati, A., Paulus, P., Corhay, J.L., Hustinx, R., Ghaye, B., Radermecker, M., Rigo, P. (1997) Whole-body ^{18}FDG positron emission tomography in the staging of non-small cell lung cancer. *Eur Respir J* Vol 10, pp 2529-2534.

10. Thomas, D.M., Mitchell, P.L.R., Berlangieri, S., Tochon-Danguy, H., Knight, S., Clarke, C.P., Scott, A.M. (1998) The role of positron emission tomography in assessing response to neoadjuvant chemotherapy for non-small cell lung cancer. *Med J Aust* Vol 169 pp 227.

11. Schwaiger, M., Ziegler, S. (1996) Cardiac Application of Positron Emission Tomography. In: *Diagnostic Nuclear Medicine.* Sandler MP, Coleman RE, Wackers FJT, Patton JA, Gottschalk A, Hoffer PB (eds) Williams & Wilkins (3rd edition) Baltimore. pp 517-542.

12. Butler, R.E., Costa, D.C., Katona, C.L.E. (1994) PET and SPECT imaging in the dementias. In: *Nuclear Medicine in Clinical Diagnosis and Treatment.* Murray IPC and Ell PJ (eds). Churchill Livingstone Edinburgh. pp 613-628.

Nuclear Medicine in Oncology

PROFESSOR JAMES F BISHOP MD MMed MBBS FRACP FRCPA
Director, Sydney Cancer Centre, Royal Prince Alfred Hospital
Professor of Cancer Medicine, The University of Sydney

The Cancer Problem

Cancer is increasingly prevalent in our society. There is a life-time risk that 1 in 3 Australian men and 1 in 4 Australian women will get cancer before the age of 75 years. Overall, 27% of the deaths in NSW are currently related to cancer (1). The common cancers for men are prostate, lung, melanoma, colon, rectum and bladder (see table 1). For women the common cancers are breast, colon, melanoma, lung and unknown primary. However, overall lung cancer remains the major cause of cancer deaths (20%) followed by colo-reetal (13%), unknown site (8%), breast and prostate. Breast and lung cancer are the major causes of death in women.

Recent information on 5 year survivals reveal good 5 year survival rates for breast (78.6%), prostate (72.4%) and melanoma (92%), while some tumours such as lung cancer (10.7%) have poor survival. Colon cancer has intermediate survival (57.1%). Projections for cancer incidence suggests rates of cancer will increase for colo-rectal cancer, melanoma, lung cancer in females but decrease for breast, lung in males and prostate cancer (2).

Major strategic directions in cancer research are understanding carcinogenesis, identification of high risk groups, screening and early detection, chemo-prevention, new cancer therapies, combined modality therapy and quality of life issues. Nuclear medicine will play an important part in many of these areas.

Understanding Carcinogenesis

The cancer cell is characterised by a change in gene expression which renders the cell with a growth advantage over normal tissue (3). Mutations in DNA which lead to such changes and their downstream effects are the subject of most cancer research today.

Changes in expression of oncogenes or tumour suppression genes have been identified as fundamental to some cancers. For example, the retinoblastoma RB oncogene is implicated in retinoblastoma of childhood and oestogenic sarcoma in adults. APC is the inherited colon cancer gene and WT1 is an oncogene identified in the carcinogenesis of Wilm's Tumours. Such gene mutations or their downstream up regulation of cellular processes or overexpression provide an exciting array of potential targets for new anti-cancer therapies.

The *C-erb*B receptor over expression in breast cancer has been associated with poor prognosis but has provided a target for new cancer therapy (4). An antibody against HER2 receptor was shown to have specific anti-cancer activity in breast cancer, but more importantly, was shown to improve sensitivity of anti-cancer drugs and significantly prolonged survival in metastatic breast cancer (4).

Since the genetic mutations are becoming increasingly well understood, this knowledge should provide multiple other targets for antibodies, vaccines or antibodies coupled with chemotherapy drugs or radioisotopes. The latter is an underdeveloped area of research which has great potential.

Identification of High Risk Groups

Future screening and surveillance for early detection of *de novo* cancer or to detect early relapse will require a deeper understanding of high risk groups. People at high risk for cancer have been identified from epidemiology studies, history of exposures to carcinogens or genetic risk. Epidemologically, the most important exposures are tobacco which accounts for one third of all fatal male cancers in the world (5).

Genetic risk can be identified by the presence of known inherited genetic abnormalities which inevitably lead to cancer, such as BRCA 1 or the Li-Fraumeni Syndrome or familial adenomatous polyposis (FAP) (6). In the successful screening example of breast cancer, screening plus an increased public awareness and more successful therapies, such as adjuvant treatment has resulted in improvement in breast cancer survival. In the period 1973-1977, the 5 year survival from breast cancer in NSW was 72.7%. In the period 1987 to 1995 it was 81.5% (7).

The challenge is to firstly identify high-risk groups in all cancers. For example, in lung cancer obviously it would be heavy to moderate smokers, over the age of 45 years or with a history of other exposures such as asbestos or chloromethylesters. However, the future high risk patient may be one with identified p53 mutation or loss of heterozygosity of 3p or 9p or mutations of the RAS oncogene (8).

Secondly, screening and early detection may lend itself to new imaging approaches. Antibodies against CEA, CA- 125 or other surrogate tumour markers have been traditionally studied. Since the above mutations or overexpression could be used for antibody development, radioisotope based imaging should be investigated for early detection strategies.

Early Detection, Staging and Surveillance for Relapse

An oncologist suspicious of tumour or investigating for early relapse wants to know where the abnormality is, what it is, if it can be biopsied or removed and if there are other abnormalities present. The usual imaging devices used are plain x-rays, CT scans, MRI, bone scans, liver scans, gallium or thallium scans and PET scans.

Bone Scans

Tc-99 bone scans appear more sensitive than plain x-rays and have been valuable in detecting early metastatic disease in bone. Bone scans have been used to follow disease response in bone following treatment where the bone scan results are taken together with bone alkaline phosphatase and bone pain to determine the success of treatment. The bone scan results can be misleading in the presence of an hormonal flare reaction in breast and prostate cancer or when using biophosphonate therapy with control of bone resorption even with evidence of cancer progression elsewhere.

Liver Scans

Tc-99 liver scans have been largely supplanted by CT scanning of the liver. However Tc-99 labelled red blood cells can be useful in differentiating haemangioma from tumour.

Gallium Scans

Ga-67 gallium is bound to transferrin and transported into tumour cells after binding transferrin receptors present on the cell surface. Ga-67 imaging is useful for monitoring responses in gallium avid intermediate or high grade lymphomas. Since determination of complete response is an important prognostic factor gallium may assist in looking for residual disease after definitive therapy and in follow up. However, many low grade tumours and others are not gallium positive in which case the test is not useful.

Thallium Scans

Tl-201 thallium scans have been useful to follow low grade lymphomas. Thallium scans have been correlated with the viability of residual brain tumours and the avidity may relate to tumour grade (9).

Novel Scans

As above, radioisotopes lend themselves to novel forms of imaging by linking them to other molecules or antibodies of importance in cancer. For example Indium-111 labelled octreotide can detect occult neuro-endocrine tumours. Octreotide is an 8-amino acid analogue of somatostatin that binds with high affinity to somatostatin receptors, highly expressed in neuro endocrine tumours such as gastrinomas or carcinoids (10).

Positron Emission Tomography

Positron emission tomography (PET) images position emitting radionuclides produced by a cyclotron. These includeoxygen (0-15), nitrogen (N-13), carbon (C-1 1) and fluorine (F-18) which have half lives of 2, 10, 20 and 100 minutes respectively. F-18 fluorodeoxyglucose (FDG) has been used extensively to image cancers. Intravenous FDG is transported across capillary membranes by a carrier modulated process. Both FDG and glucose are phosphorylated by hexokinase, but FDG-6-PO_4 cannot be metabolised through the glucolytic cycle and accumulates intracellularly. This technique provides a measure of glucose metabolism with the F-18 in tissue proportional to glucose utilisation.

Possible applications of F-18 FDG PET scanning in cancer include staging presurgery, early detection of *de novo* or recurrent disease, early response to therapy, screening of high risk groups, pharmacokinetics and developing the PET signal as an independent prognostic factor.

A good correlation has been reported between increased FDG accumulation in brain tumours and the grade of tumour (11). Vansteenkiste et al reported that the FDG uptake was an important prognostic factor in lung cancer (12). Experience at the Royal Prince Alfred Hospital, Sydney would suggest that an important subset of patients presenting for conventionally resectable lung primary or secondary tumours, are upstaged and deemed unresectable by PET scan. In many instances the combination of CT and PET has provided high accuracy in identifying mediastinal disease pre-operatively (13). Some active infections or inflammatory conditions may have significant FDG uptake. These include tuberculosis, cryptococcosus, aspergillosis, sarcoid and radiation reactions.

Other potential applications of PET using other emitters include oxygen (0-15) water or carbon dioxide to measure blood flows (14). This may be an important future application if anti-angiogenesis agents, such as thalidomide, prove to be useful anti-cancer drugs. F- 18 fluoromisonidazole has been demonstrated to bind hypoxic cells and has been used to demonstrate the kinetics of tracers in human tumours (15). Identification of such hypoxia may be important in the future for understanding radioresistance in some patients and with the development of hypoxic cell radiation sensitisers such as tiripazamine.

The pharmacokinetics of several chemotherapeutic drugs have been determined using PET. These include.5-fluorouracil (F-18), bleomycin (Co-57), cisplatin (N-13), BCNU (N-13 or C- 1) and oestrogens (F-18) (16).

New Cancer Therapy

Molecular biology, an understanding of the process of carcinogenesis and the mechanisms of drug action are leading to a plethora of anti-cancer therapies in preclinical and early clinical development. These include traditional analogue development of cytotoxics, new methods of packaging chemotherapy drugs, new agents attacking new DNA or downstream targets of cancer cells, gene therapy, antibodies, vaccines, anti-angiogenesis factors, anti-metastasis factors and optimal drug radiation interactions. Nuclear medicine may have an important role in some aspects of this development.

There are exciting new anti-cancer drugs derived from successful older drugs. These include new platinums (oxaliplatin), new vinca alkaloids (vinorelbine), new taxanes and new inhibitors of thymidine synthase (MTA). The targets for these agents are DNA, tubulin or mitochondria. Radiopharmaceuticals have a potential role for studying the distribution and uptake of these agents.

New targets include mutations that occur in p53, RAS or from overexpression of receptors or antigens such as the antibody against HER2 receptor (Herceptin) in breast cancer or CD20 in lymphoma (16,17). Monoclonal antibodies are now being tested in a number of new indications including melanoma and small cell lung cancer. When more specific antibodies are discovered such antibodies can be linked to toxins, such as Ricin A chain or radioisotopes. Preliminary work with anti-CD20 antibody coupled with 131-iodine or 90-yttrium have been encouraging in early clinical trials (18,19).

Finally, in the future, disease response may be best determined by new imaging such as PET. Early response or lack of it may be documented early in the course of new drug trials and thus prevent useless therapy but also identify new active drugs.

The response of tumours to new approaches like anti-angiogenesis agents cannot be determined adequately with current methods. Blood flow measurements with 0-15 or FDG require further study.

Table 1 Common Cancers

	New Cases NSW pa	**Standardised Incidence ***	**Lifetime Risk 0-74 years**
MALES			
Prostate	4,150	141.1	1 in 9
Lung	1,750	58.9	1 in 19
Melanoma	1,413	46.7	1 in 26
Colon	1,189	40.3	1 in 31
Rectum	817	27.1	1 in 41
FEMALES			
Breast	3,448	101.0	1 in 11
Colon	1,131	30.6	1 in 40
Melanoma	967	28.8	1 in 41
Lung	825	23.1	1 in 46
Unknown primary	572	15.3	1 in 87

* per 100,000

REFERENCES

1. Coates M.S. & Armstrong B.K. (1998), Cancer in New South Wales, Incidence and Mortality 1995., Sydney, NSW Cancer Council.
2. Coory M. & Armstrong B.K. (1998), Cancer incidence projections for Area and Rural Health Services in New South Wales, Sydney, NSW Cancer Council.
3. Sutherland R.L. (1998), Molecular basis of carcinogenesis. In "Cancer Facts: a concise oncology test". Bishop J.F., ed., Amsterdam Harwood Academic Pub, pp 13-16.
4. Salmon D., Leyland-Jones B., Shah S. et al. (1998), Addition of Herceptin (humanised anti-HER2 antibody) to first line chemotherapy for HER2 overexpressing metastatic breast cancer (HER2+/MBC) markedly increases anti-cancer activity: a randomised, multi-national controlled phase III trial, Proc. Amer. Soc. Clin. Oncol. 17:98a (abstract).
5. Burton R.C., Giles G.G. (1998), Cancer prevention, screening and early detection. In "Cancer Facts: a concise oncology test", Bishop J.F., ed., Amsterdam Harwood Academic Pub, pp 28-32.
6. Mulcahy G.M., Goggins M., Willis D. et al. (1997), Pathology and genetic testing, Cancer 80(3):636-648.
7. Supramaniam R., Smith D.P., Coates M.S. et al. (1998), Breast Cancer Survival in New South Wales in 1973 to 1995, Sydney, NSW Cancer Council.
8. Minna J.D., Molecular Biology Overview (1996), In "Lung Cancer: principles and practice", Pass H,I,, Mitchel J,B,, Johnson D,H,, Turrisi A,T, (eds), Philadelphia, Lippincott-Raven Pubs pp,143-148.
9. Black K.L., Randall A., Hawkins R.A., Kim K.T. et al. (1989), Use of Thallium-201 SPECT to quantitate malignancy grade of gliomas, J. Nuerosurg. 71:2342-2350.
10. Krenning E.P., Kwekkboom D.J., Bakker W.H. et al. (1993), Somatostatin receptor scintigraphy with In-111 DTPA-Phe and 1-123 tyr-octreotide: the Rotterdam experience with more than 1000 patients. Eur J Nucl Med 20:67 1-680.
11. DiChiro G. (1986), Positron emission tomography using F(F-18)-fluorodeoxyglucose in brain tumours: a powerful diagnostic and prognostic tool, Invest. Radiol. 2:360-67.
12. Vansteenkiste J., Stroobants S., Dupont P. et al. (1999), Prognostic importance of fluorodeoxyglucose uptake (FDG) on PET scan in non small cell lung cancer: an analysis of 125 cases, Proc. Amer. Soc. Clin. Oncol., 18:464a (abstract).
13. Boiselle PM, Patz EF, Vining DJ et al. (1998) Imaging of mediastinal lymph nodes: CT, MR and FDG PET, Radiographics 18(5):1061-9.
14. Huang S.C., Phelps M.E., Hoffman E.J., Juhl D.E. (1979), A theoretical study of quantitative flow measurements with constant infusion of short lived isotopes. Phys Med Biol 24:1151-57.
15. Valk P.E., Mathis C.A., Prados M.D. et al. (1992), Hypoxia in human gliomas: demonstration by PET with fluorine-18 fluoromisonidazole, J.Nucl.Med. 33:2133-2138.
16. Strauss L.G., Conti P.S. (1991), The application of PET in clinical oncology, J. Nucl. Med. 32:623-629.
17. Maloney D., Grillo-Lopez A.J., Bodkin D. et al. (1995), IDEC -C2B8 antiCD20 antibody: results of long term follow up of relapsed NHL phase II trial patients, Blood 86:54a (abstract).
18. Pass 0., Eary I., Applebaum F. et al. (1998), Radiolabelled - antibody therapy of B-cell lymphoma with autologous bone marrow support, N. Engl. J. Med. 329:1219-28.
19. Kiminski M.S., Zasadny K.R., Frances I.R. et al. (1993), Radioimmunotherapy of B-cell lymphoma with {131-I} anti-B 1 (anti-CD20) antibody, N. Engl. J. Med. 329:459-465.

Medical Radioisotopes for the Next Century

STUART W CARR, Australian Nuclear Science and Technology Organisation
PMB 1 Menai 2234 NSW Australia

SUMMARY. Radioisotopes are widely used in medicine (Nuclear Medicine) for diagnosis, palliation and therapy of heart disease, cancer, muscoskeletal and neurological conditions. The radioisotopes used are both reactor and cyclotron produced. The utilisation is currently growing and is expected to continue to grow over the next 10-20 years. The combination of radioisotope and delivery vehicle can be designed to meet the intended end use.

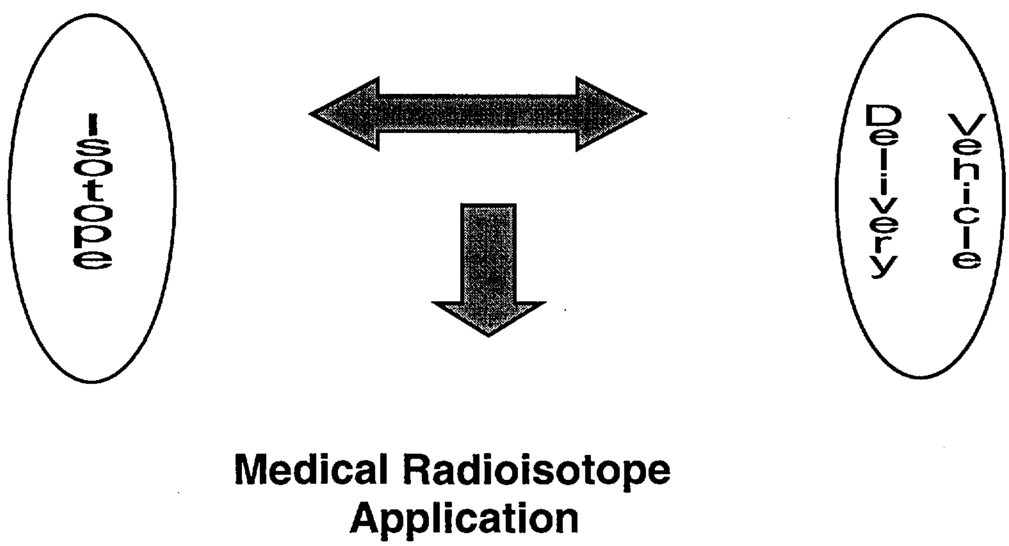
1. INTRODUCTION

The application of radioisotopes in medicine (called Nuclear Medicine) was first established over 30 years ago. In the early years of its application, Nuclear Medicine was an effective adjunct to the management of patient care. However, in recent years, with the development of newer agents and the dramatic improvement in gamma camera technology, medical radioisotopes have become an indispensable and growing component of the nation's health care system.

One important application of Nuclear Medicine makes a major contribution to the field of diagnostic imaging. Diagnostic Nuclear Medicine, X-ray, Computed Tomography (CT), ultrasound and Magnetic Resonance Imaging (MRI), all image internal body structures in a non-invasive way. CT scans use X-rays to build images of soft and hard tissues within the body, and MRI applies a nuclear magnetic resonance to image soft tissue. The images provided by CT and MRI are primarily of tissue structure with very little direct information provided on tissue function. In contrast to these techniques, diagnostic Nuclear Medicine provides functional information which enables not only visualization of structure but also information on how the structure is behaving and changing in real time.

This paper will deal with the main approaches to the use of radioisotopes for Nuclear Medicine and the future prospects for the area.

Figure 1. Schematic of the essential features of a clinical radiopharmaceutical.



2. DEVELOPMENT OF NEW RADIOPHARMACEUTICALS

Radioisotopes combined with a "delivery vehicle" (Figure 1) present increasing opportunities to improve patient care. The requirements for an effective medical radiopharmaceutical are:

- selectivity for disease state/organ of concern
- specificity
- optimum time to localisation
- low toxicity
- time of clearance from body
- physical and chemical properties of the radioisotope.

Each of these criteria needs to be satisfied for an effective radioisotope medical application. These factors will, of course, vary with the proposed application.

Table 1 gives an indication of how the properties of the radioisotope, for example half-life and range, can vary for different radioisotopes. This gives significant flexibility in selecting the properties of the clinical products.

Table 1. Physical characteristics of radioisotopes used for therapy arranged in order of maximum range

Nuclide	Half life	Emission	Maximum range
^{80m}Br	4.42 h	Auger	< 10 nm
^{125}I	60.0 d	Auger	10nm
^{211}At	7.2 h	alpha	65 μm
^{169}Er	9.5 d	beta	1 mm
^{67}Cu	2.58 d	beta/gamma	2.2 mm
^{131}I	8.04 d	beta/gamma	2.4 mm
^{153}Sm	1.95 d	beta/gamma	3.0 mm
^{198}Au	2.7 d	beta/gamma	4.4 mm
^{186}Re	3.77 d	beta/gamma	5.0 mm
^{165}Dy	2.33 h	beta/gamma	6.4 mm
^{89}Sr	50.5 d	beta	8.0 mm
^{32}P	14.3 d	beta	8.7 mm
^{90}Y	2.67 d	beta	12 mm

Likewise, the "delivery vehicle" needs to be chosen to enable effective localisation of the chosen radioisotope. Examples of the range of current and potential delivery vehicles include:

- small molecule ligands
- peptides
- antibodies / fragments
- particulate solids

The choice is a function again of the designed outcomes.

There are a number of radiopharmaceuticals under development as new diagnostic and therapeutic agents. At present, there are over 100 new radioisotope procedures under preclinical and clinical evaluation. These cover a wide range of applications and are mainly directed at new applications of the radioisotope moiety.

3. DEMAND FOR RADIOISOTOPES

Over the past several years there have been four major reports on the projected future requirements for radioisotopes for medical application. These reports focus on the North American market (Table 2), and all predict a substantial increase in the application of radioisotopes over the next 20 years. An expert panel composed of physicians, government and industrial representatives recently reviewed these projections[1] and concluded that the expected growth rate of medical radioisotope usage during the next 20 years will be between 7-16% per annum for diagnostic applications, and 7 - 14% for therapeutic applications. The panel also reported the need to support the development of radioisotopes that have not yet been commercialised.

While these figures address the North American situation historically, the growth of radiopharmaceutical applications in Australia has mirrored that of North America since clinical requirements are similar in most developed countries.

While there are no reports of the application of radioisotopes for specific medical conditions, there are general trends of use. The general trend over the last few years has been an increase in the number of patient doses. The main difference is the usage rate; in the USA it is approximately 40 procedures per 1000 population compared to just over 20 in Australia[2].

respectively. More recently I-123 labelled compounds have found application in thyroid and oncology imaging.

The second type of imaging modality is Positron Emission Tomography (PET). PET is a more recently developed technique and is reliant on short lived positron-emitting radioisotopes. With the PET camera, imaging depends on the simultaneous detection of two gamma rays produced when a positron annihilation occurs. PET cameras are only just coming into general use and although there are only a few PET cameras in Australia, substantial growth is expected over the next few years. The most common PET radioisotope is F-18 produced by a cyclotron. The radiopharmaceutical widely used is fluro-18 deoxyglucose (FDG) produced in a complex process from F-18 (half-life 109 minutes). FDG is particularly useful in imaging areas of higher than normal metabolic activity and is therefore very effective in the detection and staging of cancers.

Table 2. List of recent reports on the use of radioisotopes in medical applications.

Beneficial Uses and Production of Isotopes. AEN/NEA Report, 22 May 1998
Medical Isotopes Market Study (2001- 2020). Frost & Sullivan, 20 November 1997
Evaluation of Medical Radionuclide Production with the Accelerator Production of Tritium (APT) Facility Medical University of South Carolina, University of South Carolina and Westinghouse Savannah River ompany, 15 July 1997
Worldwide Isotope Market Update. Arthur Andersen & Co. SC, November 1994

4. TYPICAL APPLICATIONS OF RADIOPHARMACEUTICALS

Radioisotopes find application in three medical areas, namely for diagnosis, palliation or therapy.

In diagnostic Nuclear Medicine, a small amount of a radiolabelled compound is either injected, swallowed or inhaled. This compound becomes localised in the region of interest and radioactive decay is imaged using a suitable device (camera). There are basically two types of imaging modality. In the first type, conventional photon imaging systems and Single Photon Emission Tomography (SPECT) imaging techniques utilise gamma emitting radioisotopes. The most commonly used radioisotope is Tc-99m which is used in more than 60% of all diagnostic Nuclear Medicine procedures. Tc-99m based radiopharmaceuticals find application in the imaging of most forms of tissue since it is readily available to most, if not all, nuclear medicine practices. Tc-99m is readily produced from a "generator" which uses Mo-99 as a precursor, and the Tc-99m can be drawn off as required. Tc-99m is typically compounded with one of a number of biologically active substances to ensure that it specifically localises to the region of interest in the body. In this way Tc-99m is a very versatile agent and is called the "workhorse" of modern Nuclear Medicine. Because of the clinical convenience outlined above, where possible diagnostic agents are labelled with Tc-99m. Other radioisotopes in routine clinical use are Tl-201 and Ga-67 for cardiac and soft tissues imaging

In addition to diagnostic Nuclear Medicine, palliation of pain associated with bone secondary metastases is a very important application of radioisotopes. Several studies have established the benefit of radiation in relieving the dramatic pain associated with this disease state. Bone seeking radioisotopes such as Sr-89 and Sm-153 are approved for this application[3]. Other agents based on Sn-117 and Re-188 are under development. Benefits to the patient include a reduction in the use of opiate analgesics and improved quality of life.

The most well established application in therapeutic Nuclear Medicine is the use of I-131 to treat thyroid cancer. This has been successfully applied for over 30 years with excellent remission rates. The success of this treatment is largely due to the high selective localisation of I-131 in the thyroid.

5. RECENT DEVELOPMENTS IN CLINICAL RADIOPHARMACEUTICALS

Table 3 is a list of recently approved radiopharmaceuticals for medical application.

Table 3. Recently approved medical radioisotopes.

Product	Isotope		Approval Body
CEA Scan	Tc-99m	colorectal cancer	FDA
Leukoscan	Tc-99m	Infection imaging	EU
Prostascint	In-111	prostrate cancer	FDA
Octreoscan	In-111	oncology - brain, breast	FDA/EU
Acutect	Tc-99m	thrombosis	FDA
CEAcide	Y-90	ovarian cancer therapy	FDA

Interestingly these products are mainly radiolabelled antibodies and peptide. CEA scan and Leukoscan are Tc-99m based monocolonal antibody products for selective imaging of colorectal cancer and infection, respectively. Prostacint, also an antibody, is labelled with In-111 and is used for imaging of prostate cancer. The peptide based agents, octreoscan (In-111) and acutect (Tc-99m), are applied to the imaging of brain/breast cancers and thrombosis, respectively.

Very recently, CEA-cide, the therapeutic analogue of CEA-Scan, was approved for clinical use in the treatment of breast cancer.

Research is very active in the development of therapeutic radioisotopes and there are a large number in preclinical and clinical investigation. The applications are diverse but mainly focus on cancer.

6. THE FUTURE

Medical radioisotopes have entered the mainstream of clinical practice because of their application and their special characteristics. With the Replacement Research Reactor and other developments at ANSTO Australia is well placed to take full advantage of these developments to provide the latest agents to improve quality of life.

REFERENCES

1. Forecast Future Demand for Medical Isotopes, March 1999, http://www.ne.doe.gov.
2. 1997/1998 Nuclear Medicine Census. Summary Report Analysis. TMG. September 1998.
3. Radioisotopes in the Treatment of Bone Metastases. Annals of Medicine, **29** (1997) 31-35.

AU0019558

The Uranium Enrichment Industry and the SILEX Process

M. GOLDSWORTHY

Managing Director, Silex Systems Ltd
PO Box 75 Menai Central NSW 2234

SUMMARY Silex Systems Limited has been developing a new laser isotope separation process since 1992. The principle application of the SILEX Technology is Uranium Enrichment, the key step in the production of fuel for nuclear power plants. The Uranium Enrichment industry, today worth ~ US$3.5 Billion p.a., is dominated by four major players, the largest being USEC with almost 40% of the market. In 1996, an agreement was signed between Silex and USEC to develop SILEX Technology for potential application to Uranium Enrichment. The SILEX process is a low cost, energy efficient scheme which may provide significant commercial advantage over current technology and competing laser processes. Silex is also investigating possible application to the enrichment of Silicon, Carbon and other materials. Significant markets may develop for such materials, particularly in the semiconductor industry.

1. BACKGROUND TO SILEX SYSTEMS LTD

Silex Systems Limited (Silex) was established in 1988 (by Dr. M. Goldsworthy) as the research subsidiary of Sonic Healthcare Limited (Sonic), an Australian publicly listed company. Silex has been developing its unique, laser based, isotope separation technology known as SILEX (Separation of Isotopes by Laser EXcitation) since 1992.

The company is currently pursuing the following commercial applications of SILEX Technology:

- Uranium Enrichment – for the civilian Nuclear Fuel Cycle. Current market value is approximately US$3.5 Billion pa.
- Silicon Enrichment - for potential application in the semiconductor wafer industry (production of Si-28 wafers).
- Carbon Enrichment – for potential application in the semiconductor (heatsink) industry (C-12) and the medical diagnostics industry (C-13).

Silex was divested from Sonic through a distribution in specie in February 1996, and immediately set out to form a strategic alliance with an industry partner.

In November 1996, a Licence and Development Agreement for the application of SILEX Technology to uranium enrichment was signed with the United States Enrichment Corporation (USEC), the largest supplier of enrichment services in the world. Formerly part of the US Department of Energy, USEC was privatised through a listing on the New York Stock Exchange in July 1998. The privatisation was the largest in the US in the last 10 years and USEC is now capitalised at approximately US$1.2 Billion, with annual revenues of approximately US$1.4 Billion p.a.

Silex listed on the Australian Stock Exchange on 7th May 1998, and currently (Sept '99) has a market capitalisation of approximately $400M, with over 4000 shareholders. Subject to the continued successful development of the company's technology, Silex intends to consider a future listing on either the NASDAQ or NYSE exchange in the US.

In November 1998, the company commenced a Feasibility Study on the application of SILEX Technology to Silicon and Carbon enrichment, for potential use in the Semiconductor Industry. This is being conducted in conjunction with Isonics Corporation, an advanced materials company in the US, and SDI Pty Ltd, a South African technology company.

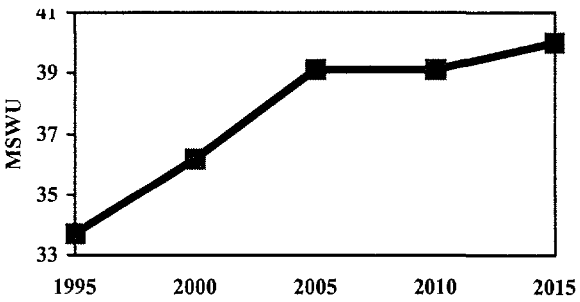
2. THE URANIUM ENRICHMENT INDUSTRY

The main focus of the Company's current activities is on the Uranium Enrichment application through the Agreement with USEC. Uranium Enrichment is the key step in the production of fuel for the global Nuclear Power industry, which currently provides approximately 18% of the world's electricity, a figure which is likely to increase with continuing economic development in Asia and the growing environmental problems associated with the use of fossil fuels.

Enrichment is a technically difficult process, which constitutes a major component of nuclear fuel costs (approximately 30% of the total fixed costs). Enrichment involves increasing the concentration of the 'active' U-235 isotope from 0.7% to approximately 3% - 5%. The work required to perform enrichment is measured in *Separative Work Units (SWUs).*

The world-wide uranium enrichment market is currently worth nearly US$3.5 billion p.a., constituting an annual demand of approximately 35 million SWUs. Current and projected enrichment demand for the period 1995 to 2015 is shown in Figure 1. The steady increase in estimated demand to 40 MSWU in 2015 assumes little growth in the nuclear industry. The only expanding market is in Asia, but this is to some extent negated by continuing plant shutdowns in other markets.

Figure 1: Current & Projected Enrichment Demand 1995 - 2015



3. CURRENT ENRICHMENT TECHNOLOGIES

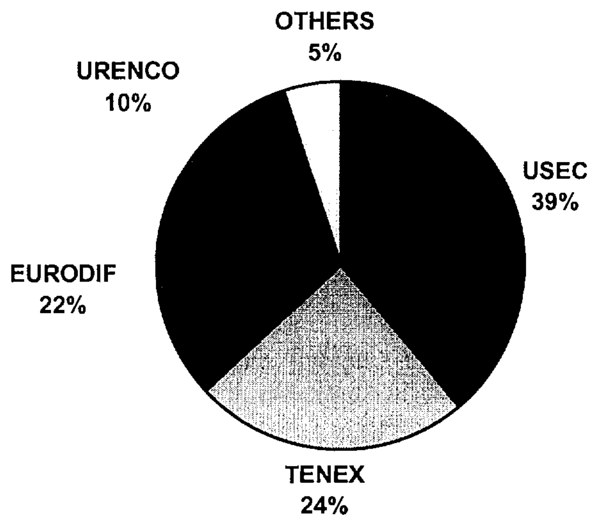
Two technologies, gaseous diffusion and gas centrifuge, are currently used to enrich uranium for nuclear electricity plants. Both use UF_6 as the chemical form of uranium for feedstock, primarily because UF_6 is gaseous at room temperature but becomes solid under moderate pressure. As a result, UF_6 is readily and safely transported in large quantities in steel cylinders. Both processes rely on the small mass difference between the U-235 and U-238 Isotopes to achieve separation, either by *diffusion* through a semi porous membrane or by *centrifugation* (spinning) at high speed.

More than half of current demand for enrichment services is supplied by three gas diffusion plants, two in the United States (operated by USEC) which are 45 years old and one in France (operated by Eurodif) which is 20 years old. Over one third of current demand for enrichment services is supplied by gas centrifuge Technology located in Europe (Urenco), Russia (Tenex) and Japan (JNFL).

Some proportion of USEC's market may be satisfied by highly enriched uranium (HEU) derived from the Megatons to Megawatts Agreement, under which HEU from weapons dismantling is being blended down to levels which are directly useable for power station fuel. Figure 2 shows approximate world enrichment market shares for 1998.

Total operating costs for centrifuge SWU are around one tenth of diffusion. However, the high capital costs of establishing a centrifuge plant and the fact that the existing diffusion plants have excess capacity relative to current demand, have resulted in the slow development of centrifuge capacity.

Figure 2: Approximate Enrichment Market Shares -1998



4. NEW ENRICHMENT TECHNOLOGIES

Industry participants, in particular the US Government, have invested heavily over the last three decades searching for a new enrichment technology which will not only replace diffusion, but will also be significantly more economic. The processes currently expected to replace the diffusion enrichment plants are advanced centrifuge technology developed by Urenco, and laser-based technologies.

USEC, which operates the US diffusion plants, had been developing a technology known as AVLIS (**A**tomic **V**apour **L**aser **I**sotope **S**eparation), which it took control of from the US Department of Energy upon privatisation. AVLIS was for many years the front-running laser technology.

However, in June 1999, USEC shutdown the AVLIS Development Program, citing poor economic prospects as the driving issue. USEC intends to continue with its evaluation of the SILEX Technology to determine whether it has sufficient economics and reliability to be deployed as its future enrichment technology. It will also continue an evaluation of the gas centrifuge option.

The laser-based processes currently being developed around the world are described briefly below.

AVLIS The United States Government is estimated to have invested more than US$2.0 billion since the late-1960's on the development of AVLIS. Development continued at the Lawrence Livermore Laboratories in California under USEC's sponsorship post privatisation, until it was shutdown recently. A process similar to AVLIS called SILVA is still being developed by a French Government agency, but this effort is also understood to be winding down.

MLIS (**M**olecular **L**aser **I**sotope **S**eparation). This UF_6-based process has been the subject of well funded development projects in several countries since the early 1970's, including Germany, Britain, USA, Japan and South Africa (in conjunction with the French). All of these efforts have since been disbanded, except for a small continuing project in Japan, which also appears to be in decline.

SILEX This laser based process was invented by Silex and is currently under development in conjunction with USEC. Since the shutdown of AVLIS, SILEX is the only laser based technology being pursued by USEC for possible future replacement of its diffusion plants.

5. FEATURES OF THE SILEX PROCESS

The SILEX Process and engineering concept represents a new approach to laser enrichment of uranium. The intrinsic qualities of SILEX are found in novel techniques and innovative use of relatively simple engineering concepts, which are based on well established principles and technologies. The main features and advantages of the SILEX proposal, which set it apart from other laser enrichment schemes, can be summarised thus:

- SILEX is a very low energy process.
- SILEX utilises the current industry feedstock- UF_6, making industrial integration simple.
- SILEX is based on relatively simple and practical separation modules.
- SILEX is a modular technology providing versatility in deployment.
- Innovative engineering designs allow truly continuous operation with SILEX.
- SILEX is expected to have low overall power consumption and capital costs.

6. THE USEC AGREEMENT

An agreement was reached with USEC in late 1996, under which an exclusive licence to use the technology for uranium enrichment was granted. In return, the Agreement sets out the conditions under which USEC funds the development program and pays milestone payments and royalties. The main commercial terms of the Agreement are as follows:

- A US$7.5M fee for exclusive rights to uranium enrichment was paid by USEC to Silex in November, 1996.

- USEC continues to fund the entire development program, including the cost of the Pilot Module and Pilot Plant programs, and patent protection.

- Three milestone payments totalling US$18M are to be paid over the next three to four years provided technical targets are met.

- US$15M in fees (3 x $5M pa) will be paid to Silex during construction of a commercial plant assuming USEC ultimately decides to commercialise SILEX.

- A royalty of 5% - 8.75% of gross revenue derived from the technology will be paid to Silex. (The rate varies depending on the relativity between costs and revenues.) If all revenues are derived from SILEX the annual royalty could be as high as US$130M pa.

In order to facilitate the joint Silex-USEC development of SILEX Technology, a new Australia-US Bi-lateral Treaty for Nuclear Cooperation had to be negotiated and enacted. The Treaty drafting and negotiations took almost 2 years to complete. Whilst the approval process has since been completed by the Australian Government, it has taken a little longer in Washington. However, at the time of writing this report, the Secretary of Energy and the Secretary of State had signed off, and signature by President Clinton was imminent. The Treaty is therefore set to come into effect in early 2000, enabling the full technology transfer process to proceed thereafter.

7. THE SILEX DEVELOPMENT PROGRAM

The SILEX Process was initially proven to "work in principle" on a laboratory scale for Uranium in 1994. In the subsequent Pilot Module Program (being completed at the time of this report), the scalability and preliminary economics of the technology have been investigated. USEC will assess the results of this Program in its sole discretion. If they are satisfactory, USEC will formally proceed to the next program (the Pilot Engineering Study), and the first half of the 'First Milestone' payment (US$2.5M) will be made to Silex. The second US$2.5M payment will be made when the Bi-lateral Treaty comes into effect (early 2000). An outline of the future development program is given in the table below:

Program Stage	Earliest Completion	Milestone Payment
Engineering study	Mid 2001	US$ 3M
Pilot Plant Program	End 2003	US$10M
Commercial Deployment	End 2007	Royalties

8. OTHER POTENTIAL APPLICATIONS OF SILEX TECHNOLOGY

The SILEX core technology has other potential applications which may prove to be commercially viable. These will be pursued actively over the next few years and include:

8.1 Semiconductor Materials

Semiconductors, which are integral to all computer and electronic systems, are generally made from Silicon (Si). Today's computer chips and electronic devices are reaching the limits of performance, dictated by technical barriers inherent in natural Silicon material, principally heat build up. In recent years increasing interest has been shown in semiconductors which have been made from isotopically enriched Silicon. The use of isotopically enriched Silicon has been shown to offer technical advantages in two areas:

- Increased thermal conductivity (ie, better heat dissipation). Recent published results verify increases of up to 60% in the thermal conductivity of enriched Silicon-28. In a typical computer chip, this may translate to a drop in operating temperature of 30~40°C – potentially providing improved semiconductor performance.

- Significant improvements in advanced semiconductor production via Neutron Transmutation Doping (NTD). The NTD method is used to make sophisticated, high power silicon based semiconductor devices.

Several research and commercial organisations around the world have been investigating these phenomena for a number of years, but without consideration of an economic source of enriched material. To date, no economically viable source of enriched Silicon has emerged. The SILEX Process may be able to provide this source for the first time.

Synthetic diamond heat spreaders and heat sinks, made today from natural carbon, are also used extensively in the semiconductor industry. Published research results show that synthetic diamond made from enriched carbon (> 99.9% C-12) also exhibits significantly improved thermal conductivity. The potential for SILEX Technology to produce enriched C-12 is also being investigated. The 'by-product' from this application (Carbon-13) is already used extensively in bio-medical applications, and could therefore add value to a SILEX carbon isotope separation venture if successfully undertaken.

8.2 Nuclear Engineering Materials

Special materials are used in the construction and operation of commercial nuclear reactors, and in nuclear fuel assemblies. These materials exhibit particular properties when in the presence of neutrons (ie in the reactor). Such properties are utilised to enhance reactor performance resulting in cost reductions for electricity generation. The properties of several of these materials, including Boron (B), Zirconium (Zr), Zinc (Zn) and Gadolinium (Gd), can be significantly improved if enriched. The SILEX Process, with its potential for inherently low enrichment costs, may provide a commercially superior route for the production of some of these materials.

8.3 Medical Isotopes

The medical isotopes of primary commercial interest are Carbon-13, Molybdenum (for Technetium production), Xenon, Palladium, Thallium and Zinc (for Gallium production). These isotopes form the basic materials used for bio-medical and in-vivo diagnostic procedures, including detection of cancer and organ disease. Whilst the technical advantages of using enriched materials for medical radioisotope production are reasonably well understood, further studies are required to establish the associated economics and the size of potential markets.

Accelerator Driven Nuclear Energy and Transmutation Systems

J.W. BOLDEMAN
Australian Nuclear Science and Technology Organisation, PIM 1, Menai, N. S. W.

1 INTRODUCTION

Nuclear power generation has been a mature industry for many years. Presently (30 June 1999) there are 428 operational power reactors in 37 countries with an installed power generation capacity of 348,879 MWEN and an additional 98 reactors are either in construction or planned. Nuclear power accounts for 17% internationally of all electricity generation and in countries such as France it comprises the prime source. Despite comments of some commentators, the safety record of the nuclear power industry has been extremely good. By the end of 1996, in a total cumulative operating experience of 8135 years, there has only been the Chernobyl accident with consequences to the outside community. This accident did demonstrate that a very severe accident has the potential to cause national and regional radioactive contamination and has caused nuclear authorities to redouble their efforts to increase safety. However, despite the overall safety record and the great attractions of nuclear power, especially in times of concern about green house gases emissions, there continues to be some lack of public acceptance of this technology. This sensitivity to nuclear power has several elements in addition to the concern of a potential nuclear accident. These include the possible diversion of plutonium into nuclear weapon production and the concern about the long term storage of plutonium and other transuranic elements.

A concept which seeks to allay these fears but still takes advantage of the nuclear fuel cycle and utilises decades of research and development in this technology, is the idea of using modern accelerators to transmute the long lived radio nuelides and simultaneously generate power. Of the various proposals at the present time, the most developed is the Energy Amplifier Concept promoted by Rubbia1). The possibility of using high-energy, high-current accelerators to produce large fluxes of neutrons has been known since the earliest days of accelerator technology. E.O. Lawrence, for example, promoted the concept of producing nuclear material with such an accelerator. The Canadians in the early 50s considered using accelerators to produce fuel for their heavy water reactors and there were well advanced designs for a device called the Intense Neutron Generator2). The speculative idea of using accelerator produced neutrons for the transmutation of transuranic elements (i.e. elements such as neptunium, plutonium and other elements with higher Z atomic number) has also been studied extensively, notably at a number of laboratories in the US, Europe and Japan. However at this time, all facilities that have actually been constructed have been designed primarily for condensed matter studies i.e. studies of the structural properties of materials. These include the ISIS facility at the Rutherford Appleton Laboratory in the UK, facilities at Los Alamos National Laboratory and the Argonne National Laboratory, USA, the SINQ facility at the Paul Scherrer Institute, Switzerland and the KENS facility at the KEK laboratory, Japan. Such experimental facilities, with the possible exception of SINQ, have relatively low accelerator beam power and would not be suitable for a serious study of transmutation or ultimately energy production. However, they have provided extremely valuable data which can be used in the design of more powerful facilities.

In recent years, accelerator technology has advanced to such an extent that the possibility of building a proof of principle facility which explores, experimentally, ideas in transmutation and energy production, has become viable and proposals exist for several different plants.

2 SYSTEMATICS OF NEUTRON PRODUCTION VIA THE SPALLATION PROCESS

The physical process that is involved in the production of large numbers of neutrons using high energy accelerators is called the Spallation Process. The typical spallation neutron source comprises a proton accelerator with a full energy of about 500 - 3000 MeV in which the proton beam is directed into a cooled heavy element

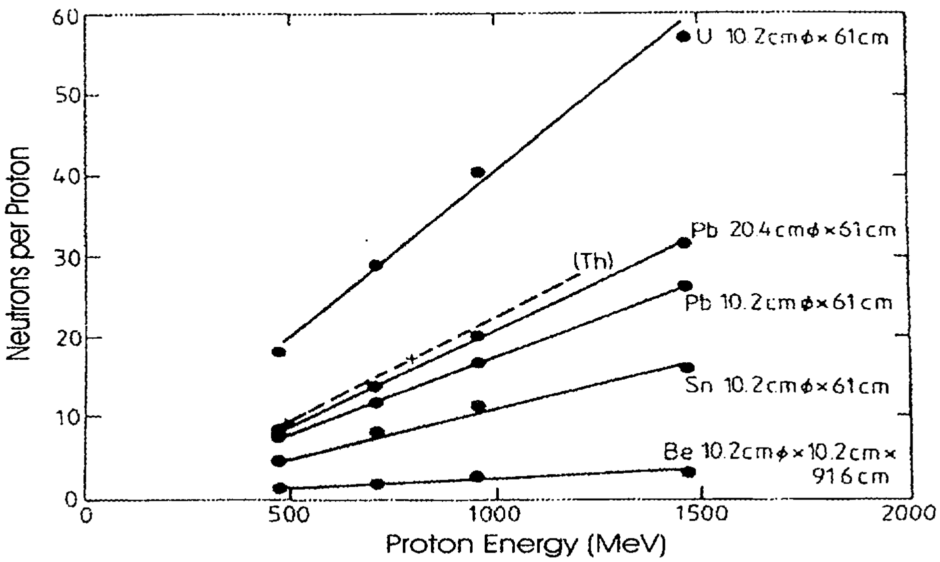


Figure 1. Neutron yield as a function of proton energy for various sizes of target materials

target. The neutron production caused by the interaction of the high energy proton beam with the target material is shown in Figure 1 as a function of incident proton energy for various target elements[3)]. The neutron yield/MeV of proton energy increases with target atomic number and, for a 1000 MeV (1 GeV) facility, is approximately 1 neutron/28 MeV for a reasonably large ^{238}U metal target and 1 neutron/40 MeV for a lead metal target

3 NEUTRON ECONOMY IN A NUCLEAR POWER SYSTEM

In a critical nuclear power system, heat generation occurs through nuclear fission of the atoms of a fissile core, typically ^{235}U. In an average fission event in ^{235}U, 200 MeV of energy is released and this is accompanied by the emission, on average, of 2.43 neutrons. These neutrons can be absorbed by many of the structural elements in the reactor and can also induce additional fission events in other ^{235}U nuclei. The process is self sustaining if, on the average, one of these neutrons induces a new fission event. The parameter that describes the state of criticality is called *k*. For a steady state nuclear reactor, $k = 1$. If $k < 1$, the reactor will shut down. If $k > 1$, then an incident will occur unless there is some intervention by the safety systems to reduce *k*.

In all spallation systems currently in operation (such as the ISIS facility at the Rutherford Appleton Laboratory), the neutrons produced in the heavy element target have a relatively small probability of causing an additional fission event i.e. *k* is close to zero. Thus the total heat in the spallation target is very little greater thathabrought in by the accelerator beam. However, in the new concepts being investigated, the spallation target is surrounded by a region containing nuclear material that will readily undergo neutron fission, e.g. isotopes of elements such as uranium, plutonium and, to a lesser extent, thorium. To ensure that the resulting system is subcritical, i.e. that it will cease to function immediately the accelerator beam is switched off, the criticality constant *k* must be less than 1. Values that have been considered in various studies range from $k = 0.89$ to 0.98. It can be shown that, in a subcritical system, each external neutron introduced into a subcritical assembly will induce, on the average, a chain of fission events given by the parameter M_f

$$M_f = (1/\eta)(k/(1-k).$$

where η is the average number of neutrons emitted per absorbed neutron in the surrounding fissionable material. Thus for a subcritical assembly with $k = 0.95$, each external neutron entering the assembly will give rise on the average to a chain of 9.5 fission events. Since the energy required to produce one neutron in a lead target is approximately 40 MeV and each fission in ^{235}U for example releases 200 MeV, the energy multiplication M_e is given by

$$M_e = (200/40)M_f$$

and in the case being considered is approximately 50. Thus, if the design intention were to achieve a total energy generation of 1000 MW, the required accelerator beam power feeding a subcritical system with k =0.95 would be 20 MW. For a 1 GeV proton accelerator, this translates into an average beam current of 20 mA. Of course, the fissile material in which fission is induced is burnt up in the process. If this material were say plutonium then the process which produces power would at the same time convert or transmute the long lived plutonium into shorter lived fission products. This process is called transmutation. Thus a facility based on this idea would have the dual property of energy production and transmutation. In an energy producing installation, the generated heat would have to be converted into electrical energy part of which would have to be fed back to drive the accelerator. It is essential therefore that the high energy accelerator driving the system has to be extremely efficient in converting the operational power into beam power. In the following sections, various components of an operating system, i.e. the accelerator structure, the spallation target, the multiplying assembly and blanket and the fuel composition are considered.

4 High Energy High Current Accelerators

High energy physics studies and the numerous synchrotron radiation sources that have been developed as a byproduct of these studies have driven major advances in accelerator technology. Not only has the capability for high energy generation and the reliability for high current operation increased significantly but the energy efficiency, i.e. the proportion of the total operational power that goes into the beam energy, has also increased. This increase in efficiency is illustrated in Table 1 where the efficiencies for several accelerator facilities are compared. The table includes the tandem accelerator at Lucas Heights, ANTARES[4], which is an upgraded nuclear physics facility of the 1960s modified for applied physics studies notably Accelerator Mass Spectrometry, and several high energy physics facilities at CERN. It should be pointed out that high efficiency for beam power was not a prime consideration in the design of these accelerators. However, for the National Medical Cyclotron (NMC), the cyclotron at the Paul Scherrer Institute and the more advanced version of that design listed in the table, high power efficiency was a key feature of the design.

Table 1

Efficiencies of Proton Accelerators

Accelerator	Energy (GeV)	Power Consumption (MW)	Beam Power (kW)	Efficiency %
ANTARES [4]	0.02	0.1	0.1	0.1
CERN SC	0.5	1	0.62	0.065
CERN PS	24	12	40	0.3
CERN SPS	400	52	360	0.69
NMC ANSTO	0.03	0.1	20	20
PSI[5]	0.6	3	1000	30
PSI design [5]	1.0	13	6000	46

To achieve the design requirements for an energy amplifier - transmutation facility, two different types of accelerator structure can be considered to drive the spallation targets. These are illustrated in Figure 2. The first is a three stage cyclotron[6] which is an extension of the SINQ accelerator at the PSI [5]. It consists of two small injector cyclotrons feeding an intermediate energy cyclotron which then feeds a separated sector cyclotron providing a final energy of about 1000 MeV. Mandrillon has described a version of this concept[6]. The approximate cost of the accelerator hardware for the PSI design[4] is about $250M[6].

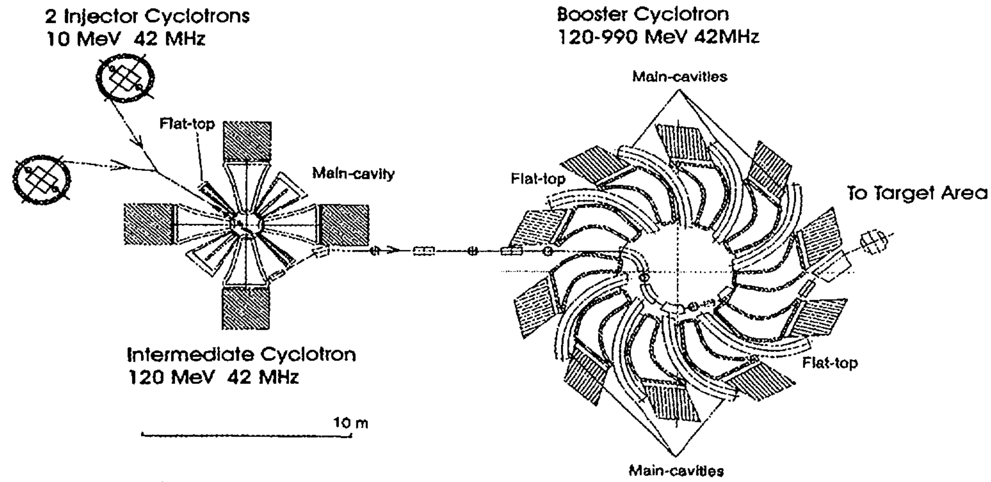


Figure 2(a). Cyclotron based Accelerator[6)]

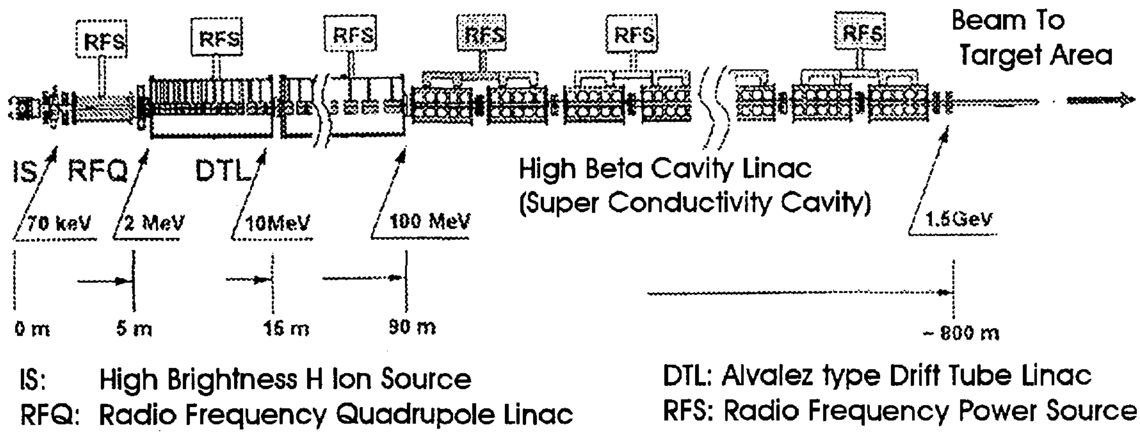


Figure 2(b). Linac based Accelerator

An alternative option which uses the experience in accelerator design at the Los Alamos, Argonne, Rutherford, CERN and other laboratories is based on a linear accelerator. An example of this option is shown in (b) which is taken from the Japanese proposal propounded by Mizumoto[8)]. The higher energy stage of this accelerator would be a superconducting high beta cavity linac.

It has not been established at this time which of the two options would be the more economical. Rubbia[8,9)], for example, has given consideration to both options. However some comments can be made. For design energies below 1 GeV, the cyclotron would probably be preferred. Above this energy, cyclotron design becomes more difficult. For beam power exceeding 15 MW, there would also be some problems with the design of a cyclotron and multiple units driving the same target system would be required. However it should be emphasised that both accelerator concepts are well within current design capability and it is now considered that beam efficiencies approaching 60% can be achieved. Recently because studies associated with the ATP project at LASL considerable progress has been made in the development of the linear accelerator option[10)].

5. SPALLATION TARGET - HEAT GENERATING UNIT - MULTIPLYING ASSEMBLY

A very large range of options have been considered for the beam target, the fuel in the multiplying assembly and even the chemical composition of the fuel material. The range of possibilities reflects the increasing interest internationally of this development. Table 2 lists the target materials along with the beam powers of several operational spallation sources.

Table 2

Beam Powers and Target Systems for Operational Spallation Sources

Spallation Source	Beam Energy (MeV)	Beam Power (kW)	Target Material
ISIS - RAL	800	160	Tantalum,Uranium
LANSCE-LASL	800	60	Tungsten
SINQ - PSI	600	900	Liquid Lead
IPNS Argonne	550	7	Depleted Uranium
KENS	550	3	Depleted Uranium
ESS under design	1334	5000	Mercury

These facilities as stated before are relatively low power installations, they are not part of multiplying assemblies and they have been designed primarily for studies of the structure of materials using the neutrons generated in the target system. Although designs for high power target systems take advantage of the experience gained from the operation of the facilities listed in Table 2, when the multiplying assembly and the cooling circuits are included, the designs become much more complex. Figure 3 adapted from the most recent proposal of Rubbia illustrates the various features of a full blown facility. The high energy proton beam enters the system through a window and then proceeds through a long beam port into the liquid lead spallation target. The liquid lead target is also part of the cooling system and convection cooling is used to transfer the heat generated in the lower part of the assembly to the heat exchangers at the top. The operating temperature at 600° - 700° C is higher than that usually employed in a pressurised water power reactor and so the conversion of the power generation is more efficient. Neutron generation via the spallation process occurs in the liquid lead in the centre of the fuel region. The spallation neutrons then enter the fuel region which surrounds the spallation source region where multiplication occurs.

There are a number of isotopes which could be considered for the fuel in the multiplying region. These include all odd atomic number isotopes of uranium (i.e. ^{233}U and ^{235}U), odd isotopes of plutonium (^{239}Pu and ^{241}Pu) and odd isotopes of Np and other transuranic elements. All of these isotopes have a high probability of absorbing a neutron and subsequently undergoing nuclear fission, thereby producing energy and contributing to the multiplication process. The reaction process for the even isotopes of these elements is different. These isotopes generally have a small probability of undergoing fission following neutron absorption and the principal reaction process is neutron capture. To illustrate the consequences of this process consider the case of ^{238}U. Neutron capture in ^{238}U leads to the isotope ^{239}U which has a very small half life and decays relatively quickly to ^{239}Pu which as explained above has a high probability of undergoing fission following neutron absorption. In other words, the non-fissile isotope ^{238}U is converted into the fissile isotope ^{239}Pu. This process is called breeding. It is seen therefore that this concept has, in principle, the capability of ultimately converting all isotopes heavier than ^{232}Th into useful energy sources

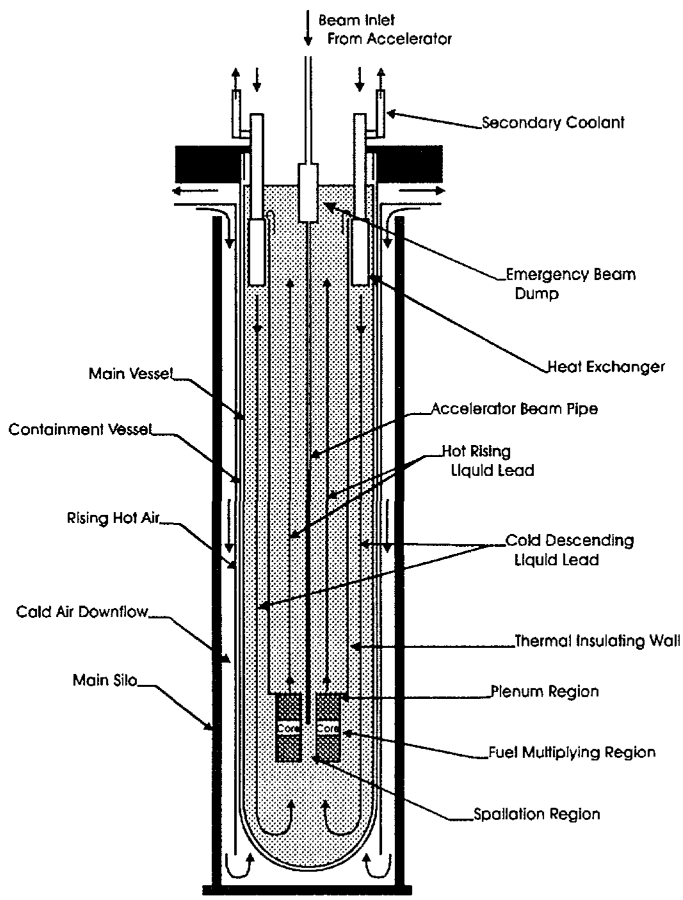


Figure 3. Target and Multiplying Assembly from Rubbia

For the Rubbia design, the fuel at the beginning of operation is a combination of natural thorium and ^{233}U although some plutonium fuel has been considered particularly at the beginning of a fuel load. The principal source of the multiplication at the onset is ^{233}U as thorium has a significantly lower probability (cross section) for fission than that of ^{233}U, as explained previously. The additional neutrons generated in the fission process, as well as inducing additional fission events in the ^{233}U (or plutonium), will also be captured by thorium leading to the radioactive isotope ^{233}Th which decays relatively quickly to ^{233}U. In essence, the proposal is effectively a fuel breeder based on the thorium - ^{233}U fuel cycle. Although this fuel cycle has been studied in the past in the context of traditional nuclear reactors, the lack of neutron economy in a critical reactor made it less attractive as a breeder reactor (essentially because $\eta = 2.08$). However with a *k*-value now less than 1, there are more neutrons available to breed additional fuel. The thorium - ^{233}U has many attractive features as there are very large deposits of thorium in the world, the residual radioactivity in the mining process is lower than for uranium ores and all of the thorium material can be used as a fuel rather than the 0.71% of uranium deposits. Slightly more than 700 kg of thorium would generate the same power through this process as 29 tons of natural uranium in a standard pressurised water power reactor which matches the power output of 1,000,000 tons of coal. A principal disadvantage of the thorium fuel cycle is the difficulty in processing thorium. A key feature of the Rubbia proposal is that the fuel would be loaded and left untouched for the first five years of operation of a facility. A second feature of the detailed proposal is that the buildup of plutonium in the Energy Amplifier is very much less than that typical of a power reactor of similar output.

It is clear from the description above that the primary objective of the Rubbia proposal is energy generation with the possibility of some transmutation as an added bonus. An alternative philosophy is that propounded in the Japanese OMEGA project as presented by Saito[11)]. Here the intention is the transmutation of long lived radioactive waste with energy generation a secondary issue. This is part of a larger concept for nuclear power generation titled the double strata fuel cycle[12)]. The double stratum fuel cycle comprises the power reactor fuel cycle (the first stratum) and the Partitioning-Transmutation cycle as the second stratum. Essentially the overall package comprises a group of power reactors coupled with a partitioning plant and a transmutation plant, the latter two of which would be colocated on the same site. It is envisaged that one transmutation facility would be able to support about 10 large scale light water reactors with 1000-MWe. The second stratum is called the OMEGA which has the two major R & D areas i.e. the study of the group separation of elements from HLW based on their physical and chemical properties and the potential value of utilisation and the nuclear transmutation of long lived radioactive species into shorter lived or stable nuclides. The studies of partitioning are outside the scope of this paper.

In principle, the transmutation facility is similar in conceptual design to that of Rubbia. The Japanese research favours a linac accelerator as indicated previously in Figure 2 (a) with a beam power of 15 MW and ultimately 60 MW[7)]. Two target fuel concepts are being studied. In the first, the spallation target consists of multi-layers of solid tungsten surrounded by solid actinide fuel with liquid sodium cooling used to transport the heat to the steam turbine plant. The second concept is the use of a molten-salt target/core system. Chloride salt is used for both fuel and target material and also acts as the primary coolant. Details of the specification of the OMEGA plans are listed in Table 3.

The philosophy underlying French research is similar to that of the Japanese. They envisage that, if the technology can be demonstrated to be viable, then a typical nuclear cell would consist of one transmutation - energy amplifying system supporting about 8 power reactors. The Commissariat a l'Energie Atomique decided in 1995 to launch a program[13)] devoted to the experimental validation of the major items related to a generic accelerator driven system including items such as accelerator technology, target physics and the physics of multiplying sub-critical assemblies. The French activities6[)] in accelerator design are mostly carried out in collaboration with Rubbia's group at CERN, aspects of the spallation process itself including studies of thin and thick targets, spallation residual nuclei measurements, double differential cross-section measurements are in progress at the SATURNE accelerator[14)], and studies of subcritical assemblies[15)] at the MASURCA facility at Cadarache.

In the United States there have been proponents of Accelerator Driven Systems (ADS) for transmutation - energy production for many years. Bowman et al.[16,17)] have made extensive studies of possible developments of the accelerator technologies. These studies at the Los Alamos National Laboratory have been partly stimulated by the presence on the Los Alamos site of the LAMPF facility, a 800 MeV proton linear accelerator which has provided significant experience for the development of accelerator technology. This laboratory has relatively advanced plans[17)] for the construction of a 270 MW proton accelerator for tritium breeding. This facility for tritium production is competitive with an alternative reactor based option. The design of the accelerator complex[18)] has been completed and it is understood that the lower energy stages of the accelerator complex are being tested. Although this facility is not for energy production or transmutation, the specifications are listed in Table 3 for completeness. In fact this facility may be the first to receive funding.

Table 3

Proposed Spallation Sources for Transmutation and Energy Production

Facility	Energy Amplifier	OMEGA	APT
Location	CERN ?	Japan	Savannah River
Organisation	Rubbia- CERN	JAERI	LANL
Beam Energy	1.0 (2.7) GeV	1.5 GeV	1.3 GeV
Beam Power	30 MW	60 MW	130 MW
Accelerator			
Injector	Cyclotron/Linac	Drift Tube Linac	Drift Tube Linac
Final Acc	Super-Conducting Linac	High Beta Super-Conducting Linac	Coupled Cavity Linacs /Super Cond. Linac
Target	Liquid Lead	Tungsten	Extended Tungsten
Fuel	ThO_2 +0.1 ^{233}U	(a) Np - 15Pu - 30Zr AmCu - 35Pu - 10Y (b) 64NaCl - 5$PuCl_3$ - 31$MACl_3$	-
k eff.	0.95	0.89	-
Coolant	Liquid Lead	Liquid Sodium	Heavy Water
Coolant Temp Inlet / Outlet	400° / 600°	330° / 430°	
Blanket	Pb 3m		Pb (^{3}He flow through)
Total Power	1500 MW	820 MW	-
Electric Power	625 MW		
Reprocessing	Thorex/1		
Construction Time		Start 1997 Phase I 2003 Phase II 2007	1998 decision 2007 for production
Facility Cost*	≈ $1.3 B	≃ $1.3 B	≈ $2.3 B

* Private Discussion of notional costs

6 CONCLUSIONS

The possibility of accelerator driven energy production and transmutation of long lived radioactive waste has been a goal of scientific studies for decades. The rapid development of accelerator technology, which has taken place in recent years, has brought the realisation of this concept very close. However the complexity of the problem makes it extremely difficult for theoretical models to provide an accurate assessment of the long term viability of the technology. In addition when the history of reactor technology is reviewed it will be appreciated that a long term study similar to that for reactors will be necessary before this new technology can have the same reliability and accompanying safety of power reactors. To start this process requires the construction and development of a proof of principle plant. This is a major capital item costing in excess of $1B which, despite the promise of the current studies, still involves some financial risk.

It is also likely that the technology, if successful, will be an adjoiner to traditional power reactors in accordance with the philosophy discussed previously of Japanese and French planners. It should also be appreciated that the transmutation technology is very difficult to apply to the treatment of fission product waste and current technologies such as SYNROC[23)] are absolutely essential for this waste. However the success of this accelerator technology would contribute to better community acceptance of the whole nuclear industry, which is necessary to ensure long term large scale power generation which in turn addresses the problem of reducing greenhouse gas emissions.

7 REFERENCES

1. F. Carminati, C. Geles, R. Klapish, J.P. Revol, Ch. Roche, J.A. Rubio and C. Rubbia, "An Energy Amplifier for Cleaner and Inexhaustible

Nuclear Energy Production Driven by a Particle Beam Accelerator", CERN/AT/93-47(ET) (1993).
2. G.A. Bartholomew and P.R. Tunnicliffe, AECL-2600, 1966.
3. S. Cierjacks et al., KfK-3098B, 1980.
4. J. W. Boldeman, "Applied Accelerator Technology", Transactions ANS 70 Supplement 1, p. 353.
5. T. Stammbach, S. Adam, W. Joho, M. Olivo, U. Schryber and P. Sigg, "The 0.9 MW Proton Beam at PSI and Studies on a 10 MW Cyclotron, Proc 2nd Int. Conf. on Accelerator-Driven Transmutation Technologies and Applications", Kalmar, Sweden, Vol.2, page 1013, 1996.
6. P. Mandrillon, N. Fietier and C. Rubbia, "A High Intensity Cyclotron Complex for Driving the Energy Amplifier", Proc 2nd Int. Conf. on Accelerator-Driven Transmutation Technologies and Applications", Kalmar, Sweden, Vol.2, page 984, 1996.
7. T. Stammbach, private communication.
8. M. Mizumoto, J. Kusano, K. Hasegawa, N. Ito, H. Oguri, Y. Touchi, K. Mukugi and H. Ino, "Development of a High Intensity Proton Accelerator", Proc 2nd Int. Conf. on Accelerator-Driven Transmutation Technologies and Applications", Kalmar, Sweden, Vol.2, page 1004, 1996.
9. C. Rubbia, J.A. Rubio, S. Buono, F. Carminati, N. Fietier, J. Galvez, C. Geles, Y. Kadi, R. Klapisch, P. Mandrillon, J.P. Revol and Ch. Roche, "Conceptual Design of a Fast Neutron Operated High Power Energy Amplifier", CERN/AT/95-44(ET).
10. C. Rubbia and J.A. Rubio, "A tentative Programme towards a Full Scale Energy Amplifier", CERN/LHC/96-11 (EET).
11. S. Saito, "Research and Development Program on Accelerator-driven Transmutation at JAERI", Proc 2nd Int. Conf. on Accelerator-Driven Transmutation Technologies and Applications", Kalmar, Sweden, Vol.1, page 52, (1996).
12. T. Mukaiyama et al. "Importance of the Double Strata Fuel Cycle for Minor Actinide Transmutation", Proc. 3rd OECD, NEA Int. Information Exchange Meeting on P-T, Cadarache (1994).
13. M. Salvatores, J.P. Schapira and H. Mouney, "French Programs for Advanced Waste Management Options", Proc 2nd Int. Conf. on Accelerator-Driven Transmutation Technologies and Applications", Kalmar, Sweden, Vol.1, page 60, 1996.
14. S. Leray et al., "Spallation Neutron Studies at SATURNE", Proc 2nd Int. Conf. on Accelerator-Driven Transmutation Technologies and Applications", Kalmar, Sweden, Vol.1, page 455, 1996.
15. M. Salvatores, M. Martini, I. Slessarev, R. Soule, J.C. Cabrillat, J.P. Chauvin, Ph. Finck, R. Jacqmin and A. Tchistiakov, "MUSE-1 : A First Experiment at MASCURA to Validate the Physics of Sub-Critical Multiplying Systems Relevant to ADS", Proc 2nd Int. Conf. on Accelerator-Driven Transmutation Technologies and Applications", Kalmar, Sweden, Vol.1, page 513, 1996.
16. C.D. Bowman, "Optimisation of Accelerator-Driven Technology for Light_Water Reactor Waste Transmutation", Proc 2nd Int. Conf. on Accelerator-Driven Transmutation Technologies and Applications", Kalmar, Sweden, Vol.1, page 11, 1996.
17. C.D. Bowman et al., Nucl. Instr and Methods in Physics Research, Vol A320, page 336, 1992.
18. J.C. Browne, J. L. Anderson, M.W. Cappiello, G.P. Lawrence and P.W. Lisowski, "Status of the Accelerator Production of Tritium (APT) Project", Proc 2nd Int. Conf. on Accelerator-Driven Transmutation Technologies and Applications", Kalmar, Sweden, Vol.1, page 101, 1996.
19. S. Scriber, "Development of Linacs for ADTT in the USA", Proc 2nd Int. Conf. on Accelerator-Driven Transmutation Technologies and Applications", Kalmar, Sweden, Vol.2, page 994, 1996.

A Decade of Industrial Tracer Applications in Australia

STUART CHARLTON
Tru-Tec Services
Lucas Heights Science & Technology Centre
Private Mail Bag 1 Menai NSW 2234

Summary

The application of radiotracer technology to the solution of problems in Australian industry dates back to the 1950's and has been well chronicled elsewhere.

However, it may confidently be asserted that the most significant growth in industrial applications has taken place over the last decade.

This is no accident. In the last Quarter of 1989, Tracerco Australasia was established as a partnership between ICI Australia and ANSTO with the specific remit of promoting and selling radioisotope applications to industry. Effectively, this marked the commencement of the 'commercialization" of industrial radiotracing in Australia.

Though organizational and ownership changes have subsequently taken place, the business established in 1989 continues to flourish and now, one decade after its inception, it is appropriate both to review the achievements of the last ten years and to identify the challenges and opportunities of the future.

Accordingly, this paper describes the growth of the radiotracer applications business, analyses its current activities both geographically and by industrial sector and examines trends in technology utilization.

The criteria which need to be met to ensure the continuing expansions and development of industrial radiotracer applications are also discussed.

*****

The Institution's Position on Sustainable Energy

M A SARGENT, M.A.Sargent & Associates Pty Ltd

SUMMARY

The twenty-first century will be an era in which sustainability will be a powerful value espoused by the community. The sustainability of energy, in terms of production and consumption, and in relation to the broader impacts of energy on society and the environment, will be a particular focus of the community. Australia, as a nett exporter of energy, and with a high per capita energy consumption, has both an economic and environmental imperative to be a leader in sustainable energy concepts and technologies. Australia therefore needs to position itself strategically, with a policy framework that facilitates the strategic positioning, to use and foster its diverse resources to provide for the social and economic needs of this generation, in a manner that ensures that the energy needs of the future generations can be met. The Institution is developing a sustainable energy statement that sets out the principles and actions through which the country's transition to a sustainable energy future will be managed.

1. INTRODUCTION

Energy is a basic necessity and the major driving force in modern societies and economies. It is largely responsible for the high standard of living and advanced level of industrialisation of much of the world, and our communications, industry and lifestyle have over the years become increasingly dependent on the availability of cheap and reliable energy. Not only is energy a basic necessity of our modern society, it is also a major contributor to the Australian economy both directly and indirectly.

2. THE PAST DEVELOPMENT OF THE STRUCTURE OF THE AUSTRALIAN ENERGY INDUSTRY

The development of energy industries in Australia to the present time can be broadly categorised into four phases:

i. ***The First Market Objectives Phase:*** a period, broadly from about 1880 until the early years of the 20th century, in which energy was distributed for street lighting and for various buildings, typically as private commercial ventures on a small scale;
ii. ***The First Social Objectives Phase:*** a period, extending from the turn of the century until about mid-century, in which energy production and distribution was organised on a franchise basis, with the social objective of making energy available to the broader community. Responsibility for supply of energy in the franchise area (which was often related to shire or municipal boundaries) being either municipal, local government or private companies;
iii. ***The First Planning Objectives Phase:*** a period, from about mid-century until 1990, in which production, transmission and distribution of energy was consolidated and coordinated on (generally) a Statewide basis, as a fundamental driver of economic development. This period was characterised by central planning of energy development, Government investment in key facilities (particularly interconnecting transmission networks) and central control of commercial outcomes.
iv. ***The Second Market Objectives Phase:*** the period from 1990 until the present, in which the Commonwealth Government (in effect) intervened to create a national competitive market for energy. The entry of the industry into its fourth (and current) phase marked the resurgence of market objectives as the driver for the industry.

While there are many rationalisations of this change, it derived partly from the ideological inclinations of its owners, partly from the need for governments around the world to find other sources of capital for the industry and of income for budgets, and partly from the fact that the community that the industry serviced had undergone significant cultural change. There was a decreasing inclination to view infrastructure development as an innate good, and the industry was seen by the community as a business rather than as an agent of Government. There was increasing attention paid to the efficiency and effectiveness of the industry by the community, greater demands for improved performance and service, and less acceptance of the status of the industry as independent from the forces of commerce. Australian society's innate suspicion of perceived large monopolies reinforced theoretical economics tendencies to restructure the industry to encourage intra-sector (as well as inter-sector) competition in the energy market

3. THE FUTURE - AN ERA OF SOCIAL OBJECTIVES

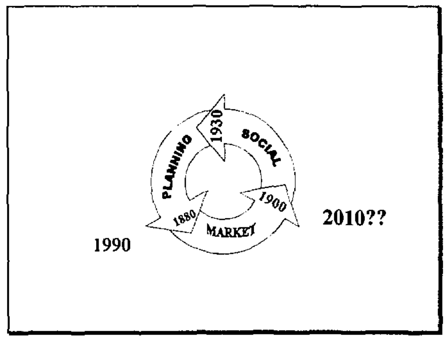
What then are the factors that will determine the future of the energy industry in Australia?

Perhaps the most significant is that Australia is in many aspects a mature country in the critical sense that it has lost its `frontier' culture. Increasing standards of living, globalisation of attitudes and knowledge, and an increased awareness of community rights and obligations indicate that social and cultural values will play a critical part in the future evolution of the energy industry.

Modern societies are increasingly dependent on secure supplies of energy, both at the level of the individual and at the level of the economy. At the economy level, the correlation between energy intensity of an economy and the wealth of that nation is compelling, while the correlation between economic growth and energy is strong for developing economies, less so for developed economies. At the personal level, our health and welfare depends on secure supplies of energy. These factors will continue the pressure on achieving efficient outcomes from the industry, and will increase the regulatory presence.

At the same time, Australian society generally is now more concerned about the environment and society of the future, and sees the need to start doing now those things which will yield a sustainable future. Thus, there will be increasing demand for the industry to pursue sustainability strategies which will be focussed on the achievement of composite economic, societal and environmental outcomes.

Thus, while the 'market' objectives of the present era will be sustained, the industry will face increasing demands to deliver not only efficient commercial outcomes, but also effective societal outcomes. The early signals are there in the evolving regulatory, environmental and policy frameworks, both Australian and international. The next century will certainly usher in the fifth phase of energy industry development, the ***Second Social Objectives Phase.***



History moves in cycles! The arrival of the 21st century will herald the new millenium version of the changes that occurred at the arrival of the 20th century.

4. THE CHALLENGE OF THE 21ST CENTURY - SUSTAINABILITY

4.1. Sustainability

Sustainability is about ensuring energy for all our present needs, and all our future needs to the ends of time. It is not just about environment, but about sustaining our energy future. It is not about targets, or quotas, but about strategies. It is not just about technologies, but about transitional processes

Australia has adequate energy resources for the foreseeable future for its population, a situation which is quite different from many other countries. Provision of inexpensive electricity based on these reserves has lead to the development of energy-intensive industries in the country, and while Australia is a country with relatively high energy per capita reserves it needs to consider the longer term to ensure a desired energy mix. The exhausting of a particular energy resource does not necessarily mean that this is an unsustainable process, unless it sets in train other irreversible and increasing degradation processes.

The main issue for Australia is sustainability of energy utilisation, rather than simple environmental goals such as greenhouse gas (GHG) abatement. While this latter issue may be important, it is a subset of broader sustainability goals, and while Australia may attain targets for GHG reduction, it will have little effect on global GHG figures and will not of itself lead to sustainable energy frameworks. We need to be pragmatic about the rationale and impact of various options as they impact on the national and global issues. While it is nice to be an exemplar for the world, the realities are that our impact on global issues is small. Thus our "leadership" has to be more than just a moral stance, it has to be founded on sound business principles as well – for example, deriving technological advantage in export markets to improve our economic position.

The strategies pursued by Australia in achieving sustainability in energy have to be positioned in relation to several "market" arenas: local, regional, national and global. Addressing the issue of sustainability for each of these arenas will yield a suite of strategies that will maximise the impact of the Australian effort. Most evident in this respect is the fundamental need for sustainable energy supplies to raise living standards in developing economies. Australia, as a key energy exporter, has a role and an opportunity to assist those countries meet their aspirations in a sustainable manner, while enhancing its own economic position and society.

Thus sustainability requires us to expand future energy choices (including new conversion and utilisation technologies), rather than narrow them on ideological or ignorant grounds.

4.2. A Sustainable Energy Future in a Sustainable Environment

The objective for a sustainable energy future must be to use and foster Australia's diverse resources to provide for the social and economic needs of this generation, in a manner that ensures the energy needs of future generations can be met, while preserving and enhancing the condition of the environment that those future generations will inherit.

The evolution of a strategy, and a policy framework, to achieve this needs to be underpinned by a number of principles:

- The transition to a sustainable energy future is not about sustaining the present, but depends on actively creating new energy futures which:
  - draw upon our fossil fuel resource and technology base;
  - prioritise renewable energy sources, energy efficiency and transitional fuels and enabling technologies; and
  - recognise these technologies and areas of expertise as key growth areas to contribute to Australia's long term wellbeing.
- Energy production, delivery and consumption must yield sustainable ecological (environmental, social and economic) outcomes.
- The sustainability of fossil fuels must be enhanced through increased efficiency in supply and end-use, and appropriate resource allocation where resources are identifiably in decline (e.g. valuing oil for future chemical & fertiliser production).
- Continuous improvements must be stimulated in energy related technologies across the spectrum of production, conversion, transmission, storage, distribution, demand management and use.
- Sustainable energy structures require balancing energy production (supply) with the requirements of energy consumption (demand), and demand (need) growth must be substantially reduced via new technologies and cultural change processes.
- The ultimate goal is for all sources of energy to be based on non-depleting and non-polluting sources.
- Continuous improvement of the environmental performance of the total sector must be stimulated; and
- A consistent and committed national and state approach must be taken in terms of market reform, environmental policies and regulation and investment and taxation policy.

5. SIGNIFICANT FACTORS IN A SUSTAINABLE ENERGY STRATEGY

5.1. Sustaining Energy Industry Exports

Australia exports over 60% of its raw energy production as energy products (that is, excluding embedded energy in processed and manufactured goods), constituting about 10 percent of Australia's total export value. Of these exports, approximately one half is represented by coal exports and one-third by uranium exports. Gas exports, while only a small percentage, represent a probable area of growth as a transitional fuel to a sustainable energy future.

As a major contributor to Australia's foreign trade income, and as a source of low cost energy in world markets, Australia will be a net energy exporter for a considerable time. The source industries will continue to have significant economic impact, and therefore significant political and social support. To sustain this export industry while contributing to the transition to a sustainable energy future on a global basis, it is important that Australia be at the leading edge of technologies for the conversion, management and utilisation of the energy forms that Australia exports.

This will represent a transition for Australia from a simple exporter of raw energy to an integrated energy industry exporter of resource **and** technologies. A major inhibitor of this process is that energy export is dominated by focussed resource companies. Therefore, there is a need to provide facilitation mechanisms to extend the activities of these companies into appropriate energy technology

R&D, and production/manufacture of the associated technology outcomes.

A key element in achieving the above is to enhance Australia's position in clean coal technology.

Australia's competitive low cost electricity position is based upon large coal fired power stations. The design life of these generating facilities is in excess of 40 years. New clean coal technologies now being applied at large generating units, are demonstrating 25% reduction in greenhouse gas release, significant reductions in NO_x release, and conversion efficiencies up to 50%. These new technologies can be used to re-power older units, providing an economic option in a competitive energy market that eliminates the possibility of stranded assets, and will extend the life of available coal reserves.

Improved materials now allow new thermal stations to be constructed use supercritical technology, with efficiencies over 40%. Improving technologies are now making feasible gas fired combined cycle and co-generation power stations with conversion efficiencies of up to 60%.

5.2. Technological Impacts

A major factor in future strategies is technology. On the demand (or user) side of the equation advances in technology have produced remarkable improvements in the capacity of energy users to control and minimise the use of energy, which reflects in the lower growth rates in demand for electric energy. Perhaps more importantly, there is an increasing capacity for energy users to provide for their own energy requirements in an economically viable way - for example, gas turbine, co-generation, and alternate energy such as solar.

The potential for advances in these technologies as well as in solar technology and in fuel cells suggests that the era of the major central power station, while not drawing to an end, may well be entering a phase of intense competition from distributed generation sources. The growth in distributed generation or co-generation could defer for some time the need to augment grid facilities, and in fact raises the question whether grid-based supply will not decline as the basic framework for energy supply in the future. A key to a number of these systems approaches is the ability to store energy. Intensive research and development is required for small and large high energy density storage devices.

5.3. Allocative Issues

Allocative strategies – providing efficient economic, ecological and societal signals which direct energy resources to their most appropriate use – are key elements of a sustainable energy framework, and of the transitions from the present position to a sustainable energy future. Allocative strategies are required in order to direct resources on an efficiency, priority and best-option/resource value-maximisation basis.

5.4. Community Education

With the residential and commerce sectors of the Australian energy market representing less than 15% of the total market, the direct relationship between energy and the individual is limited, as the 'embedded' energy in the goods and services is quite invisible. Any changes in product price, accessibility and convenience as a consequence of changes in energy mix or cost is therefore somewhat disconnected from the objectives and benefits of those changes. The achievement of sustainable energy goals depends heavily on a broad-based community education and commitment program, to change the underlying assumptions and norms of Australian society.

Particularly critical in this is dealing with the perceptual issues relating to various forms of energy, such as the negative perceptions surrounding nuclear and fossil-fuels, and the unrealistic short-term positive expectations of some innovative energy sources.

5.5. Efficiency and Effectiveness Issues

Efficiency in production, transportation and use of energy will be key to achieving the 'quantity' goals of sustainability, while improved effectiveness in the management and development of energy resources will be critical to achieving the 'quality' goals of an essential commodity in modern society.

In respect of efficiency goals, there is a pressing need for the sustainability strategies to provide incentives for research in this area, and to provide tax incentives for companies to convert to lower energy technologies.

While it is fashionable to focus on the activities of the energy producers/converters, there are many issues of community and political action that need to be addressed if sustainability is to be more than an ideological flag. Market structures, regulatory environments, taxation regimes, laws establishing resource access regimes, as just a few examples, all have significant aspects which are inimical to energy sustainability. In developing the sustainability strategy, we need to adopt a systems approach rather than sectional promotion/target approach to ensure that there is a much higher probability of achieving the desired outcomes, and a much lower probability of creating undesired outcomes.

We also need to think laterally. For example, better transport contributes to energy sustainability; improved land planning and denser urban development will make a contribution.

5.6. Technologies for Australian Competitive Advantage

Australia already has a comparative advantage in a number of the energy technologies. This advantage has been gained as a consequence of:

- ongoing R&D activities largely undertaken at public institutions;
- an abundance of natural resources including renewable and non-renewable; and
- the strength and depth of the energy sector in the Australian economy.

The potential areas of comparative advantage include:

- solar – photovoltaics
- energy efficiency technologies
- hybrid solar/fossil fuel systems
- solar thermal
- biomass
- geothermal
- hydro - mini
- storage technologies
- fuel cells
- alternative liquid fuels (such as methanol, ethanol)
- transitional fuels (e.g. gas for liquid fuel substitution)
- transitional fuels (for electricity generation: e.g. gas, briquettes?)
- nuclear
- tidal
- sequestration technologies - capture and reuse
- co-generation

In seeking drivers to advance this position, it is appropriate to look to both long and short term beneficiaries of the changes in the energy industry. These beneficiaries must include the Australian population as a whole represented by government, the energy sector and industry and commerce in general. These stakeholders should be encouraged to be forward looking and to take appropriate action to ensure that Australia does indeed capitalise on its comparative advantage. We need structures and mechanisms that foster and support long term investments to secure a stake for Australia in key emerging technologies and areas of expertise

6. CONCLUSIONS

Energy is the foundation of the modern economy. In today's competitive global environment, a National Sustainable Energy Strategy must build upon Australia's physical and intellectual resource base and its economic and social structures and must support the creation of a sustainable energy culture and a forward looking economy, appropriate to the challenges of the 21st century. Australia's future living standard depends upon our ability to reconcile the demand for energy, our role as an energy exporter, the need to conserve resources and ecosystems for future generations.

Accelerators for the Australian Environment & Heritage

C TUNIZ, Australian Nuclear Science and Technology Organisation
PMB 1 Menai 2234 NSW Australia

SUMMARY Australian researchers have access to a variety of natural systems where records of the Earth's past environment have been stored. These archives include sediment cores, Antarctic ice, Tasmanian pine trees, rock surfaces, corals, etc. Each of these media contain information on past environmental conditions but the records must be carefully deciphered and compared with one-another. The AMS analysis of long-lived cosmogenic radionuclides is essential for providing absolute time scales for these natural archives. Other analytical methods based on high-energy ion interactions are well suited to characterise environmental and archaeological samples with high sensitivity. The use of ANSTO's accelerators in research programs related to the environment in the Australian region is reviewed.

1. INTRODUCTION

The Australian region offers direct access to environmental archives and archaeological records fertile for study with accelerator-based methods. Research programs aimed at the study of the Australian environment and heritage are carried out at ANSTO using two ion accelerators, the 3 MV Van de Graaff and the ANTARES 10 MV Tandem.

The 3 MV Van de Graaff accelerator has been used for Ion Beam Analysis (IBA) since 1964 for a large number of scientific projects coordinated by the Australian Institute of Nuclear Science and Engineering (AINSE). IBA provide analytical tools for the characterisation of elemental concentrations and distributions in materials. The versatility, sensitivity and non-destructive nature of IBA methods such as proton-induced X-ray emission (PIXE), proton induced gamma-ray emission (PIGE), Rutherford Backscattering (RBS) and nuclear reaction analysis (NRA) have resulted in ion beams being applied to solve problems in many diverse fields such as archaeology, biology, geology and environmental science.

The ANTARES accelerator is used for both, IBA and Accelerator Mass Spectrometry (AMS) analyses. This accelerator was manufactured in 1962 by High Voltage Engineering Corporation in the USA and relocated to Australia in 1989. Complete refurbishment and enhancement has resulted in a multi-purpose facility providing thousands of accelerator analyses per annum in support of Australian research. Figure 1 shows the accelerator usage during the last year. All the analytical facilities on the ANTARES accelerator are represented in Figure 2.

The use of the high-energy heavy ions from ANTARES enhances the performance of IBA methods for elemental depth profiling. Techniques such as elastic recoil detection analysis (ERDA) can be applied to a wider range of light elements such as carbon, nitrogen and oxygen, not accessible with the smaller 3 MV accelerator.

An IBA microprobe has been installed on ANTARES and is based on a magnetic quadrupole triplet focussing heavy-ion beams (up to iodine). This instrument is used to analyse lateral variations in sample composition with a resolution of a few microns. Two-dimensional maps of titanium, chromium and other elements in individual grains of sand have been recently reported.

The major uses of ANTARES are in high-precision ^{14}C dating and in the AMS analysis of the long lived radionuclides ^{10}Be, ^{26}Al, ^{36}Cl and ^{129}I. A new beamline for the detection of ^{236}U and other rare actinides in the environment has been recently constructed.

A national research program in Quaternary and environmental science based on the AMS analysis of ^{14}C and other cosmogenic radionuclides started at ANTARES in 1993. Thirty five Australian universities are accessing the ANTARES AMS facility via AINSE. In the last 12 months, Lucas Heights scientists performed AMS analysis of more than 2000 samples from about 100 projects covering a wide range of disciplines, such as archaeology, geomorphology, hydrology, palynology, glaciology and palaeo-climatology (Figure 3).

Some examples of research directions based on the application of AMS and IBA analysis in quaternary science, environmental issues and heritage studies are reviewed in the following sections.

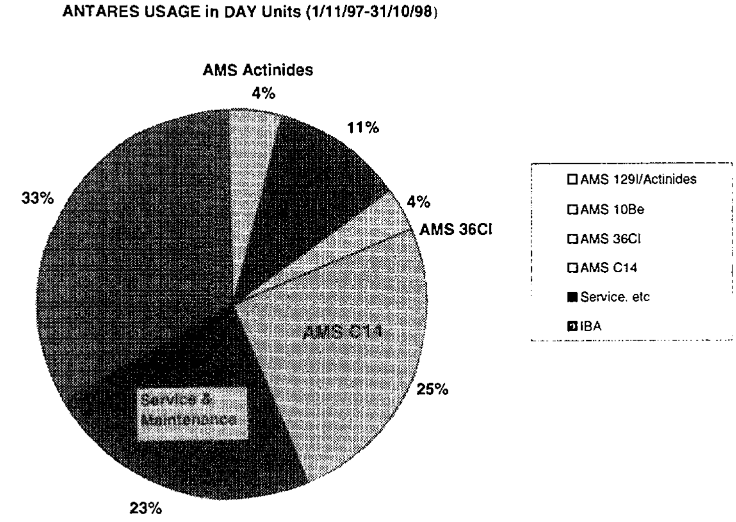


Figure 1 - ANTARES usage during 1998

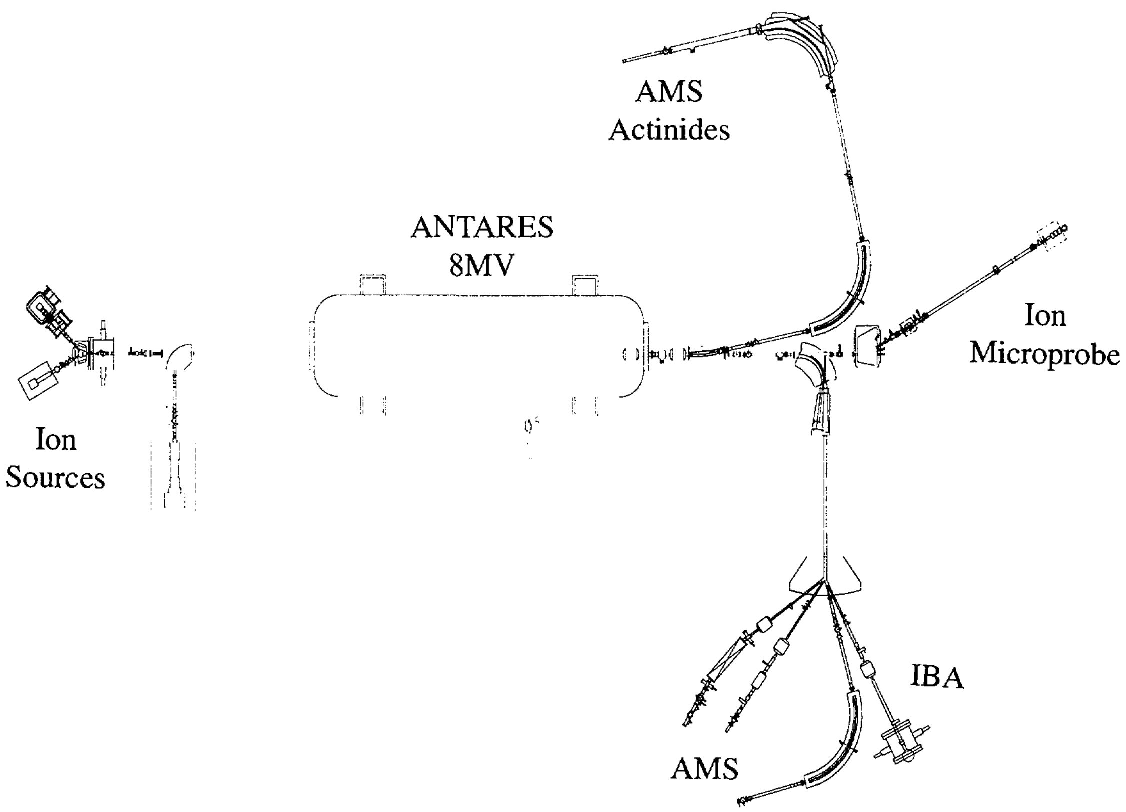


Figure 2 - Layout of the ANTARES facility

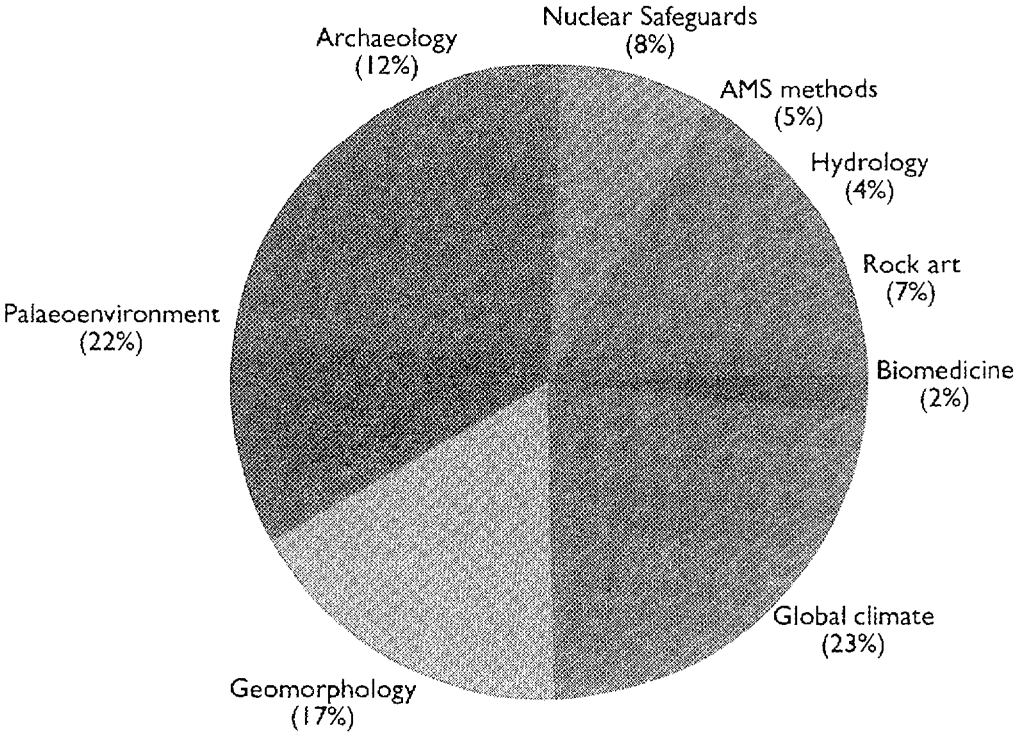


Figure 3 - Applications of AMS at ANTARES

2. ENVIRONMENT: PAST, PRESENT AND FUTURE

The Quaternary period covers the last two million years of terrestrial history. It is significant because within this time frame there were great climatic upheavals and human kind spread across the world. Quaternary science includes a variety of scientific disciplines such as archaeology, biology, climatology, geography and geology, providing the knowledge needed for reconstructing the past of the environmental conditions on the global scale.

Cosmogenic radionuclides, such as ^{14}C and ^{10}Be, provide radiometric clocks to establish an absolute time scale for the environmental events of the Quaternary. AMS is the analytical method of choice for the efficient analysis of long-lived radioisotopes, with typical sensitivities of one million atoms.

2.1 Sediments

Ancient sediments archive environmental events, such as climatic changes, that have taken place in the past before the existence of instrumental records. ^{14}C analyses by AMS of microscopic samples from charcoal, pollen and other organic materials provide the time scale for the last fifty thousand years. ^{10}Be in sediments can be used to extend this chronology providing time markers related to reversals of the geomagnetic field or other processes that affect the production of cosmogenic radionuclides during the Quaternary.

The Earth's environmental systems have undergone many changes and investigating these provides insight into how environmental changes are driven and the effect they have on the biosphere. Australia has many of these kinds of archives and they can help us to understand how global scale environmental changes have been expressed in the biota and palaeo-hydrology of the continent. These records can then be used to help identify the kinds of forcing factors which influence the climate and the sensitivity of vegetation to environmental changes.

Major research projects are under way at the University of Western Australia to understand the late Quaternary history of vegetation, fire and climate. One of these projects aims to investigate how very high bio-diverse vegetation in Australia responds to change, and the bearing of this in relation to maintenance of high bio-diversity. Another project involves the history of dust load in the atmosphere from Quaternary records in Australia. Records of vegetation change, fire history, land clearance and land-use in relation to the onset and development of salinity in lakes are being reconstructed.

A research program at the University of Newcastle involves examination of sea level change and deglaciation chronologies from Antarctica, freshwater stromatolites in southern Australia and vegetation histories derived from lake sediment cores from Tasmania and NSW.

Dating techniques that yield high-precision age estimates of these terrestrial archives are essential. The AMS ^{14}C dating technique is well suited to the sort of organic materials encountered in this research. As a technique capable of measuring ^{14}C levels in sub-milligram samples, AMS ^{14}C dating is the only option available when trace amounts of datable material are preserved. In addition, many samples dated from lake and swamp sediments are contaminated by mobile humic acids that cannot be removed totally. Although AMS dating of specific organic fractions refines the radiocarbon analysis, a more secure approach is provided by the direct dating of pollen extracts from the samples.

2.2 Tree rings

Ancient conifer logs exhumed from the bed and banks of the Stanley River in western Tasmania have been sampled by researchers from the University of Sydney for dendrochronological and atmospheric ^{14}C studies. They range in age from Last Interglacial to the present.

The main significance of this research program lies in the remarkable length of the tree-ring chronology being developed for the Stanley River, with year-by-year precision. The interpretation of climatic change from the tree-ring widths, and the determination of radiocarbon variations from wood tied to this chronology, will contribute much to our understanding of major and abrupt climatic changes during the last deglaciation (15,000 to 11,700 years ago). Much can be learnt about the subtle style of climatic variations dating from this period, and changes in ocean currents and convection patterns before and after the sea-level stabilised at present levels (around 7,000 years ago). Changes in recent centuries can be determined with annual precision from tree rings in the tropical regions in Australia and Southeast Asia, and are highly relevant to studies of the monsoon system which brings rain from the northern Indian and western Pacific Oceans to these two regions, in alternate seasons each year.

2.3 Ice cores

Ice cores provide preserved air from which to reconstruct levels of greenhouse gases over recent centuries to millennia. Ice cores from Law Dome, East Antarctica, characterised by high accumulation rates, provide a high-resolution record through the Holocene and possibly beyond. In addition, air extracted from the firn permits direct comparison of entrapped trace gas concentrations with modern records. One of the problems is that recent CO_2 growth rate variations are difficult to interpret due to the smearing of ice-core signals induced by the diffusion of air in the firn. In collaboration with CSIRO and Antarctic Division, we used the ^{14}C "bomb spike" to determine the age spread and age of CO_2 in Antarctic ice and firn.

Profiles of long-lived cosmogenic radionuclides, as a function of depth and thus age, provide key information on past solar variability, production rate changes, and atmospheric transport and deposition mechanisms. In particular, ANSTO scientists have recently measured ^{10}Be in ice cores from Law Dome to study snow accumulation rates during the past.

2.4 Stick-nest rat middens

^{14}C is being used to give the essential framework for interpreting information locked in the ancient dwellings and middens of stick-nest rats which are built in arid areas from local materials and preserve plant and animal material for up to 10 ka. The material found in nests from Western Australia, Northern Territory and South Australia includes bones and hair from extinct species and pollen from plants growing thousands of years ago in the arid centre of the continent. AMS dating is being used to reconstruct the past distribution of Australia's arid zone mammals and provide much needed information about the last few thousand years.

2.5 Rocks

Cosmogenic radionuclides such as ^{10}Be, ^{26}Al and ^{36}Cl produced in rocks can provide information on glacial histories in the southern hemisphere. Although only a million atoms of the cosmogenic isotope ^{10}Be are produced during a 100 ka exposure period per gram rock, AMS can be applied to measure this telltale signal. The ANSTO research program is targeting three geographic regions that show distinct glacial formations and deposits: Tasmania, New Zealand and Antarctica. The ANTARES AMS spectrometer is used to analyse glacially polished bedrock surfaces, large erratics and boulders deposited on lateral and terminal moraines and within glacial outlet valleys. A number of ice cap advances during the Quaternary have been identified from the radionuclide signals. This study involves also the search of the Younger Dryas (11-13 ka BP) in the southern hemisphere. This is a major short term reversal during the last deglaciation which appears throughout the climatic records of the northern hemisphere.

2.6 Oceans

The accelerator analysis of radiocarbon in ocean waters helps to understand the influence of ocean circulation on the world's climate. Australia has considerable responsibilities in supporting international programs in ocean circulation. Preliminary studies, funded by the National Greenhouse Advisory Committee, have been carried out by ANSTO in collaboration with Flinders University and CSIRO Division of Marine Science.

The aim of the project is to examine the role of the Southern Ocean as a source region for water masses, to determine its contribution toward the ventilation of the world ocean, and to quantify its performance as a sink for anthropogenically produced greenhouse gases. The database from oceanic field observations available for model validation purposes is sparse, and the role of the Southern Ocean within the global carbon cycle represents, to date, the largest unknown quantity in discussions of an anthropogenically enhanced greenhouse effect.

Water samples from locations within the Australian sector of the Southern Ocean were obtained to determine their ^{14}C content. The determination of the ^{14}C distribution as a function of depth and location is necessary to validate predictions obtained from the tracer model which was developed for the world ocean region south of 24°S. Subsequently, this model is applied to integrate the observed ^{14}C distribution in space and time, and to establish a ^{14}C budget for the Southern Ocean.

First ^{14}C AMS measurements have been obtained and are consistent with the observations made during the Geochemical Ocean Sections Studies (GEOSECS) programme conducted in the late 1970's for the southeast Indian Ocean.

2.7 Atmosphere

The effect of airborne fine particles on public health is of increasing national and international concern. Research projects are being undertaken to determine a picture of air quality in Australian cities, together with their concomitant elemental signatures and emission sources. The data being obtained is providing valuable information on the composition and dispersal of natural and anthropogenic sources. This is assisting in the development of control strategies for remedial and pollution management programs.

These atmospheric fine particles are typically produced by anthropogenic sources such as combustion processes, motor vehicles, industrial plants and mining operations and by natural sources such as windblown soil and sea spray. They may remain in the atmosphere for weeks, and can travel hundreds or even thousands of kilometres from their original source. It is therefore important to understand the regional and even global movement of these atmospheric aerosols.

The PIXE technique in aerosol analysis is used to measure the commonly occurring elements Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Br and Pb. A typical PIXE analysis is obtained in less than 5 minutes of accelerator running time.

Each element present in the aerosol can be apportioned to a particular source. For example, aluminium and silicon are primarily associated with windblown soil, sulphur with fossil fuel burning, industry and motor vehicles, chlorine with sea spray, potassium with smoke and wood burning, metals with industrial processes, and lead and bromine from motor vehicles. Major studies at the University of NSW and Griffith University have established the composition of local fine particle pollution as well as its temporal and spatial variability.

3. THE AUSTRALIAN DREAM TIME

Several joint projects between ANSTO and Australian universities involved in radiocarbon dating of Aboriginal rock pictures, burial and occupational sites, have been funded in the last several years by the Australian Research Council, the Australian Institute of Nuclear Science and Engineering and the Australian Institute of Aboriginal and Torres Strait Islander Studies. ANSTO has developed special methods for the non-destructive dating and characterisation of rock art in the Kimberley, Chillagoe, Laura and other Aboriginal sites. This work involves close collaboration between physicists, archaeologists and Aboriginal people.

Several archaeological projects include detailed research into the probable antiquity of the rock art of Chillagoe and Laura, North Queensland, and the Kimberley, Western Australia. A variety of materials are being analysed, including pigments, oxalate minerals, silica coatings, plant fibres, carbonised plant matter, fatty acids, beeswax and mud-wasp nests.

3.1 Chillagoe

The Chillagoe region of North Queensland has been under intensive archaeological scrutiny since the early 1980's. To date, a series of excavations led by Bruno David and co-workers, have revealed cultural deposits dating back to at least 26,000 years BP, with dramatic increases in the quantities of archaeological materials recovered during the mid to late Holocene. These increases appear to signify important cultural and demographic changes in past Aboriginal social systems, probably including a major population increase. The geographic distribution of rock art conventions through time in northern Queensland are being investigated showing that the earliest rock art is relatively homogeneous. The later rock art - estimated to date to the last 3500 years or so by indirect dating methods - is, however, geographically heterogeneous, indicating a regionalisation of artistic, and by implication social, networks around that time. Our initial results date the Chillagoe pictographs to the last 800 years or so, in support of the existing model of a mid to late antiquity for most of the regionalised art of the region.

3.2 Kimberley

The Kimberley rock art sequence is likely to be one of the longest and most complex in the world. On the basis of superimpositions and differential weathering, Grahame Walsh has constructed a very detailed rock art sequence of which the major phases include Pecked pits, Irregularly Infilled Animals, Bradshaws, Clawed Hand figures and Wandjinas. This sequence depicts major changes in Aboriginal culture, ideology and local fauna over time. Fieldwork in the region started in 1994 with the aim of providing absolute dates for the Kimberley rock art sequence. Small samples of pigments, beeswax, mudwasp nests, and associated mineral crusts have been collected. Mudwasp nests, which sometimes overlie or underlie rock paintings, can provide minimum or maximum ages and may be dated by AMS or optically stimulated luminescence (OSL). AMS dating of such samples has helped to provide the first age estimates for the well-known Bradshaw painting style and allowed comparison between results from two very different dating techniques.

3.3 Mount Mulligan

Ngarrabullgan or Mount Mulligan, located some 100 km northwest of Cairns, is a large table top mountain bordered by 300 m high cliffs along most of its periphery. A different vegetation can be noted on the top of Ngarrabullgan and in the savanna woodlands which surround the mountain. Ngarrabullgan Cave, on the top of Ngarrabullgan, is one of the earliest radiocarbon dated archaeological sites in Australia (37,000 yr BP). The deposits at this site show very low erosion and a near-total absence of territorial vertebrate fauna. Our AMS dates show that intensive use of the mountain started around 5000 yr BP, after 27 millennia of total abandonment. In this work we have also obtained the first paired ^{14}C/OSL determination for pre-30 ka archaeological deposits.

3.4 Jinmium

The question of when humans came to Australia is of great interest. AMS and OSL were used to show that the controversial thermoluminescence dates of greater than 116 ka for the Jinmium rock shelter in the Northern territory were incorrect and were not associated with a new earlier estimate for the colonisation date of Australia. AMS/radiocarbon and OSL dating analyses demonstrated that the Jinmium site was occupied less than 10 ka ago.

3.5 Selwyn Ranges

The Selwyn Ranges contain a rich selection of Aboriginal rock art motifs such as stick figures, kalkadoons and animals painted in a variety of ochres from nearby deposits. The PIXE method has allowed a range of paint samples to be analysed and compared with the ochres from quarried sources. The results indicate that there were clear trends between the types of ochre used to paint certain motif types. For the first time, on any rock art in the world, rock art has been able to be interpreted by considering how the use of ochre reflected considerations of the artists, and provides a unique insight into the process of producing rock paintings by Aboriginal people.

4. AUSTRALIAN FAUNA

Australian animals inhabiting the arid zone are faced with long periods of poor or inadequate nutrition during times of low or no rainfall, and must depend for their survival on the efficient utilisation of their stored body reserves. They have developed a highly specialised morphology and behaviour which attest to a long evolutionary association with their specialised habitat.

Ion beam analysis of biological tracers is being used to provide an understanding of the nutritional requirements. Native animals are dosed with a small quantity of water enriched with ^{18}O and blood samples are taken after a specific period spent by the animal in the natural environment. The ^{18}O in blood samples, determined by IBA, allows one to estimate the rate of production of carbon dioxide and calculate the metabolic rate of a free ranging animal. The Australian animals studied include the desert Dragon and the pollen-feeding Honey Possum.

ACKNOWLEDGEMENTS

This paper presents examples from the programs carried on by the Accelerator Mass Spectrometry Group and the Accelerator Applications Group in

the Physics Division, in collaboration with many scientists from other ANSTO Divisions, CSIRO and Australian universities.

Part of the research illustrated in this paper has been funded by the Australian Institute of Nuclear Science and Engineering, the Australian Research Council and the National Greenhouse Advisory Committee.

BIBLIOGRAPHY

(1) Tuniz, C., Fink, D., Hotchkis, M.A.C, Jacobsen, G.E., Lawson, E.M., Smith A.M. and Hua, Q. (1997) Research and measurement program at the ANTARES AMS facility, Nucl. *Instr. and Methods in Phys. Res.*, Vol 123, pp 73-78.

(2) Tuniz, C., Bird, J.R., Fink, D. and Herzog, G.F. (1998) Accelerator Mass Spectrometry: ultrasensitive analysis for global science, *CRC Press, LLC.*

(3) Levchenko, V.A., Francey, R.J., Etheridge, D.M., Tuniz, C., Head, J., Morgan, V.I., Lawson, E.M. and Jacobsen, G.E. (1996) The ^{14}C "bomb spike" determines the age spread and age of CO_2 in Law Dome firn and ice, *Geophysical Research Letters*, Vol 23, pp 3345-3348.

(4) Roberts, R., Walsh, G., Murray, A., Olley, J., Jones, R., Morwood, M., Tuniz, C., Lawson, E.M., Macphail, M., Bowdery D. and Nauman, I. (1997) Luminescence dating of rock art and past environments using mud-wasp nests in northern Australia, *Nature* Vol 387, pp 696.

(5) David, B., Roberts, R., Tuniz, C., Jones R. and Head, J. (1997) New optical and radiocarbon dates from Ngarrabulgan Cave, a Pleistocene archaeological site in Australia: implications for the comparability of time clocks and for the human colonisation of Australia, *Antiquity* Vol 71, pp 183-188.

(6) Armitage, R.A., David, B., Hyman, M., Rowe, M.W., Tuniz, C., Lawson, E.M., Jacobsen, G. & Hua, Q. (1998), Radiocarbon determinations on Chillagoe Rock Paintings: Small Sample Accelerator Mass Spectrometry, *Records of the Australian Museum*, 50, 285-292.

(7) David, B., McNiven, I., Bekessy, L., Bultitude, R., Clarkson, C., Lawson, E.M., Murray C. and Tuniz, C. (1998) More than 37,000 years of aboriginal occupation, in B. David (ed.), Ngarrabulgan: Geographical Investigations in Djungan Country, Cape York Peninsula, *Monash Publications in Geography and Environmental Science* 51,157-178.

(8) Siegale, R. and Cohen, D., (1999) Mapping of light elements with the ANSTO high energy heavy ion microprobe, Proceedings of the International Conference on Ion Beam Analysis, 26-30 July 1999, Dresden, Germany.

(9) Fink, D. et al., (1999) Improving the glacial chronologies of Tasmania and Antarctica using in-situ cosmogenic isotopes, Proceeding of the International conference on Accelerator mass Spectrometry, 6-10 September 1999, Vienna, Austria.

(10) Smith, A.M. et al. (1999) Factors affecting ^{10}Be record in firn and ice at law Dome, Antarctica, *ibidem.*

(11) Lawson, E.M. et al. (1999) ANTARES AMS contributions to Aboriginal pre-history in Australia, *ibidem.*

Implications of International Protocols on Energy Markets

VIVEK TULPULE

Australian Bureau of Agricultural and Resource Economics
GPO Box 1563 Canberra ACT 2601

SUMMARY

Ratification of the Kyoto Protocol will have significant medium and long term implications for the economies of Annex B and non-Annex B countries. It is shown that the adoption of a system of internationally tradable emission quotas would result in three 'dividends' compared with an outcome where Article 17 trading - relating to emissions trading - is prohibited. First, trading would improve the environmental effectiveness of the protocol because the extent of carbon dioxide equivalent leakage would be reduced. Second, the overall cost of meeting the agreed Annex B targets would be reduced thus leading to greater certainty that the protocol will be implemented in full. Third, a disparity in the differential impacts of Annex B abatement policies on different developing countries would be reduced under emissions trading, leading to a more equitable outcome for these countries.

AU0019564

Factors in Public Perception of Nuclear Energy

IAN HORE-LACY, Uranium Information Centre, Melbourne.

Public communication about nuclear energy needs to relate to the cultural undercurrents which determine how people perceive the environment. The paper discusses some of these and suggests ways of responding to them. It also outlines major ethical considerations relevant to uranium mining and nuclear energy and communication about both. Competent discourse about values is fundamental.

1. INTRODUCTION

Why would anyone object to nuclear energy?

I wonder if we have really spent enough time answering that question, rather than simply reacting to particular points raised?

Of course the answers could be ignorance, fear, distrust, and a whole lot more. But while ignorance is fairly straightforward, that doesn't tell us why the bias is to hostility and scepticism, nor why there is any fear or distrust.

The question is pushed up into high profile by the apparent *prima facie* assumption of so-called ethical trusts that uranium mining and nuclear energy should fall outside their criteria, something which needs challenging. While it may reflect the moral pride and pedantic self-righteousness of particular interest groups, any challenge to it must avoid the same traits.

A review of environmentalism and of people's attitudes to nuclear power over the last fifty years is instructive. But the roots are deeper than that in our culture and history, and those roots influence the fruit. The aesthetic and Romantic attachment to the green and pleasant land, or to the unspoiled bush, is strong and real, even if it allows little place for all that sustains our standard of living and ability to enjoy such.

I want to suggest that public communication about nuclear energy needs to start further back that simply addressing the four topics of radiation, wastes, safety and proliferation. It needs to be tuned to the presuppositions of identified target groups, and to be very open.

To some extent it may be appropriate to expose the presuppositions of the extreme elements and individuals, but that is a separate tactical issue I want to leave to one side here. It is also liable to imply extremism where none exists in what is realistically our target audience.

2. TWO PARADIGMS

A study of the dynamics of the environmental movement as it has matured over the last 20 years from my perspective (in the kind of industry which has brought us all out of the caves since Neolithic times) suggests that there is clearly a tension between two paradigms, whereby the environment is perceived predominantly as either:

- **a physical construct**, understood and approached scientifically and rationally, and having instrumental values, or
- **a moral construct**, "nature", understood metaphysically and having aesthetic and spiritual values, which are intrinsic.

There are obviously those who identify with each, and because the second is economically marginalised and radical, it throws up passionate and committed advocates who feel that they have a monopoly on ethics. But **perhaps most people span both paradigms to some degree.** Operationally they accept the first, but with reservations which make them open to the rhetoric of the second, and seeking the vicarious satisfaction of some alignment or flirtation with it. Perhaps also they are attracted by a certain quixotic element associated with it.

Another way of looking at the question is in terms of Maslow's hierarchy, with people's basic needs being abundantly met in the western world, so that attention turns to self-actualisation and all the diverse elements which may be involved, particularly anything related to quality of life.

Probably some reservations about the first paradigm arise from observing people who operate entirely on the basis of it, and whose values are limited to instrumental rather than aesthetic appreciation of nature, or who espouse "a doctrine of freedom with the ethics squeezed out", to quote Chase (1). If they depend on those people for their physical welfare and comfort there is perhaps a guilt dimension as well. At any rate, they are likely to see the environment as a factor of social critique and perhaps dissent, the latter taking the form of some degree of simplified lifestyle.

Other writers bring insights on how these paradigms are expressed. Maurie Cohen (2) contrasts two modern streams of environmentalism, with roots in the Romantic and Rational traditions. He sees postmaterialism as the engine of environmentalism in countries such as Sweden and Netherlands, while Japan and Norway stand out as having a more pragmatic conception of nature, with greater reliance on technology in their approach to environmental quality. "This strategy shares with its utilitarian predecessors a scientific understanding of nature and avoids interpreting human behaviours toward the environment in cumbersome ethical terms."

The result is most clearly seen in respective approaches to whaling – the Romantic tradition seeking bans, the rational, favouring controlled harvest. Cohen sees business as a major factor in pushing environmental policy formulation in the Rational direction, as exemplified by Norway and Japan, so as "to regain control of the debate over sustainable development and to advance a new interpretation that does not undermine the essence of free enterprise". He sees "even the most strident advocacy groups" in several countries "stepping back from their Romantic commitments," and the main manifestation of business interests being eco-efficiency emerging as a management strategy which blunts the assault of the green stakeholders and consumers.

Avner De-Shalit (3) notes a propensity by "a large part of the environmental movement" to use "the concept of the 'environment' in a political and instrumental manner in order to talk about something else and to evoke certain political attitudes." He calls this "conceptual environmentalism" and suggests that it is a deliberate tactic rather than a straightforward expression of values. For instance he sees Deep Ecology as a political theory based in faulty science and pop psychology, rather than being an expression of environmental ethics, and he quotes advocates of it who refer to its "metaphysical teachings". He concludes by lamenting the conflation of environmental philosophy and political theory, and suggests it might "be better for the environment if we concentrate separately on the moral grounds for environmentalism and the democratic theory about the institutions which best guarantee a cleaner environment, animal welfare, etc, let alone social justice." This would be widely supported among those working on the basis of the first paradigm.

The challenge for us is to enable people to feel more positive about what they know to be practical and necessary. Life becomes an unsatisfactory compromise if one lives in the real world but is persuaded that ethical virtue lies in either the monk's cell or in tree hugging and coercive utopianism.

Ethically the two paradigms contrast mankind as steward (benign, but definitely over nature) and mankind as the enemy of nature, leading to deep ecology or biocentrism in which the ecosystem rules. The contrast extends to technology being prima facie positive with nature subordinate on the one hand, and nature (as ecosystems, not individuals) paramount with technology generally suspect on the other. Any human disturbance of nature, upsetting its stability or polluting it, is then morally wrong.

This leads one to question to what extent the following truisms (to us) are understood by those in the middle ground, influenced by the deep green or biocentric paradigm:

- the environment can be measured and understood scientifically
- it is constantly changing on its own
- it can and must be managed
- management may be for nature conservation and/or other purposes
- the environment can be rehabilitated when disturbed or degraded
- it has recuperative capacity on its own in relation to some pollution
- it has value with reference to human needs (including recreation and aesthetic)
- it can and should be utilised economically
- our living standards depend absolutely on that utilisation
- mineral resources are much more abundant than commonly realised
- nuclear energy is the only large-scale technology available for generating electricity without greenhouse gas emissions (other than hydro)
- wastes from nuclear generation are contained and managed, not released to the environment
- environmental management needs to be based on science, not folklore or ideology
- science has been consistently abused in environmental debates
- the above observations arise from thoughtful reflection, not hubris.

While the two-paradigm model may help us discern where others are coming from, it needs to be said that on the Jabiluka and Beverley issues, simple misrepresentation is what the companies and government are immediately contending with. And moving further afield, or downstream, fear plus folklore are the stock in trade of the anti-nuclear activist. But the self-righteousness, the moral momentum and the emergence of the green gestapo checking people's ID in the North blockade revealed the underlying paradigm all too clearly.

3. RISK AND RADIATION

Another dimension of thinking about the two paradigms relates to risk.

The word "Chernobyl" is enough to rule all further thought or discussion superfluous for many people. The fact that they themselves are actively and passively exposed to demonstrably greater risks than is any member of the public from nuclear energy is beside the point.

Is this simply another case of double standards? Is it an outworking of the second environmental paradigm I have described? Last month I spoke to a year 9 gathering where, according to the teacher, the students had studied Chernobyl but not looked at nuclear energy or what it was for! With that group I was not even able to run my usual pitch that Chernobyl is about as relevant to nuclear energy as airline crashes in West Africa are to my safety on Qantas or Ansett, – notwithstanding that the law of gravity is the same in both places.

Perhaps a key to getting to grips with the question is to focus on radiation. X-rays are accepted, uranium tailings are not. Smoke detectors are OK in the home, but as low-level waste buried in central South Australia they are not OK. Microwave ovens, a cheaply mass-produced consumer item, are safe in our homes while radiation in other contexts, where no expense is spared on safety, is not. A senator will fly to Darwin but not get out of the bus at the Ranger mine site, for fear of radiation. Activist groups have got away with murder in purporting to quote (and actually misquoting[1]) ICRP that "there is no safe level of radiation", but I have yet to hear them assert with the same logic that there is no safe level of air pollution or no safe level of caffeine or alcohol intake, though these might equally be guidelines for public health.

Of course perception of risk has never been objective, let alone scientific. As well as frequency and severity of possible effects defining a hazard we have been introduced to the outrage factor, which relates to whether we one opts in to a risk or has it imposed. But there are other social factors brought out in a recent paper by Anthony Wallace (4). He makes the point that while they are totally unfamiliar with nuclear energy, Australians are at home with medical technology which they feel they know. Therefore they readily accept any level of risk associated with medical procedures using radiation, but are intolerant of any risk from the same radiation in another, unfamiliar context. In nuclear medicine, ICRP60 is a credible and conservative reassurance, regarding nuclear power, it is an unjustified licence to endanger people. Same science, different perception round here, but obviously[2] this difference is very much less in countries such as Germany and Sweden whose people are familiar with nuclear power, depend on it, and have been forced to think about it rather than take it for granted.

Wallace suggests that "the scientific community fails to recognise that the societal evaluation of risk is a contest between competing views of reality and in a pluralist society there are many claims to truth, science being only one of them".

As Wallace says, to a large extent the question comes down to trust. People trust doctors but when did they last meet a nuclear engineer? - or any engineer in a context where they sought or knowingly relied on his or her services? So perhaps they default to Homer Simpson. It is the socio-technical system in which ICRP60 is embedded that gives it the credibility for medicine, and its lack of credibility in the case of nuclear energy, at least in Australia. That will take a lot to change.

A starting point may be NORM, coupled with smoke detectors. A plutonium derivative (Am-241), depending entirely on nuclear reactors, is not only a life-saver, its use is now compulsory. And as more kitchens get granite bench tops, ...

4. PERCEPTION AND COMMUNICATION

What are the values which work against our industry?

Moral perceptions (tending to rule nuclear out of contention without further thought) include:

- Nuclear power is too dangerous
- The nuclear establishment is not trustworthy
- It is immoral to produce nuclear wastes and plutonium
- There is an inexorable link with weapons
- We <u>ought</u> to be able to rely on renewables
- Big is bad

Ethical perceptions ("OK, we need the electricity but...")

- The end doesn't justify the means

[1] confusing a conservative principle guiding radiation protection with a fact (or conclusion based on the clear weight of scientific evidence).

[2] from public opinion polls showing around 70-80% for nuclear energy.

Where the moral positions are strongly held as part of the second paradigm discussed above, they are impervious to reason or change. But within the sphere of influence of such people and ideas, the perceptions are often effectively unchallenged and there is a great deal of scope to change them.

What about postmodernism?

The nuclear industry is big (ie its main projects cost $1-10 billion), involving long-term political and economic commitment, highly technological, highly organised, relatively inscrutable and sometimes even secretive, and inexorably reasonable in depending on hard scientific knowledge to deliver energy outcomes for consumers. It is anchored to absolute values and is justified by what it delivers.

Thus it is the very antithesis of folksy, human/cottage scale, subjective-oriented, flexible, short-term ways of organisation (?) which value dissent and marginal voices for their own sake, with an indifference to the distinction between fact and fiction, and where relativism reigns supreme.

If these crude and perhaps extreme generalisations are accepted then the problem of developing nuclear energy in a world where many political processes are under the influence of postmodernism is clear, and we return to the two paradigms:

Our colleagues, conforming to a rational modernist view of the world, ask:

What is the best way to supply a lot of electricity?

- at acceptable cost
- at low risk
- environmentally clean

Others in the developed world, who take for granted comfortable abundance and who have never known serious shortage of anything, ask:

What makes me feel good? What ought to be true?

- but at acceptable cost
- with no imposed risk
- environmentally clean
- minimum level of technology (technology is suspect, big is bad)

Here the two mindsets or paradigms contrast:

- Rational, fact-based, logical, management, *with:*
- Subjective, disconnected from logic and reality, romantic (emphasise what they think should be and proceeding as if it were true), relativist.

This suggests a broad communications agenda which may achieve more than simply addressing nuclear energy on its own. The problem is that much of the two paradigms problem goes back to the educational philosophy and sometimes folklore in which students are immersed at school, and this is clearly a starting point.

But more immediate lessons may be to:

- identify with salient environmental concerns
- talk the language of aesthetics and values
- articulate and display values other than economics and technology/technique
- talk up smoke detectors and NORM
- articulate ethical principles
- show how these are most effectively addressed from "our" side
- focus on simple but not simplistic messages.

5. SOME ETHICAL ASPECTS OF URANIUM MINING AND NUCLEAR ENERGY

Moving on from immediate problems of communication to the wider social context, nuclear energy raises a number of quite proper ethical questions. Most are individually not unique to nuclear energy, but coupled with cultural attitudes to technology and an association with atom bombs and the cold war, they coalesce powerfully.

By ethical questions I mean more than simply personal opinions. Ethical views must be supported with reasons, whereas biases and preferences need no justification. Furthermore, ethical views result in action, or at least guide action and behaviour, so therefore require thought about the consequences of that behaviour.

The following is an attempt to open up a range of issues to ethical scrutiny and discourse. It is based on a conviction that we have nothing to hide nor fear from such scrutiny, but rather that it may erode some negative presuppositions.

1. To what extent is Australia morally obliged to provide resources through trade to other countries? In particular: energy resources for electricity production?
2. What priority should be given to enabling the provision of energy at realistic prices in a developed country's economy? Or for developing countries?
3. How important is sustainable development? How much should we strive to utilise co-products and by-products? What preference should be given to utilising abundant rather than less abundant energy resources? Those with no significant other uses rather than those which are versatile? Those with least environmental impact due to wastes?

4. How does our generation minimise any burden or imposition on future generations, arising from our activities? How do we maximise the benefits passed on to our grandchildren?

5. What priority should be given to minimising pollution, greenhouse gas emissions and land clearance (albeit temporary) for mines? How is environmental stewardship in a broad sense best exercised?

6. How important is job creation in Australia (assuming it is in legal and proper enterprises)?

7. To what extent is development of Australia's remote areas important? How can this be coupled with improved environmental management in those areas?

8. What are legitimate expectations regarding the safety of industrial processes, for workers and the general public? How is safety reasonably maximised in energy production? How is harm from radiation avoided? How is fear of low-level radiation avoided or dealt with?

9. If nuclear energy is intended for electricity and not weapons, how is any contribution to weapons proliferation avoided? Now and for the future? How is the legacy of the Cold War, in weapons stockpiles etc, best removed?

10. How is respect for democracy and the better functioning of democracy fostered through addressing energy issues? What are the civil implications of various energy options in terms of concentration of power, civil liberties, authoritarian systems?

11. What are the implications for Aboriginal land and mineral rights of mining, export and use of different fuels? How are rights and responsibilities defined? Who actually has relevant rights, and how are these balanced?

12. How is rational debate about energy issues facilitated while avoiding misrepresentation and ensuring wide access to relevant facts?

The above points might form a useful discussion agenda with those who classify sharemarket investments into categories, purporting to identify whether they are "ethical' or not. They are not exhaustive.

Some points, notably # 1-5, would be usable in public discourse, advocacy advertising, etc. In fact arguably they should be the core of advocacy for the industry.

6. CONCLUSIONS

As I said in a paper nearly three years ago:

"(It is our target audiences) whose values need to determine what we say and how we say it. This will involve becoming capable of discourse in areas which have not been the traditional practical and technocratic ground of the industry, in order to challenge the quite unjustified grabbing of moral authority by the industry's detractors in relation to those target audiences.

- What assumptions are we making about our hearers and their motivation?
- Have we sufficiently been addressing questions of value, purpose and meaning?
- Have we even been making the most of arguments about environmental quality?
- How do we grapple with the question of risk, especially its outrage component?
- Can we occupy, carefully and not too assertively, some of the moral high ground?

"The notion of a sense of stewardship of the earth and its resources is one which seems to me to have much more potential than we have yet utilised. This may be ..... based on the sense of responsibility to future generations, as in the Brundtland Report (5) and the ongoing ethic of sustainable development. It will, or should, result in a measure of humility in the application of technology and also the elevation of ethical considerations.

"Questions of sustainable development, conservation, as well as values, purpose and moral perspective, can all be encompassed in the area of ethics. It is vital that people in the nuclear industry are able to engage competently in ethical discourse. We are kidding ourselves if we think that we can counter moral stances simply with practical arguments, perhaps it is ultimately even counterproductive.

"Our messages need to be congruent with higher order items on Maslow's hierarchy and/or with the broader liberal concerns of prosperous, content societies. Most people in Western societies don't want to hear that they <u>need</u> nuclear energy for secure electricity supplies. They have grown up to assume that electricity will always be provided somehow. Whether or not they are correct in this assumption, their felt concerns are altogether different."

If we understand the public perceptions of nuclear energy better, we can communicate better.

Public perceptions have deep roots and are formed from impressions more than facts. But with reference to the two paradigms, people's actual values are arguably shown by their behaviour more than their words. How do we persuade those living in the modern world but idealising some greener vision that there is both virtue and good sense in sustainable development which in practical terms delivers more environmental benefits than countercultural alternatives? How do we help people feel more positive about what they know to be practical and necessary?

We need to recognise, debate and communicate values (without preaching or hectoring). Idealism and altruism can be practical and consistent with the efficient provision of all people's needs.

The nuclear industry, including uranium mining, should be able to withstand intense ethical scrutiny without the need to be defensive.

ACKNOWLEDGEMENTS

The paper draws on discussions over several years with many people associated with industry, and particularly Ted Mole, World Energy Council (formerly Uranium Institute) and Jim Byth in relation to the earlier paper quoted.

REFERENCES

(1) Alston Chase, 1995, *In a Dark Wood*, Houghton Mifflin Co.

(2) Maurie J Cohen, 1997, *Evidence of a New Environmentalism: Investor and Consumer Activism as Expressions of Postmaterial Values*, OCEES Research paper # 10.

(3) Avner De-Shalit, 1997, *Where Philosophy meets Politics: the Concept of Environment*, OCEES Research paper # 13.

(4) A.B.Wallace, *The vexed question of risk for ionising radiation*, Radiation Protection in Aust (1999), 16,2.

(5) World Commission on Environment and Development, 1988, *Our Common Future*, Oxford University Press.

Nuclear Reaction and Interaction

JOHN MULCAIR
ANSTO Communications
Private Mail Bag 1 Menai NSW 2234

The text of this paper was not available when the Conference Handbook went to the printer.

A Science Think Tank

FRANK DEVINE
The Australian

I stayed with some friends in their house near Tarragona in Spain some time ago and each morning, from the balcony of my room, I could look out at the shiny white dome of the local nuclear energy plant.

It was a couple of kilometres away but looked so close at hand I almost felt I could reach out and touch it with the end of my toast. Other people in the house - and for that matter, in the neighbourhood - hardly noticed it.

But I was personally very conscious of the Tarragona reactor. I had first visited the Tarragona area in 1963 and it was then one of the poorest, most ramshackle corners of Western Europe, a notch above Third World standards - but not two notches.

Now Tarragona and the jigzaw of small towns around it would fill in as a Sydney suburb - with more interesting architecture. The area gleams with prosperity. Well-made roads and efficient public transport, handsome public buildings, unlimited fresh running water, not a broom cupboard without electricity. Virtually a century's leap forward has been made in 30 years.

The end of Franco's dictatorship and the arrival of democracy and a free economy helped Tarragona reach the 20th century. So did the Western European boom of the past 40 years, and the discovery of Spain by tourists.

But at the centre of it was the white dome alongside my balcony. I felt comfortable with the dome, anyway, but if I had bought some Tarragona real estate in 1963 I would have felt like getting out my chamois and running down to give it a polish every morning.

One more traveller's tale.

As a newsaper correspondent I lived for six years in Japan, and made several visits to Hiroshima. To be honest, I grew a little impatient with Japanese harping on their suffering at Hiroshima and Nagasaki, and on the unique perspective they brought to worldwide movements opposing nuclear weaponry.

However, I admired and still admire the coolness and commonsense with which the Japanese have embraced nuclear energy. They have more than 50 nuclear plants, and get more than a third of their electricity from them. Japan would not have become Asia's economic giant without nuclear energy.

I think it remarkable that Japanese pragmatism seems even to have withstood the impact of the accident at the nuclear test facility at Tokai-mura - especially in view of the bungling and secrecy with which the company operating the facility behaved.

This was by far the largest accident that has happened to a Japanese nuclear facility, exposing some 350,000 people to atmospheric radiation, without apparent ill-effect to more than a handful. However, this accident brought to public attention the fact that there had been seven lesser accidents at nuclear plants in the previous four years.

Some reports here made mention of a revival of the nuclear phobia of the Japanese, as a result of Hiroshima.

But the events at Tokai-mura appear to have been treated quite phlegmatically by the majority of Japanese. Perhaps experience of disaster caused by natural phenomena has hardened them to risk. Perhaps they have also grown philosophical about human error as a source of disaster.

They have seen a local government official order the turning back on of electrical power after the Kobe earthquake - and cause a devastating explosion of leaking gas. They have lived through a Japan Airlines pilot named Captain Aso making a perfect landing on a sand bar off the Californian coast - which would have been more conventionally directed at the nearby Los Angeles airport.

However, I think the real reason for Japanese calm about the mishap at Tokai-mura is that most of the population has an understanding - not so much of science and technology but of the role of nuclear energy in public policy. This may be the case with science generally.

In other words, most Japanese have a good idea of the consequences of discarding its nuclear power stations - either a ruinous reduction of productivity or a deadly increase in industrial pollution.

By contrast, the cries of horror and dismay about Tokai-mura in Australia suggests that you could probably launch a political party here, with a chance of getting a few seats in a State Upper House, with the sole platform of closing down Japanese nuclear facilities.

My own newspaper, The Australian, topped its front page with the heading: Nuclear Death Sentence. I saw another headline: It couldn't happen here - could it? above an article adding further to Lucas Heights's undeserved glamour.

I wouldn't point fingers too aggressively at newspaper headline writers, however. They have often to work fast with sparse information. A ration of three or four words doesn't permit a great deal of pro and con, either.

What perturbed me most about the Australian media's reaction to Tokai-mura was the space and air time given to the blathering of organised conservationist groups, like Greenpeace.

Here are people who dress up their children in gas masks and death masks to demonstrate against the evil of burning coal. But who won't let a valley be flooded to generate hydro-electricity. But who were now spruiking away about nuclear energy as the devil's creation.

Of course, I'm not telling anybody in this room anything he or she doesn't already know. But I want to introduce myself as a journalist with some appreciation of the public policy significance of nuclear energy. I am far from being the only member of my profession who is in this position.

I even find myself interested in the arguments in favour of Australia's storing of nuclear waste.

However, I almost never write as a contributor to popular newspapers on such subjects - except occasionally to deride people hugging trees or camping out at Jabiluka.

The truth of the matter is that there is virtually nothing Australian to write about in connection with nuclear energy. When the University of New South Wales closed down its department of nuclear engineering in 1991, science, government and the academy made sure that there wouldn't be this kind of teaching - nothing sensible, anyway.

You will remember that the New South Wales department had undergraduate as well as graduate courses. Consider the consequences if the department had flourished for the past 18 years.

It would have become at least a repository of and probably a participant in edge-of-the knife international research. It may have made significant original contributions.

It would by now have instructed perhaps as many as 400 men and women. They would constitute a corpus of expertise whose existence alone may have influenced private industrial and government planning in Australia.

It is possible that many of the Department's undergraduates at least would have gone off to careers in occupations other than nuclear engineering. Some would no doubt have become secondary school general science teachers.

Some would have become journalists - especially during the last 10 years or so, when value has come to be placed on journalists having some depth of specialised knowledge.

Closing the New South Wales school has, in fact, cost the whole country just that - some depth of specialised knowledge. Poor Australians have no depth, no knowledge at all, really. I don't know any country as phobic as we are about nuclear energy.

Like the Americans we have have chosen other energy sources because we have them in cheap, copious supply. Unlike the Americans, however, we are at risk of degenerating into Luddite zombies cattle-prodded through the desert by frauds and zealots.

My limbs grow numb when I hear and see Greenpeace taking the lead in policy matters of any kind.

Some might say the media is to blame for this situation. Hardly at all, I would respond. The task of the media is to report and comment on events. It is the task of others to provide the events, which include football games, crimes, books, movies, paintings, sexual provocation - and shared ideas.

Not to be too uppity, I believe Australia's nuclear science conununity has been far too reticent in sharing its ideas, leaving a lot of the job to Greenpeace. Much the same could be said of other physical sciences.

As you would all be aware, university enrolments in graduate science courses are in sharp decline. This may be because students come to universities from a society unacquainted with science as part of intellectual life.

Australia could use a really good scientific think tank.

The two outstanding think tanks of the moment, the Centre for Independent Studies in Sydney and the IPA in Melbourne, began essentially as analysts of economics in public policy formation.

Both have expanded over the years to consider political, social and cultural issues. The Centre for Independent Studies recently added a religion and policy unit.

Through seminars and forums, public lectures, learned papers, books and quarterly journals the two organisations have had significant influence on the thinking of national leaders in many fields.

The Centre for Independent Studies has assembled a formidable list of scholarly consultants. Its objective is not popular education, nor propaganda, but genuinely to promote independent thinking of a high order on matters of consequence to a civil society.

Is science not such a matter? It would a badge of honour for nuclear scientists if they were to be the ones to found a science think tank.

Cost should be no great concern, Greg Lindsay founded the Centre for Independent Studies 25 years ago on his own in his toolshed.

The Young Generation Network

URS MEYER
The Young Generation Network
The European Nuclear Society

SUMMARY

The decline in nuclear science education in Europe has parallels in Australia. Dr Meyer will address the impact of declining nuclear science educational opportunities on the outlook for nuclear research and industrial applications such as neutron scattering, radiotracing in environmental studies, the testing of industrial plant and equipment, nuclear medicine and research of basic and strategic relevance.

AU0019567

Amorphization of Ge and InP studied using Nuclear Hyperfine Methods.

A.P. BYRNE[1], E. BEZAKOVA[2],
Department of Nuclear Physics, Research School of Physical Sciences and Engineering, Australian National University, Canberra, ACT 0200, Australia

C. J. GLOVER and M.C. RIDGWAY
Department of Electronic Materials Engineering, Research School of Physical Sciences and Engineering, Australian National University, Canberra, ACT 0200, Australia

SUMMARY
The ion beam amorphization of InP and Ge has been studied using the Perturbed Angular Correlation (PAC) technique. Semiconductor samples were preimplanted with the radioisotope ^{111}In using a direct production-recoil implantation method and beams from the ANU Heavy-ion Facility. Following annealing samples were amorphized using Ge beams with doses between 2 x 10^{12} ion/cm^2 and 5000 x 10^{12} ion/cm^2. For InP the PAC spectra identified three distinct regimes, crystalline, disordered and amorphous environments, with a smooth transition observed as a function of dose. The dose dependence of the relative fractions of the individual probe environments has been determined. A direct amorphization process consistent with the overlap model was quantified and evidence for a second amorphization process via the overlap of disordered regions was observed. The PAC method compares favorably with other methods used in its ability to differentiate changes at high dose. The results for InP will be compared with those in Ge. The implantation method will be discussed, as will developments in the establishment of a dedicated facility for the implantation of radioisotopes.

1. INTRODUCTION

Ion implantation is an increasingly important technique in the fabrication of semiconductor devices. The understanding of irradiation produced disorder is thus of important scientific and technological significance. While many techniques have been applied to the study of semiconductor materials, no single method can provide a full characterization and a detailed understanding of the physical processes relies on the application of a diverse range of complimentary techniques. In this paper we discuss the application of the Perturbed Angular Correlation technique to the study of ion beam amorphization in semiconductor materials.

2. PERTURBED ANGULAR CORRELATIONS

The nuclear hyperfine method of Perturbed Angular Correlations (PAC) uses radioactive atoms at very low concentrations to provide information about the local electronic or magnetic structure around the probe atom. The method relies on the change in the radiation pattern observed when an excited nucleus decays in an extra-nuclear field. A good description of the fundamental principles of the PAC method and its application to semiconductors is provided by the recent review of Wichert (1). The current measurements have used the ^{111}In probe nucleus. This nucleus decays via electron capture to the daughter, ^{111}Cd, which is formed in an excited state. The nucleus then de-excites by the emission of two gamma-rays. It is the perturbation of the γ–γ angular correlation of these two γ-rays by the presence of non zero electric field gradients at the probe site which is observed in the current measurements.

3. IMPLANTATION OF ^{111}In

Critical in the application of PAC techniques to semiconductors is the introduction of the radioactive probe into the sample. In the work to date ^{111}In was produced in heavy ion reactions, using beams from the 14UD tandem accelerator at Australian National University, then directly implanted into semiconductor samples positioned behind the target.

[1] Joint Appointment Department of Physics, The Faculties ANU.
[2] Present Address: Department of Medical Physics Royal Adelaide Hospital Adelaide

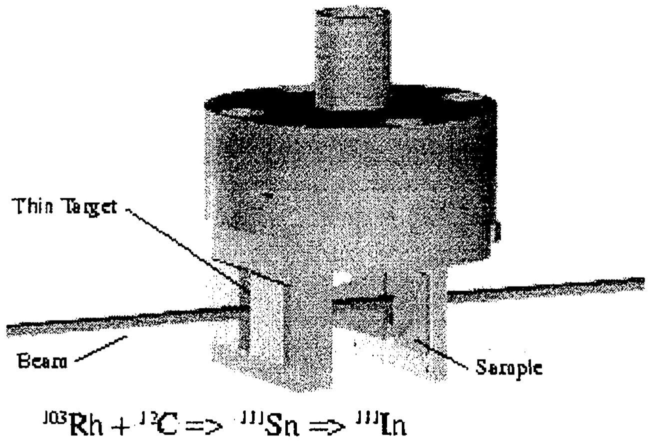


Figure 1. Production/Recoil implantation facility

The following nuclear reactions were used for production:

$^{103}Rh(^{12}C, p3n)\,^{111}Sn \rightarrow (35min)\,^{111}In$ and

$^{103}Rh(^{12}C, 4n)^{111}Sb \rightarrow (1.5min)\,^{111}Sn\ (35min)\,^{111}In$

with both dominant reactions leading to ^{111}In. An average production cross-section of approximately 600 mb was obtained using a 69 MeV carbon beam and 2.5 μm rhodium foil.

A schematic of the irradiation facility is indicated in figure 1. In this arrangement most of the carbon beam passes through the target without significant dispersion, with an average exit angle of approximately 1°. The indium ions, on the other hand, have a much larger average exit angle of approximately 20°, and exit from the back of the target foil with average energy of around 4.0 MeV. The samples were mounted approximately 2 cm behind a the target with the edge offset by about 1.7 mm from the beam axis, allowing the undeflected beam to pass between them. Up to 60% of all ^{111}In nuclei that leave the target, foil can be collected on the samples. The typical activity of each sample after implantation was about 0.1 MBq, with TRIM calculations indicating that most of the ^{111}In ions come to rest within 1 to 2.5 microns.

4. PAC MEASUREMENTS

4.1. Amorphization measurements in InP

^{111}In was implanted into LEC semi-insulating (100) InP(Fe) wafers using the direct production and recoil-implantation technique. After the implantation the samples were annealed using rapid thermal annealing (RTA) (800°, 10 s) before subsequent processing. Off-line PAC measurements on annealed samples confirmed that the samples were undamaged (no electric field gradients present) prior to implantation sequences designed to produce amorphization.

Ion beam amorphization of the samples was performed on the ANU 1.7 MeV ion implanter, by implanting ^{74}Ge beams with dose concentrations between $2x10^{12}$ and $150x10^{12}$ ions/cm^2 at liquid nitrogen temperature. These doses give a range of samples (11 in total) from unperturbed to completely amorphous material. A range of ion beam energies was used for each implantation dose in order to produce uniform depth profile of damage from the surface to 2.5 μm depth. The samples were tilted at 7° during implantation to avoid channeling.

After implantation, PAC measurements were performed using a spectrometer, with four BaF_2 detectors arranged in a plane, at close geometry at angles 0°, 90°, 180° and 270°. The samples were positioned perpendicular to the detector plane and at 45° with respect to the detectors. The time differential intensity of the correlation pattern is measured for all possible detector pairs.

The ratio function, R(t), was formed from the data after the background subtraction and time alignment of the spectra (1). The ratio function removes the effect of the exponential lifetime of the intermediate state and produces a signal directly proportional to the nuclear perturbation function. Some of the ratio functions are shown in figure 2.

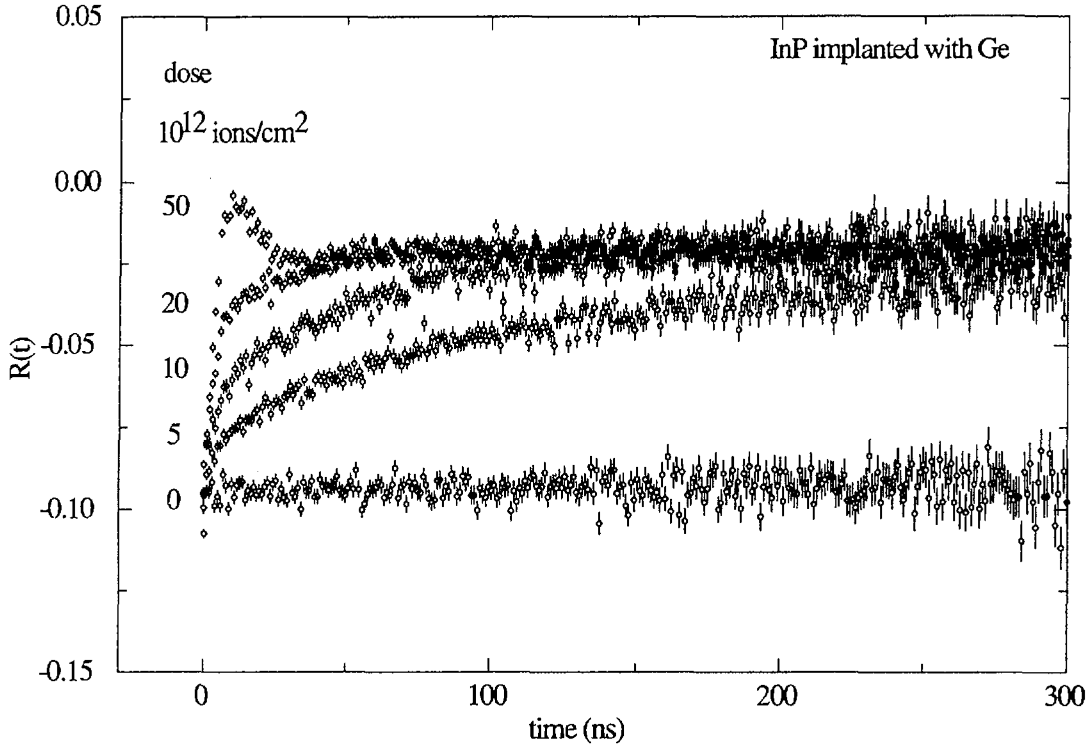


Figure 2. Time differential ratio functions for ^{111}In in amorphized InP

The spectrum for the unimplanted sample (0 dose) shows no change in time, indicating that the damage caused by the introduction of the radioisotope into the sample has been removed by the RTA and that the probe nuclei are now situated a substitutional sites where they experience no net electric field gradient.

At low implantation dose a very gradual loss of alignment is observed consistent with the presence of long range disorder, similar to previous measurements of residual disorder in annealed heavily doped InP samples (2). As the implantation dose is increased a very rapid loss of alignment occurs, before the ratio function returns to the "hard-core" value.

The measured spectra show a smooth transition from crystalline to amorphous behaviour as a function of implantation dose. Two regimes can be delineated, one where the ^{111}In sits on a weakly disturbed site and the other related to a very damaged (amorphous) environment. Accordingly, the spectra were fitted with the "two fraction" perturbation function:

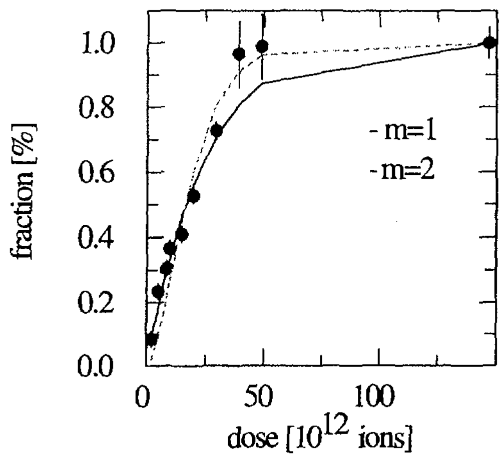
$$G_2(t) = f_1 G_2(\omega_1, t) + f_2 G_2(\omega_2, t)$$

where fractions, f_1 and f_2 correspond to the number of indium nuclei associated with amorphous and non-amorphous fractions and $G_2(\omega_1, t)$ and $G_2(\omega_2, t)$ describe quadrupole interactions, with a Lorentzian distribution of transition frequencies centered around ω_1 and ω_2 at these sites. The transition frequency of the amorphous site was found to be 197 MHz (with a distribution of 69 MHz). The low-damage site was associated with the distribution of frequencies (up to 15 MHz) around zero.

The current PAC measurements show that the disorder in InP is a result of the coexistence of regions resulting from simple defect production and the amorphization processes.

The initial linear dependence of the amorphized fraction on the implantation dose shown in figure 3 indicates that heterogeneous nucleation is probably the main mechanism of amorphization at least up to doses resulting in amorphization of 70% of the irradiated volume.

Existing amorphization models can be characterized by the number of hits, m, required to produce amorphization. Figure 3 shows the fit to the experimental data using a direct amorphization model (m=1) (3). It confirms that the amorphization of InP is achieved by accumulation and overlap of amorphous and heavily damaged clusters.



Deviation of the experimental data at implantation doses around $40x10^{12}$ ions/cm^2 indicates that other processes may also be involved,
for example the increased overlap of simple defected regions (4) or a growth of an amorphous phase stimulated by the defective crystalline surroundings. The fit for m=2 is also shown.

We have also performed more conventional Rutherford Backscattering measurements on a samples with the same amorphizing doses. A comparison the two methods (5) indicates that the PAC method may provide a greater effective resolution, particularly at high doses.

Structural relaxation effects resulting from room temperature annealing have also been measured in InP with the measurement of PAC spectra in damaged samples as a function of time. This work has identified two relaxation lifetimes, one on the order of 6 hours and the second on the order of 5 days (6). The exact origins of these lifetimes are not known. The short lifetime is probably the result of local recombination of point defects and the longer lifetime is associated with the migration of vacancies and other defects further into the lattice.

4.2. Amorphization measurements in Ge.

A similar methodology to the InP study has been applied for the PAC study of amorphization in Ge. Again ^{111}In was produced and recoil implanted using the facility described in section 3. An RTA cycle of 750° for 20 seconds was applied after radioisotope implantation to remove initial damage. Amorphization was achieved using Ge beams at energies chosen to reproduce the depth distribution of the ^{111}In. Ratio spectra from these measurements are shown in figure 4. While similar differentiation into fractions associated with highly damaged amorphous and disordered environments and also be distinguished here additional features can be identified in the Ge case which are absent in the InP measurements. In particular, two additional frequencies, 390 and 49 MHz, can be distinguished, notably in the sample which has an implant dose of $2x10^{12}$ ions/cm^2. These frequencies are in contrast to those observed in InP which are associated with a broad distribution of frequencies. Here the frequencies are well defined, and consequently can be associated with a specific defect configuration. Our results are similar to those seen in a recent PAC study by Haesslein *et al.* of point defects introduced into Ge by electron irradiation (7) and the point character of the defects has been confirmed using positron annihilation spectroscopy (8). Haesslein *et al.* ascribe the lower frequency as arising from an ^{111}In-vacancy pair, with the larger frequency arising from a self-interstitial trapped at the substitutional ^{111}In probe. Earlier PAC studies using ^{111}In in Ge associated the higher frequency with the vacancy (9). At this stage we are unable to distinguish between the two defects.

The difference in spectra between the Ge and InP occurs because of the nature of the PAC probe itself. With InP the radioisotope exactly replaces one of the atoms of the lattice, preserving the original lattice environment. In the germanium lattice the indium atom sits at a substitutional site, but is much larger than the Ge atom that it replaces. Consequently a gettering of defects occurs and these migrate to the probe site.

We have also performed extended X-ray absorption fine structure spectroscopy (EXFAS) and RBS measurements on a similar range of samples to more fully characterize the effect of ion beam induced damage (10).

5. DIRECT IMPLANTATION OF RADIO-ISOTOPES.

The current facility has provided a useful tool for the study of a variety of materials and is particularly convenient in that the radioisotopic material is produced and implanted in one step without any intermediate handling. The principle disadvantage of the method is the rather large range distribution of implanted ions (up to several microns). While, for the type of experiments described above, this is not a problem since subsequent implants can be chosen to completely overlap the region of active nuclei, this is not the case in many other applications. For example, the study of gettering layers or heterostructure devices, the regions of interest are much smaller in extent. In order to address this problem we have recently commissioned an ion implanter designed for use with radioisotopes. This facility, which has been build as part of a collaboration between the ANU and the Department of Physics, University College ADFA, consists of SNICS II ion source on a

150kV deck, followed by a 90° bending magnet. This facility is shown in figure 5 and has currently been tested with stable ions. A depth distribution of Less than 40 nm will be obtainable for ^{111}In with this implanter.

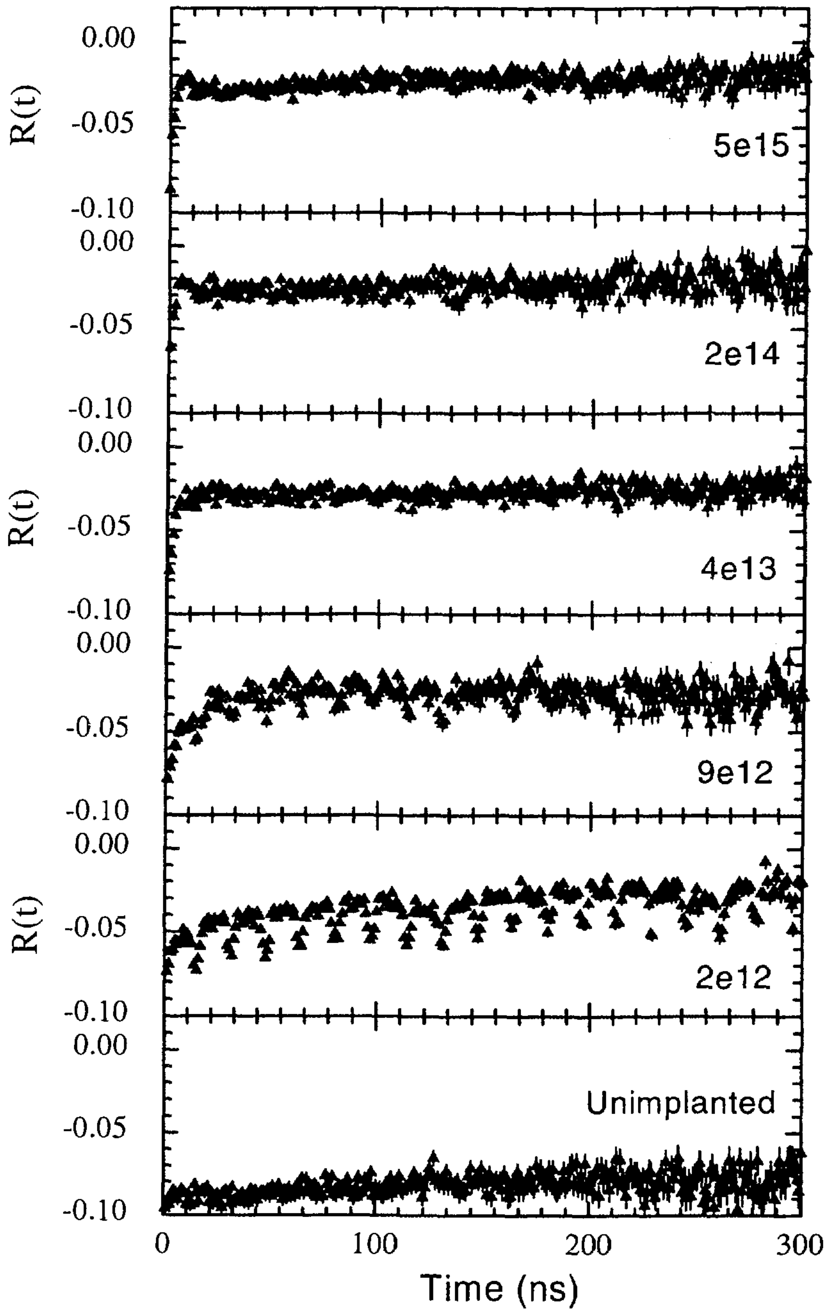


Figure 4. Ratio spectra for disordered Ge samples as a function of ion does. The curves are labeled by the dose in units of ions/cm^2.

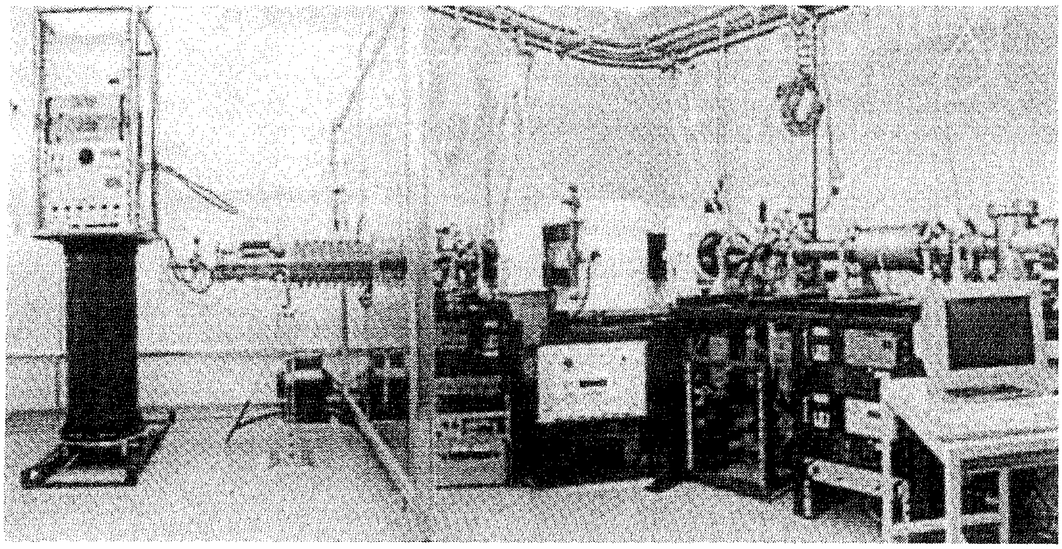


Figure 5. ADFA/ANU ion implanter for radioisotopes.

ACKNOWLEGDMENTS

The authors would like to thank the staff in the Departments of Nuclear Physics and Electronic Materials Engineering , ANU for their continuing support. We would also like to thank staff members of the Department of Physics, University College, ADFA for their support in the construction of the ion implanter for radioisotopes

REFERENCES

(1) Wichert, Th., *Hyperfine Interactions* Vol 97-98 135 (1996)
(2) Ridgway M.C., Byrne, A.P., Bezakova,E., Wehner,M., and Vianden,R., *Proc. 1996 Conf on Optoelectronic and Microelectronic Materials and Devices,* ed. Jagadish,C., (IEEE,Piscataway) 1997 146
(3) Gibbons, J.F., *Proc. IEEE* Vol 60 (1972) 1062
(4) Dennis, J.R. and Hale, E.B., *J. Appl. Phys.* Vol 49 (1978) 1119
(5) Bezakova, E., Byrne, A.P., Glover, C.J., Ridgway, M.C. and Vianden, R., *App. Phys. Lett.* (In Press)
(6) Bezakova, E, Byrne, A.P., Ridgway, M.C. Glover, C.J. and Vianden, R. *Hyperfine Interactions* (In Press)
(7) Haesslein, H., Sielemann, R., and Zistl, C., *Physical Review Letters* Vol 80 2626 (1998)
(8) Polity, A., and Rudolf, F., *Physical Review* Vol B59 10025 (1999)
(9) Feuser, U., Vianden R., and Pasquevich, A.F., *Hyperfine Interactions* Vol 60 829 (1990)
(10) Glover, C.J., Ridgeway, M.C., Byrne, A.P., Yu, K.M., Foran, G.J., Clerc, C., Hansen, J.L., and Nylandsted Larsen, A. (to be published)

A Direct Measurement of the Thermal-Spike Lifetime After Ion Implantation

ANDREW E. STUCHBERY and EVA BEZAKOVA
Department of Nuclear Physics Research School of Physical Sciences & Engineering
The Australian National University Canberra ACT 0200

The effective hyperfine magnetic fields acting on short-lived excited nuclear states ($27 < \tau < 127$ ps) have been measured for $\sim$ 7.5 MeV Ir and Pt ions immediately after implantation into iron hosts at room temperature. The observed field strengths decrease with the lifetime of the probe state and are consistent with the hyperfine field being absent for about 6 ps after implantation. As the hyperfine field is quenched while the local temperature exceeds the Curie temperature, these results give a direct measure of the thermal-spike lifetime. The results generally confirm molecular dynamics computer simulations and suggest that electron-phonon coupling does not play a major role in cooling the heat spike.

I. INTRODUCTION

When a heavy ion with an energy of several MeV is implanted into a solid it loses energy initially by causing ionization along its path. Once the ion nears the end of its trajectory, however, the energy loss is predominantly through quasielastic atomic collisions which set in motion a cascade of host-atom collisions. The energy density in this collision cascade is so high that a collective 'hot spot' or thermal spike is believed to occur for at least a few picoseconds after the ion has come to rest. The thermal spike plays an important [1], but sometimes controversial [2], role in processes such as sputtering, atomic mixing, the clustering of vacancies and the production of defects. The effects of radiation on solids must be understood for many applications, including ion implantation processing of materials and damage of materials in high radiation environments (e.g. both fission and fusion reactors, nuclear waste storage containers, etc.)

Controversies arise concerning the thermal spike regime largely because there has been little direct experimental evidence of the thermal spike itself and model-dependent inferences must be made from measurements of the properties of the modified solid long after the thermal spike is fully quenched. Recently, there has been progess in the theoretical interpretation through developments in molecular-dynamics computer simulations [3,4] which show, among other things, that in the region around the implanted ion local melting often occurs and persists for several picoseconds [5,6].

In a recent Letter we presented the first direct measurement of the thermal-spike lifetime for heavy ions implanted into magnetized iron, obtained by studying pre-equilibrium effects in the hyperfine magnetic fields experienced by the implanted nuclei [7]. Some preliminary aspects and related work was published in Refs. [8–10]. The present paper summarizes our results and discusses them in relation to other experiments and model-based expectations. Some avenues for future research are suggested.

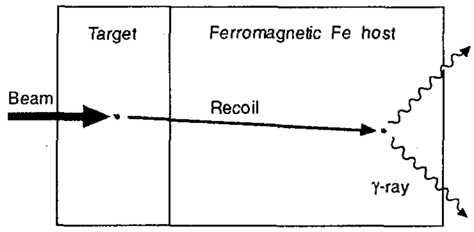


FIG. 1. Schematic illustrating the implantation perturbed angular correlation (IMPAC) technique.

II. EXPERIMENTAL METHODS

The experiments used the Implantation Perturbed Angular Correlation (IMPAC) technique [8–11] to excite, implant and measure the hyperfine interactions experienced by heavy probe ions within an iron host. A schematic of the two-layer targets used in this technique is shown in Fig. 1. Nuclei in the first, 'target' layer are simultaneously excited and recoil-implanted into the second, 'host' layer by impacts between a heavy-ion beam and target nuclei. While the recoiling target ions slow within the ferromagnetic host, their nuclei experience a large hyperfine magnetic field called the *transient* field. After coming to rest another hyperfine magnetic field, called the *static* field, acts. It is the static field that is of principal interest here. These intense magnetic fields cause the nucleus to precess on a timescale of a few picoseconds. In the absence of any pre-equilibrium effects due to the implantation process, the net precession angle of the nucleus is

$$\Delta\theta = -g \frac{\mu_N}{\hbar} B_{st}\tau + \Phi_{tf} \quad , \qquad (1)$$

where Φ_{tf} is the transient-field contribution, τ is the meanlife of the excited nuclear level, g is the g-factor of the state and the static hyperfine field strength is B_{st}. The precession of the nucleus in an excited state can be measured by observing changes in the angular distribution of the γ-ray radiation de-exciting that nuclear level [12]. In the present work levels with independently known lifetimes and g-factors were used to determine the effective static-field strength, B_{st}. Since the observed precession samples the static-field strength throughout the lifetime of the nuclear state, pre-equilibrium effects in the hyperfine field will cause the average measured hyperfine field to depend on the lifetime of the probe state [9]. For example, if it is assumed that the hyperfine field is absent initially and then turns on suddenly after an equilibration time t_s, the effective field observed in an IMPAC measurement will be

$$B_{\rm IMPAC} = B_0 \times e^{-t_s/\tau}, \qquad (2)$$

where ideally $B_0 = B_{st}$, but in reality B_0 is usually a few percent smaller due to long-term radiation damage. The equilibration time, or spike lifetime, t_s may be determined by measuring $B_{\rm IMPAC}$ for several probe states with different lifetimes.

The key measurements [7] employed beams of 40 MeV ^{16}O from the ANU 14UD Pelletron accelerator to Coulomb excite the low-excitation states of ^{191}Ir, ^{193}Ir and ^{198}Pt and simultaneously recoil-implant the excited nuclei into an iron host. These nuclei were chosen because the hyperfine fields for platinum and iridium in iron are large ($\sim 10^2$ T) and the lowest $5/2^+$ and $7/2^+$ levels in the iridium isotopes have lifetimes that range between 27 ps and 127 ps. The ^{198}Pt layer provided a comparison with previous work [8].

Backscattered beam ions were registered in an annular counter around the beam axis. Perturbed particle-γ angular correlations were measured by placing a pair of Ge γ-ray detectors at $\pm 115°$ to the beam direction, to serve as monitors, while a further pair of detectors were placed in the forward quadrants at a sequence of angles between 0° and $\pm 65°$. To enhance the sensitivity of the measurements to the precessions of the shorter-lived $7/2^+$ states, longer runs were performed with the forward-placed detectors at $\pm 35°$ and $\pm 65°$ to the beam direction. The iron foil was polarized perpendicular to the detector plane and the direction of the polarizing field was reversed frequently. The target assembly was maintained at room temperature throughout the measurements.

In these measurements, the recoiling iridium and platinum ions enter the iron layer of the target with energies between ~ 5 and ~ 10 MeV, on average with 7.5 MeV after spending 0.08 ps in the layers of Ir and Pt. An average recoiling ion stops after ~ 0.75 ps with a range in Fe of ~ 0.8 μm (0.6 mg·cm^{-2}). Further aspects of the recoil-implantation process have been discussed in Ref. [9].

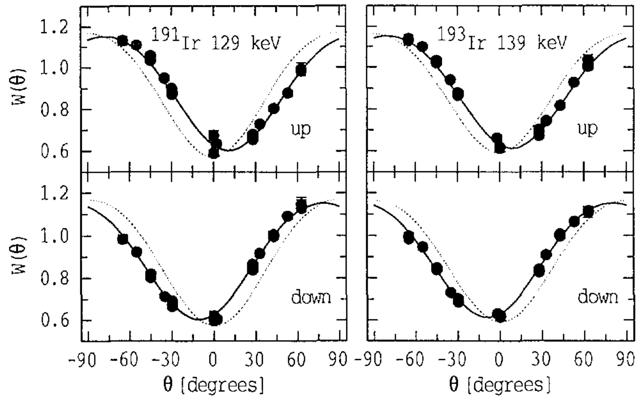


FIG. 2. Perturbed angular correlations for the 129 and 139 keV $5/2_1^+$ states in ^{191}Ir and ^{193}Ir.

As the transient-field precession must be taken into account when extracting the static-field strength, the present measurements were performed with 40 MeV ^{16}O beams, rather than higher-energy heavier ions that would lead to larger transient-field effects. The Φ_{tf} values applicable in the present work were evaluated from the data in Refs. [9,10,13], which include measurements on the present target with 100 MeV ^{32}S beams.

III. EXPERIMENTAL RESULTS

Fig. 2 shows the perturbed angular correlations for the $5/2_1^+ \to 3/2_1^+$ transitions of energy 129 and 139 keV in ^{191}Ir and ^{193}Ir, respectively. The static-field precession angles, $\omega\tau = -g\frac{\mu_N}{\hbar}B_{st}\tau$, were extracted to give the results summarized in Table I.

TABLE I. Measured precessions and hyperfine fields.

Level	g [a]	τ [b] [ps]	$\Delta\theta_{tr}$ [c] [mrad]	$\omega\tau$ [mrad]	$\lvert B_{\rm IMPAC}\rvert$ [T]
^{191}Ir					
$5/2_1^+$	0.322(20)	128(2)	−8(1)	207(3)	106(7)
$7/2_1^+$	0.401(18)	30(1)	−10(1)	51(2)	89(6)
^{193}Ir					
$5/2_1^+$	0.356(16)	101(2)	−9(1)	177(3)	103(5)
$7/2_1^+$	0.441(16)	27(1)	−11(1)	48(2)	84(5)
^{198}Pt					
2_1^+	0.314(11)	33(2)	−7(1)	45(2)	90(6)

[a] g-factors from transient-field measurements [14–16].
[b] Lifetimes from Refs. [14,15,17–19].
[c] Calculated transient-field precessions. See Ref. [10] and text.

The effective static-field strengths derived from our IMPAC measurements on the iridium isotopes (Table I) are clearly smaller for the shorter-lived states. These data, from precise, simultaneous measurements of the effective fields for states of differing lifetimes in the same atomic species, give the first unambiguous evidence for picosecond-duration pre-equilibrium effects in hyperfine fields following implantation.

The observed lifetime dependence of the IMPAC fields cannot be attributed to electric quadrupole interactions caused by local damage, or to the possibility that the hyperfine fields might not be quite parallel to the applied field, because these effects imply *larger* effective fields for the shorter-lived states, which is the opposite trend to that observed. Furthermore, because the lifetimes of the probe states in the present study are short (< 130 ps), (i) electric quadrupole interactions are negligibly small and, (ii) in the absence of any pre-equilibrium effects, the states experience the same average magnetic interaction whether there is a unique site or several sites, and whether or not the internal field is exactly parallel to the external field [10,14].

IV. DISCUSSION

A. Thermal-spike interpretation of IMPAC data

We interpret the observed lifetime dependence of the effective hyperfine field in terms of a pre-equilibrium quenching of the local magnetization during the collision-cascade and thermal-spike phases of the implantation process. Initially, we assume that the hyperfine field is absent during the thermal spike, after which it rises rapidly to its equilibrium value.

The observed hyperfine field in an integral IMPAC measurement, $B_{\rm IMPAC}$, then depends on the lifetime of the probe state as given in equation(2). It is useful to plot $B_{\rm IMPAC}$ as a function of the inverse lifetime (i.e. the decay rate) of the probe state. Our results for the states in ^{191}Ir and ^{193}Ir are plotted in panel (a) of Fig. 3 along with the average field obtained from previous radioactivity measurements on the $5/2_1^+$ states [20,21], re-evaluated with the present g-factors and lifetimes, and plotted at $1/\tau = 0$. The fit of Eq. (2) to the present IMPAC data alone gives $t_s = 7.3 \pm 0.8$ ps and an effective B_0 value that happens to agree with the field obtained in the radioactivity measurements [20,21].

As, in general, there will be considerable sub-cascade formation following the implantation of heavy-ions with energies of several MeV [1], the thermal-spike process would be expected to cause a similar quenching of the hyperfine field for all heavy atomic species implanted into iron under similar conditions. The behaviour shown in Fig. 3(a) would then be a global feature of IMPAC measurements on short-lived states ($\tau \lesssim 100$ ps). We have surveyed the literature and, in panels (b-d) of Fig. 3, we show those cases of sufficient precision to suggest lifetime-dependent hyperfine fields. Along with the present and previous [8,22,23] results for the Pt isotopes, the data for the rare-earth ions Dy [24], Nd and Sm [11] are suggestive. While these cases are not compelling in isolation from the present results for iridium, they are all consistent with a thermal-spike lifetime of $t_s = 7.3$ ps, which falls within the expected range of between a few and ~ 10 ps [1,3].

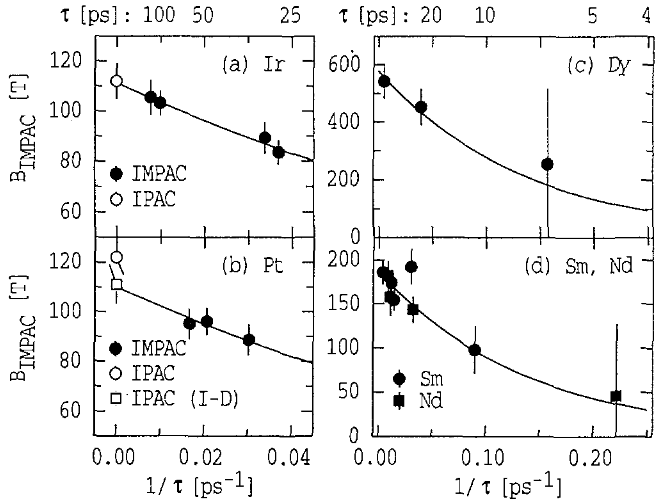


FIG. 3. Static hyperfine magnetic fields from IMPAC measurements plotted as a function of the inverse lifetime (or decay rate) of the probe state. Off-line data from other techniques are plotted at $1/\tau = 0$. The curves correspond to Eq. (2) with $t_s = 7.3$ ps, obtained from fitting the present iridium IMPAC data alone. (a) Present IMPAC and previous radioactivity (integral perturbed angular correlations, IPAC) results [20,21] for ^{191,193}Ir. (b) Present and previous [8] IMPAC results for the Pt isotopes, with IPAC [22] and implantation-decay (I-D) IPAC [23] results. (c) Data for ^{162}Dy, from Ref. [24]. (d) IMPAC data for Nd and Sm [11] re-evaluated with g-factors from Refs. [25,26] and lifetimes from Ref. [19] and Nuclear Data Sheets.

The assumed time dependence of the hyperfine field embodied in Eq. (2) is clearly an over simplification. We have therefore performed a more realistic modeling of the pre-equilibrium behaviour of the hyperfine fields. Guided by the molecular dynamics calculations and discussion of Hsieh *et al.* [27], we assume that the local temperature, T, varies with time, t, approximately as

$$T(t) = T_1/t^q + T_0, \tag{3}$$

where T_1 and q are parameters, and $T_0 = 300$ K is the ambient temperature. Noting that Eq. (3) has no physical implications until the local temperature falls below $T_C = 1043$ K, the Curie temperature of iron, we put $q = 1.35$ [27] and treat T_1 as a fit parameter. We then assume that the hyperfine field follows the temperature dependence of the host magnetization, which for Fe is given approximately by the Brillouin function for $J = 1/2$. It follows that $B_{st}(T)/B_0 = M(T)/M(0) = m(T)$, where $m(T)$ is the magnetization at temperature T relative to that at absolute zero, and $m(T) = \tanh(m(T) \cdot T_C/T)$. The lifetime dependence of the observed hyperfine field is then given by

$$B_{IMPAC}(\tau)/B_0 = \int_0^\infty m(T[t])e^{-t/\tau}dt/\tau. \qquad (4)$$

Fits to the IMPAC data obtained by numerically evaluating Eq. (3-4) are shown in the lower panel of Fig. 4; the associated time-dependencies of the local temperature and the hyperfine field are shown in the upper panels. Since the solid-line fit to the IMPAC data in the lower panel of Fig. 4 is almost indistinguishable from Eq. (2) with $t_s = 7.3$ ps, Eq. (2) can be used as a convenient means of analyzing IMPAC data, provided it is kept in mind that t_s may then over estimate the time for which the hyperfine field is actually absent.

The behaviour of the local temperature implied by the IMPAC data is similar to that found in molecular dynamics calculations. For example, 5 keV cascades in Cu take about 5 ps to fall to 1000 K [27], while the atomic rearrangements are over within 5 to 7 ps following 5 keV cascades in Si [6]. Bearing in mind that the energy deposited into collision cascades is several keV, even for MeV ions [1], it is reasonable to find that ~ 8 MeV ions with $140 < A < 200$ implanted into Fe give rise to local heating that takes about 6 ps after implantation to cool below 1000 K.

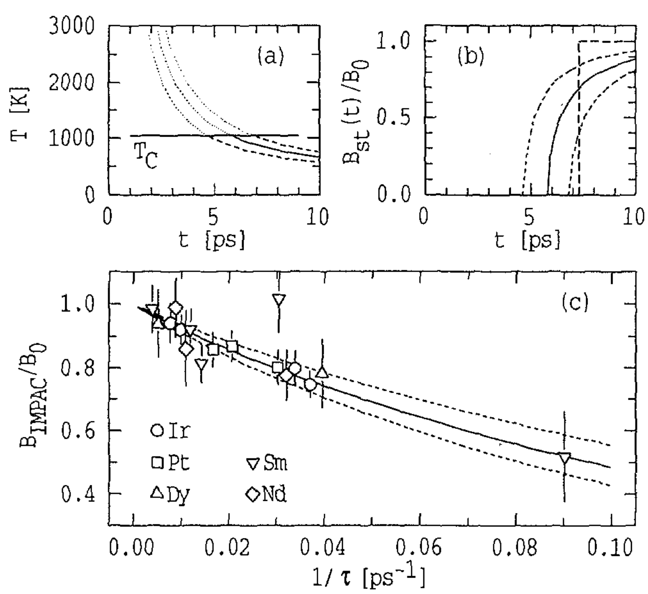


FIG. 4. Thermal-spike model interpretation of IMPAC data, Eq. (3-4), for $T_1 = 8000 \pm 2000$ K. (a) Time dependence of the local temperature. (b) Time variation of the hyperfine field. The step function (long dashes) shows B_{st} implied Eq. (2) with $t_s = 7.3$ ps. (c) Resultant lifetime-dependence of the IMPAC data. The solid line ($T_1 = 8000$) is not significantly different from that given by Eq. (2) with $t_s = 7.3$ ps.

B. Comparison with related measurements

Our work can be compared with the in-beam Mössbauer measurements of Hardy *et al.* [28] and Chien *et al.* [29] on rare-earth ions implanted into rare-earth oxides following Coulomb excitation, in which the recoilless fraction was found to decrease as the lifetime of the probe state decreased. In those measurements the hyperfine fields could not be measured and the analysis reported in Refs. [28,29] is strongly dependent on a simplified thermal model. If the absence of the Mössbauer effect is taken as indicating violent atomic motion, these measurements suggest a thermal-spike lifetime in the range between about 20 ps and 100 ps [2]. Although this is somewhat longer than we observe, better agreement is likely to emerge from a more rigorous analysis. Our IMPAC results support the thermal-spike interpretation of these Mössbauer data.

Finally, a clear distinction must be made between the present work, which concerns the local effect caused by the implantation of the individual implanted ion itself, and the heavy-ion *beam* induced effects that have been identified and studied in detail by Speidel and coworkers (see Ref. [30] and references therein). While the effect introduced by Speidel evidently does involve a perturbation of the host magnetization on a timescale of picoseconds, it is associated with the flux of beam ions striking the target and is not correlated with the implantation of the individual probe ion. Thus in our measurements, the 'Speidel effect' could affect the value of B_0, but not t_s. Furthermore, the high-energy heavy beam ions of relevance in Speidel's work lose energy to the solid primarily through the electronic stopping process, whereas the ions that produce the pre-equilibrium effects underconsideration here are in the nuclear stopping regime. While the two phenomena could be related somehow, the details of any such relationship are not yet clear. Note that Speidel and co-workers [30] clearly draw the distinction between the two effects and that their work on the implantation of ^{56}Fe into Fe is in harmony with our thermal-spike interpretation of the IMPAC data.

C. Future work

Having established that the thermal-spike regime can be studied directly via observations of pre-equilibrium effects in hyperfine fields immediately following ion implantation, it is important now to extend the experimental studies to include a range of hosts, and examine the influence of the host temperature on the thermal-spike lifetime. By making such measurements we can address issues such as (i) the extent to which coupling between the conduction electrons and lattice vibrations affects the spike lifetime and (ii) whether there is any component in the equilibration process that should be associated with the impurity-host spin-spin interactions that generate the hyperfine field rather than with the thermal-spike mechanism.

Molecular dynamics simulations suggest that the thermal-spike lifetime is influenced by the density, melting point and atomic mass of the host. Coupling between the electrons and phonons of the host, which is not included in molecular dynamics simulations, could also affect the lifetime [31]. While the present results already suggest that electron-phonon coupling has a minor influence on the thermal-spike lifetime, it is nevertheless important to make measurements on hosts other than iron.

The lifetime of the thermal spike also depends on the temperature of the host. In many cases the hyperfine field shows a temperature dependence that differs from that of the magnetization of the bulk solid. The behaviour of neighbouring species can be rather different in this respect. By studying the temperature dependence of the pre-equilibrium effects for neighbouring atomic species that have hyperfine fields with very different temperature dependencies, one can gain further insights into both the thermal-spike mechanism and the spin-spin interactions that give rise to the hyperfine field.

V. CONCLUSIONS

In conclusion, we have observed picosecond-duration pre-equilibrium effects in hyperfine magnetic fields following ion implantation, consistent with the hyperfine field being absent for several picoseconds after implantation. The data can be interpreted in terms of a thermal-spike induced quenching of the hyperfine field and as such give the first direct measure of the thermal-spike lifetime. The observed lifetime is consistent with the results of molecular dynamics simulations which suggests that coupling between the motion of the atomic centres and the conduction electrons does not greatly affect the cooling of the heat spike.

ACKNOWLEDGMENTS

We are most grateful to our colleagues T. Kibédi, F.G. Kondev, S. Bayer, N.M. Thakur, S.M. Mullins and R.A. Bark for assistance with the experiments. This work was supported in part by the Australian Research Council.

[1] Thompson, D.A., (1981) *Radiation Effects* Vol **56**, p. 105.
[2] Miotello, A. and Kelley, R., (1997) *Nucl. Inst. Meth. in Phys. Res.* Vol **B122**, p. 458.
[3] English, C.A., *et al.*, (1992) *Mat. Sci. Forum.* Vol **97-99**, p. 1.
[4] Diaz de la Rubia, T. and Guinan, M.W. (1992) *Mat. Sci. Forum.* Vol **97-99**, p. 23.
[5] Diaz de la Rubia, T., Averback, R.S., Benedek, R. and King, W.E. (1987) *Phys. Rev. Lett.* Vol **59**, p. 1930.
[6] Diaz de la Rubia, T. and Gilmer, G.H. (1995) *Phys. Rev. Lett.* Vol **74**, p. 2507.
[7] Stuchbery, A.E. and Bezakova, E., (1999) *Phys. Rev. Lett.* Vol **82**, p. 3637.
[8] Anderssen, S.S. and Stuchbery, A.E. (1995) *Hyperfine Interact.* Vol **96**, p. 1.
[9] Stuchbery, A.E., Anderssen S.S. and Bezakova, E. (1996) *Hyperfine Interact.* Vol **97/98**, p. 479.
[10] Stuchbery, A.E. and Bezakova, E. (1998) *Aust. J. Phys.*, Vol **51**, p. 183.
[11] Kugel, H.W., Borchers, R.R. and Kalish, R. (1972) *Nucl. Phys.* Vol **A186**, p. 513.
[12] Recknagel, E., Nuclear spectroscopy and reactions, Part C, ed. Cerny, J. (Academic Press, New York, 1974) p. 93.
[13] Stuchbery, A.E., *et al.*, (1994) *Hyperfine Interact.* Vol **88**, p. 97.
[14] Bezakova, E., (1998) PhD thesis, Australian National University, unpublished.
[15] Bezakova, E., Stuchbery, A.E., Bolotin, H.H., Seale, W.A., Kuyucak, S. and Van Isacker, P, submitted for publication.
[16] Anderssen, S.S., Stuchbery, A.E. and Kuyucak, S. (1995) *Nucl. Phys.* Vol **A593**, p. 212.
[17] McGowan, F.K., *et al.*, (1986) *Phys. Rev. C* Vol **33**, p. 855.
[18] McGowan, F.K., *et al.*, (1987) *Phys. Rev. C* Vol **35**, p. 968.
[19] Raman, S., *et al.*, (1987) *At. Data Nucl. Data Tables* Vol **36**, p. 1.
[20] Owens, W.R., Robinson, B.L., and Jha, S. (1969) *Phys. Rev.* Vol **185**, p. 1555.
[21] S. Gustafsson, S., *et al.*, (1967) *Arkiv För Fysik* Vol **34**, p. 169.
[22] Bodenstedt, E., *et al.*, (1997) *Z. Phys. A* Vol **342**, p. 249.
[23] Stuchbery, A.E., *et al.*, (1996) *Phys. Rev. Lett.* Vol **76**, p. 2249.
[24] Alfter, I., *et al.*, (1997) *Hyperfine Interact.* Vol **110**, 313.
[25] Stuchbery, A.E., Lampard, G.J. and Bolotin, H.H. (1990) *Nucl. Phys.* Vol **A516**, p. 119.
[26] Stuchbery, A.E. (1995) *Nucl. Phys.* Vol **A589**, p. 222.
[27] Hsieh, H., *et al.*, (1989) *Phys. Rev. B* Vol **40**, p. 9986.
[28] Hardy, K.A., Walker, J.C. and Shnidman, R. (1972) *Phys. Rev. Lett.* Vol **29**, p. 622.
[29] Chien, C.L., Walker, J.C. and Shnidman, R. (1979) *Phys. Rev. B* Vol **19**, p. 1363.
[30] Speidel, K.-H., *et al.*, (1997) *Nucl. Inst. Meth. in Phys. Res. B* Vol **122**, p. 84.
[31] Flynn, C.P. and Averback, R.S. (1988) *Phys. Rev. B* Vol **38**, p. 7118.

Elastic recoil detection using heavy ion beams

H. TIMMERS [a,b], R. G. ELLIMAN [b], T.R. OPHEL [a], T.D.M. WEIJERS [a,b]
Departments of [a]Nuclear Physics and [b]Electronic Materials Engineering, Research School of Physical Sciences and Engineering, Australian National University, Canberra ACT 0200

SUMMARY Elastic Recoil Detection using heavy ion projectile beams allows compositional depth-profiling of materials to a depth of about 2.5 μm. The technique is sensitive to all chemical elements including hydrogen. It is particularly suited for the analysis of thin film materials. Large solid-angle position-sensitive gas ionization detectors have been developed for the efficient detection of the recoil ions. With the set-up at the Australian National University, measurement and analysis are greatly simplified by using a new detector design. A grid electrode allows a direct determination of the ion energy, while a divided anode enables the simultaneous detection of ions with largely different atomic numbers and also provides linear position information. A diverse spectrum of materials has been analyzed including photosensitive doped silica, high-T_c superconductors and dielectric films.

1. Introduction

Heavy ion beams produced by electrostatic tandem accelerators such as the 14 UD Pelletron at the Australian National University can be utilized to depth-profile the composition of material surfaces and thin films using the Elastic Recoil Detection (ERD) technique (1). During a brief exposure of the sample to the beam, employing a glancing geometry, the incident beam particles eject, in elastic collisions, recoil ions out of the sample. These ions are detected and distinguished according to their atomic number. Since the energy of the ions is related to the depth inside the sample from where they originate, the yields detected for different ion species accurately reflect the material composition as a function of depth. Thus the total number of atoms of a chemical element present at a certain depth can directly be inferred from the measurement. The energy-depth relation is established using the stopping power of the material for the incident and the recoiling ion.

In order to increase detection efficiency and minimize beam related sample modifications, large solid-angle (~ 5msr) position-sensitive gas ionization detectors have been developed (2). With such detectors the atomic number of the ions is determined from their initial energy loss inside the detector. Total energy information is obtained by collecting all ionization electrons. The position information allows the correction of kinematic energy differences of ions from the same depth, but with different scattering angles. Thus the large acceptance angle can be reconciled with optimum energy resolution. In contrast to solid state detectors, gas ionization detectors are not degraded by ion damage.

All chemical elements, including hydrogen, can be detected simultaneously, with similar sensitivity and depth-resolution. Elemental separation is best for the lighter elements, with neighbouring elements being fully

resolved for atomic numbers up to about Z=20.
Concentrations of ~ 0.1 atomic percent can be detected. The sampling depth depends on the sample material and is of the order of 1.5-2.5 μm. For the surface region a depth-resolution of 10 nm can be achieved. It deteriorates, however, with increasing depth because of the energy straggling and multi-scattering of the ions in the sample.

The ERD detector (3-5) at the Australian National University includes several new design features which greatly simplify detection and analysis. Among those are *the subdivision of the energy loss electrode*, which allows the simultaneous identification of heavy and lighter ions at the same detector gas pressure, *a novel grid electrode* for the total energy measurement, which obviates the need for relative calibrations of electrodes, and *a saw-tooth electrode within the anode*, which provides linear position information.
The applications of the technique are diverse, with thin film analysis being a particular strength. Among the thin film materials analyzed at the Australian National University were photo-sensitive doped silica films for opto-electronic applications, magnetically sensitive films for data storage, dielectric films, such as silicon nitride and tantalum oxide, hydrogenated carbon films and high-T_c superconducting films. Other applications included nitrided stainless steels, where nitrogen and hydrogen depth-profiles were of particular interest, and the measurement of oxygen depth-profiles in high-T_c superconductors.

2. Experimental Set-up

Figure 1 shows the detection geometry.

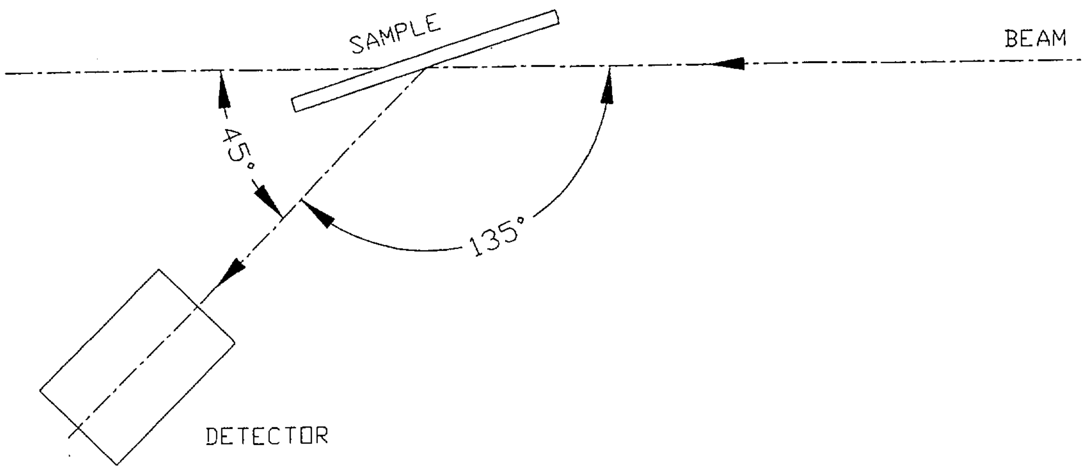


Figure 1. Schematic diagram of the detection geometry.

Typical projectile beams are gold and silver, at beam energies greater than 1 MeV/amu. The detector is mounted on a movable arm inside a large scattering chamber with a diameter of 2 m. The detection angle can be varied continuously between 30° – 60°. The distance between detector and sample is 28 cm. The vacuum inside the scattering chamber is ~10^{-7} mbar. The sample holder accommodates six samples and can be rotated to vary the angle between the incident beam and the sample surface. The samples are loaded through a vacuum lock.

Propane gas is passed through the detector at a constant pressure in the range 40 - 100 mbar, which is chosen to stop the lightest ions. Ions recoiling from the sample enter the detector through a grid-supported mylar window which is 0.5 μm thick. The detector is collimated with a circular aperture (diameter 20 mm).

A schematic diagram of the detector interior is shown in Figure 2. The electrode-stack consists of a cathode, a Frisch grid, a grid electrode and an anode. The anode is divided into two ΔE sections (ΔE_1 and ΔE_2) and a residual energy section (E_{res}). The middle section (ΔE_2) is subdivided using a saw-tooth geometry. Signals are obtained from all anode sections, the grid electrode and the cathode.

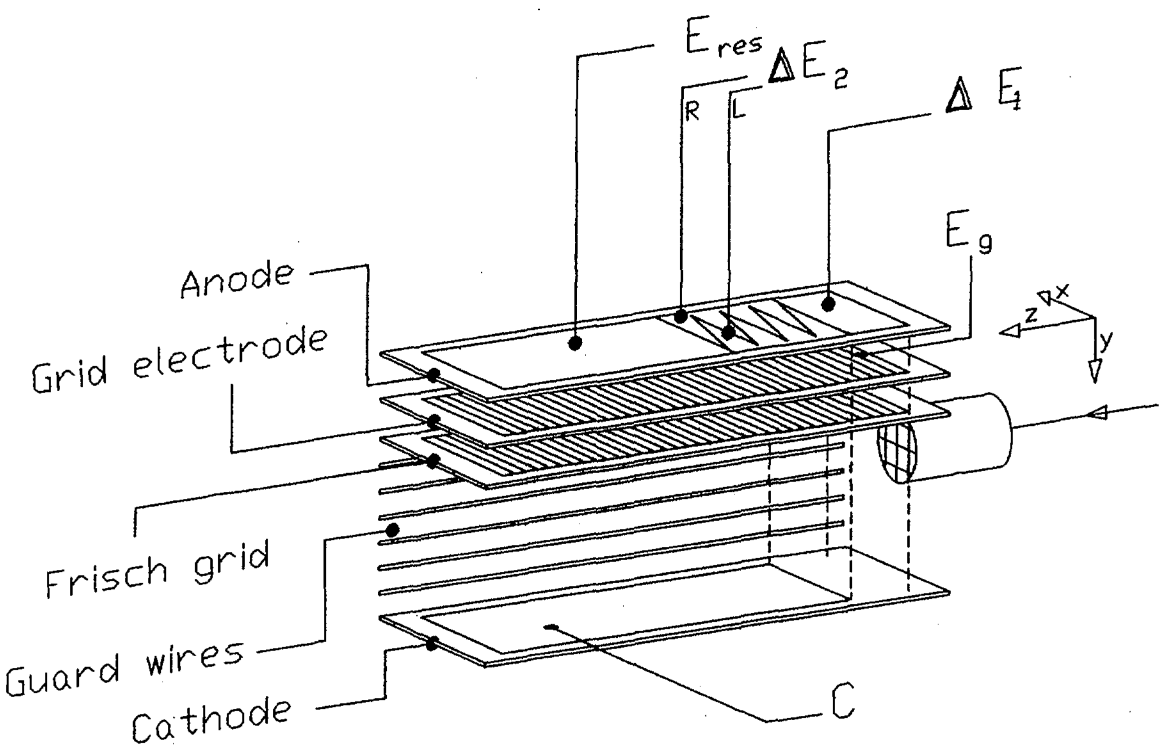


Figure 2. The new detector design used at the Australian National University.

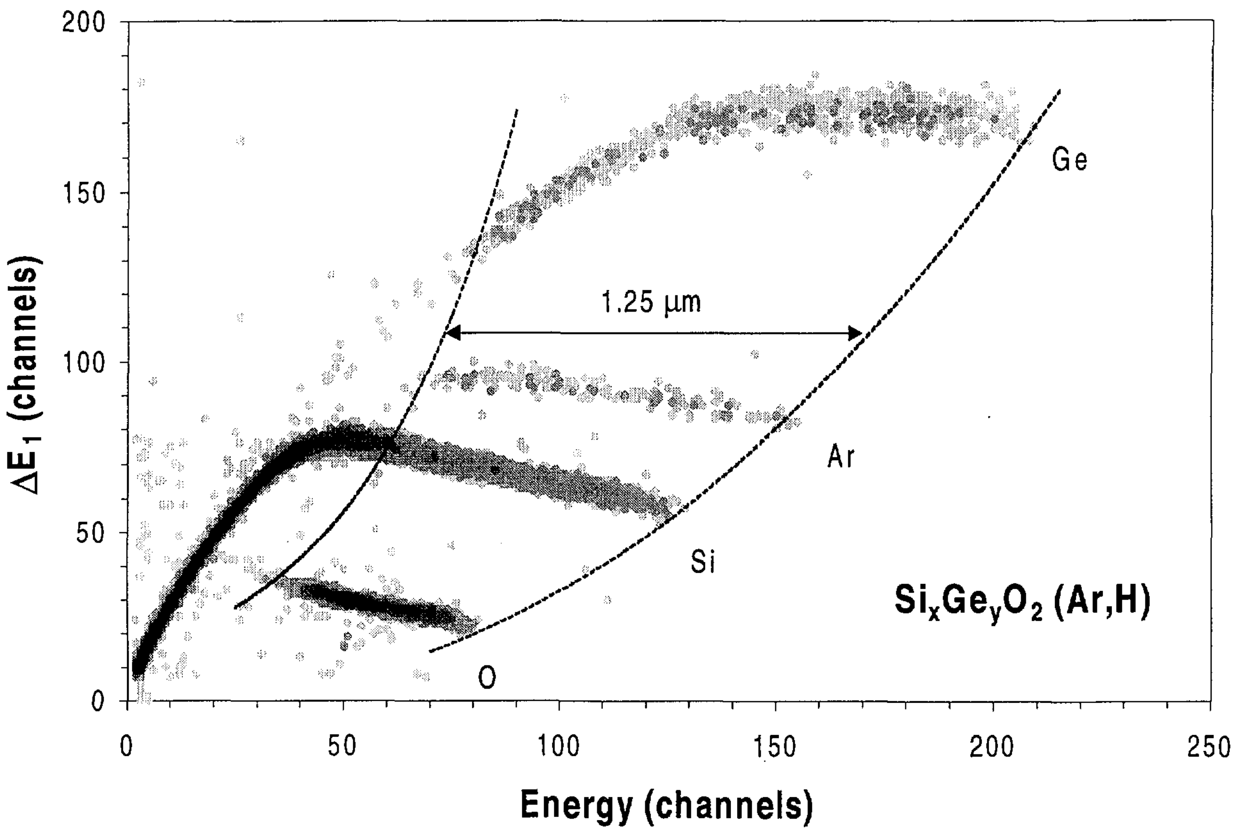


Figure 3. A two-dimensional spectrum of the ΔE_1 and energy signals detected for recoils from a Ge-doped silica film. The hydrogen content is detected simultaneously (not shown here).

Total energy information is either obtained by combining the signals from the anode, or directly from the grid electrode. The signals ΔE_1 and ΔE_2 are proportional to the initial energy loss rate of the recoil ions in the detector, which is a function of the atomic number *Z*, and allow the separation of different ion species.

The horizontal position of the ion track is determined by combining the amplitudes of the signals from the right (R) and left (L) saw-tooth electrodes according to (R-L)/(R+L). The vertical position of the ion track is obtained from the ratio of the cathode signal and the sum of ΔE_2 and E_{res}. With this position information and given detector angle and detector distance, the scattering angle θ can be determined.

The energy *E* of the recoiling ions changes with θ according to

$$E = \left[4m_p m_r / (m_p + m_r)^2\right] E_p \cos^2\theta$$

where E_p is the projectile energy and m_p and m_r are the masses of projectile and recoil ion, respectively. The kinematic energy difference of the ions over the detector acceptance is corrected with

$$E^{cor} = E\frac{\cos^2\theta_0}{\cos^2\theta}$$

where θ_0 is the detector angle and E^{cor} the corrected energy.

3. Photosensitive doped-silica films

The capabilities of the technique may be demonstrated using the example of photosensitive germanium- and tin-doped silica films. These materials are being developed for integrated photonics applications. Such films can be deposited by plasma assisted deposition techniques and their initial refractive index and photosensitivity are determined by the dopant:Si:O stoichiometry. The presence of hydrogen in the film is deterimental to their performance, because it causes optical absorption in the 1.3-1.5 µm wavelength range of interest for telecommunications. Characterization of the films therefore requires accurate determination of the film composition, including the presence of hydrogen (5). Figure 3 shows a plot of the ΔE_1 signal as a function of the total energy signal, as detected for recoil ions from a germanium-doped film. The contours represent the detected ion yield. Germanium, argon (present as a contaminant), silicon and oxygen can be identified. The film limits are indicated. The stoichiometry can be extracted from the total number of recoils from within the film, after normalisation with the scattering cross sections. This assumes that all elements are distibuted uniformly throughout the film. The film uniformity can be assessed when individual energy spectra are extracted from the two-dimensional projection of ΔE_1 versus energy. This is shown in Figure 4.

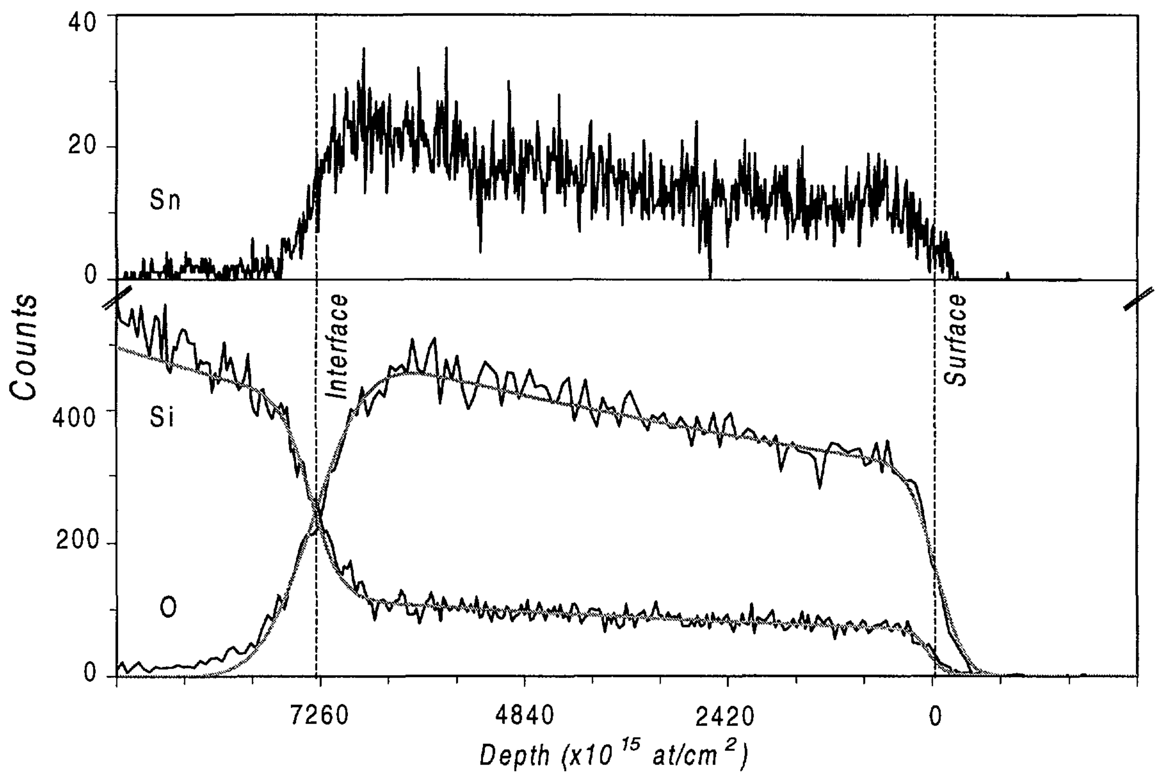


Figure 4. Energy spectra obtained for a tin-doped silica film. The spectra in the lower part of the figure are compared with simulations assuming uniform stoichiometry.

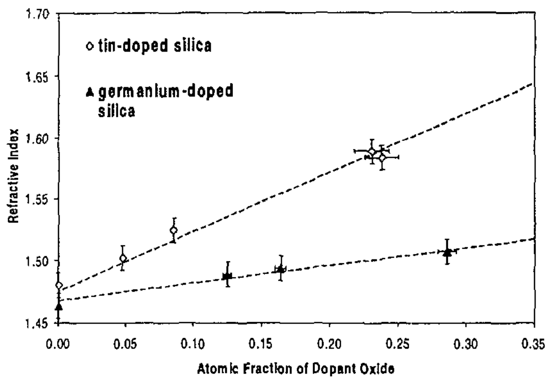


Figure 5. The refractive index of doped silica films plotted as a function of the atomic fraction of the dopant oxide as measured with heavy ion ERD.

The refractive indices of the films analyzed are plotted in Figure 5 as a function of the measured dopant fraction. Both sets of data exhibit a linear behaviour with different slopes.

4. Summary

Elastic Recoil Detection (ERD) using heavy ion beams can be used to depth-profile the composition of materials. It is particularly suited for thin film analysis. At the Australian National University a new large solid-angle gas ionization detector with position sensitivity is used to detect the recoil ions efficiently and with a minimum of calibrations. The capabilities of the system have been demonstrated using the example of photosensitive doped silica films.

5. References

(1) Siegele, R., Haugen, H.K., Davies, J.A., Forster, J.S., Andrews, H.R. (1994) Forward elastic recoil measurements using heavy ions *J.Appl. Phys.* 76 (8), pp. 4524-4532.

(2) Assmann, W., Hartung, P., Huber, H., Staat, P., Steffens, H., and Steinhausen, (1994) Setup for materials analysis with heavy ion beams at the MP Munich tandem. *.Nuclear Instruments and Methods B* 85, pp. 726-731.

(4) Timmers, H., Ophel, T.R. and Elliman, R.G. (1999) Improved designs of gas ionization detectors used for elastic recoil detection Invited talk at the *International Conference on Swift Heavy Ions in Materials Engineering and Characterization*, 19–22 October 1998, New Delhi, India. *Nuclear Instruments and Methods B 156,* pp 236-243.

(5) Timmers H., Ophel, T.R. and Elliman, R.G. Simplifying position-sensitive gas-ionization detectors for heavy ion elastic recoil detection. Invited talk at the 14th *International Conference on Ion Beam Analysis, 26-30 July* 1999, Dresden, Germany, submitted to *Nuclear Instruments and Methods B.*

(6) Weijers, T.D.M., Gaff, K., Timmers, H., Ophel, T.R. and Elliman, R.G. Heavy ion ERD analysis of doped-silica films for integrated photonics. Contribution to the 14th *International Conference on Ion Beam Analysis, 26-30 July* 1999, Dresden, Germany, accepted for publication by *Nuclear Instruments and Methods B.*

AU0019570

Calibration of ARI QC Ionisation Chambers Using the Australian Secondary Standards for Activity

LI MO, H. A. VAN DER GAAST, D. ALEXIEV, K. S. A. BUTCHER and J. DAVIES
Australian Nuclear Science and Technology Organisation
PMB 1 Menai 2234 NSW Australia

SUMMARY The Secondary Standard Activity Laboratory (SSAL) in ANSTO routinely provides standardised radioactive sources, traceable activity measurements and custom source preparation services to customers. The most important activity carried out is the calibration of ionisation chambers located in the Quality Control (QC) section of Australian Radioisotopes (ARI). This ensures that their activity measurements are traceable to the Australian primary methods of standardisation.

ARI QC ionisation chambers are calibrated for ^{99m}Tc, ^{67}Ga, ^{131}I, ^{201}Tl and ^{153}Sm. The SSAL has a TPA ionisation chamber, which has been directly calibrated against a primary standard for a variety of radioactive nuclides. Calibration factors for this chamber were determined specifically for the actual volumes (5ml for ^{99m}Tc, ^{131}I, 2ml for ^{67}Ga, ^{201}Tl and 3 ml for ^{153}Sm) and types of vial (Wheaton) which are routinely used at ARI. These calibration factors can be used to accurately measure the activity of samples prepared by ARI. The samples can subsequently be used to calibrate the QC ionisation chambers. QC ionisation chambers are re-calibrated biannually.

1. INTRODUCTION

The National Measurement Act of 1960 requires that measurements made for any legal purpose should be traceable to Australian National standards of measurement. The CSIRO has been assigned the responsibility for maintaining Australia's national measurement standards. With regards to the standard for ionising radiation activity, the CSIRO has appointed the Australian Nuclear Science and Technology Organisation (ANSTO) as an agent.

Australian Radioisotopes (ARI), as a producer and supplier of radiopharmaceuticals, must be able to demonstrate traceability of their activity measurements to the National standard of measurement for ionising radiation activity. The Therapeutic Goods Administration (TGA) conducts regular inspections of ARI. Part of their requirements relates to the traceability of ARI's activity measurements. The Radiation Standards Project within the Physics Division at ANSTO maintains the Australian standard of measurement for radioactivity. A coincidence counting system is used to perform primary standardisations. The results of such standardisations may then be used to calibrate a secondary standard ionisation chamber. The secondary standard ionisation chamber or working standard ionisation chamber located in the SSAL is a "TPA" ionisation chamber which has been directly calibrated for a variety of radionuclides. For those nuclides for which the chamber has not been directly calibrated, it is possible to determine a calibration factor indirectly using the interpolation method. The results of primary standardisations may be compared with the results of other National standards institutes through the auspice of the Bureau International des Poids et Mesures (BIPM) via either full-scale international intercomparisons or the Internaional Reference Sysem (SIR).

Calibration factors for this chamber were determined specifically for the actual volumes (5ml for ^{99m}Tc, ^{131}I, 2ml for ^{67}Ga, ^{201}Tl and 3 ml for ^{153}Sm) and types of vial (Wheaton) which are routinely used at ARI. The calibration factors can be used to accurately measure the activity of samples prepared by ARI. The same samples can subsequently be used to calibrate the ARI QC Vinten and TPA ionisation chambers. The QC Vinten and TPA ionisation chambers were established as the ARI in-house standard.

2. SAMPLE PREPARATION

The calibration of the working standard ionisation chamber against a primary standard requires careful handling of the radioactive solutions to ensure that all of the samples are gravimetrically related to the stock solution.

Radioactive stock solutions are usually supplied by ARI. Prior to dispensing, the solutions are mixed using an ultrasonic bath to ensure homogenity of the solutions. 1M HCl Diluent is used to prevent both "plating – out" and precipitation of the nuclides. The solutions are diluted and then dispensed to provide five $4\pi\beta-\gamma$ counting sources to determine the activities of the solutions using the coincidence counting system. Five solutions are provided from the same stock in Wheaton vials and standard ampoules to calibrate the SSAL working standard ionisation chamber. Solutions in Wheaton vials will be used to calibrate QC's ionisation chambers. Standard ampoules may also be used for international comparison. All solutions are weighed before and after dispensing to determine the mass of solution added to each vial.

For the biannual re-calibration of QC ionisation chambers against the SSAL working standard ionisation chamber, only three solutions in Wheaton vials need to be dispensed from stock solution.

3. SECONDARY STANDARD IONISATION CHAMBER AND ITS CALIBRATION

The SSAL Ionisation chamber has characteristics of high sensitivity, long term stability, and simplicity of operation. Once calibrated it can be used to measure or calibrate further samples of the same radionuclide to give secondary standards at any later date.
The secondary standard ionisation chamber [1] shown in figure 1 provides an almost 4π geometry and is filled with argon to a pressure of about 20 atmospheres (~ 2026 kPa). Perspex holders have been made to allow source solutions to be introduced to the chamber.

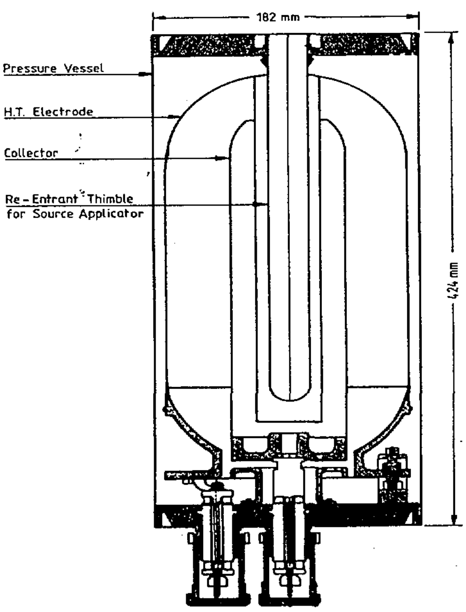


Figure 1. TPA ionisation chamber [1]

When a radioactive sample is inserted into the chamber, ion pairs will be generated within the gas. When there is no voltage, the ion pairs will re-combine and as a result no current will flow between the electrodes. However, applying a voltage will cause the positive and negative ions to drift in opposite directions toward their respective electrodes. This results in an electrical current being produced [2]. If the voltage is further increased, a saturation voltage will be reached at which all of the ion pairs are collected at the electrodes. As long as the charged particles lose all of their energy within the gas volume, the number of ion pairs produce will be proportional to the kinetic energy of the charged particles.

For a particular nuclide , for which the activity has been determined using one of the Australian primary methods of standardisation, the specific ionisation current (or calibration factor) i_c is given by

$$i_c = \frac{I_m - I_b}{A_m} \qquad (1)$$

where I_m is the ionisation current of the standard solution for that nuclide, I_b is the current due to background radiation, A_m is the activity of the solution which has been determined using primary standardisation and corrected for radioactive decay. To estimate the activity of this nuclide a long time after the chamber calibration, the stability of the chamber needs to be verified by comparing the ionisation current from a radium reference source at sample measurement time t_m with the current predicted based on measurements made at calibration time t_c.

Calibration factors for the working standard ionisation chamber, which were determined for the ARI calibration program are listed in table 1.

Table 1. Calibration factors for working standard ion chamber

Nuclide	Volume (ml)	Factor i_C (pA/MBq)
^{67}Ga	2	6.24 ± 1%
^{99m}Tc	5	5.68 ± 1%
^{131}I	5	11.48 ± 1%
^{201}Tl	2	4.693 ± 1%
^{153}Sm	3	2.03 ± 1.5%

4. CALIBRATION OF ARI QC IONISATION CHAMBERS

ARI QC has two ionisation chambers, a Vinten and a TPA chamber. They work on the same principle as the standard ionisation chambers described above.

Solutions were repeatedly measured in both the ARI TPA and Vinten chambers to obtain ionisation currents for each sample. Then the solutions were transported to the SSAL where their activities were determined in the standard TPA ionisation chamber.

The decay corrected activities were then used to calibrate ARI ionisation chamber using equation (1). Calibration factors for the ARI Vinten and TPA chambers are list in table 2.

Table 2. Calibration factors for the ARI ion chambers

Nuclide	Volume (ml)	Factor i_C (pA/MBq)	
		ARI TPA	ARI Vinten
^{67}Ga	2	5.12 ± 2%	1.55 ± 2%
^{99m}Tc	5	4.69 ± 2%	1.216 ± 2%
^{131}I	5	9.37 ± 2%	3.894 ± 2%
^{201}Tl	2	3.93 ± 2%	0.845 ± 2%
^{153}Sm	3	-	0.54 ± 3.7%

Once the calibration factors for the ARI chambers are determined, the bi-annual re-calibration is conducted by measuring the activities of 'standard' sources using the ARI chambers and comparing these measurements with the activities determined using the SSAL working standard.

5. CONCLUSION

The ARI QC ionisation chambers has been calibrated for the actual volumes (5ml for ^{99m}Tc, ^{131}I, 2ml for ^{67}Ga, ^{201}Tl and 3 ml for ^{153}Sm) and types of vial (Wheaton) which are routinely used at ARI. The calibration factors can be found in table 2. The activity measurements on these nuclides are traceable to the Australia primary methods of standardisation.

ACKNOWLEDGMENTS

The author likes to thank the ARI QC's support for this work.

REFERENCE

[1] Urquhart, D.F., (1986) Calibration and operation of the AAEC working standard of measurement for the activity of radionuclides, Part 1: The measurement system, *AAEC/E627.*

[2] NCRP., (1985) A handbook of radioactivity measurements procedures, *NCRP Report No. 58, second edition.*

The Standardisation of Samarium-153

JUSTIN DAVIES, H.A VAN DER GAAST, LI MO, HUGH WYLLIE, DIMITRI ALEXIEV

ANSTO-Physics, Radiation Standards Group

SUMMARY

Samarium-153 (^{153}Sm) is a beta-gamma emitting radionuclide. When it is labelled to a bone-seeking compound and administered to a patient with painful bone metastases it can provide palliative treatment of the disease. The purpose of this work was to produce an Australian primary standard of activity measurement for samarium-153. At the Australian Nuclear Science and Technology Organisation (ANSTO), the Australian primary standard method of activity is 4πβ-γ coincidence counting. The activity determined would be used to calibrate secondary standards of activity measurement such as the Australian working standard method, a 4π-γ ionisation chamber. Two methods of activity determination were used. The first was efficiency extrapolation, where a drop of water was added to the source during counting. The efficiency steadily increased as the water dried and this was extrapolated to find the true disintegration rate. The second method used was tracer extrapolation. A tracer nuclide of known activity was added to the source. An efficiency extrapolation was performed as before and the tracer activity subtracted. Comparing the two methods showed the activity estimate of ^{153}Sm had an uncertainty of ± 3.5%. The activity and consequent calibration factors were compared with international standard methods for activity measurement.

1. INTRODUCTION

As yet there is no Australian primary standard method applied to the determination of activity for samarium-153. Current estimates of its activity could be in error by about 20%. The purpose of this work was to produce an Australian primary standard measurement of samarium-153. An activity estimate of samarium-153 using the Australian primary standard method is used as a calibration of secondary standard methods. For activity determination the absolute method of standardisation and the Australian primary standard method is the technique of 4πβ-γ coincidence counting (1). The activity determined would be used to calibrate secondary standard methods such as the Australian working standard, the 4π-γ ionisation chamber.

2. METHODS

For β-γ emitting radionuclides, a β particle is followed almost immediately by a γ-ray. The 4πβ-γ coincidence counting system uses a detector for β radiation and a detector for γ radiation. A coincidence mixer registers a count when a pulse from the β detector arrives in coincidence with a pulse from the γ detector (2). The coincidence count rate relative to the β and γ count rates is a measure of the disintegration rate of the source. Figure 1 below illustrates the principle behind coincidence counting.

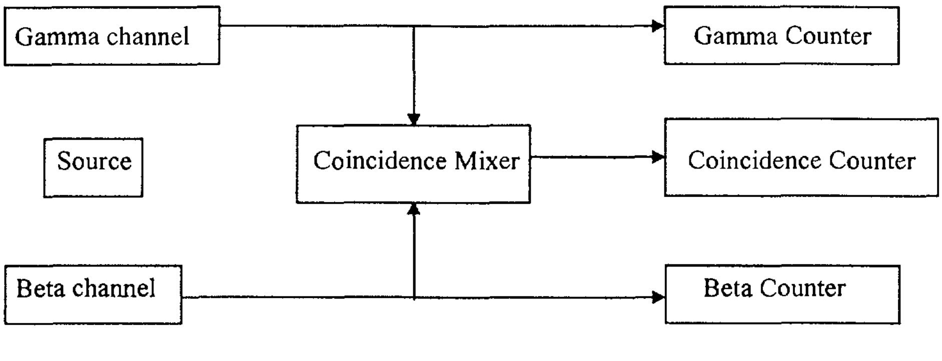


Figure 1. Simplified β-γ coincidence setup (3)

The coincidence counting system at ANSTO uses a 4π steradian proportional counter for β particle detection and a NaI(Tl) crystal coupled to a photomultiplier tube for γ-ray detection (Figure 2). Ideally, the β detector would be insensitive to γ radiation, and the γ detector would be insensitive to β radiation.

The disintegration rate (activity), N_0, of a β-γ emitting radionuclide can be found by using the following equations (4):

$$N_\beta = N_0\varepsilon_\beta \quad (1)$$
$$N_\gamma = N_0\varepsilon_\gamma \quad (2)$$
$$N_c = N_0\varepsilon_\beta\varepsilon_\gamma \quad (3)$$

where N_β is the observed β count rate
N_γ is the observed γ count rate
N_c is the observed coincidence count rate
ε_β is the β detection efficiency (fraction of β particles observed)
ε_γ is the γ detection efficiency (fraction of γ rays observed)

Rearranging equations 1-3:

$$N_0 = \frac{N_\beta N_\gamma}{N_c} \quad (4)$$

$$\varepsilon_\beta = \frac{N_c}{N_\gamma} \quad (5)$$

Equation 4 shows that the absolute disintegration rate is independent of the efficiency of either detector.

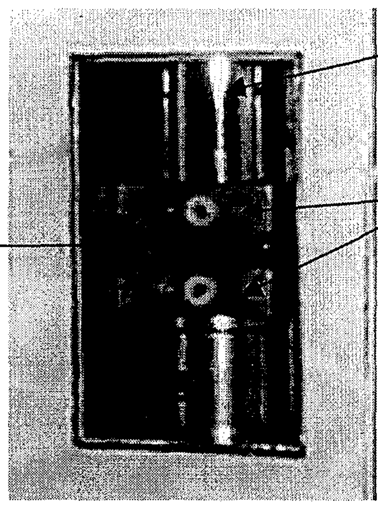


Figure 2. The detector system at ANSTO

2.1 Efficiency Extrapolation

The activity calculation will depend on the proportional counter efficiencies for conversion electrons, ε_{ce}, and γ rays, $\varepsilon_{\beta\gamma}$ (4, 6). A correction formula for the proportional counter response to conversion electrons and γ rays is given by (4, 6, and 7):

$$\frac{N_\beta N_\gamma}{N_c} = N_0\left[1 + \frac{(1-\varepsilon_\beta)}{\varepsilon_\beta}\left(\frac{\alpha\varepsilon_{ce} + \varepsilon_{\beta\gamma}}{1+\alpha}\right)\right] \quad (6)$$

where N_β and N_γ are the β and γ count rates corrected for background and dead times
N_c is the coincidence count rate corrected for background and resolving times
α is the internal conversion coefficient (the ratio of the number of conversion electrons to the number of γ rays) (3). Equation 6 can be simplified as follows (4, 5):

$$\frac{N_\beta N_\gamma}{N_c} = N_0\left[1 + \frac{(1-\varepsilon_\beta)}{\varepsilon_\beta} \times K\right] \quad (7)$$

where

$$K = \frac{\alpha\varepsilon_{ce} + \varepsilon_{\beta\gamma}}{1+\alpha} \quad (8)$$

The ^{153}Sm efficiency of the proportional counter to β radiation, ε_β, is at best about 90%. If the efficiency was 100% ($\varepsilon_\beta = 1$), then equation 7 would become:

$$\frac{N_\beta N_\gamma}{N_c} = N_0 \quad (9)$$

which is equation 4. It can then be seen that at $\varepsilon_\beta = 1$, the value of K becomes irrelevant. Equation 9 reduces further since $\varepsilon_\beta = \frac{N_c}{N_\gamma}$, then N_β ($\varepsilon_\beta = 1$) = N_0. By varying the proportional counter efficiency, an efficiency function, $f(\varepsilon_\beta)$, may be extrapolated to $\varepsilon_\beta = 1$, thus giving the true activity of the source. That is (2, 6):

$$N_\beta = N_0 f(\varepsilon_\beta) \rightarrow N_0 \qquad \text{as } \varepsilon_\beta \rightarrow 1 \quad (10)$$

This is known as efficiency extrapolation (2, 5, 6, and 7). Efficiency dependent corrections include that due to self-absorption of the source (5, 8, and 9). The principle of efficiency extrapolation is such that any efficiency dependent correction is eliminated (5). One of the simplest ways to vary the β efficiency is to add a drop of water to the source just before counting (5). As the water evaporates, the efficiency (and count rate) will steadily increase. A plot of N_β versus $(1 - \varepsilon_\beta)/\varepsilon_\beta$ can be extrapolated to $\varepsilon_\beta = 1$ (that is $(1 - \varepsilon_\beta)/\varepsilon_\beta = 0$) so that the β count rate is equal to the disintegration rate of the source ($N_\beta = N_0$).

2.2 Tracer Extrapolation

Tracer extrapolation involves the addition of a suitable β-γ emitting 'tracer' nuclide to the source (9, 10). The known activity of the tracer is subtracted from the total count rate to yield the activity of ^{153}Sm. The count rate is to be plotted as a function of the β-efficiency for the tracer nuclide (9). The efficiency tracing method was originally intended for the activity determination of pure β-emitters (9). The γ channel SCA must then be gated on the γ energies of the tracer nuclide only (4).

In this work cobalt-60 (^{60}Co), a β-γ emitter, is used as the tracer nuclide. ^{60}Co emits γ rays of energies (1.17 & 1.33 MeV) much greater than that of ^{153}Sm. This has the advantage of assuring that no γ ray from ^{153}Sm will contribute to the γ count rate if the γ window is set on the ^{60}Co peaks (4).

After the addition of ^{153}Sm onto a ^{60}Co source, a drop of water is added for an efficiency extrapolation. The β-efficiency, ε_β, is due to the ^{60}Co count rates only. The β count rate of the ^{60}Co-^{153}Sm mixture is a function of both the β efficiency and the time of measurement, t. The ^{60}Co activity must be found as a function of the same ε_β and t. The β count rate due to ^{60}Co can be calculated by multiplying the β efficiency by the predetermined activity of ^{60}Co (3), using equation 1. The result is then subtracted from the $^{60}Co/^{153}Sm$ β count rate to reveal N_β of ^{153}Sm as a function of ε_β and t. This count rate may now be corrected for decay to a reference time. A plot of the decay corrected count rate versus an efficiency function can be extrapolated to give the true activity, N_0.

3. RESULTS

Below is a comparison between efficiency extrapolation and tracer extrapolation.

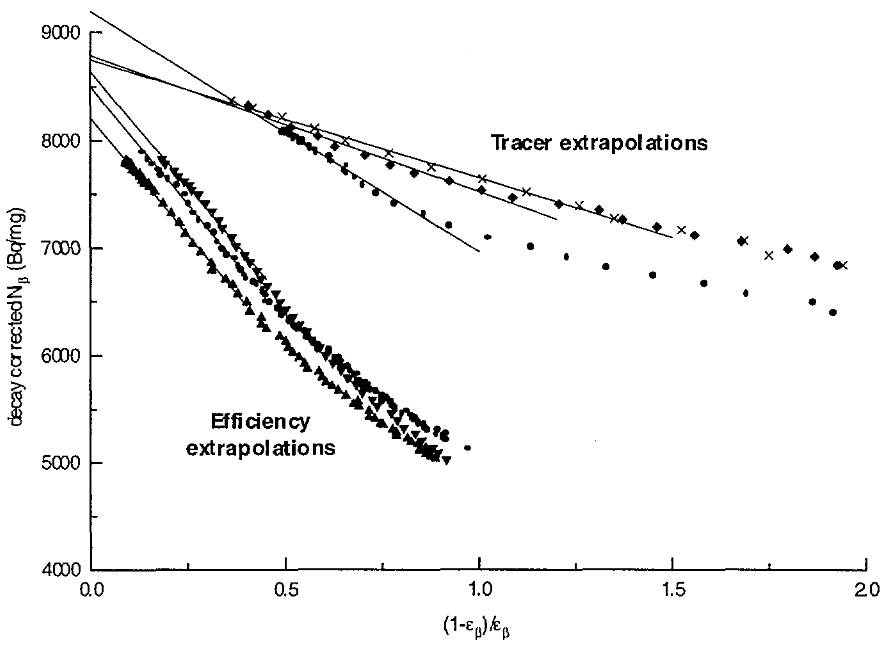


Figure 3. Comparing efficiency & tracer extrapolations for ^{153}Sm (12)

The mean and standard deviation of all the results yields an activity estimate of; $N_0 = 8.68 \pm 0.30$ MBq/g. The uncertainty here is $\pm$ 3.5% at one standard deviation from the mean. A sample of ^{153}Sm was sent to the NPL (13), and another sent to NIST (14). The reported activities were compared with ion chamber measurements calibrated using the Australian primary standard method of measurement. The results reported from NPL and NIST were found to be in disagreement by approximately 10%, with the Australian primary standard method falling between the two.

4. CONCLUSION

This work was based on the comparison between efficiency tracing and efficiency extrapolation. Both methods of activity measurement are equally valid. Further work needs to be done to acquire an international standard of activity for samarium-153.

5. REFERENCES

1. Campion, P.J "The standardization of radioisotopes by the beta-gamma coincidence method using high efficiency detectors" *Int J Appl Radiat and Isot., 4; 232-248, 1959.*

2. NCRP Report No. 58 "A handbook of radioactivity measurements procedures", 1978.
3. Van der Gaast, H.A "Development of Australian Commonwealth standards of measurement for cyclotron produced radionuclides" PhD Thesis, University of Technology, Sydney, 1996.
4. Campion, P.J "The standardization of radioisotopes by the beta-gamma coincidence method using high efficiency detectors" *Int J Appl Radiat and Isot., 4; 232-248, 1959.*
5. Van der Gaast, H.A., personal communications; Radiation standards group, Physics division, ANSTO.
6. Zajic, V "A simple way of varying the source efficiency for the extrapolation method in 4π (PC)-γ coincidence counting" *Appl Radiat Isot., 38, 7; 549-552, 1987.*
7. Baerg, A.P "The efficiency extrapolation method in coincidence counting" *Nucl Instru and Meth 112 (1973) 143-150.*
8. Miyahara, H "Optimisation of efficiency extrapolation functions in radioactivity standardisation" *Appl Radiat and Isot., 37 (1); 1-5, 1986.*
9. Houtermans, H "4πβ-γ Coincidence counting for the calibration of nuclides with complex decay schemes" *Int J Appl Radiat and Isot., 13; 137-142, 1962.*
10. Campion, P.J et al. "The efficiency tracing technique for eliminating self-absorption errors in 4πβ-counting" *Int J Appl Radiat and Isot., 8; 8-19, 1960.*
11. Baerg, A.P et al., "Extension of the efficiency tracing method for the calibration of pure β-emitters" *Int J Appl Radiat and Isot., 15; 279-287, 1964.*
12. Davies, J.B "The standardisation of samarium-153", Honours thesis, University of Wollongong, 1998.
13. National Physical Laboratory (NPL), Middlesex, England.
14. National Institute of Standards and Technology (NIST), USA

AU0019572

Recent Progress with Digital Coincidence Counting

K. S. A. BUTCHER, G. C. WATT and D. ALEXIEV

Australian Nuclear Science and Technology Organisation
Private Mail Bag 1 Menai NSW 2234

SUMMARY Digital Coincidence Counting (DCC) is a new technique, based on the older method of analogue coincidence counting. It has been developed by ANSTO as a faster more reliable means of determining the activity of ionising radiation samples. The technique employs a dual channel analogue to digital converter acquisition system for collecting pulse information from a 4Π beta detector and a NaI(T*l*) gamma detector. The digitised pulse information is stored on a high speed hard disk and timing information for both channels is also stored. The data may subsequently be recalled and analysed using software based algorithms. The system is operational and results are now being routinely collected and analysed. Some of the early work is presented for Co-60, Na-22 and Sm-153.

1. INTRODUCTION

The ANSTO Radiation Standards Group, more recently in collaboration with the National Physical Laboratory in the United Kingdom, has been pioneering the development of a digital acquisition and analysis system for coincidence counting applications (1,2). Development of this new technique of ionising radiation activity determination began at ANSTO in the early part of the decade and has now progressed to the stage where Digital Coincidence Counting (DCC) has been realised as a working technique.

Analogue based coincidence counting has been used for many years in radiation metrology to accurately determine the activity of radioactive samples. Campion pioneered the present technique, which is called 4Πβ-γ coincidence counting, though his work was itself reliant on the still earlier work of Dunworth (4). Since the time of Campion there has been little change in the apparatus used in coincidence counting for metrology purposes. For typical experiments two radiation species are detected from the radioactive decay of a sample, usually a beta particle and a gamma photon (though gamma-gamma and alpha-gamma counting are also quite common). The efficiency of pulse detection for both these species is usually not well known due to variations in the sample preparation, and in the detector efficiencies. This means that there could be associated inaccuracies in determining the activity of the sample by simple counting methods. For the emission of particles which occur through the same decay branch there are relationships in time which allow coincidence counting to accurately determine source activity – for instance a beta decay is often very promptly followed by a gamma decay. By counting both species; the number of times that detected pulses from both species are coincident in time, and by applying appropriate corrections, the activity of the sample can be found with a high level of accuracy. This can be shown with a set of idealised equations:

$$N_\gamma = \varepsilon_\gamma N_o \qquad (1)$$

$$N_\beta = \varepsilon_\beta N_o \qquad (2)$$

$$N_C = \frac{N_\beta N_\gamma}{N_o} \qquad (3)$$

where N_γ, N_β, and N_C are the count rates for gamma photons, beta particles and their coincidences; N_o is the absolute activity which is required, and ε_γ and ε_β are the efficiencies of the two detectors used (usually a NaI(T*l*) scintillation counter for gammas, and a 4Πβ proportional gas counter). It can be seen from the equations that, for a simplistic analysis, counting beta particles, gamma photons and their coincidences will allow you to find an absolute activity via equation 3, while the detector efficiencies can subsequently be found using equations 1 and 2.

DCC represents a significant departure from the traditional methods of coincidence counting, although the same analysis equations are used, and the same detector systems, the analogue electronics which has been used for over forty years is now largely redundant.

Traditionally coincidence counting is carried out by banks of dedicated analogue modules, typically NIM based nucleonic modules. These would include separate modules for amplifiers, single channel analysers, multichannel analysers, time to amplitude converters, coincidence mixers, nucleonic pulse delay units, etc. And with these units there would be a considerable effort in set up time, a high cost for rack type analogue electronics and a large expenditure in system maintenance. With Digital Coincidence Counting (DCC) all these analogue units are eliminated. A data acquisition card digitises the pulse data for the two counting species in two separate channels and the pulse data for both channels are time stamped. The data - including timing and pulse shape information - is stored on a high-speed hard disk where it can be recalled at a later stage for analysis. A suite of offline user friendly analysis routines have been developed to carry out the functions of the NIM based modules. At present these enable conventional coincidence counting and the so called "computer discrimination method" (5,6) to be carried out, however they also provide a baseline for the development of counting techniques which are generally regarded as being too expensive to implement in analogue electronic form – see Buckman (7) for a listing and explanation of alternative techniques.

The advantages of the DCC system are many. It is a more cost affective means of implementing coincidence counting than standard nucleonics. The measurement set up time is considerably less than for traditional analogue systems. Less system maintenance is required. Electronic drift is removed from much of the system by using software algorithms instead of electronic modules. There can be a reduction in dead time corrections. Methods of activity determination not widely used because they are thought to be too expensive to implement for routine analysis, such as selective sampling or correlation counting (see Buckman (7)) can be applied using software routines. Other forms of analysis can also be introduced including pulse shape analysis that can be implemented in conjunction with coincidence counting for greater accuracy in activity determination. Finally the data can be stored for future referral. This last point is important from a quality assurance point of view since the analysis can be re-checked at any later stage.

2. DCC ACQUISITION SYSTEM

The ANSTO Radiation Standards Group has already started to use a second generation prototype DCC system using technology developed by the ANSTO Nucleonics Systems Group. CPLD (translated to FPGA format) and front end data acquisition technology developed by the Nucleonics Group has been incorporated onto a PCI high-speed data transfer card independently developed by a British company sourced by our NPL partners. The first prototype system was delivered to ANSTO in the April of this year, with an identical system being delivered to NPL at a later date. The testing of the card was carried out at ANSTO by Radiation Standards Group and Nucleonics Systems Group staff. Minor electronic bugs have been identified and solutions have been found for all of these. Data collection now proceeds with reliable integrity. The system is in regular operation with results being checked against the old analogue system, as described in the section 4, below.

Some of the properties of the data acquisition system include: two independent nuclear pulse input channels with 12 bit resolution; a 20 MHz data acquisition rate (per channel) with data capture above a user set threshold. Continuous data hard-disk transfer for 1 microsecond wide pulses at repetition rates of up to at least 30 kHz (dependent on computer and platform). This can equate to samples with activity of greater than 30 kBq. Files up to 2 GigaByte can be and have been collected. Data collection periods depend on sample activity, but continuous data collection has been achieved for periods of greater than an hour for ~ 5 kBq samples.

3. ANALYSIS SOFTWARE

The DCC software is being written with a Labview version 5.1 user interface, while processor intensive operations are carried out by faster turbo C++ routines, which operate transparently to the user. The software is presently in operation and can be used for radiation calibration purposes, however work still proceeds in improving the user interface. The hardware is now ready for commercialisation and with improvements to the DCC software it is hoped that system commercialisation will occur early in the year 2000.

4. MEASUREMENTS

DCC calibrations at ANSTO have been carried out to confirm that the new hardware and software is operating so that it provides the same isotope activity as the traditional analogue system. So far measurements have been carried out on Co-60, Na-22 and Sm-153.

Samples were prepared on gold/palladium alloy coated VYNS foils for counting in the ANSTO 4πβ-γ counting apparatus. The stock solution from which the samples were prepared had been calibrated previously with the Australian secondary activity standard, at ANSTO, in a TPA ionisation chamber using standard geometry. An accurately measured mass of solution was used in preparing the source so that the activity was known at a specified date and time.

Measurements for Co-60 and Na-22 were carried out using the standard coincidence counting techniques available with the DCC system, corrections were made for background counts, accidental coincidences and resolving time. The calculated activities were corrected to a standard reference time for comparison. Results are given below and all errors are for confidence levels of 99.7%.

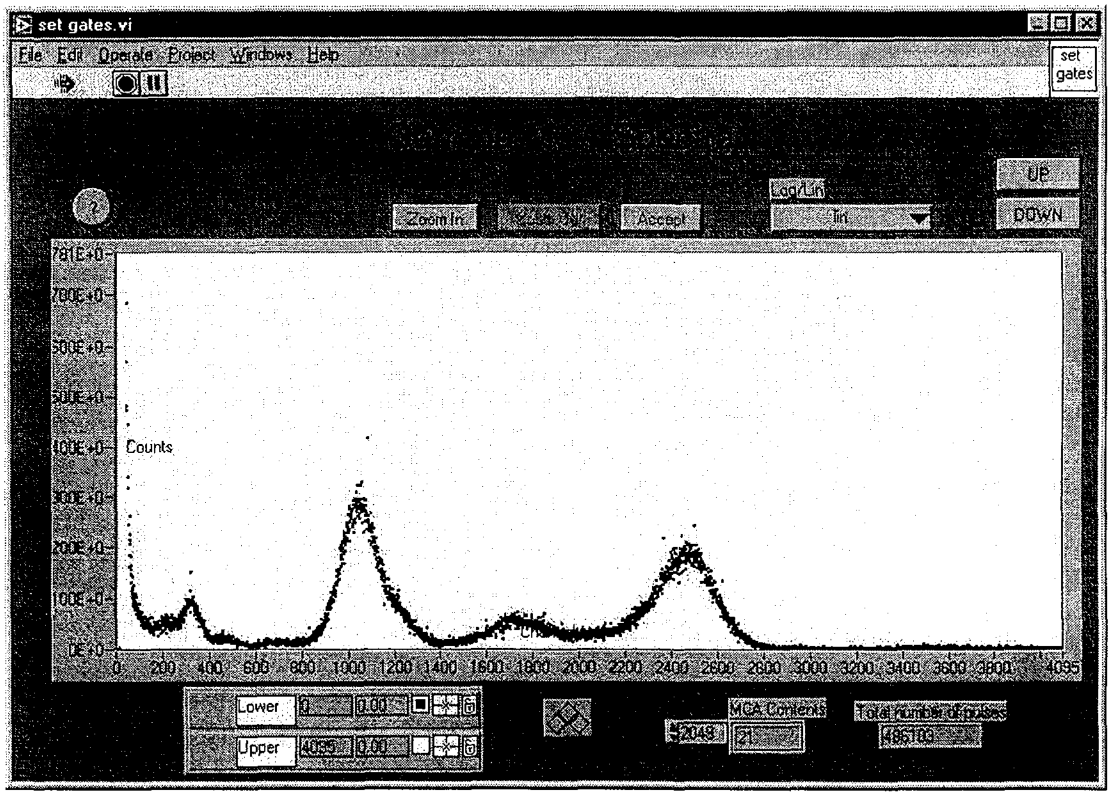
Using the analogue system VYNS foil 7249 had a Co-60 activity of 4893.4 Bq +/- 0.3%. For the same sample the DCC system measured 4881.9 Bq +/- 0.8% so that the analogue and DCC results were within 0.3% of each other.

For Co-60 VYNS foil sample 7250 the analogue system gave an activity of 4600.1 Bq +/- 0.4%. DCC measurements for the same sample gave an activity of 4589.4 Bq +/- 0.9%, so for this foil the analogue and DCC results were within 0.2% of each other.

For Na-22 foil 7269 the DCC gave 5770.5 +/- 0.3% Bq; the analogue measurements gave 5781.7 +/- 0.4% Bq. This gives a 0.19% difference between the two. All of these results for Na-22 and Co-60 are well within statistical error. There was also statistical agreement with the secondary standard measurements.

The gamma spectra displayed by the DCC software for a Sm-153 sample (to allow the setting of a single channel analyser window) is shown in figure 1 over page. For Sm-153 the DCC computer discrimination method was used and preliminary results were again in agreement with the secondary standard measurements. There is also some pleasing agreement with the analogue coincidence counting unit, for which efficiency extrapolation was used. However, further work is still necessary for comparisons with Sm-153.

Figure 1: Gamma Spectra for Sm-153



5. CONCLUSIONS

To date excellent agreement has been obtained between the old analogue system and the DCC system for the standardisation of Co-60 and Na-22 - to within statistical error. More recent work has been carried out on Sm-153 – though this is still preliminary. Further standardisation's will continue throughout the year. The hardware and software for DCC now constitute a working system and it is envisaged that commercial units will begin to be sold by the end of the year. Inquiries by interested parties are welcome before hand.

ACKNOWLEDGEMENTS

The development of the DCC system has been an ongoing project at ANSTO for a number of years with a large number of staff participating in its evolution. In particular we would like to acknowledge the early work of Dr Stephen Buckman who put into train the development of the system based on Stewart Sherlock's original vision. Our beloved Division Leader Dr Claudio Tuniz is much thanked for his ongoing support of the project, the general divisional support received is also much appreciated. We would like to thank Mr Dino Ius for his electronic and audiovisual contributions. Thanks also to members of the ANSTO Radiation Standards Group for their support including Dr Haitse van der Gaast, Mr Justin Davies, Ms Li Mo and Dr Hugh Wyllie. The contribution of Marie-Pierre Pertus-Hopman in her efforts to help with commercialisation is also much appreciated.

Finally we would like to thank our NPL collaborators who have contributed substantially to the DCC software development. Members of that team include Mr John Keightley, Dr David Smith and Mr. Mike Woods.

REFERENCES

(1) Buckman, S. M. and Ius, D. (1996) Digital Coincidence Counting, *Nucl. Instr. And Meth. in Phys. Res. A* Vol.369 pp 368-374.

(2) Buckman, S. M., Keightley, J. D., Smith, D., and Woods, M. J., (1998) The Validation Of a Digital Coincidence Counting System, *Appl. Radiat. Isot.* Vol. 49 pp 1135-1140.

(3) Campion, P.J. (1959) The Standardization of Radioisotopes by the Beta-Gamma Coincidence Method Using High Efficency Detectors, *J. Appl. Radiat. Isot.* Vol. 4 pp 232-248.

(4) Dunworth, D.V. (1940) The Application of the Method of Coincidence Counting to Experiments in Nuclear Physics *Rev. Sci. Instr.* Vol. 11 pp 167-180.

(5) Smith, D. (1975) An Improved Method of Data Collection for $4\Pi\beta$-γ Coincidence Measurements, *Metrolgia* Vol. 11 pp 73-77.

(6) Smith, D. and Chen, Y. (1985) The $4\Pi\beta$-γ Coincidence Method for Parent-Daughter Decay in Non-Equilibrium: The Measurment of the Disintegration Rates of ^{47}Ca-^{47}Sc, ^{45}Ca, *Nucl. Instr. And Meth. in Phys. Res. A* Vol. 236 pp 321-329.

(7) Buckman, S.M., Metrology and Statistical Analysis for the Precise Standardisation of Cobalt-60 by $4\Pi\beta$-γ Coincidence Counting, *Macquarie University PhD Thesis, Sydney,* 1995 pp 63-71, 233-238.

AU0019573

Tracing Discharges of Plutonium and Technetium from Nuclear Processing Plants by Ultra-sensitive Accelerator Mass Spectrometry.

L.K. FIFIELD, P.A. HAUSLADEN, R.G. CRESSWELL and M.L. DI TADA

Department of Nuclear Physics, Research School of Physical Sciences and Engineering, Australian National University, Canberra, ACT 0200, Australia

J.P. DAY and R.S. CARLING

Department of Chemistry, University of Manchester, Oxford Road, Manchester, M13 9PL, United Kingdom.

D.H. OUGHTON

Laboratory for Analytical Chemistry, Agricultural University of Norway, Oslo, Norway

ABSTRACT

Historical discharges of plutonium from the Russian nuclear processing plant at Mayak in the Urals have been traced in sediments, soils and river water using ultra-sensitive detection of plutonium isotopes by accelerator mass spectrometry (AMS). Significant advantages of AMS over other techniques are its very high sensitivity, which is presently ~10^6 atoms (1 μBq), and its ability to determine the $^{240}Pu/^{239}Pu$ ratio. The latter is a sensitive indicator of the source of the plutonium, being very low (1-2%) for weapons grade plutonium, and higher (~20%) for plutonium from civil reactors or fallout from nuclear weapons testing. Since this ratio has changed significantly over the years of discharges from Mayak, a measurement can provide important information about the source of plutonium at a particular location. Similar measurements have been performed on samples from the Kara Sea which contains a graveyard of nuclear submarines from the former Soviet Union.

AMS techniques have also been developed for detection of ^{99}Tc down to levels of a few femtograms. This isotope is one of the most prolific fission products and has a very long half-life of 220 ka. Hundreds of kg have been discharged from the nuclear reprocessing plant at Sellafield in the UK. While there may be public health issues associated with these discharges which can be addressed with AMS, these discharges may also constitute a valuable oceanographic tracer experiment in this climatically-important region of the world's oceans. Applications to date have included a human uptake study to assess long-term retention of ^{99}Tc in the body, and a survey of seaweeds from northern Europe to establish a baseline for a future oceanographic study.

AU0019574

Barriers to Fusion

A.C. BERRIMAN, R.D. BUTT, M. DASGUPTA, D.J. HINDE, C.R. MORTON AND J.O. NEWTON

Department of Nuclear Physics, Research School of Physical Sciences and Engineering, Australian National University, Canberra, ACT 0200, Australia

SUMMARY The fusion barrier is formed by the combination of the repulsive Coulomb and attractive nuclear forces. Recent research at the Australian National University has shown that when heavy nuclei collide, instead of a single fusion barrier, there is a set of fusion barriers. These arise due to intrinsic properties of the interacting nuclei such deformation, rotations and vibrations. Thus the range of barrier energies depends on the properties of both nuclei. The transfer of matter between nuclei, forming a neck, can also affect the fusion process. High precision data have been used to determine fusion barrier distributions for many nuclear reactions, leading to new insights into the fusion process.

1. INTRODUCTION

It is well known that fusion reactions are largely controlled by two forces, the long-range repulsive electrostatic Coulomb force and the short-range attractive strong nuclear force. The "fusion barrier" corresponds to the energy where these two forces are balanced. In classical terms, it describes the minimum energy required for fusion to occur. However, nuclear fusion is a quantum mechanical process and can occur by tunneling through the fusion barrier.

2. FUSION BARRIER DISTRIBUTIONS

ANU research into the fusion of heavy nuclei has shown that fusion is not governed by a single fusion barrier but a set of fusion barriers known as a "fusion barrier distribution". This is the result of nuclei not being inert spherical objects but exhibiting properties and dynamics, which affect the fusion process. These include nuclear deformation, rotations and vibrations, transfer of nucleons from one nucleus to the other, and breakup of nuclei.

3. MEASUREMENT OF FUSION BARRIER DISTRIBUTIONS

The distribution of barriers can be extracted directly from precise fusion cross section measurements at energies around the fusion barrier, through a simple and elegant transformation [1]. Many high precision fusion cross section measurements have been conducted using beams from the ANU 14UD accelerator. The resulting fusion barrier distributions show clearly the characteristics of the interacting nuclei in each reaction. This new technique provides far more detail of the reaction dynamics than was possible by previous studies which were limited to understanding the largely smooth and featureless variations of cross sections as a function of energy.

4. THE ^{16}O + $^{144,154}Sm$ REACTIONS

The figures in this paper show fusion barrier distributions for the reactions ^{16}O + ^{154}Sm and ^{16}O + ^{144}Sm [2]. The dashed lines show the single fusion barrier calculations. The ^{154}Sm nuclei are deformed which gives rise to a wide range of barrier energies, with different probabilities, having a non-symmetric

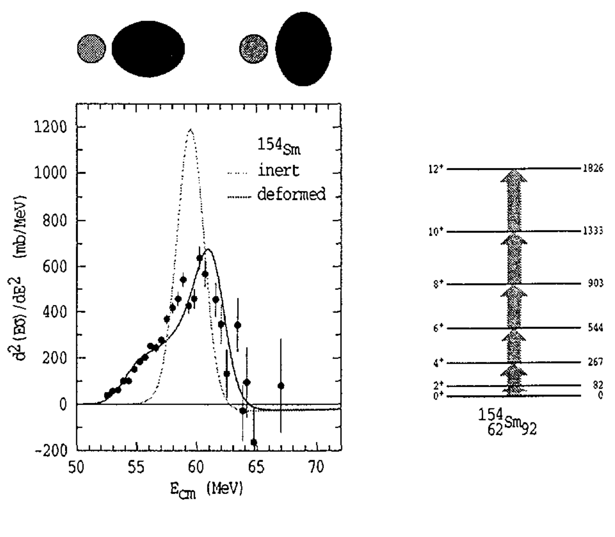


Figure 1: Measured and calculated fusion barrier distributions for ^{16}O + ^{154}Sm, with classical and quantum-mechanical representations.

distribution. This can be understood geometrically. Compared to spherical nuclei, the barrier is lower when the projectile approaches the "pole" of the deformed ^{154}Sm nuclei and is higher when it approaches the "equator". Taking into account all possible orientations produces a distribution of barrier heights, some lower and some higher than the single barrier. The spherical ^{144}Sm nuclei undergo an octupole vibrational excitation during the fusion process. This leads to a two peaked fusion barrier distribution. The position and size of the two peaks are determined by the energy and magnitude of the vibration.

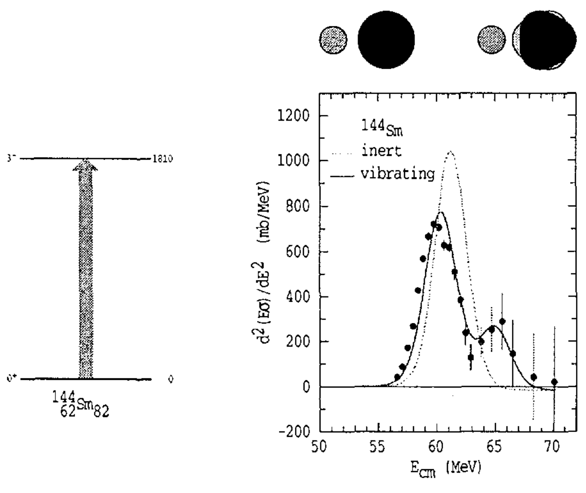


Figure 2: Measured and calculated fusion barrier distributions for ^{16}O + ^{144}Sm, with classical and quantum-mechanical representations.

5. CONCLUSION

The measurement of fusion barrier distributions has allowed detailed investigation of the interaction of the two nuclei during the fusion process. It has opened a new window into the microscopic world of nuclei, and allowed measurement and identification of the processes which occur. Experimental fusion barrier distributions have shown that collective excitations (rotation, vibration and deformation) play a dominant role in the fusion process, although nucleon transfer can determine the energy of the lowest barrier.

The use of fusion barrier distributions has also allowed investigation of the strong nuclear force itself. The strength of the nuclear force varies with the distance between the two nuclei in a complex manner. As heavy-ion fusion reactions occur at closer proximity than other reactions such as scattering reactions, they provide a tool with which to probe the form of the nuclear force. The fusion barrier distributions are sensitive to these effects. It has already been shown that the process of nuclear fusion is much more complex than previously thought. The effect of the fusion barrier distribution on the subsequent reaction dynamics, for example fission, is now being investigated.

REFERENCES

[1] Rowley N, et al., *On the "distribution of barriers" interpretation of heavy-ion fusion*, Phys. Lett. B 254:25 (1991)

[2] Leigh J.R., et al., *Barrier Distributions from the Fusion of Oxygen Ions with ^{144,148,154}Sm and ^{186}W*, Phys. Rev. C 52:3151 (1995)

AU0019575

A Charcoal Canister Survey of Radon Emanation at the Rehabilitated Uranium Mine Site at Nabarlek

JOHN R. STORM* and JOHN R. PATTERSON

Department of Physics and Mathematical Physics
University of Adelaide Adelaide SA 5005

* Now at the Environmental Research Institute of the Supervising Scientist
Jabiru Northern Territory 0886

SUMMARY

This paper describes a recent survey of radon emanation measurements from the rehabilitated Nabarlek mine site. It was mined out in 1979, decommissioned in 1995 and provided a good test bed for assessment of rehabilitation, in terms of radon flux attenuation. Measurements have been made with charcoal canisters. Studies to measure the radon-220 flux by observing Tl-208 progeny of thoron, the effectiveness of trial covers and meteorological considerations will be reported.

1. THE NABARLEK MINE SITE

The Nabarlek uranium mine-site is located 150 km NE from Jabiru, near Cooper Creek, a tributary of the East Alligator River. Queensland Mines Ltd mined out the Nabarlek high-grade orebody in just over 4 months in 1979. The company stockpiled 600 000 tonnes of average 2% grade ore (1). The mineralisation extended to a depth of 72 metres, with a variable thickness of about 10 metres. Rehabilitation and decommissioning works at the site ended in 1995.

In the Environmental Impact Statement, Queensland Mines stated that rehabilitation would involve transfer of tailings to the pit, evaporation of surplus water in the pit during the dry season and then backfilling and covering with layers of low permeability clay, then sealing with waste rock. The plan was then to reapply the topsoil initially removed and revegetate the landscape. The resultant rehabilitation has included a "rip-rapped" surface to inhibit surface erosion and forming trenches about 1.5 metres deep. By 1999, these appeared in most places to have to have been filled in to a present depth of about 0.3 to 0.6 metres.

It is well established that inhalation of radon progeny from the radioactive decay of radon gas, is a potential health hazard, so that exposure limits (4 Working Level Months/yr) are recommended for the site by advisory and regulatory bodies (2). In a survey of the Nabarlek mine site, Leach and Lokan (3) measured the radon flux using brass canisters, filled with charcoal and set out as an array over the area of interest.

The aim of the present survey was to continue previous surveys of the site most recently that conducted by Martin (4) in the early 1990's. The grid locations of sites for the new survey were selected according to their average gamma dose rates measured in the earlier work. They included the former pit, plant runoff pond, ore stockpile area, ore stockpile run off pond, evaporation ponds and topsoil stockpile areas. The photograph in figure 1 which shows a control point on site with 9 charcoal canisters and 4 electrets in foreground.

2. MEASUREMENT DETAILS

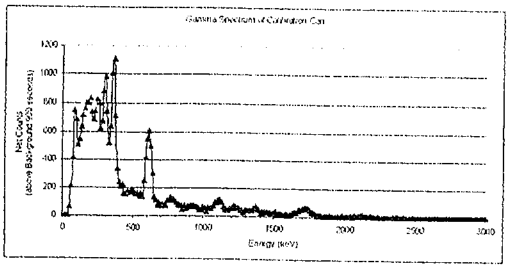
2.1 Detection by Charcoal Cups

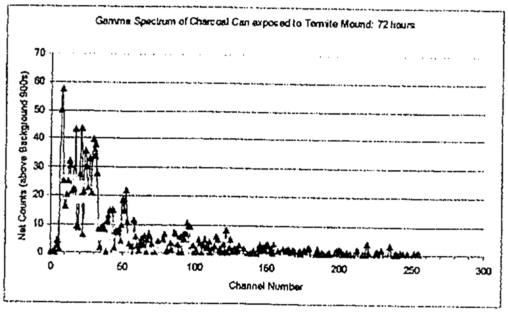
The charcoal cup method for determining radon emanation or concentration, uses the adsorption capacity of activated charcoal for radon-222 (radon) and radon-220 (thoron). One gram of activated charcoal typically adsorbs 2 to 6 Bq radon from the air with a radon activity concentration of 1 Bq l^{-1} (5). The minimum detectable activity for a 25 g charge of charcoal, based on background counts in our counting chamber is 2.2 Bq for the 100 litre air volume sampled or ~ 0.02 Bq l^{-1} (at 95% confidence).When used as a detector in a standard brass canister of area 0.002922 m^2, exposed to the surface for 3 days.

emanometer, an area sensitivity of 3 mBq m^{-2} s^{-1} may be inferred from the activity of 2.2 Bq measured

2.2 Spectra Measurements

Canisters used to measure emanation rates are embedded in the earth to a depth of ~1 cm, or mud is applied around the rim to prevent leakage of radon. In hard rock, the can may be fixed to and then sealed with a convenient putty such as *KneadIt*. The effect of temperature variation at the site was studied by a test site at ERISS.





Detection of the radon is measured by the radioactive emanations of its progeny and gamma ray spectroscopy is a method of doing this. Usually, a single channel analyser is used to record the gamma ray emanations from the Bi-214 radon daughter, which emits gamma photons at an energy of 609 keV. The authors previously used this method (6) and estimated emanation rates from a system with a counting efficiency of 0.7 %. (0.007 counts.s^{-1} Bq^{-1})

Counting is performed at least three hours after the canisters are collected, to allow secular equilibrium to be established for the progeny Pb-214 (half-life 27 minutes) and Bi-214 (20 minutes), which are relatively short-lived compared with their parent radon (3.82 days). In the current survey, gamma spectrometry furnished a method for counting peaks due to several progeny of radon and also determining possible contamination due to other radioactive species (such as thoron). A portable 3" × 3" NaI(Tl) spectrometer counted gamma ray emanations in a lead castle in 256 channels over a range from 12 keV to 3 MeV, in windows of width 12 keV. This meant that as well as Bi-214 (609 keV), counts from Pb-214 (295 and 395 keV) and Bi-214 (1120 and 1740 keV) could be used to improve counting efficiency. The remaining lines from Pb-214 contributed to a counting efficiency of about 3 % (0.03 counts s^{-1} Bq^{-1}).

The portable spectrometer uses a 15 kBq Cs-137 source as a reference and for internal spectrum stabilisation. However it had to be removed so that it would not interfere with the Bi-214 (609 keV) line. No internal stabilisation was employed. Instead, the regions of interest for the Pb214 (295, 353 keV) and Bi-214 (609 keV) were defined in every survey, by comparing the strongest spectrum from the charcoal cans to that of the calibration can, normalised to the Pb-214 and Bi-214 peaks of interest. Drift in the counts in channels within each Region of Interest (ROI), was checked and the variation over the ten minute counting interval per canister, was found to be indistinguishable from Poisson statistics.

The radon emanation rate J in Bq m^{-2} s^{-1} is then calculated using the formula (7):

$$J = \frac{N.\lambda^2.e^{(\lambda.td)}}{\varepsilon.A.(1 - e^{(-\lambda.te)}).(1 - e^{(-\lambda.tc)})}$$

where N is the net counts in the regions of interest,
λ is the decay constant for radon,
t_d is the delay period from the end of exposure to the beginning of the counting interval
ε is the counting efficiency of the system in the regions of interest
A (m^2) is the area of the canister
t_e is the period of exposure of the charcoal in the canister
t_c is the counting interval of the charcoal.

The radon activity concentration in the air in Bq m^{-3} is calculated using the formula (8):

$$[Rn] = \frac{N.e^{(\lambda.(te/2 + td)}}{\varepsilon \; CF \; t_e}$$

where CF (m^3 s^{-1}) is the calibration factor, or volume sampling rate at a specific temperature and humidity relating the radon concentration to activity in the can.

2.3 Thoron Contamination

It has been remarked that the photopeak due to the 609 keV gamma rays from Bi-214 must be determined after the thoron progeny Tl-208 has decayed, so that the photopeak of the latter, at 580 keV, does not pile onto that of the former (9). Indeed, the consequences of the photopeak at 2,600 keV from Tl-208 could also result in a contribution to the counts for Pb-214 (295 and 353 keV) as well as the Bi-214, due to Compton scattering.

To investigate this, an exposed charcoal canister was corrected for background and then subject to spectrum stripping, by subtracting from it the spectrum of the cali-bration can which is solely due to radon-222 progeny. The results are presented in Figure 2 and by inspection, it appears that from 25 g of charcoal, there is no contribution from thoron progeny; certainly no obvious photopeaks due to Tl-208 at 2,600, 510, 580 or 860 keV.

This would be supported by an estimation of the amount of radon-220 adsorbed relative to the radon-222. Given that the flux ratio of radon to thoron at Nabarlek is expected to be 1:40, while the decay constants are 6,000:1, it is expected there will be about 140 times the number of radon atoms adsorbed onto the charcoal.

3. METHODOLOGY

Since the rip-rapped surface at Nabarlek follows an undulating pattern across the landscape, it was important not to introduce bias in the location of survey points. A regular grid may have located points on the crests or troughs of the landscape, rather than an equal selection of both. Moreover, revegetation has produced heavily grassed areas and patches with significant leaf litter. It was decided therefore to randomise the selection of survey points, to ensure independence.

A grid was mapped onto each location, each square 50x50 m^2 and co-ordinates for the survey point in each grid were computed from randomly generated numbers. Given the limitations of time, the number of points was typically limited to about 10. When more than about a dozen grid squares covered a given location, the restriction of time demanded that certain grid squares be selected and a random number generator was again used to choose which these would be. In total, 84 survey points were established on and off site; including nine environmental sites selected at arbitrary points that ranged from 50 to 2 000 metres from the perimeter fence. The x and y coordinates in each selected grid square were transformed to r,θ coordinates (range and bearing) and then a prismatic compass and tape measure used to approximately locate these points on site. The exact co-ordinates were then established using the Aircheck Digital Global Positioning System (DGPS), as eastings and northings in accord with WGS84. Additionally, three of the survey points were repeatedly measured over the 40 days of the survey, to gauge possible variation due to seasonally dependent parameters over that time. These control points included one point 500 metres off site, at the turnoff to the Myra Camp.

4. RESULTS

Table 1 includes the radon flux and radon activity concentration measured at the Control Sites. It is concluded that the radon flux has not been measurably affected by temperature variations of the canisters under field conditions. Similarly, the deployment of canisters in the morning or evening appears to be of little consequence and the use of insulation marginally reduces the standard deviation in the flux measured from the ground.

Table 2 shows the radon flux from selected locations on the Nabarlek Site. These results compare with the survey by Kvasnicka 3 years ago, when he estimated 4710 $mBq.m^{-2}\ s^{-1}$ for the former pit and 840 $mBq.m^{-2}s^{-1}$ for the Evaporation Pond 2. From the photograph of the site, it is clear that embedded rock forms a significant portion of the emanating surface, and their inclusion reduces the flux from measurements exclusively based on soft, porous material of the surrounding earth. These results must be normalised to their radium-226 content and, with radon in-growth over the next month, the samples will be assayed for this content.

By way of intercomparison, electrets were deployed with the charcoal canisters used to measure radon concentration and both were deployed alongside the radon station.

In 1993, the design for rehabilitating the pit area was unchanged; mill arisings of 680 000 tonnes compacted by a bulldozer, a top layer of stockpile pad and waste rock, then surface preparation for seeding. A 23 m cover at the centre and 14 m at the edge was planned, with a 1:20 slope. There was no anticipated problem from gully erosion at these slopes and slope lengths. The estimated erosion rate of 25 to 100 mm per 1,000 years in 1985, was revised to 22 mm per 1 000 years, with a calculated 635 000 years before exposure of the highest point of the tailings. It was further calculated that 5% of its present radioactivity would remain after that time.

The half value layer for compacted clay and screened (35mm) waste rock were both determined in 1986 to be approximately 80 mm for gamma radiation, which they assumed adequately attenuated, by the minimum 14 m thick cover. The radon flux from the bare tailings was calculated at 3.63 $Bq\ m^{-2}\ s^{-1}$ and the attenuation factor of the cover to be 2.00×10^{22} , following the Code of Practice and assuming 2.39×10^{12} Bq radium in secular equilibrium with the uranium, in the 680 000 tonnes of deposited tailings.

The calculations were similar to those performed in 1985, where the radon flux was determined to be 1.81×10^{-22} $Bq\ m^{-2}\ s^{-1}$ and the clay layer was removed from the design, since it was considered to have minimal effect.

We suggest that the source of radon contributing to an average flux from the pit of 1080 ± 860 $mBq\ m^{-2}\ s^{-1}$ is the waste rock.

ACKNOWLEDGMENTS

We acknowledge the permission of the Northern Land Council for access to the site and the advice and help of Paul Martin.

REFERENCES

(1) Uranium Information Centre, Melbourne (1997), *Former Australian Uranium Mines*
(2) Archer V. F. (1973) Lung cancer among uranium miners in the US, *Health Phys* 25, 351
(3) Leach, V. A. & Lokan, K. H. (1982) A Study of Radiation Parameters in an Open Pit Mine, *Health Phys* **43** (3) 363-375
(4) Martin, P. (1999) Radiological Impact Assessment of Uranium Mining, Ph D thesis
(5) Cohen B. L. & Cohen E. S. (1983) Theory and Practice of Radon Monitoring with Charcoal Absorption, *Health Phys* 45 (2) 501-508
(6) Storm J R & Patterson J R (1999) *ANZ Physicist* 36 (3) 97-101 Errata 36 (4) 150
(7) Spehr W. Johnston A. (1983) The Measurement of Radon Emanation Rates using Activated Charcoal, *Radiation Protection in Australia* 1 (3) 113-116
(8) Blue T E & Jarzemba M S (1992) A Model for Radon Gas Absorption on Charcoal for Open-faced Canisters in an Active Environment, *Health Phys.* 63 (2) 226-232
(9) Megumi K and Mamuro T. (1972) A Method for Measuring Radon and Thoron from the Ground, *J Geophys Res* 77 (17) 3052

TABLES

Table 1 includes the radon flux and radon activity concentration measured at the Control Sites.

Table 1: Summary of the Flux and Concentration at the Control Sites

site:								
	MYRA	month	Aug	Aug	Aug-Sep	Sep		
		date	13-16	20-23	30-2	10-13		
	J	(mBq.m-2.s-1)	**18**	**17**	**21**	**17**		
	[Rn]	(Bq.m-3)	**47**	**-11**	**32**			
	RADON STATION	Month	Aug	Aug	Aug	Aug-Sep	Sep	Sep
		Date	13-16	20-23	24-27	30-2	4-7	10-13
	J	(mBq.m-2.s-1)	**90**	**95**	**95**	**107**	**93**	**97**
	[Rn]	(Bq.m-3)	**98**	**139**	**201**		**133**	
	PLINTH D	month	Aug	Aug	Aug	Aug-Sep	Sep	Sep
		date	13-16	20-23	24-27	30-2	4-7	10-13
	J	(mBq.m-2.s-1)		**1125**		**857**		**866**

The average values for the radon-222 flux from each location on the Nabarlek site are presented in Table 2 below:

Table 2: Radon Flux from selected locations on the Nabarlek Site

SITE	J	+/- s.d.
	(mBq/m2 /s)	(mBq/m2/s)
PIT	1082	865
PROP	273	205
ORE STOCKPILE	77	60
ORE STOCKPILE RUNOFF POND	152	131
EVAPORATION POND 1 / TAILINGS DAM	172	86
EVAPORATION POND 2	105	101
TOPSOIL STOCKPILE	25	21
ENVIRONMENTAL SITES	90	137

AU0019576

The Internationalisation of Research Facilities

EMERITUS PROFESSOR T. M. SABINE
34/215 Bridge Rd Glebe NSW 2037

Summary

During the past twenty five years arrangements have been made for sharing the use of major national research facilities amongst the world community of neutron users.

The administrative requirements are simple. Scientists are invited to apply for measurement time. The scientific merit of the application is assessed by a committee appointed by the host organisation. If the application is considered to have sufficient merit time is allocated. The only costs to the user are transport and living expenses.

These arrangements have advantages for users and for hosts. The user can apply for time on the most suitable instrument. The host in the user country is freed from the responsibility of supplying all instruments. It can specialise in those instruments in which it has particular expertise.

The host retains, through its committee, complete control over the use of instruments. The amount of time allocated to international users is dependent on the national demand. The result is efficient use of national facilities.

An equally important result is the interaction between members of the international scientific community.

Australian scientists routinely use overseas facilities however Australia has refused to join the international group. There is international resentment to this attitude. We have, for example, powder diffraction facilities which others wish to use. We have no small-angle scattering facilities and must do our experiments at international centres.

I will argue that we should join the international community now. The capacity of the replacement reactor will be far greater than the internal Australian requirements. We will become the natural host for users from countries in the Asian region.

To enable us to make a smooth transition to this stage we should immediately advertise an international program for HIFAR.

*****

Application of Radiotracer Technology to the Study of Coastal Processes

PETER AIREY, RON SZYMCZAK, MYINT ZAW, JIYUAN TU, THOMAS KLUSS and JERRARD BARRY Australian Nuclear Science and Technology Organisation, Menai NSW 2234

SUMMARY: Recent progress at ANSTO in the applications of radiotracer techniques to the study of coastal processes is reviewed. Tracers are used in detailed studies of specific components of complex environmental systems and are applied to the evaluation and extension of numerical models. Examples include studies of the aggregation of sewage particles following release from ocean outfalls. The use of tracers to study the impact of storm events on bedload transport at depth has also been demonstrated.

1. INTRODUCTION:

In 1958, when the HIFAR reactor achieved criticality, radioisotope applications at Lucas Heights began expanding rapidly. By the mid-1960s radiotracing was being used in most major industrial sectors. The program expanded and matured over the intervening years to the extent that in 1999 ANSTO's interests in commercial industrial tracing were sold to the private sector. This paper will therefore focus on environmental applications.

The direction of the program has been determined by a number of factors including:

Advances in technology Although the techniques for monitoring radiotracers in the field have not altered greatly over the years, there have been major advances in a) micro-electronics, leading to enhanced instrument reliability and the ability to link detectors and associated instrumentation to global positioning systems and b) the visualisation of complex data.

Advances in numerical modelling: Applications of mathematical modelling techniques to environmental science are now very widespread and underpin much of our detailed understanding of coastal ecosystems. ANSTO's program involves the applications of tracers to the evaluation and extension of numerical codes.

Environment protection: Competition for environmental resources in a populated coastal zone is a major challenge. Indeed, the pollution of regional seas from land based activities is the first key issue for large-scale sustainability in the South East Asian region listed in the SARCS1999 *Integrated Study Science Plan* (1).

Much of ANSTO's recent work has involved the studying the fate and behaviour of particulates released from ocean outfalls (Szymczak et al (2), Zaw et al (3), Airey et al (4), (5)). The aim of this paper is to present readers with a report of the current status of the program.

2. CONTAMINANT TRANSPORT IN THE NEAR FIELD

2.1 Source Term Prediction

The prediction of a pollutant source term from its behaviour at a downstream observation point is a classical problem in tracer technology. The solution of the general problem requires inverse mathematical techniques. Because of the complexity of sewage systems, Barry *et al* (6) decided, as a first step, to address the simpler problem of predicting the response of the contaminant to a known source term. The essence of the research was to compare a conventional modelling with an artificial neural network (ANN) approach. Experimentally, the response at the Cronulla Treatment Plant to the approved low level releases of tritium in ANSTO's normal effluent was studied. In sewage systems there are countless extraneous factors which are not included in either modelling approach. Although this was a driving force in exploring the neural networks, the ANN approach did not prove superior in this study.

2.2 Near Field Dilution Factors

In most investigations of sewage released to the ocean, the tracers ^{198}Au and tritium in the form of tritiated water HTO have been chosen. ^{198}Au is a gamma emitting isotope and can be detected by field detectors deployed from the survey vessel. Tritium is the 'perfect' tracer for water and is used to obtain absolute dilution factors. ANSTO and the Unisearch Water Research Laboratory (WRL) were involved for a number of years in the radiotracer evaluation of predictive models for the transport of sewage from the deep ocean outfalls off Sydney (Pritchard (7)). The outfalls were modelled by WRL using the RMA suite of codes (King *et al* 1973 (8), King 1998 (9)).

Subsequently, the two groups were involved in tracer studies at the North West New Territories (NWNT) sewage outfall, Hong Kong. The work was undertaken for the HK Environmental Protection Department through a consultancy managed by Montgomery Watson HK and involving the survey company EGS (Asia) and the University of Hong Kong. One of the outcomes of this work was a comparison of observed effluent dilutions from tracer studies with those predicted by the near-field numerical model JETLAG (Horton *et al* (10), (11)). Good agreement was found. This enhanced the confidence with which the model could be used for predicting near field dilution factors.

2.3 Radioisotope and Fluorescent Dye Tracers

The above mentioned study also involved a comparative evaluation of the radiotracer gold-198 and the fluorescent dye tracer rhodamine-WT. The tracers were released simultaneously by ANSTO and EGS (Asia) respectively. The outputs of the scintillation probes and the fluorimeter were integrated into a central computer and linked to the navigation system. The correlations were excellent. Under the conditions of the experiment, the sensitivities of the two techniques were comparable. Special attention is therefore being paid to investigations where fluorescent tracers are not so effective. These include studies of sand and sediment transport and work in highly polluted areas.

2.4 Near Field Dispersion Modelling

To better understand the fate and behaviour of effluents released to the sea from engineered structures, a two phase turbulent flow model of the prototype of the Malabar outfall near Sydney has been developed. A Lagrangian approach is being used to track individual particles and the output is presented as a flow field or a particle density field. Advances in computational efficiencies have been made (Tu (12), Ye *et al* (13)).

3. CONTAMINANT TRANSPORT IN THE FAR FIELD

3.1 Particle Aggregation

Research is currently focused on the fate and behaviour of particulates, because they are little understood, they play a significant role in the transport of environmental pollutants and there are currently no cost-effective alternatives to radioisotopes for tracing. Complementary laboratory and field studies have been made of the behaviour of particulates released from the Burwood Beach Outfall near Newcastle NSW (Zaw et al (3), Airey et al (4) and (5)). Briefly, it was found that both the particle size, and the porosity (monitored by the fractal dimension) increased with distance from the outfall.

Enhanced porosity leads to entrainment of water within the structure. Since the particles are moving from a lower density effluent to higher density sea water, the entrained water will lead to a net buoyancy effect. This is consistent with the observation that the sewage particulates did not settle from the radiolabelled plume during the five hour field observations. There would be clear advantages in complementing radiotracer studies with emerging technologies for the *in situ* measurement of particle size distributions.

Significant success has been achieved in modelling particle aggregation in the laboratory (4). The ultimate goal is to incorporate the physical model into an environmental fluid dynamic code.

3.2 Environmental Fluid Dynamic Modelling

Far field modelling at Burwood Beach is being progressed using the Environmental Fluid Dynamic Code (EFDC) of the Virginia Institute of Marine Science (Hamrick (14)). Detailed information on the dispersion of the sewage plume over a five hour period was obtained from the radiotracer study. As indicated above, the plume rose to the surface on the day of the study. There was no evidence for settling of the particulates. Consequently, the tracer plume could only be modelled satisfactorily by taking into account the impact of the wind field on the current patterns in the upper layers of the water column. A Lagrangian approach is being used to model the migration of the labelled sewage particles (4).

4 SAND AND SEDIMENT TRANSPORT

4.1 Sediment gauge

ANSTO has assembled a sediment gauge based on an Amdel ^{137}Cs gauge designed for the on-line monitoring of mineral slurry densities. The output of the radiation detector is linked to a marine water quality meter through the Labview® virtual instrument package.

4.2 Bedload transport

Radiotracer techniques have been used for decades to study bed load transport and applied to engineering problems associated with port development and dredge spoil dumping. In more recent times there has been a growing interest in the impact of major, infrequent events on sediment transport.

In the first instance, an attempt has been made to study the impact of storms on the migration of sediment at depth. ^{192}Ir glass with a particle size distribution matching that of the glass was used as a tracer. The ^{192}Ir (half life 74 days) was chosen because it emits gamma rays of convenient energy and can be used for studies over many months. Specifically, three vials each of 10 GBq ^{198}Ir were released 2 km from the Bondi, NSW coastline at the 68m contour.

A preliminary flume study was undertaken by the WRL to assess the strength of the current needed to mobilise the sized iridium glass beads. Wave climate data and current vectors near the surface and 12 m from the bottom were available from the Ocean Reference Station located in the general vicinity.

Observations of tracer contours were made over a nine month period with a resolution of less than 4 m. At the end of the period, the points of release of each vial could still be identified. Some dispersion was observed, but no systematic migration despite three significant storm events.

5. GENERAL IMPACT OF THE PROGRAM

5.1 Commercial

ANSTO supports commercial activities principally concerned with the applications of tracers to the post commissioning trials of sewage outfalls. Between 1991 and 1994, a series of investigations was undertaken for the NSW Environment Protection Authority and Sydney Water in association with Unisearch WRL. Over the past three years ANSTO, WRL and EGS (Asia) have contributed to a number of such trials in Hong Kong. The ultimate client is the HK Environment Protection Department with managing consultants either Montgomery Watson (HK) or Mouchel (Asia).

5.2 IAEA programs

ANSTO actively supports IAEA programs. Australia through ANSTO is a designated lead country for the IAEA/UNDP Regional Cooperative Project: *Management of the Marine Coastal Environment and its Pollution.* This project is a vehicle for building specific capabilities underpinning the application of nuclear techniques to sustainable development in the coastal zone.

6. CONCLUSIONS

Tracer techniques complement the modelling approach to the study of complex systems. Tracers permit the detailed study of individual components of a system and are particularly useful in evaluating predictive models. This was illustrated with a number of examples including the transport of effluent along sewage pipelines, as well as contaminant transport in the near and far fields.

Advances in technology have enabled the linking of radiation detectors and associated instrumentation to global position fixing systems. Much more precise data can be collected, with the consequences that a reduced level of radiotracer is frequently required and more sophisticated questions may be addressed. Examples of the latter include studies of the aggregation sewage particles in the field and of the impact of storms on the migration of sand at depth.

ACKNOWLEDGMENTS:

Gratitude is expressed to the many organisations with which ANSTO has worked over the years in implementing the program. Those supporting programs referenced in this text include: Unisearch Water Research Laboratory, the Hunter Water Corporation, the NSW Environment Protection Authority, the Sydney Water Corporation, the Hong Kong Environment Protection Department, Montgomery Watson (HK) and EGS (Asia).

The special contributions of the following colleagues are acknowledged with gratitude: Mr Graham Spelman, Mr Nigel Wood, Dr Jagoda Crawford, Dr Garry Pantelis of ANSTO and Dr Qing He of the State Key Laboratory for Estuarine and Coastal Research, Shanghai, China.

REFERENCES

(1) South East Asian Regional Committee for START (1999) *Integrated Study Science Plan,* Chap. 1 "The Changing Environment of South East Asia" Section 'Sustainable Development Strategies'

(2) Szymczak, R., Airey, P. and Tu, J.Y. (1999) Application of Radioisotope Tracer Technology to the Development and Validation of Computational Models for Sediment and Contaminant Transport in the Coastal Zone. *International Atomic Energy Agency TecDoc on Marine Pollution,* IAEA-TECDOC-1094, p. 536-537.

(3) Zaw M., Szymczak R. and Airey P. (1999). "Influence of Salinity on the Aggregation of Sewage Particles Discharged to a Coastal Marine Environment". *Proc. of the Australian Water and Wastewater Association, 18th Federal Convention,* Adelaide, CD ROM, 8 pp

(4) Airey P., Zaw M., Szymczak R, Kluss T., Tu J.Y. Barry J. and Qing He (1999), 'Application of Radiotracer Techniques to the Validation of Contaminant Transport Models at Sewage Outfalls' *Proc of the Conference Global 99* (Jackson Hole Wyoming, August 1999) CDROM Paper 145.

(5) Airey P., Zaw M., Tu J.Y., Kluss T., Szymczak R. and Qing He (1999)'The Role of Radiotracer Techniques in Off-shore Contaminant Transport Studies' *Proc Third International Conference on Isotopes (3ICI)* Vancouver 6-10 September 1999.

(6) Barry J, Crawford J and Airey P (1999) Predicting Transit Times and Flow Concentrations through a Metropolitan Sewage System. *Proc. CTAC 99 Conference* Canberra 20 - 24 September 1999.

(7) Pritchard T.R., Lee R.S. and. Davison A (1993)., "Sydney Deepwater Outfalls: In situ Observations of Plume Characteristics", *Proc. Eleventh Conference on Coastal and Ocean Engineering,* Townsville pp 53 - 58

(8) King, I.P., Norton, W.R. and Orlob, G.T. (1973), A Finite Element Solution for Two-Dimensional Density Stratified Flow, report prepared by Water Resources Engineers, Walnut Creek California, for the U.S. Department of the Interior, Office of Water Resources Research.

(9) King, I.P. (1998). RMA2 - A Two Dimensional Finite Element Model for Flow in Estuaries and Streams - Version 6.5. Dept of Civil Engineering University of California Davis, Ca., August, 1998.

(10) Horton P.R and Wilson J.R (1996) 'NWNT Sewage Outfall, Urmston Road, Hong Kong, Comparison of Near-Field JETLAG Model-ing with Tracer Experiments' Australian Water and Coastal Studies Report 96/29.

(11) Horton, P.R, Airey P.L and Wilson J.R (1997) 'Radioactive and Dye Tracer Studies for the NWNT Sewage Outfall, Hong Kong and Comparison to Near-Field Modelling' Proc .Second Int Conf Isotopes (2ICI) Sydney

(12) Tu J.Y. (1997) ' An Efficient Method for Modelling Two-Phase Flow' ISAC'97 High Performance Computing on Multi-Phase Flow (Ed Y Matsumoto, A Prosperetti) p105

(13) Ye S.Z. and Tu J.Y. (1997) ' Numerical Modelling of Mixing Flow near an Ocean Outfall' *ibid*

(14) Hamrick J. M. (1992) *A three-dimensional environmental fluid dynamics computer code: Theoretical and computational aspects* Special Report in Applied Marine Science and Ocean Engineering (Virginia Institute of Marine Science, Gloucester Point, VA 23062)

AU0019578

Historical Rates of Erosion of the Australian Landscape as Measured with Beryllium-10

S. RYMERS, E. MANCINI and L. HARMAN
Ecology Group, Lake Gininderra College, Canberra

L. K. FIFIELD, M. L. DI TADA, P. A. HAUSLADEN and G. DOS SANTOS
Department of Nuclear Physics, RSPhysSE, Australian National University

R. J. WASSON
Centre for Resource and Environmental Studies, Australian National University

David Culley Memorial Award Scheme for Nuclear Science in Secondary Schools

The Australian Nuclear Association makes an annual award to a selected secondary school with an interest in furthering its activities in nuclear-related science. This award is in memory of the ANA's past treasurer, David Culley, a former secondary school science teacher, who was involved in nuclear science and technology training programs for many years as an Ansto employee. The award for 1999 has been made to the Ecology Group at Lake Gininderra College in Canberra for the project outlined below. It is being carried out in collaboration with researchers from the Department of Nuclear Physics and the Centre for Resource and Environmental Studies at the Australian National University.

The project - Historical Rates of Erosion of the Australian Landscape as Measured with Beryllium-10

The Australian landscape is a very old one. It is a continent of low relief, and hence soil production rates are very low. Further, it has not been glaciated for millions of years so that the rock from which the soil is forming is very well weathered and low in nutrients. Farming practises introduced by European settlers have resulted in accelerated soil loss, and along with the realisation of this problem has come the desire to minimise further loss and to develop a sustainable system of agriculture. In order to address these issues, it is necessary first to know what were the pre-European rates of soil production and soil loss.

It is possible to use the isotope beryllium-10 (^{10}Be) to shed some light on these processes. Beryllium-10 is a radioactive isotope with a very long half life of 1.5 million years. It is produced naturally in the atmosphere when high energy cosmic rays strike and fragment the nuclei of nitrogen and oxygen atoms. The ^{10}Be atoms so formed attach readily to aerosols and fall out to the surface in rainfall at a rate of about 1.5×10^4 atoms /cm^3 of rainfall.

As the rainwater percolates into the soil, these ^{10}Be atoms attach very firmly to soil particles. To a first approximation, they may be considered to follow that soil particle throughout its subsequent history. Hence, the total inventory of ^{10}Be in a soil column can tell us the residence time of that soil, while the surface concentration of ^{10}Be can tell us the rate at which it is being lost.

Because the number of ^{10}Be atoms is extremely small, typically 10^8 atoms (about 2 femtograms - 10^{-15} grams) per gram of soil, an extremely sensitive technique is required in order to measure them. The only technique with the required sensitivity is accelerator mass spectrometry, and we are using the 14 UD tandem accelerator of the Department of Nuclear Physics at the ANU for this purpose.

The site chosen for this study is a forested hill-slope in the Tinderry Ranges near Burra, south of Canberra. Three pits were dug, and soil profiles collected, near the top, middle and bottom of the slope in order to obtain information not only on residence times and erosion rates of the soil, but also on its movement down the slope. In addition, samples were collected from an erosion cut in the gully at the bottom of the slope. At this site, rainfall is about 70 cm per year, and hence the ^{10}Be fallout rate is about 10^6 atoms/cm^2/year.

The poster will present details of the site and sample collection, of the chemical preparation of the samples, and of the accelerator mass spectrometry measurements. A preliminary interpretation of the data in terms of residence times, erosion rates, and down-slope processes will be presented.

An Application of Neutron Activation Analysis to Determine the Pathways of Underground Streams using Bark from Eucalypt Trees (Ironbark) within an Afforested Region near Rushworth, Central Victoria

KARL NELMS
Trinity Grammar School Kew Victoria 3101

David Culley Memorial Award 1998-1999

A group of Year 11 students from Trinity Grammar School, Kew, Victoria, together with advice from Dr David Garnett of Becquerel Laboratories, Lucas Heights, devised a program seeking evidence for the delineation of the pathways(s) of underground stream(s) within a uniform region of eucalypt (ironbark) forest in the Rushworth region of Central Victoria.

Bark and soil samples from representative grid sectors within the forest region were prepared for irradiation at HIFAR by the students and onforwarded to Lucas Heights for irradiation. After removal from the reactor the samples are to be analysed for evidence of differential elemental transfer rates in bark and soil.

The display presents examples of the various stages of the overall project resulting from the award to the School of the David Culley Memorial Award of the Australian Nuclear Association.

Assistance throughout the project from Dr David Garnett is appreciated.

INDEX OF AUTHORS