NSAC Subcommittee on Isotopes

Charge 1

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AND

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Science Goals in Nuclear Physics

- Quark Structure of Nucleon
- Quark gluon plasma
- Nuclear Structure
- Nuclear Astrophysics
- Fundamental Studies
- Nuclear Physics Applications
  - Nuclear Data, Isotopes
ESSAY

Accelerating production of medical isotopes

The global problem of a safe and reliable supply of radioactive isotopes for use in critical hospital procedures can be solved with accelerators, not nuclear reactors, says Thomas Ruth.

February 17, 2009
Mo-99 production resumes at troubled European isotope reactor

DiagnosticImaging.com
The Fiscal Year (FY) 2009 President's Request Budget proposes to transfer the Isotope Production Program from the Department of Energy (DOE) Office of Nuclear Energy to the Office of Science's Office of Nuclear Physics and rename it the Isotope Production and Applications Program. In preparation for this transfer, NSAC was requested to establish a standing committee, the NSAC Isotope (NSACI) sub-committee, to advise the DOE Office of Nuclear Physics on specific questions concerning the National Isotope Production and Applications (NIPA) Program.

NSACI constituted for a period of two years as a subcommittee of NSAC. It will report to the DOE through NSAC who will consider its recommendations for approval and transmittal to the DOE.

The Subcommittee is asked to establish the priority of research isotope production and development, and to form of a strategic plan for the NIPA Program.
Workshop in August

Questions Asked

Who uses isotopes and Why?

Who produces them and Where?

What are the needs today and in the future?

What is the status of the supply/what is missing?

What options for increasing availability/technical hurdles?
A reliable program in isotope production at DOE is crucial for the long term health of developments in medicine, basic physical and biological sciences, national security and industry.

Many of isotopes in domestic use are produced only by foreign suppliers.

Affordability

The production capability of the NIPA program relies on facilities that are operated by DOE for other primary missions.

There is a pressing need for more training and education programs in nuclear science and radiochemistry to provide the highly skilled work force for isotope application.

NP resources...
Nuclear Science Advisory Subcommittee on Isotopes

Charge 1:

As part of the NIPA Program, the FY 2009 President’s Request includes $3,090,000 for the technical development and production of critical isotopes needed by the broad U.S. community for research purposes.

NSACI is requested to consider broad community input regarding how research isotopes are used and to identify compelling research opportunities using isotopes.

The subcommittee’s response to this charge should include the identification and prioritization of the research opportunities; identification of the stable and radioactive isotopes that are needed to realize these opportunities, including estimated quantity and purity; technical options for producing each isotope; and the research and development efforts associated with the production of the isotope. Timely recommendations from NSACI will be important in order to initiate this program in FY 2009; for this reason an interim report is requested by January 31, 2009, and a final report by April 1, 2009.
NSACI Subcommittee

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Kenny Jordan
Association of Energy Service Companies
Nuclear Science Advisory Subcommittee on Isotopes

Nov. 13-14, 2008  Organizational meeting
                 Publicize our charges, seek community input
Dec. 15-16, 2008  Get input from government agencies
Jan. 13-15, 2008  Input from customers,
                 Ideas for production research R&D
                 Research priorities recommendations
Jan. 31, 2009     First interim report due
Feb. 10-12, 2009  2-day Meeting to hear plans for facility and
                 infrastructure improvements
Mar. 25-27, 2009  3 day meeting
                 Finalize report for 1st charge
                 Decide on recommendations for Long Range Plan
April 1, 2009     Final report for first charge submitted by NSACI
April 2009        Write report on second charge
June 2009         Meeting to finalize 2nd report
July 31, 2009     Final report for second charge submitted by NSACI
Federal Agencies Contacted

Air Force Office of Scientific Research, Armed Forces Radiobiology Research Institute, Department of Agriculture, Department of Defense, Department of Energy - Fusion Energy Sciences, Department of Energy-National Nuclear Security Administration - Nuclear Non-proliferation, Department of Energy-Basic Energy Sciences, Department of Energy-Biological and Environmental Research, Department of Energy-Nuclear Physics, Department of Homeland Security, Environmental Protection Agency, Federal Bureau of Investigation, National Cancer Institute, National Institute of Allergy and Infectious Disease, National Institute of Biomedical Imaging and Bioengineering, National Institute of Drug Abuse, National Institute of Environmental Health Science, National Institute of General Medical Science, National Institute of Standards and Technology, National Science Foundation - Directorate for Engineering, National Science Foundation - Directorate for Mathematical and Physical Sciences, National Science Foundation- Directorate for Biological Sciences, Office of Naval Research, State Department, U. S. Geologic Survey

DOE-NIH Working Group
Professional Societies Contacted

Academy of Molecular Imaging, Academy of Radiology Imaging, Academy of Radiology Research, American Association of Physicists in Medicine, American Association of Cancer Research, American Chemical Society, American Chemical Society - Division of Nuclear Chemistry and Technology, American College of Nuclear Physicians, American College of Radiology, American Medical Association, American Nuclear Society, American Nuclear Society - Division of Isotopes and Radiation, American Pharmacists Association - Academy of Pharmaceutical Research and Science (APhA-APRS), American Physical Society, American Physical Society - Division of Biological Physics, American Physical Society - Division of Material Physics, American Physical Society - Division of Nuclear Physics, American Society of Clinical Oncology, American Society of Hematology, American Society of Nuclear Cardiology, American Society of Therapeutic Radiation and Oncology, Council on Ionizing Radiation and Standards, Health Physics Society, National Organization of Test, Research and Training Reactors, Radiation Research Society, Radiation Therapy Oncology Group, Radiochemistry Society, Radiological Society of North America, Society of Molecular Imaging, Society of Nuclear Medicine
Trade Groups contacted

Association of Energy Service Companies

Council on Radionuclides and Radiopharmaceuticals

Gamma Industry Processing Alliance

International Source Suppliers and Producers Association

Nuclear Energy Institute
Nuclear Science Advisory Subcommittee on Isotopes

Report Outline

1. General Introduction on the broad use of isotopes

2. Landscape of production
   Common issues to all areas....
   stables/radioactives, nat/int.

3. Medicine, Pharmaceutical and Biology
   Research in Biology/Pharma
   Diagnostic and Therapeutic

4. Basic Physical Science/Engineering Research

5. Security Applications of Nuclear Science
   DHS, NNSA, AFCI, GNEP

6. Summary and Recommendation
Chapter 1: Introduction

Introduction to the use of isotopes
(vital to health of US science & Technology)

Basic Nuclear Science
Medicine (imagine/therapeutic)
Energy
Security
Forensics
Nuclear Physics Applications

Energy
- ADS systems
- Fusion confinement
- Nuclear Waste
- Nuclear Data

Nuclear Forensics
- Homeland Security
- Risk Assessments
- Nuclear Trafficking
- Proliferation

Life Science
- Medical Diagnostics
- Medical Therapy
- Radiobiology
- Biomedical tracers

Material Analysis
- Ion Implantation
- Material Structure
- Geology & Climate
- Environment
- Art & Archaeology

Nuclear Defense
- Weapon Analysis
- Functionality Simulation
- Long-Term Storage
Chapter 2: Production Landscape

Landscape of Isotope Production at DOE

Reactors
Accelerators
Private sector production: distillation, chemical exchange, thermal diffusion...

How do we define Research?
Chapter 3: Biology, Medicine, Pharma

Science and Application
  Therapeutic
  Imaging
  RadioPharma
Nuclear Imaging

Blood flow with radiopharmaceuticals

- Gamma Camera
- SPEC & PEP

Tumor mapping & visualization by radioactive isotope accumulation.

Imaging software and analysis

Imaging system development
Radiation Treatment

- Brachytherapy
- Gamma therapy
- Neutron therapy
- Heavy ion therapy

Treatment plan with 2 heavy ion fields

Treatment plan with 9 photon fields IMRT
<table>
<thead>
<tr>
<th>Research activity</th>
<th>Isotope</th>
<th>Issue/Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha therapy</td>
<td>$^{225}\text{Ac}$, $^{211}\text{At}$, $^{212}\text{Pb}$</td>
<td>extraction of $^{229}\text{Th}$ from $^{233}\text{U}$, cyclotrons capable of $^4\text{He}$ acceleration</td>
</tr>
<tr>
<td>Diagnostic dosimetry</td>
<td>$^{64}\text{Cu}$, $^{86}\text{Y}$, $^{124}\text{I}$, $^{203}\text{Pb}$</td>
<td>$^{67}\text{Cu}$ therapy, $^{90}\text{Y}$ therapy, $^{131}\text{I}$ therapy, $^{212}\text{Pb}$ therapy</td>
</tr>
<tr>
<td>Diagnostic tracer</td>
<td>$^{89}\text{Zr}$</td>
<td>stem cell trafficking</td>
</tr>
<tr>
<td>Therapeutic</td>
<td>$^{67}\text{Cu}$</td>
<td>high energy production (enriched target)</td>
</tr>
</tbody>
</table>
Chapter 4: Basic Physical Sciences/Engineering

Nuclear Science-
  Structure -
  Fund. Symmetries/Physics Beyond Standard Model
Energy
Chemistry
Environmental
Materials
Material Treatment and Analysis of Artifacts

Implantation and irradiation from silicon chips to solar sails

Dating real and false mummies
Neutrino Physics -
Particle and Nuclear Physics

Last decade opened new era of nuclear physics, the study of low energy neutrinos from sun and supernova and in laboratory decay.
Fundamental Symmetries

Standard Model Initiative

What are the neutrino masses?
Tritium decay measurements with KATRIN

Are neutrinos their own antiparticles?
Neutrino less double beta decay measurements
In background free underground environments
(Gran Sasso, SNO, WIPP, ...)

Violation of CP symmetry (matter anti-matter balance) by neutrino oscillation and neutron EDM measurements (ultra-cold neutrons at Los Alamos, SNS, PSI ...
designed for experiments that require extremely low cosmogenic backgrounds: in particular, the search for neutrino-less double beta decay and relic dark matter.
OECD Report: Roadmap for existing and planned underground laboratories with the size of the box corresponding to the relative space for experiments at each depth. These facilities are typically shared or primarily funded by other disciplines such as particle astrophysics.

### Accelerators

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</thead>
<tbody>
<tr>
<td>Rare Isotope Beams</td>
<td>Canada</td>
<td>ISAC I</td>
<td>ISOLDE</td>
<td>ISAC II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CERN</td>
<td>France</td>
<td>GANIL/SPIRAL</td>
<td>SPIRAL II</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Germany</td>
<td>Japan</td>
<td>SIS</td>
<td>IARF</td>
<td>RIBF</td>
<td>FRIB</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>USA</td>
<td>NSCL/HIBF</td>
<td>LHC</td>
<td>FAIR</td>
<td>FAIR</td>
<td>RHIC II</td>
</tr>
<tr>
<td>High Energy Heavy Ions</td>
<td>CERN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>USA</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Hadrons</td>
<td>Germany</td>
<td>KEK-PS</td>
<td></td>
<td>J-PARC</td>
<td>FAIR</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>USA</td>
<td>AGS</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Electrons</td>
<td>Germany</td>
<td>MAMI</td>
<td></td>
<td>MAMI C</td>
<td>CEBAF</td>
<td>CEBAF-12 GeV</td>
</tr>
<tr>
<td>USA</td>
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<tr>
<td>Canada</td>
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<tr>
<td>Europe</td>
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<tr>
<td>Japan</td>
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</tbody>
</table>
Goals far off Stability

- Nuclear Masses & decay properties
- Neutron halos
- Disappearance of shell structure
- Emergence of new shapes
- New collective modes of excitation
- Mapping the driplines
- Islands of stability
## Science Opportunities

<table>
<thead>
<tr>
<th>Order</th>
<th>Isotope</th>
<th>Use</th>
<th>Supplier</th>
<th>Status</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$^{252}$Cf (2.6 yr)</td>
<td>Fission source for CARIBU at ANL</td>
<td>HFIR/ORNL</td>
<td>Possibly available in required form</td>
<td>~1 Ci/3yrs ~$0.5M/Ci</td>
</tr>
<tr>
<td>2</td>
<td>$^{225}$Ra (15 d)</td>
<td>EDM expt at ANL</td>
<td>ORNL; $^{233}$U/$^{229}$Th decay</td>
<td>Needs to be extracted and processed</td>
<td>~5 mCi/2 months Need 10mCi/2 mos.</td>
</tr>
<tr>
<td>3</td>
<td>Various actinides</td>
<td>Targets for searches for super heavy elements</td>
<td>HFIR/ORNL</td>
<td>Some are available; $^{241}$Am, $^{249}$Bk, $^{254}$Es not available</td>
<td>10 - 100 mg on a regular basis; purity is important</td>
</tr>
<tr>
<td>4</td>
<td>$^{28}$Si</td>
<td>Avogadro project - worldwide weight standard based on pure $^{28}$Si crystal balls</td>
<td>DOE Russia</td>
<td>Concern about future supply and cost</td>
<td>kilograms</td>
</tr>
<tr>
<td>5</td>
<td>$^{236}$Np, $^{236,244}$Pu, $^{243}$Am, $^{229}$Th</td>
<td>Isotope dilution mass spectrometers</td>
<td>ORNL; Russia?</td>
<td>Most available; high purity $^{236}$Np is not</td>
<td>10 - 100 mg on a regular basis; purity is important</td>
</tr>
<tr>
<td>6</td>
<td>$^{76}$Ge</td>
<td>Double beta decay expt</td>
<td>Russia</td>
<td>US cannot produce quantity needed</td>
<td>~ 1000 kg</td>
</tr>
<tr>
<td>7</td>
<td>$^{202,203,205}$Pb, $^{206}$Bi, $^{210}$Po</td>
<td>Spikes for mass spectrometers</td>
<td>ORNL Russia</td>
<td>$^{202,205}$Pb difficult to get in high purity</td>
<td>Grams</td>
</tr>
<tr>
<td>8</td>
<td>$^{3}$He</td>
<td>Neutron detectors, EDM, etc</td>
<td>Savannah River Russia</td>
<td>Total demand exceeds that available</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>$^{147}$Pm</td>
<td>Radioisotope micropower</td>
<td>Not available</td>
<td>Fission product</td>
<td></td>
</tr>
</tbody>
</table>
Chapter 5: Security and other applications

Detection ($^3$He...)
Forensics
Standards
Nuclear Forensics

Homeland Security

Trafficking of nuclear materials & material loss assessments

Border control & radiation exposure (instrumentation)

Provenance of radioactive material by isotope composition or material structure analysis

- Signature identification,
- Detector array development
- Sensitivity analysis
Recommendations for Charge 1

Compelling Research Opportunities Using Isotopes

There are compelling research opportunities using alpha-emitters in medicine. Development and testing of therapies using alpha emitters are very promising for the medical field. NSACI is aware of the research opportunities and the timeliness of the issue since the downbleeding of $^{233}$U.

1. Invest in new production approaches of alpha-emitters, ex: $^{225}$Ac. Extraction of the thorium parent from $^{233}$U is an interim solution that needs to be seriously considered for the short term until other production capacity can become available.
A unified conclusion of the NSACI panel was to maximize the production and availability of domestic isotopes in the US through investments in research and coordination activities between existing accelerators. The panel felt that such a network could benefit all areas of basic research and applications from security to industry.

2. We recommend investment in coordination of production capabilities and supporting research to facilitate networking among existing accelerators.

This should include R&D to standardize efficient production target technology and chemistry procedures.
Recommendations for Charge 1

Compelling Research Opportunities Using Isotopes

The basic physical sciences and engineering group prioritized the availability of californium, radium and other trans-uranic isotopes as particularly important for research.

3. We recommend the creation of a plan and investment in production to meet these research needs for heavy elements.
Experts in the nuclear security and applications areas strongly feel the vulnerability of supply from foreign sources. Additionally, the projected demand for $^3$He by national security agencies far outstrips the supply. This would likely endanger supply for many other areas of basic research. While it is beyond our charge, it would be prudent for DOE and DHS to seriously consider alternative materials or technologies for their neutron detectors to prepare if substantial increases in $^3$He production capacity cannot be realized.

4. We recommend a focused study and R&D to address new or increased production of $^3$He
Compelling Research Opportunities Using Isotopes

While no single stable isotope except $^{28}\text{Si}$ ($^3\text{He}$ is stable but obtained from the beta-decay of $^3\text{H}$, not by isotope separation) reached the level of the highest research priority, the broad needs for a wide range of stable isotopes and the prospect of no domestic supply raised this issue in priority for the subcommittee. NSACI feels that the unavailability of a domestic supply poses a danger to national security. The subcommittee also recommends:

5. Research and Development should be addressed to preparing to re-establish a domestic source of stable research isotopes.
Recommendations for Charge 1

Compelling Research Opportunities Using Isotopes

Vital to the success of all scientific endeavors is the availability of trained workforce. While the scientific opportunities have expanded far beyond the disciplines of radiochemistry and nuclear chemistry, the availability of trained personnel remains critical to the success of research in all frontiers of basic science, homeland security, medicine, and industry.

6. We therefore recommend that a robust investment be made into the education and training of personnel with expertise to develop new methods in the production, purification and use of stable and radio-active isotopes.

Skilled workforce in areas of National Need