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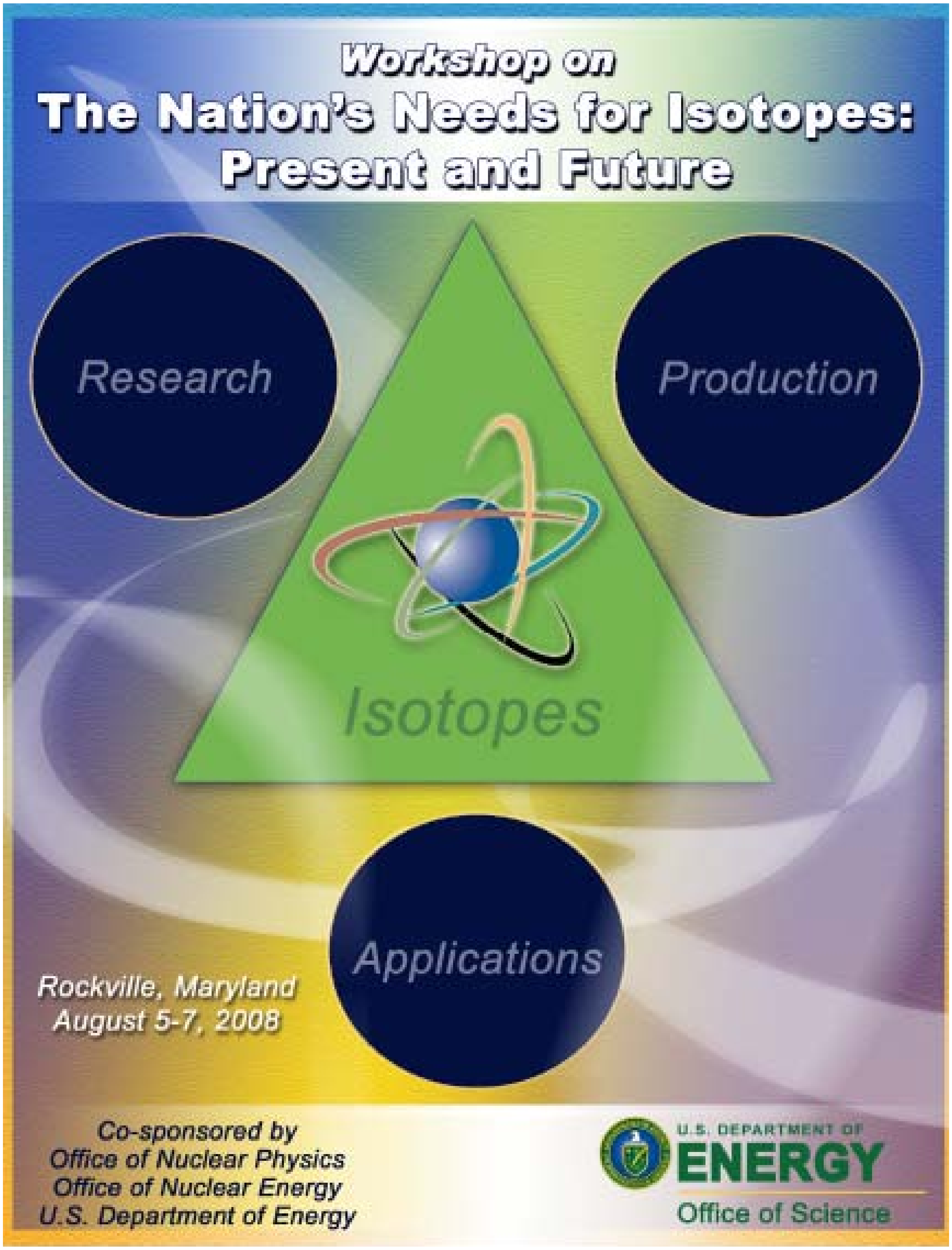

Workshop on

The Nation's Needs for Isotopes: Present and Future

Rockville, Maryland
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Jeff Norenberg, University of New Mexico
Parrish Staples, National Nuclear Security Administration
Robert Atcher, Los Alamos National Laboratory
Robert Tribble, Texas A&M Cyclotron Institute
Jack Faught, Spectra Gases, Inc.
Lee Riedinger, University of Tennessee

Table of Contents

EXECUTIVE SUMMARY

Today, hundreds of different stable and radioactive isotopes – each with unique physical and chemical properties – play critical roles in a variety of technological applications of importance to our modern society and are also vital to scientific research in medicine, physics, chemistry, and environmental and material sciences. Areas in which isotopes play important roles include homeland and national security (e.g., defense programs and stockpile stewardship), drug discovery, nutrition research, the search for and development of new energy resources (both nuclear and petrochemical), industrial applications (material and food sterilization, tracers, radiography, nuclear energy), agriculture, and clinical health care diagnostics and therapeutics.

The U.S. Department of Energy (DOE) has supplied isotopes and isotope-related services to the Nation and to foreign countries for more than 50 years. The DOE Isotope Program produces, within the constraints of available funds, isotopes that are not produced commercially or that are identified as being in short supply. With the fiscal year (FY) 2009 President's Budget Request to Congress, DOE proposes to move the Isotope Program, currently in the Office of Nuclear Energy (NE), to the Office of Nuclear Physics (NP) within the Department's Office of Science. The NP's goal is to create an optimized and prioritized program for the development and production of key isotopes for use in research, medicine, industry, and national security, while obtaining broad community input and operating within available resources. To help guide the NP in this endeavor, the *Workshop on the Nation's Needs for Isotopes: Present and Future* was held in Rockville, Maryland on August 5-7, 2008. The workshop assembled, for the first time, stakeholders from all the different areas of the diverse isotope community – universities, medical institutions, national laboratories, the private sector, and the U.S. government – to discuss the Nation's current and future needs for stable and radioactive isotopes and to consider options for improving the availability of needed isotopes. The workshop was intended to be the first step in developing a robust and prioritized program for NP.

More than 200 isotopes were discussed at the workshop, and more than 30 key isotopes were identified by the community as being in short supply (for specifics, see Table 11 in the Conclusion). To simplify and focus the discussions, the isotopes were divided into three broad categories: stable and enriched isotopes, radioisotopes for research and development, and radioisotopes for applications. For each of the categories a working group outlined the current situation and needs for the future, and discussed options for meeting those needs:

- *Stable and Enriched Isotopes*: Although most, but not all, of the current demands for stable and enriched isotopes are being met by either domestic or foreign suppliers, it was noted that there has been no active domestic production since the Electromagnetic Calutrons Enrichment Facility at Oak Ridge National Laboratory (ORNL) was put into standby in 1998. As a result, the supply of several isotopes has been exhausted, and the supply of others is becoming critically low. About 12 stable isotopes were identified as no longer available domestically or estimated to have less than three years before the supplies are completely consumed. In particular, the demand for the isotope helium-3 (^{3}He), which is a by-product of tritium, exceeds the current supply and production capability. ^{3}He is used in neutron detectors, which are of great importance for national security. Germanium-76 (^{76}Ge) is needed in macro quantities for key nuclear physics experiments, but at present it is not available domestically. Demand is increasing for certain enriched isotopes (e.g., calcium-48 [^{48}Ca]) to generate special accelerator beams for research. Because of the lack of production capabilities in the United States, several stable isotopes – such as oxygen isotopes for the production of such important positron emission tomography (PET) radioisotopes as fluorine-18 (^{18}F) – are not produced domestically.

- *Radioisotopes for Research and Development*: Radioisotopes are used for a broad range of purposes in research and development (R&D). For example, medical R&D efforts require a steady and reliable source of radioisotopes for use in clinical trials. The interface between the production of the isotopes and their use is difficult to coordinate because multiple agencies provide funding and because isotope production schedules are often out of synchronization with research plans, which then severely limits research efforts. The workshop identified 14 isotopes that are in short supply and which are important for either diagnostic or therapeutic research in nuclear medicine. The need for reliable and robust production of heavy-element alpha emitters for medical research was emphasized. Furthermore, the supply of actinides for use in basic science programs that are searching for new heavy elements is decreasing with few plans to replenish that supply.
- *Radioisotopes for Applications*: Radioisotopes are used extensively in various commercial applications, but many of these isotopes are available primarily or only from international sources. In particular, the dependence on foreign sources for such key medical isotopes such as molybdenum-99 (^{99}Mo) puts the ability to provide reliable health care in the United States at great risk, and workshop participants emphasized the importance of re-establishing domestic production of this and other key, commercially important isotopes. These commercially important isotopes include californium-252 (^{252}Cf), americium-241 (^{241}Am), and cesium-137 (^{137}Cs), which are used in a wide range of applications across the country including oil exploration, national security, clinical medicine, and basic nuclear science. One of the keys messages that emerged from the workshop was the need to develop a "cradle–to–grave" stewardship in order to introduce a measure of accountability and to improve the public's awareness of these critical isotopes.

Many of the isotopes for domestic use are produced only by foreign suppliers. While these isotopes are commercially available via importers, there is strong concern in the isotope community about how reliable the supply is, and to some degree, about the purity of these imported isotopes. Given the potential vulnerability of the supply to a variety of disruptions, including political, transportation, and supply disruptions, many workshop participants stressed the need to reduce the dependence on foreign suppliers.

Isotopes for PET, such as nitrogen-13 (^{13}N), oxygen-15 (^{15}O), and ^{18}F requiring low energy accelerators for their production, are produced in sufficient amounts to meet present demand and are not considered in short supply.

Overall, concern was expressed about the affordability of isotopes, particularly for research isotopes. The current practice of batch-costing in combination with current pricing policies has constrained DOE into providing only a very limited number of isotopes to the research community. The community, as represented at the workshop, felt that a robust domestic supply of radioactive isotopes for research and development is critical. The new initiative in the FY 2009 NP President's Request for the development and production of research isotopes addresses, albeit in a modest way, the need for increased availability of research isotopes.

The DOE isotope production depends heavily on reactors and accelerators that are operated by DOE for other missions, which limits their full potential for isotope production. Capabilities need to be enhanced to produce certain isotopes. A domestic, cost-effective, and coordinated production and supply strategy needs, which considers supplementing the present network of facilities with those existing outside the DOE complex, would be beneficial. In the near term, improved coordination between U.S. accelerator and reactor facilities could address some of the issues concerning availability of research isotopes. Given the ages of the current facilities and fact that they are used predominantly for other applications, consideration should be given to the creation of new national facilities dedicated to the production of both stable and radioactive isotopes. The creation of private/public partnerships for isotope production should also be considered.

All working groups emphasized the need for more training and education programs in nuclear science and radiochemistry in order to replace retiring technical and academic professionals from those fields. Addressing this issue will require a concerted effort that involves several federal departments.

Two positive results from the workshop were the initiation and enhancement of communication between NP/NE and the stakeholders (users and producers) of the isotope community and also the creation of new connections among the different communities. Furthermore, the various communities gained an understanding of the broad issues facing the Isotope Production program at large.

Significant shortages in the availability of key stable and radioactive isotopes could have disastrous effects on health care, the development of energy resources, national security, and the Nation's basic scientific research program. With the resources available to it today, the DOE Isotope Program is not in a position to meet the current and future demands of the Nation for isotopes. Securing the Nation's future isotope supply will demand enhanced communication with stakeholders and also the development of a prioritized and optimized research program. Shortly after the workshop concluded, NP took a first step in this direction by charging the Nuclear Science Advisory Committee (NSAC) to identify and prioritize research opportunities that use isotopes and to develop a long-term strategic plan for the development and production of isotopes.

INTRODUCTION

The *Workshop on the Nation's Needs for Isotopes: Present and Future,* co-sponsored by NP and NE, held in Rockville, Maryland on August 5-7, 2008, was the first time stakeholders from across the quite diverse isotope community assembled to discuss the Nation's current and future needs for stable and radioactive isotopes and the options for improving the availability of needed isotopes. Stakeholders, both users and producers, came from universities, medical institutions, national laboratories, the private sector, and the U.S. government, representing over 18 Federal departments and agencies, 17 academic institutions, 8 national laboratories and 14 private industries and companies. The agenda of the workshop is provided in Appendix C. The first day of the workshop was devoted to plenary sessions, which were open to all registrants. The second and third days of the workshop were devoted to breakout sessions for the working groups, with members of the various isotope user and producer communities invited to participate in the breakout sessions. The intention was to assemble representatives of the main stakeholder groups along with technical experts familiar with the production of isotopes. A summary session took place on the third day, with members from all the groups reassembling for presentations of the group summaries and a concluding discussion. A list of institutions who attended the plenary session is list in Appendix D.

The primary questions posed for the workshop were the following:

- 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 and what is missing?
- What are the options for increasing availability, and what are the associated technical hurdles?

To address these questions, participants were organized into the following three working groups:

- Stable and Enriched Isotopes
- Radioisotopes for Research and Development
- Radioisotopes for Applications

The members of the three working groups are listed in Appendix E. The chairs of the working groups submitted reports summarizing each group's discussions and providing each group's answers to the above questions. A questionnaire had been circulated to the participants before the workshop with the purpose of accumulating relevant and related background information. There was also a poster session with 31 posters, followed the plenary session on the first day. The poster session provided a venue for distributing additional information on the use and production of isotopes across the Nation. A list of the posters presented at the session is provided in Appendix F. All presentations and other relevant information on the workshop can be found on the workshop website, http://www.sc.doe.gov/np/program/isotope.html**.**

BACKGROUND

The DOE's role in supplying isotopes to the Nation and abroad dates back to the Atomic Energy Act of 1954. As a consequence of that Act, the Electromagnetic Calutrons at ORNL, which had been built to separate uranium isotopes for the Manhattan project in the 1940s, were applied to the separation of isotopes of nearly every element in the periodic table. Over the next several decades, until the early 1990s, these devices were used to separate hundreds of kilograms of stable isotopes for a diverse array of applications. The stockpile of separated stable isotopes that is used today is that the result of that effort. In an article in Physics Today in May 2005, William E. Parkins wrote, "The development and use of the Calutron to produce enriched uranium for the first atomic bomb that was exploded in warfare, and then to produce the full spectrum of separated isotopes for uses in peacetime, is the greatest example of beating swords into plowshares in the history of human kind. For its contribution in both wartime and peacetime, the physics profession can be proud."

Over the past 50 years DOE has played a central role in turning government investments in isotope production capabilities toward the development of new stable and radioactive isotopes. These isotopes in turn have been used in a wide variety of areas, including medicine; basic research in the physical, earth and life sciences; agriculture, industrial, and defense technologies; and national security. For example, the first ^{99}Mo/technetium-99 (^{99m}Tc) technology, which today is used in about 85% of all nuclear medicine applications, was sponsored by the Department and developed at Brookhaven National Laboratory (BNL). Thanks to Federal support the use of isotopes has, over the past several decades, helped to reduce health care costs, improve the ability of physicians to diagnose illnesses, and improve the quality of life for innumerable patients.

Today, stable and radioactive isotope products are used in a variety of research projects and applications in biomedicine, homeland security, environment, agriculture, and commerce that benefit society every day. Isotopes have a profound impact on the Nation's economy and, in particular, are critical for the billion-dollar nuclear medicine segment of healthcare. Each day, more than 50,000 medical patients receive clinical procedures that use radiopharmaceuticals (pharmaceuticals that contain radioisotopes). Beyond these important medical clinical applications, hundreds of other highly valuable, but less well-known applications depend on isotopes. Examples include smoke detectors, neutron detectors, explosive detectors, environmental tracers, and oil exploration. And a number detection devices essential to ensuring national security rely on isotopes as either calibration sources or as instrument components.

The Department produces and distributes isotopes by using its unique facilities (see Figure 1) such as the reactors at ORNL and Idaho National Laboratory (INL) and the accelerators at BNL and Los Alamos National Laboratory (LANL). Hot cell facilities at BNL, ORNL, and LANL are used and maintained by the program for processing and handling irradiated materials and purified products.

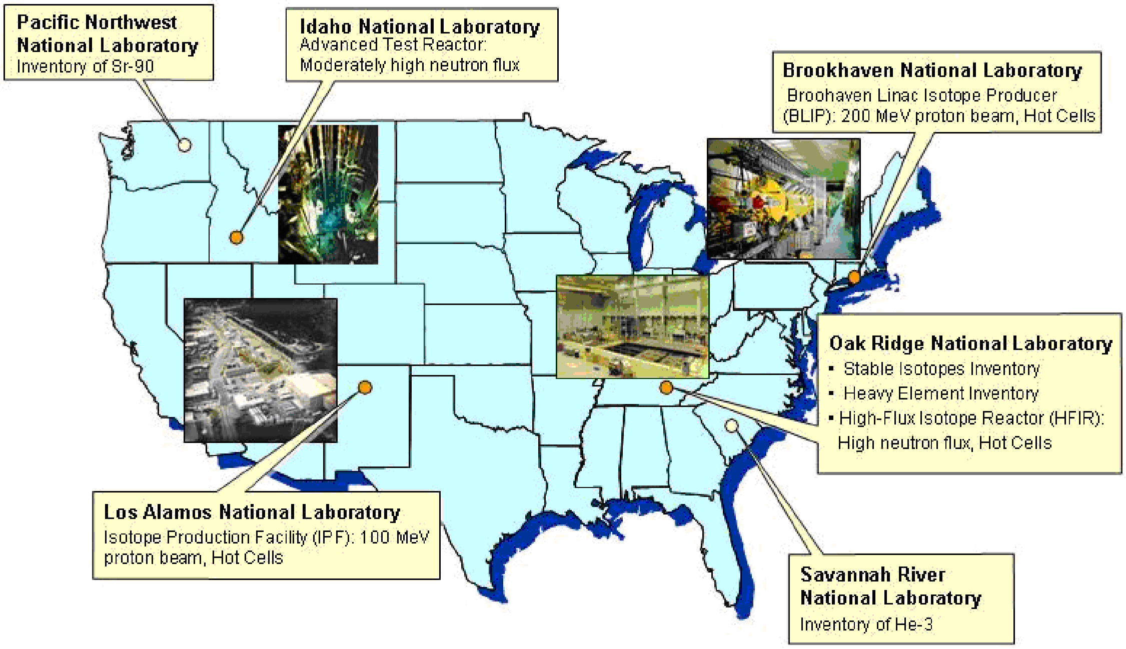


Figure 1. Present DOE Facilities where isotopes are produced or distributed from an inventory.

Stable and Enriched Isotopes

Who uses them and why?

Research in the United States that uses stable and enriched isotopes is strategically important and in the Nation's interest. The research includes, but is not limited to homeland security, drug discovery, nutrition research, energy (both nuclear and petrochemical), healthcare diagnostics, and key scientific studies in physics, chemistry, environmental science, and materials science. Many areas of research are significantly affected by limitations on the availability of funds, and it is often the case that the procurement of isotope products is the largest component of cost in a research program.

Among the areas of current research dependent on stable and enriched isotopes are health care to nutrition studies, which manipulate biochemistry at the cellular and sub-cellular level to prevent disease, as well as to offer personalized detection and treatment. Both areas require a new and much deeper level of understanding of natural biochemical processes, and isotopes are helping develop that understanding. The past decade has seen significant advances in the instrumentation used for making physical measurements, for example, isotope studies have played a significant role in these developments, allowing radioisotope tracers to be replaced with enriched stable isotopes. The safety of stable isotopes makes them ideal for use in nutrition studies in humans of all ages, from infancy to old age. They can be used at the trace levels in studies of plant growth and for the incorporation of trace levels in specific plant nutrients for subsequent studies of human nutrition..

In addition, stable and enriched isotopes are used in biomedical imaging techniques to assess pre-clinical disease, and also in the determination of human body composition and energy expenditure, which is an important aspect of addressing the obesity epidemic. Stable isotopes play an essential role in the standards of the National Institute of Standards and Technology (NIST), and spike solutions are used extensively in semiconductor technology and detector technologies. Most neutron detectors, for example, use ^{3}He. All of these studies depend on a readily available supply of diverse types of non-radioactive, enriched stable isotopes

Materials science, biology, chemistry, and the earth sciences rely heavily on stable and enriched isotopes for the development of new nanomaterials and polymers. According to one recent count, 116 different isotopes are used in Mössbauer spectroscopy experiments at over 200 institutions in the United States, and the isotope effect is a standard benchmark in superconductive materials.

The nuclear physics community requires large quantities (100-1200 kg) of specific enriched isotopes (e.g., ^{76}Ge and others) to study double-beta decay (DBD) in order to deduce fundamental properties of neutrinos. Such experiments are large international efforts that involve multiple institutions and multiple funding agencies. Low-energy accelerator-based nuclear physics experiments depend on the availability of enriched, isotopically pure isotopes to produce beams and targets across the periodic chart. Enriched stable isotopes are used as target materials to produce radioisotopes for PET, as in the use of ^{18}O which decays to produce ^{18}F.

Heavy water (^2H_2O, or water in which the normal ^1H is replaced with deuterium, or ^2H) is required for heavy-water reactors and for the Spallation Neutron Source (SNS) at ORNL as a moderator coolant; the total SNS requirement is approximately 100 tons of heavy water. Gaseous ^3He is required for neutron detectors used in homeland security systems and is also used by the nuclear power industry, medicine, and physics research. The consumption of ^3He has more than tripled since September 11, 2001, because of its use in neutron detectors used for national security purposes. Radiation portals with neutron detectors have been deployed by the Department of Homeland Security (DHS) globally to interdict fissile nuclear materials brought into the country illegally. Current supplies of this key isotope fall short of meeting United States and international needs, leaving the Nation short on its security requirements and more vulnerable to this form of weapons of mass destruction attack. Table 1 and Appendix G provide a summary of the disciplines that use stable and enriched isotopes and of the various uses of these isotopes.

Table 1. Some uses of stable and enriched isotopes for research efforts and applications

Use / Application	Isotope	Comments
Material Science	116 isotopes	Mössbauer spectroscopy
Nanoscience	oxygen, selenium, cadmium, lead	
Polymer science	hydrogen-2, carbon	
Human Nutrition	calcium-42,44, zinc-67,70, magnesium-25,26, iron-57,58	Human nutrition, obesity, disease prevention, medical imaging
Food and Agriculture	nitrogen-15, carbon-13, oxygen-17,18, selenium, chromium, zinc, calcium, iron	Plant growth research and human nutrition
Pharmaceutical and U.S. Food and Drug Administration (FDA)	hydrogen-2, carbon, oxygen, nitrogen, sulfur	Drug discovery, metabolism, quantification
Standards (NIST)	strontium-84, lead-206	Spike materials
Detector technology	indium, lanthanum, boron, lithium, silicon, xenon, sodium, gadolinium, iodine	nuclear science applications
Atmosphere and hydrosphere	mercury, carbon, nitrogen, sulfur, oxygen, bromine	
Nuclear energy	lithium, zinc, boron, heavy water (^2H_2O), noble gases, helium-3	
Homeland security, neutron dets.	helium-3, boron-10,11	Boron could replace helium
Environmental and toxicology, Cosmogenic and earth sciences	lithium, oxygen-17, 29,32-silicon, 67-70 zinc, mercury	Many different studies
World-wide weight standard	pure silicon-28 (crystal spheres)	Avogadro Project

Who produces them and where?

Over the last 25 years there has been a shift in the production of stable and enriched isotopes from the national laboratories to private sector production in the United States and abroad as well as to production in the national laboratories of other countries. The reasons are many but include a lack of capabilities and aging equipment at U.S. national laboratories as well as the emergence of more cost-effective competitive private sector suppliers.

Initially the cessation of government-produced isotopes was limited to the light isotopes of elements such as boron, carbon, oxygen, and nitrogen, and did not occur until the private sector manufacturers were in operation. At least two domestic and several foreign private companies now produce these isotopes. Some isotopes of boron, carbon, nitrogen, oxygen, and the halogens, as well as certain other elements, can be obtained internationally (with the suppliers including Argentina, Canada, China, Georgia, India, Israel, Japan, Netherlands and Romania). This has been a positive benefit to the stable isotope community, providing it with abundant supplies which exceed current demand and which are available at a significantly lower cost and higher enrichments, purity, and quality. The PET industry requirements for ^{18}O – labeled water for production of fluorodeoxyglucose are the best example. The switch to private production resulted in a decrease in the cost of more than an order of magnitude, along with increasing enrichment in a product that is now available as a cGMP (current Good Manufacturing Practices) certified product from multiple suppliers around the globe. Unfortunately, these isotopes only represent a small subset of all the stable isotopes required for various uses in the United States.

The production of light isotopes is done almost exclusively by fractional distillation and chemical exchange. These techniques were developed by the Manhattan Project but have been expanded and improved in the decades since that project. The light isotope facilities today are run with modern controls and online analytical support, and most suppliers are either International Organization for Standardization (ISO) 9001 certified or cGMP certified or both.

On the other hand, there are several hundred alkalis, alkali-earth, and metal stable isotopes that require either electromagnetic separators or gas centrifuges to produce the necessary enrichments. Electromagnetic separators are generally used when gram quantities of the isotope are needed, while gas centrifuges are used to produce kilogram quantities of isotopes. Kilogram quantities are required for such research as DBD, and suppliers who are able to produce these levels are limited internationally.

All domestic production of the gram quantities of electromagnetically separated alkali, alkali-earth, and other metals has ceased, and the supply now comes from a single foreign source, the Russian calutrons, with domestic commercial companies acting as brokers for Russian sales. The stable isotope enrichment operations at the Mound Laboratory in Ohio were shut down in the early 1990s, and in the late 1990s the aging and high-maintenance isotope separation facilities at ORNL, initially developed for the Manhattan Project, were put into standby mode in preparation for decommissioning and decontamination. Today, DOE continues to provide stable isotopes from its remaining inventory. The facilities at ORNL employed thermal diffusion columns and electromagnetic separators and represented the only U.S. source capable of producing isotopes of the higher mass elements. With no private-sector sources taking over, reliance shifted to the Russian national laboratories. The diverse community of stable isotope users is concerned that ongoing and potential future experiments might be interrupted by foreign supply problems.

Deuterium is obtained from several countries (India, Argentina, Canada, Romania, China, and Russia) as well as from a small U.S. inventory. ^{3}He is obtained via the radioactive decay of tritium (^{3}H) at the Savannah River Facility and is also available from Russia. Russia is also currently the only available supplier for large amounts of the ^{76}Ge needed in the DBD studies.

What are the needs today and in the future?

A complete list of needed stable isotopes is given in Appendix G. In general, there are suppliers, either domestic or foreign, for most of the stable and enriched isotopes. The need for ^{3}He and special isotopes, such as ruthenium-96 (^{96}Ru) is not being met, and, in particular, the demand for ^{3}He is expected to rise in the future. Certain studies in medicine, human nutrition, and materials science are not being performed because of the high cost of the required isotopes, including iron-57 (^{57}Fe), ^{17}O, tin-119 (^{119}Sn), and europium-151 (^{151}Eu). The supply of ^{17}O is currently adequate to meet demand, but the evolution of magnetic resonance imaging (MRI) techniques could lead to a large increase in the need. Large quantities of specific isotopes, such as ^{76}Ge for the DBD studies, natural silicon for the electronics industry, lanthanum for detectors, and indium for low background detection, at present can only be found outside the United States. The use of isotopes in molecular-tagged vibrational spectroscopy (nuclear resonance vibrational spectroscopy, resonant Raman, and infra-red spectroscopy) is increasing and will lead to an increased need for small quantities of many isotopes that are used to differentiate vibrational modes between different ligands. Special enriched target materials, such as very neutron-rich isotopes including ^{48}Ca, titanium-50 (^{50}Ti), ^{58}Fe, and nickel-64 (^{64}Ni), are presently still available in the DOE inventory, but demands are expected to increase with the new Facility for Rare Isotope Beams (FRIB) proposed by the nuclear science community. Without some new domestic production facility, supplies of such isotopes could be limited or only available from foreign sources.

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

Only limited quantities of deuterium (^{2}H) are currently available in the United States and current demand is met mainly through foreign sources, which can be erratic and expensive. The total supply of ^{3}He in the United States and Russia is not enough to meet current demands for ^{3}He neutron detectors, which account for about 80% of ^{3}He applications. In addition, these demands are growing and are not expected to diminish in the foreseeable future.

Boron, carbon, and oxygen isotopes are widely available domestically (from foreign producers) and the domestic supply exceeds the demand. Isotopes of nitrogen, the halogens, and the noble gases are available only from foreign sources such as China and Georgia. The large quantities of ^{76}Ge needed for the DBD study are not available domestically. Since the U.S. electromagnetic enrichment facility at ORNL was shut down there has been no domestic production of alkali, alkaline earths, and other metals. In general, most isotopes in the DOE inventory are in sufficient supply or are expected to be available to meet demands for the next 20 years based upon usage from past years. Table 2 provides a list of stable isotopes in the DOE inventory at ORNL that are currently not available or have limited availability.

While select Russian laboratories have generally met the needs for the raw isotopes, which are available through domestic brokers, the research community must occasionally rely on additional services from other sources to convert these isotopes into the physical or chemical form required for use. Generally, quality has not been a problem but there have been isolated examples of quality issues, sometimes depending on the brokers used. It was noted that the U.S.-based suppliers are ISO 9001 certified, while the Russian laboratories are not.

The absence of active domestic competitive suppliers for the electromagnetic and centrifuge isotopes and the devaluation of the American dollar against most foreign currencies have resulted in significantly higher costs for isotopic materials at a time when the availability of funds in the United States has diminished. This situation is imperiling research of strategic importance to the United States and some important research projects are not moving forward because of it.

Table 2. Stable isotopes with limited inventory in the DOE Isotope Program. Note: Second pass means higher isotopic purity due to second separation pass

Isotope	Years remaining inventory
Gadolinium-157, Second Pass	0
Lead-204, Second Pass	0
Lead-207, Second Pass	0
Ruthenium-96	0
Samarium-150, Second Pass	0
Tatalum-181	0
Tungsten-180, Second Pass	0
Vanadium-51	0
Gadolinium-157	0.2
Gadolinium-154, Second Pass	2.5
Gallium-69	3.7
Nickel-62	3.9
Osmium-187	5.2
Lutetium-176	5.5
Ruthenium-99	6.3
Osmium-186	7.5
Barium-136	7.6
Neodymium-150	7.9
Mercury-204	10.2
Cadmium-106	10.7
Mercury-202	11.5
Platinum-195	12
Palladium-106	12.6
Silver-109	14.3
Zirconium-94	18.5
Barium-137	19
Samarium-149	19.6

What are the options for increasing availability and associated technical hurdles?

The U.S. isotope community does not have access to domestic electromagnetic separators or gas centrifuges for production of over half of the isotopes in use. While there are currently reliable and dependable foreign supplies of stable and enriched isotopes, there is no assurance that they will be available domestically in the future. The DOE should consider the establishment of domestic production for all stable isotopes, particularly those that are not currently available domestically. From a risk management and disaster recovery standpoint, users prefer multiple reliable suppliers. Dependence on single-source availability of products may jeopardize research that is vital to national interest. A domestic supply insulates the United States from geopolitical influences on foreign supply including currency deflation, and ensures high-quality verification, such as through ISO 9001 certification. A diversity of suppliers usually leads to more competitive pricing. In some cases a research need for an isotope requires rapid purchase and delivery, which is best accomplished with a domestic supply. It may not be optimal for the United States to depend on foreign governments for the supply of stable isotopes because of the sensitive nature of the isotope applications, e.g., detectors for homeland security and power sources for naval reactors. Capabilities at existing accelerator facilities could be enhanced with the addition of electromagnetic separators or some other technical development.

Since ^{3}He is a by-product of tritium production for weapons systems, it is difficult to foresee a supply-based solution supported by current “production” techniques; therefore, a technology solution as well as efforts to maximize utilization of strategic reserves will be required to solve the problem of ^{3}He supply. The long-term demands will need to be defined by other agencies, such as DHS. However, current demands would deplete the reserves within two years and world production capacity meets only about 1/3 of current demand. It is possible that alternative production strategies could somewhat reduce the large anticipated demand. ^{3}He may be in some waste streams of some applications in other countries. International agreements could result in new supplies of ^{3}He for United States use, if transportation and export/import hurdles can be overcome.

In cases where technological options are not easily available for increasing the supply of a critical isotope, consideration should be given to identifying an alternate isotope that could replace the isotope in short supply, e.g., using boron-10 instead of ^{3}He for neutron detection. Production of deuterium by using new, cost-effective separation techniques from normal water should be reinvestigated. New technologies involve the need for R&D to identify a suitable replacement isotope.

An R&D plan for the development of novel separation and production techniques for stable and enriched isotopes should be generated. Access to less expensive, separated and enriched isotopes could lead to unanticipated breakthroughs in science and to new technologies. New enrichment techniques such as plasma ion cyclotron resonance separation, acoustic separation, cryogenic distillation, laser ionization, and plasma centrifuge have the potential to produce kilogram quantities of selected isotopes for specific purposes, as discussed above. In the short term, reliance on current techniques could provide the time needed to develop less expensive technologies for the future.

Coordination with domestic and international suppliers to develop a strategy for supplying stable and enriched isotopes could improve productivity. While national security, supply/demand, and pricing issues highlight the need for DOE to develop new production capability, this should be done carefully and cost effectively, taking advantage of foreign supplies whenever that is deemed cost effective and beneficial for the Nation.

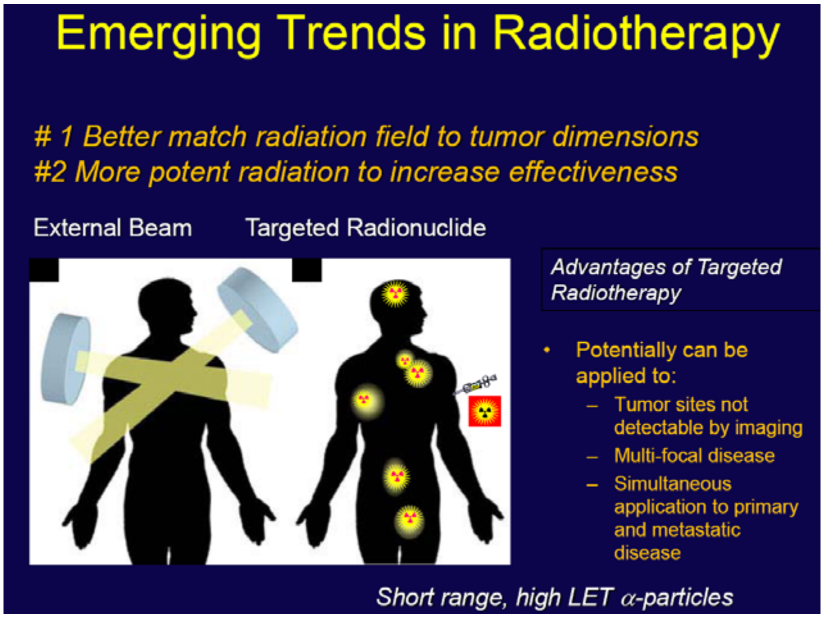
Radioisotopes for Research and Development

Who uses them and why?

Radioisotopes play a vital role in a wide and very diverse range of scientific research and development activities which are critical to many different Federal agencies, research communities, private industry, and the public. The uses of radioisotopes in research range from basic science to the deployment of new medical and biological applications and the development of power sources for homeland security, nuclear forensics, and environmental studies. In biological and medical research radioisotopes are used widely in areas ranging from the basic investigation of biologic pathways at the subcellular and cellular level to the diagnostic imaging of disease in humans. Molecular biology research relies on radioisotopes of elements found in the native molecules, so that the use of radioisotopes of carbon, hydrogen, sulfur, and phosphorous is common. Radioisotopes are also used to investigate the role of inorganic elements *in vivo*, especially when other analytical methods – in particular nuclear magnetic resonance (NMR) spectroscopy – are inadequate to follow their pathways in biological systems.

The use of radioisotopes for medical applications falls into three categories: diagnostic use, therapeutic use, and sterilization of instruments. Diagnostic applications exploit two different decay processes – photon emission (single event detection) and positron emission (PET-coincidence photon detection). Single photon-emitting isotopes currently dominate clinical nuclear medicine, but the use of positron-emitting isotopes is expanding rapidly. As molecular imaging increasingly penetrates the market, it is expected that the use of positron emitters will increase. The bulk of PET imaging to date has focused on the use of ^{18}F – labeled deoxyglucose. While there are a number of clinical applications, the potential of radioisotopes for therapeutic applications has only begun to be tapped and the majority of work in this area is currently focused on research and development of new radiotherapeutic agents. In the therapeutic category, the use of radioisotopes for medical applications continues to be more focused at the research level than the clinical level. Some isotopes are produced commercially and are used in clinical therapeutic studies and include strontium-89 (^{89}Sr), yttrium-90 (^{90}Y), iodine-131 (^{131}I), and samarium-153 (^{153}Sm). One of the most vexing problems in this work revolves around the availability of alpha-emitting radioisotopes, such as bismuth-212 (^{212}Bi) (from decay of radium-224 [^{224}Ra]), actinium-225 (^{225}Ac), or astatine-211 (^{211}At). These alpha-emitters have the potential to be major isotopes for therapy in certain types of cancer (see Figure 2) but they are in very limited supply. Sterilization of instruments involves utilizing the gamma radiation from such radioisotopes as cobalt-60 (^{60}Co) (half-life of 5.27 years) and ^{137}Cs (30.2 years) and requires a large quantity of these radioisotopes.

An active part of basic nuclear physics research is the quest to produce and study radioisotopes in the Z=104-120 range. These radionuclides exhibit properties that provide insight into questions of nuclear structure, transformation, and the fundamental properties of matter. These studies require the use of man-made, transuranium isotopes primarily as targets. Theoretical predictions suggest that there is an island of stability where the half-lives of the elements increase to such a degree that their lifetimes should be long enough to enable the examination of their chemical and physical characteristics. Typically, the amount of isotopes needed for such basic research is small (milligrams) but there are notable exceptions to this. Other nuclear physics research facilities use enriched isotopes, usually very neutron-rich, to produce desired accelerator beams. A related line of research is the chemical behavior of the actinides and trans-actinides, requiring the production of these unstable nuclides.



Emerging Trends in Radiotherapy

 # 1 Better match radiation field to tumor dimensions
#2 More potent radiation to increase effectiveness

External Beam

Targeted Radionuclide

Advantages of Targeted Radiotherapy

- Potentially can be applied to:
  - Tumor sites not detectable by imaging
  - Multi-focal disease
  - Simultaneous application to primary and metastatic disease

Short range, high LET α-particles

Figure 2. Graphical representation of value of implantation versus radiation for treating cancer.

Research and development efforts are ongoing to demonstrate technical feasibility of nuclear batteries (RIMS, or Radioisotope Micro-power Source), possibly using phosphorus-33 (^{33}P), promethium-147 (^{147}Pm), polonium-210 (^{210}Po) or others, for applications in homeland security and national defense that require power sources that can be used in remote areas and be completely self-sufficient. The key point is that the energy change "per event" in radioactive decay is 10^4 to 10^6 times greater than that of a chemical reaction, and the energy density (J/kg) of radioactive material is approximately 10^6 times greater than that of lithium ion batteries. Thus, a radioisotope-based micro power source holds great potential, particularly in applications requiring a longer life without recharging or refueling, although emission of gamma rays may limit their suitability for portable applications.

Research efforts in DHS focus on the effects of nuclear devices and "dirty bombs" and use radioisotopes of sufficiently long half-lives that are similar to those of interest to study the effects of radiation exposure to humans and the environment. Radiotracers with shorter half-lives have more easily detectable emissions and are preferable for research studies of their biologic or environmental disposition due to less potential waste problems. The research studies in this area determine the most effective method to decontaminate radioisotopes in the environment and developing agents to remove radioisotopes from an exposed individual. Radioisotopes are also used to calibrate homeland security radiation detectors such as radiation portal monitors and advanced spectroscopic portal monitors.

Environmental research has used radioisotopes in a variety of applications. One prominent use has been as tracers for radioisotopes that present long-term storage challenges in radioactive waste. In some cases, the radioisotope that would be stored does not possess emissions that can easily be detected *in situ*. For example, plutonium-239 (^{239}Pu) is not easily detected in model studies of its migration in the environment. By contrast, ^{237}Pu emits gamma rays that can easily be detected by conventional gamma detectors and has a half-life sufficiently long to enable studies of its behavior. An additional advantage of these shorter-lived tracers is that they require simpler waste management procedures. Often, the waste can be held for decay instead of being disposed of as radioactive waste.

The U.S. Environmental Protection Agency (EPA) regulates contaminants (metals and metalloids) in drinking water. An example of a metalloid contaminant is inorganic arsenic, which occurs naturally in many sources of drinking water. Chronic exposure to inorganic arsenic in drinking water may result in the development of non-cancerous effects such as diabetes and cardiovascular disease, or the development of cancer in one of several vulnerable organs. The radioisotope arsenic-73 (^{73}As) has been used extensively to study toxicology and disposition (absorption, distribution, metabolism, and excretion) at the subcellular, cellular, and whole animal level.

Who produces them and where?

Some critical radioisotopes are available only from foreign sources. This creates problems if there are disruptions in production or transport. It is particularly critical if the foreign source disappears. There appears to be the capability in the United States to produce the radioisotopes needed for most R&D activities. Indeed U.S. accelerator and reactor facilities are not being fully utilized for radioisotope production for R&D purposes for a variety of reasons. One problem is the lack of trained personnel to produce, purify and prepare radioisotopes for shipment. Operating costs are also an important consideration. The existing DOE facilities, reactors, accelerators (2) and processing facilities, have been used for some years and require upgrading of infrastructure; there is no domestic backup for High Flux Isotope Reactor (HFIR). In addition, their design and operating schedules in some instances are incompatible with routine, reliable production of radioisotopes. HFIR is mainly used for the neutron program and its schedule does not fit well for production of certain isotopes. The shipment of radioisotopes also creates problems as special shipping containers are needed, which are expensive to produce and are presently in short supply.

Researchers who use radioisotopes obtain them from domestic and foreign suppliers. Radioisotopes are produced using either an accelerator (proton, alpha, or heavy ion beam) or a nuclear reactor. Radioisotopes for PET applications (usually with short half-lives, from minutes to hours) are normally produced locally and are not part of the DOE Isotope Program. The majority (~75%) of the isotopes available from DOE is for medical purposes, but the Department does provide a few radioisotopes for commercial applications when needed. Most radioactive isotopes are produced using HFIR at ORNL (i.e., ^{252}Cf, ^{63}Ni, selenium-75, and others), the high-energy (100 MeV) accelerators at BNL (Brookhaven Linac Isotope Producer (BLIP)) and LANL (Isotope Production

Facility (IPF)) (i.e., ^{82}Sr, ^{68}Ge, sodium-22, zinc-65 and others). The HFIR provides one of the world's highest-intensity steady-state neutron beams which is ideal for the production of radioisotopes. Some isotopes are produced at the 10-MW Missouri University Research Reactor (MURR). The McClellan (Training, Research, Isotopes, General Atomics Reactor (TRIGA)) reactor at the University of California at Davis and also the Advanced Test Reactor (ATR) at INL could also provide some radioisotope production, e.g. ^{125}I at McClellan, with additional infrastructure. ^{90}Sr is distributed from Pacific Northwest National Laboratory (PNNL). Several low-energy accelerators and reactors at U.S. universities supply small quantities of a variety of isotopes needed for local research. For example, currently the cyclotrons at Duke University and the University of Washington routinely produce ^{211}At for its use locally at the campus medical center. Cyclotrons at the National Institute of Health (NIH), University of Pennsylvania, University of California at Davis, Texas A&M University and the 88-inch cyclotron at Lawrence Berkeley National Laboratory (LBNL) could also potentially produce this isotope in useful quantities. The accelerators at Washington University produce a range of isotopes for medical research efforts. Only a few private companies produce research isotopes, such as copper-67 (^{67}Cu) which has been available from Trace Life Sciences. Table 3 shows examples of current radioisotope production capabilities at DOE facilities.

Table 3. Current production capabilities at DOE facilities

Isotope	Half Life	Isotope Usage	Production Site	Production Frequency
Actinium-225	10.0 d	R&D	ORNL	special order
Arsenic-73	80.3 d	R&D	BLIP,IPF	annually
Beryllium-7	53.3 d	R&D	BLIP,IPF	special order
Californium-252	2.6 y	commercial	HFIR	special order
Cobalt-60	5.3 y	commercial	ATR	special order
Copper-67	61.9 h	R&D	BLIP	in development
Germanium-68	270.8 d	R&D, comm.	BLIP,IPF	monthly
Helium-3	stable	R&D, comm.	SRL	special order
Iron-55	2.7 y	R&D, comm.	HFIR	special order
Iridium-192	73.8 d	R&D, comm.	HFIR	special order
Lutetium-177	160.7 d	R&D	HFIR	quarterly
Magnesium-28	20.9 h	R&D	BLIP	special order
Nickel-63	100.1 y	commercial	HFIR	annually
Radium-223	11.4 d	R & D	PNNL	In inventory
Rubidium-83	86.2 d	R&D	BLIP,IPF	special order
Selenium-75	119.8 d	commercial	HFIR	quarterly
Sodium-22	2.6 y	commercial	IPF	annually
Strontium-82	25.4 d	commercial	BLIP,IPF	monthly
Strontium-85	64.8 d	R&D	HFIR	special order
Strontium-90	28.8 y	R&D, comm	PNNL	in inventory
Tungsten-188	69.8 d	R&D	HFIR	quarterly
Yttrium-86	14.7 h	R&D	BLIP	in development
Yttrium-88	106.6 d	commercial	IPF, BLIP	special order
Zinc-65	243.8 d	commercial	BLIP	annually

What are the needs today and in the future?

Medical research efforts require a steady – and reliable – source of radioisotopes for the clinical work being carried out, which limits the choices of isotopes for that community to those that are now being produced. The activity level of a radioisotope needed for a particular study can vary significantly from year to year, making anticipation of needed quantities and production strategy a challenge. This is not a major problem if the isotope can be readily produced on a local medical cyclotron that is available to the researcher. It is more challenging for isotopes supplied by the DOE isotope program which relies on facilities not dedicated primarily to isotope production. The concept of having dedicated facilities could be given higher priority as it is in many other countries. A guaranteed, reliable supply of radioisotopes is essential for the transition from R&D to clinical use in medicine. The uncertainty in the long-term availability of large quantities of radioisotopes that are now produced in very limited quantities further restricts the R&D efforts being carried out in the field. Effective coordination of back-up production capabilities is also important.

Given the installed capacity of cyclotrons optimized for ^{18}F production, a dramatic increase in the application of other positron emitters is not likely in the short term. However, there are a number of other positron emitters of interest to the community. In several cases, these are used to determine dosimetry of therapeutic radioisotopes. In particular, ^{124}I, bromine-76 (^{76}Br), ^{64}Cu, and ^{86}Y potentially can be used for this purpose. A number of these isotopes are present in the recent request for proposals by the DOE Office of Biological and Environmental Research (BER) as indicated in the following distribution of Table 4. It should be noted that proposals submitted to BER generally limit funding to only those for which isotopes are readily available.

Table 4. Isotopes Needed in DOE BER Proposals

Radioisotope	# of Proposals	Radioisotope	# of Proposals
Astatine-211	2	Indium-111*	2
Bismuth-213	3	Iodine-124	1
Carbon-11*	6	Rhenium-188	1
Copper-64	8	Rhodium-105	1
Fluorine-18*	18	Yttrium-86	1
Gallium-68	2	Technetium-99m*	10

*Routinely available from commercial sources.

Some isotopes are produced commercially and are used in clinical therapeutic studies; these include ^{89}Sr, ^{90}Y, ^{131}I, and ^{153}Sm. Alpha-emitting radioisotopes, such as ^{225}Ac or ^{211}At, have the potential to be major isotopes for therapy in certain types of cancer but are in limited supply.

The levels of radioisotope activity needed increases substantially as one progresses from an R&D phase to clinical trials and then to treatment. Currently ^{211}At and ^{225}Ac or ^{213}Bi (produced in decay of ^{225}Ac) are being considered for moving forward towards a clinical trial; isotope availability will influence the focus of medical research on a particular isotope. Table 5 provides estimates of the annual need in the coming years to support identified efforts underway utilizing ^{225}Ac and/or ^{213}Bi. A commercially viable production process needs to be developed for the production of ^{213}Bi.

Table 5. Estimated annual usage of ^{225}Ac and/or ^{213}Bi, based only on known needs without new developments. Estimates in out years vary by ±50% depending on whether the approved treatment is with ^{225}Ac or with ^{213}Bi.

Year	Amount (mCi)	Program
2008	750	Clinical trials/R&D support
2009	1,600	Clinical trials (1 multi- center) /R&D support
2010	3,100	Clinical trials (2 multi- center) /R&D support
2011	4,600	Clinical trials (2 multi- center) /R&D support
2012	7,400	Clinical trials (3 multi-center)/R&D support
2013	15,000	One approval; Clinical trials(2 multi-center)/R&D
2014	50,000+	Two approvals; Clinical trials/R&D support

ORNL currently supplies the bulk of ^{225}Ac from a single 150-mCi (milliCuries) source of thorium-229 (^{229}Th) that is milked approximately six times per year. The total annual production of ^{225}Ac by ORNL is about 600 mCi. Approximately 500-550 mCi of the ORNL supply is contracted for on an annual basis, leaving less than 100 mCi available for others. The Institute for Transuranium Elements (ITU) has a small amount of ^{229}Th that was supplied by ORNL a number of years ago, and it produces ~350 mCi of ^{225}Ac annually. ITU does not market or sell this ^{225}Ac, but it provides only to its collaborators. There have been various attempts to ship small amounts (a few mCi) of ^{225}Ac from Russia but the actual sources are largely unknown and highly sporadic in availability. Estimates are that the total current capacity is about 25-50 mCi of ^{225}Ac per shipment.

For basic nuclear physics research, in order to produce the most neutron-rich isotopes of superheavy elements (SHE), one must use the most neutron-rich beams and targets currently available. Production of elements 112, 113, 114, 115, 116, and 118 were achieved with beams of ^{48}Ca and targets (~10-20 mg) of uranium-238 (^{238}U), neptunium-237 (^{237}Np), ^{242}Pu, ^{244}Pu, ^{243}Am, curium-245 (^{245}Cm), ^{248}Cm, and ^{249}Cf. Current isotope needs for further SHE research include uranium-233 (^{233}U), ^{235}U, ^{238}U, ^{237}Np, ^{242}Pu, ^{244}Pu, ^{241}Am,^{243}Am, ^{245}Cm, ^{248}Cm, berkelium-249 (^{249}Bk), ^{249}Cf, einsteinium-245 (^{245}Es), and fermium-257 (^{257}Fm) of high purity (>99% in most cases and >90% desired). In addition, for calibration and equipment verification, targets of lead-208 (^{208}Pb), ^{209}Bi, and ytterbium-176 (^{176}Yb) are required, as well as sources of ^{252}Cf and ^{245}Cm. Finally, neutron-rich beam material such as ^{48}Ca, ^{50}Ti, ^{58}Fe, and ^{64}Ni is required to produce exotic isotopes at the limits of nuclear stability for nuclear physics and nuclear astrophysics research. The Nuclear Physics national user facility, Argonne Tandem Linac Accelerator System (ATLAS), at Argonne National Laboratory (ANL) is building an ion source for fission fragments that requires 1 Ci of ^{252}Cf. Some R&D programs require actinides and transuranium isotopes that are often in short supply or are not available at all. This particularly affects basic research efforts in actinide chemistry and some programs in nuclear physics. In some cases, a requirement for very high purity exacerbates the problem of availability.

Cross-section measurements, which are used in nuclear forensics and environmental research and by a number of Federal agencies including DHS and DOE (programs at DOE include stockpile stewardship and new reactor technologies, i.e., the Global Nuclear Energy Partnership/Advanced Fuel Cycle Initiative) require research quantities of actinides from uranium to curium and beyond (berkelium, californium, einsteinium and fermium). Fission studies require sources of ^{252}Cf and ^{248}Cm for testing of detectors and the study of the spontaneous fission of those isotopes themselves.

As mentioned RIMS are of interest in applications that require a power source that can be used in remote areas in extreme environments and be completely self-sufficient. Table 6 provides a list of isotopes, including their characteristic properties, which have been considered for RIMS and which need to be produced for research purposes. If any of these radioisotopes proves useful and valuable, the demand likely will increase dramatically, a situation that might challenge the Department's ability to produce them in sufficient quantity. This would transition one or all of these isotopes into the application or commercial category.

Table 6. Characteristics of representative beta and alpha emitters as sources of betavoltaic systems

Radioisotope[1]	E_{avg} (keV)	Half-life (y)	Maximum BOL[2] activity (TBq/cm^3)	Maximum BOL source power (mW/cm^3)	Maximum "realistic[3]" BOL P_{out} (μW/cm^2)
Hydrogen-3	5.9	12.3	1.6	1.5	1.6
Krypton-85	251.4	10.8	1.9	75.3	2,414
Nickel-63	17.4	100.1	18.5	51.7	0.2
Polonium-210	5,304	0.38	1,566	1.3E6	1.4E4
Promethium-147	61.8	2.6	247	2,448	141.1
Phosphorus-33	76.9	0.07	10,446	128,701	39,704
Strontium-90	196.4	28.8	13.3	420	456
Thalium-204	245.0	3.8	202	7,689	2,778

Environmental researchers have a continuing need for ^{73}As as an integral part of a research program that supports EPA's review of inorganic arsenic, a review that is mandated to be carried out every six years. As with the case for ^{73}As, other radioisotopes of metal contaminants (such as cobalt, germanium, and strontium) in drinking water could be needed by researchers in the future to provide regulators with scientific information on their toxicity and disposition in animal models. Silicon-32 is an example of a research isotope that is in demand for studies in marine biology and biochemistry but that is not available worldwide. It can only be made by high-energy proton reactions, and

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[1] Assumes 500 psi pressure for ^{85}Kr and ^{3}H gases.

[2] "Beginning-of-life: the start of battery operation"

[3] Areal density used; for beta emitters, assumes η_{conv} = 10%, η_{source} = 30% (utilizing 4π collection geometry) and source thickness = 2*Beta range, and a pure radioisotopic source. For alpha emitter ^{210}Po, assumes η_{conv} = 10%, η_{source} = 90% and source thickness of 1 µm.

the availability of beam-time for this purpose is limited. The availability of radioisotopes for molecular biology research has been adequate to date.

In fact, as the costs and problems associated with the use of these radioisotopes and their disposal have increased, their use in the biology lab has decreased. There still exist instances in which their use is required given the sensitivity available through radiometric analysis. The fact that early work with the sequencing of genomes was accomplished with ^{32}P was acknowledged.

<u>What is the status of the supply and what is missing?</u>

Five years ago, the Society of Nuclear Medicine (SNM) and the National Cancer Institute (NCI) sponsored a workshop on availability of radioisotopes needed for NCI-funded research and provided a list of 14 key research radioisotopes for diagnostic, dosimeter studies and therapeutic uses in research. ^{225}Ac, ^{211}At, and ^{67}Cu are examples of radioisotopes that have shown great promise for cancer therapies but for which development is inhibited because of the lack of a reliable supply for use in research and clinical trials. The list of radioisotopes generated at the earlier NCI workshop, which is exhibited in Tables 7 and 8 below, was reviewed during the current workshop and an indication of the current supply status of each of these radioisotopes is included in the tables.

Table 7. List of diagnostic research isotopes in short supply

Isotope	**Half Life**	**Radiation and Application**	**Availability**
Arsenic-74	17.8 d	β^+, Dosimetry check	Not available/high cost
Bromine-76	16 h	β^+, Dosimetry check	Only one supplier
Copper-64	12.7 h	β^+, Dosimetry check	3 sources
Yttrium-86	14.7 h	β+, Dosimetry check	Unreliable supply
Zirconium-89	3.3 d	β, Brain tumor diagnostic	Not available

Table 8. List of therapeutic research isotopes in short supply

Isotope	**Half Life**	**Radiation and Application**	**Availability**
Actinium-225/Bismuth-213 (gen)	10 d/46 m	γ, α ; Cancer therapy	Only one supplier
Astatine-211	7.2 h	β, α, Cancer therapy	Two suppliers
Bromine-77	2.4 d	β, Labeling	Not available
Copper-67	2.6 d	β, Cancer therapy	Only one supplier
Holmium-166	6.8 m	β, Arthritis, cancer therapy	Two suppliers
Lutetium-177 (high specific act.)	6.7 d	β,γ, imaging, cancer treat.	Being develop./high cost
Promethium-149	2.2 d	β, therapy	Only one supplier
Radium-224/ /Bismuth-212 (gen)	3.7 d/1.0 h	γ, α ; Cancer therapy	Not available
Rhenium-186	3.8 d	β, Cancer therapy (bone)	Only one supplier
Tungsten-188/Rhenium-188	16.9 h	β, Cancer treatment	Only one supplier

(gen) = obtained from decay of parent/generator production.

In the physical sciences, current isotope needs for transuranium and SHE research include ^{233}U, ^{235}U, ^{238}U, ^{237}Np, ^{242}Pu, ^{244}Pu, ^{241}Am, ^{243}Am, ^{245}Cm, ^{248}Cm ^{249}Bk, ^{249}Cf, ^{252}Cf, ^{245}Es, and ^{257}Fm (either as targets or in some cases as sources). Most of these isotopes are only produced at HFIR and are presently in short supply or just not available from domestic supplies. Isotopes for the development of nuclear batteries such as ^{147}Pm, ^{210}Po, ^{33}P and some others, are available from local producers on a small scale but if studies are successful, demand will eventually exceed supply. Most other research and development isotopes are available from domestic or foreign suppliers.

What are the options for increasing availability and associated technical hurdles?

The availability of radioisotopes could be improved with a strategy for better, integrated utilization of existing reactors and accelerators. Consideration should be given to increasing the portfolio and operation of facilities at which the DOE supports production of radioisotopes. Special shipping containers are needed, which are expensive to manufacture.

Research and development efforts need to be focused on new production and extraction techniques for those isotopes of interest, particularly those in short supply. For example, new processes for expanding the supply of ^{225}Ac could be explored. The most immediate way for the supply to be expanded is to access DOE-controlled sources of ^{229}Th, the parent of ^{225}Ac. However, as mandated by Congress, the DOE Office of Environmental Management has begun to dispose of the ^{233}U required for the recovery of additional ^{229}Th. Without the DOE sources, the success of ^{225}Ac and/or ^{213}Bi as a potential treatment is severely limited by the amount of radioisotope, which restricts the number of patients who could be accommodated. Unfortunately, even if the DOE supply were made available, there would not be sufficient quantities to go beyond the clinical trials. Alternative production methods have been demonstrated on a small scale but do not produce commercially available quantities. Further, all known processes not utilizing the existing ^{233}U rely on either an accelerator approach (producing ^{225}Ra or ^{225}Ac directly) or a high-flux reactor to produce ^{229}Th (requiring years to produce meaningful quantities), and all need ^{226}Ra as the target, which has its own nuclear and safety issues to consider, e.g., no central repository for safe collection and storage. The actinium is one of many alpha emitters undergoing R&D as a candidate for clinical trials. Similar discussion could be used for the alpha emitter ^{212}Bi obtained through decay of ^{224}Ra.

Another alpha-emitter of interest for therapeutic applications is ^{211}At, which has a 7-hour half-life and can only be produced by irradiating a bismuth target with a beam of helium-4 (alpha particles). There are currently a limited number of cyclotrons in the United States that can accelerate this beam and thus the production of this radioisotope has been problematic. Currently, ^{211}At is produced at the cyclotrons at Duke University and the University of Washington routinely. In addition, cyclotrons at NIH, University of Pennsylvania, University of California at Davis, Texas A&M University, and LBNL could also potentially produce it in useful quantities. Another possible production route is to irradiate bismuth targets with a beam of lithium-7 (^{7}Li) to produce radon-211. In this case, the advantage is that the parent of ^{211}At is produced, which enables one to ship the material and have the ^{211}At increase during shipment. Also, since radon is a gas, separation from the astatine daughter is quite easy. Unfortunately, the ability to accelerate ^{7}Li with beam currents useful for clinical applications limits this production option. Considering all of the issues, ^{211}At can be more easily produced in the quantities needed to support widespread clinical use than can the heavier alpha emitters. A broad portfolio of alpha emitters should be considered and a production strategy for candidates for clinical trials should be developed.

Improved communication between Federal agencies is essential to having realistic expectations in terms of which isotopes might be available in large quantities. It is necessary to project the needed quantities in order to plan for increased production. Effective coordination among the different agencies that support R&D for medical applications could help this, especially if there is sufficient lead time to react to changing needs. A mechanism for funding the increased quantities of isotopes needs to be defined. Estimating the future need for specific isotopes is a particularly difficult problem.

A key aspect related to this question is the *Catch-22* situation in which one can get grant funding to purchase an isotope, only if the isotope has been produced, but an isotope will be produced only if there is a demand for the isotope and there is some certainty that there will really be funds to pay for it. This cycle (Figure 3) is of concern to researchers.

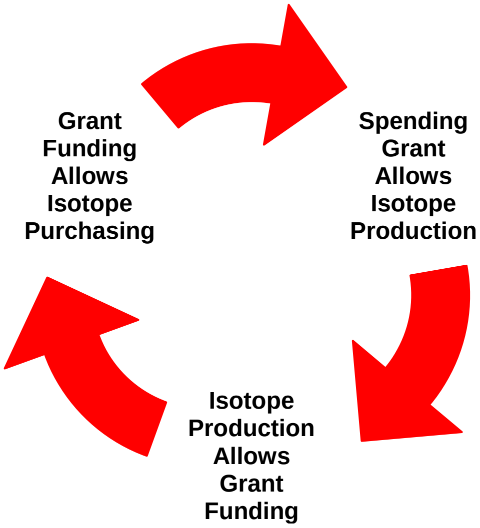


Figure 3. The challenge of predicting real needs: the isotope “merry-go-round”

Radioisotopes for Applications

Who uses them and why?

Radioisotopes for commercial applications include, but are not limited to, clinical uses for health care, exploration efforts for new energy sources, industrial process control, and use as reference materials in national security, industry, medicine, occupational health, agriculture, and environmental programs. Some isotopes are used in a wide range of applications critical to science, national security, and industry and have an enormous impact on our Nation's economy. For example, over 20 million procedures are performed annually in the United States that use radiopharmaceuticals and radiotracers for clinical (diagnostic and therapeutic) applications. ^{99m}Tc, which is generated in hospitals by using ^{99}Mo/ ^{99m}Tc generators, is needed in more than 85% of the applications, but the ^{99}Mo parent is currently available only from other countries.

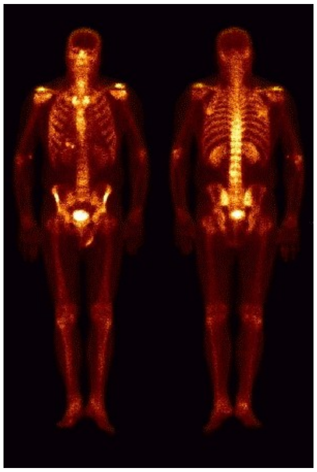
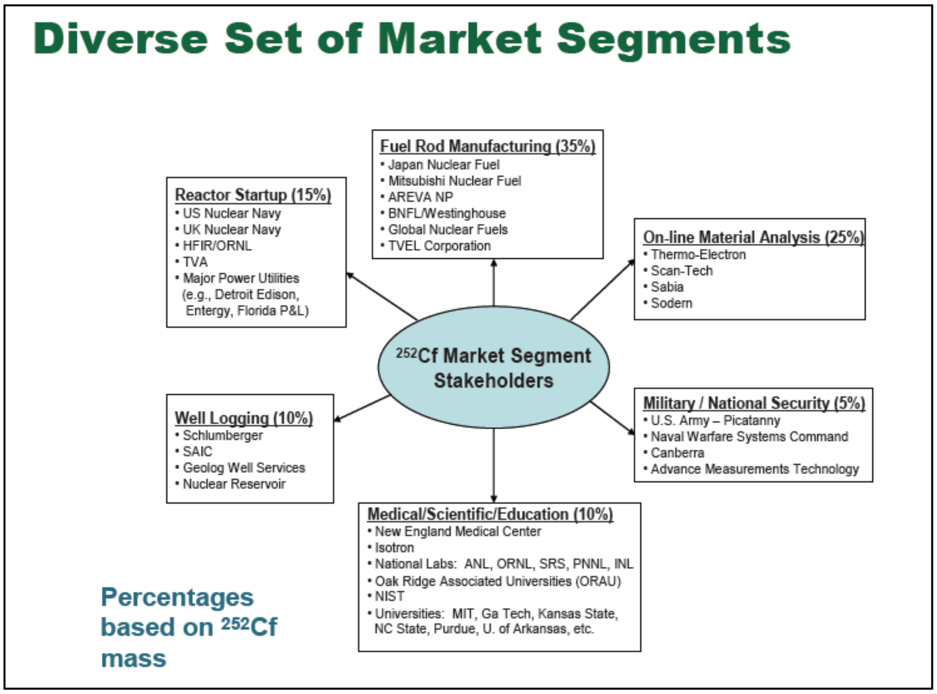


Figure 4. Bone scans locating cancerous growth by observing the radioactivity of ^{99m}Tc.

^{68}Ge and ^{82}Sr are critical to meet the increasing demand of the use of PET scanners for imaging and metabolic studies in the heart and other organs, and the detection and staging of cancer. The economic welfare of a number of industries is dependent on a reliable supply of radioisotopes. For example, ^{252}Cf – and the neutrons it emits – is needed for such applications as the start-up of civil and naval reactors, online materials analyzers for optimizing coal-fired power plants and Portland cement production, treatments for certain cancers that are not responsive to other radiation therapies (e.g., hypoxic tumors), oil and gas exploration, radiography of aircraft to detect corrosion and metal fatigue, and trace element forensic studies in U.S. Army field units. ^{241}Am is critical for well-logging procedures and for smoke detector systems in homes. ^{63}Ni and ^{3}He (obtained from decay of ^{3}H, tritium) are respectively critical for chemical agent and the radiation detectors used for national security. ^{60}Co is widely used for sterilization of medical devices and for the radiation treatment of food, materials, and blood. Iridium-192 (^{192}Ir) is extensively used in both industrial and medical environments – Non-Destructive Testing for portable gamma radiography inspection of welds and in high dose-rate brachytherapy for localized treatment of cancer. However, it has a high cost associated with its production. Appendix H includes a detailed and comprehensive description of how isotopes are used in various applications. One isotope, ^{192}Ir, can be used for gamma radiography inspection of welds and in a different application for localized brachytherapy for treating cancer. However, it has a high cost associated with its production.

Who produces them and where?

There has been a shift in the production and distribution of isotopes away from domestic sources and towards foreign sources. The production of isotopes has also shifted from the U.S. national laboratories to foreign national laboratories and government facilities such as the European Community funded reactors at Petten (Netherlands) and Mol (Belgium) and the multitude of reactor and cyclotron sites in the former Soviet Union. The primary reasons for this change include the rising costs of operations at the U.S. national laboratories, DOE past pricing policy changes that resulted in substantial price increases that were unacceptable to the user community, parasitic operation[4] of facilities in the United States leading to irregular supply schedules, the age and unreliability of the equipment at the national laboratories, retiring technical personnel, and the application of full cost recovery (Public Law 101) to the cost of "commercial" isotopes. This has resulted in an unreliable supply of isotopes year-round and has promoted the migration of business to foreign, government-subsidized facilities. The increasing dependence on foreign sources to supply isotopes critical to the economy and health care of the United States poses great risks associated with transportation, political relationships, and security with transport; both current and future applications may be severely effected.



Diverse Set of Market Segments

^{252}Cf Market Segment Stakeholders

Fuel Rod Manufacturing (35%)
- Japan Nuclear Fuel
- Mitsubishi Nuclear Fuel
- AREVA NP
- BNFL/Westinghouse
- Global Nuclear Fuels
- TVEL Corporation

Reactor Startup (15%)
- US Nuclear Navy
- UK Nuclear Navy
- HFIR/ORNL
- TVA
- Major Power Utilities (e.g., Detroit Edison, Entergy, Florida P&L)

On-line Material Analysis (25%)
- Thermo-Electron
- Scan-Tech
- Sabia
- Sodern

Well Logging (10%)
- Schlumberger
- SAIC
- Geolog Well Services
- Nuclear Reservoir

Military / National Security (5%)
- U.S. Army – Picatanny
- Naval Warfare Systems Command
- Canberra
- Advance Measurements Technology

Medical/Scientific/Education (10%)
- New England Medical Center
- Isotron
- National Labs: ANL, ORNL, SRS, PNNL, INL
- Oak Ridge Associated Universities (ORAU)
- NIST
- Universities: MIT, Ga Tech, Kansas State, NC State, Purdue, U. of Arkansas, etc.

Percentages based on ^{252}Cf mass

Figure 5. Diverse uses of the radioisotope ^{252}Cf

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[4] **The term "parasitic operation" refers to the circumstance whereby isotope production is not the primary mission, but rather a byproduct of other activities. This results in irregular and unreliable supply schedules.**

Production of certain isotopes such as ^{252}Cf can only be achieved efficiently using the highest flux nuclear reactor such as HFIR at ORNL. Also, the complex radiochemical processing required during the extraction of the ^{252}Cf from the irradiated targets has concomitant transuranic waste produced that can only be assimilated by government supported facilities. Similarly, the production of ^{241}Am is a byproduct of decay weapons grade ^{239}Pu refining and therefore only available via government supported facilities for both the production and disposal of the waste generated. These examples typify the need for "strategic isotope" classification for such nuclides as they cannot be produced in the private sector and necessarily demand use of government facilities. ^{3}He was discussed at length in the previous section and is a decay product of tritium.

Approximately 110 radioisotopes are sold by companies represented by the Council on Radionuclides and Radiopharmaceuticals (CORAR) group. Current production of many isotopes is limited to a sole source; for instance fission product extraction and purification from irradiated fuel elements is currently only available from sites in the former Soviet Union (e.g., ^{137}Cs, krypton-85 (^{85}Kr), ^{147}Pm). The recent ^{252}Cf shortage from the DOE resulted in existing customers supplementing their requirements from the Research Institute of Atomic Reactors (RIAR) site at Dimitrovgrad in Russia. ^{99}Mo is only available from abroad, and while it is produced at reactors in Australia, Europe, and South Africa, these sites are generating primarily for local requirements. Canada is the most prominent supplier of ^{99}Mo in the world and also dominates the world's ^{60}Co supply as a result of the use of cobalt metal as a flux flattener in the Canadian Deuterium Uranium reactor design. The existence of only one supplier puts the reliability of the supply at risk. This risk increases when the sole isotope source is located in a foreign country. Appendix H describes the production of each radioisotope that is important for applications.

What are the needs today and in the future?

Isotopes are widely used in a broad array of commercial applications in many areas that are strategically important to U.S. defense, industry, and medicine. The community has identified several critical radioisotope supply issues that must be addressed immediately. To address this challenge requires recognition of the strategic importance of a few of these isotopes to the Nation and will likely need attention at the government level. Specifically, the radioisotopes at issue are: ^{252}Cf, ^{241}Am, ^{99}Mo, and ^{137}Cs. ^{3}He was covered in another section of the report. For example, ^{99m}Tc (from a ^{99}Mo/^{99m}Tc generator) is used in approximately 50,000 medical procedures every day in the United States, while californium, americium, and cesium isotopes are critical to the oil and gas industry. Table 9 lists additional isotopes that are not used commercially but that are in continuous demand for national security. A description of present and future demands for these radioisotopes for applications is presented in Appendix H

Table 9. Table of isotopes essential for national security applications (not used commercially, but expected continuous future demand)

Isotope	Half-life	Application	Comments
Americium-243	7.3×10^3 y	Nuclear Forensics, isotope dilution analysis	Need high purity, No separation technology
Neptunium-236	1.55×10^5 y	Nuclear Forensics, isotope dilution analysis	Need high purity, No separation technology
Plutonium-236	2.87 y	Nuclear Forensics, isotope dilution analysis	Need high purity, No separation technology
Plutonium-242	3.75×10^5 y	Nuclear Forensics, isotope dilution analysis	Need high purity, No separation technology
Plutonium-244	8.0×10^7 y	Nuclear Forensics, isotope dilution analysis	Need high purity, No separation technology

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

Shortages in industrial isotope supplies have a profound impact on the U.S. economy, public health, and national security. This working group focused on isotope supply issues as they affect industrial applications. Many of the isotopes critically required for research and industrial applications are in short supply or not available at all, and must be imported from foreign sources. The brief interruptions in the supply of ^{99}Mo from Canada in 2007 and from Europe in 2008 are examples of the severe impact this creates on the national health care. The cessation of the production of ^{241}Am and ^{252}Cf had severe implications on energy exploration.

The table in Appendix H provides an extensive summary of all radioisotopes important for industrial/commercial interests and their status. Table 10 summarizes the isotopes of industrial interests that are currently either in short supply, not available, or only available from foreign suppliers, and that are considered of critical importance to the Nation. Other commercial isotopes in short supply, but of less strategic importance to the Nation, are included in Table 11 in the Conclusion.

Table 10. Radioisotopes for commercial applications identified as in short supply

Isotope	Half Life	Application	Problem
Actinium-225	10 d	Daughter Bi-213 used for clinical trials for treatment of AML and other cancers	Limited supplies are preventing clinical trials
Americium-241	432.7 y	Gamma source for process control, Neutron source for well logging, Alpha source for home smoke detectors	Ceased production
Californium-252	2.6 y	Neutron source for reactor start up, well logging, process control and , cancer therapy	Ceased production
Cesium-137	30 y	Industrial process control, cargo imaging, cancer treatment, blood irradiation, calibration of radiation instruments, and oil well logging (reservoir determinations)	No domestic supply Russian supply at risk
Molybdenum-99	66 h	Decay to technetium -99, needed in large amount for medical diagnostics	No domestic supply; foreign suppliers have potential problems

What are the options for increasing availability and associated technical hurdles?

The DOE Isotope Program, the national laboratories, and certain universities have the facilities and infrastructure to produce many of these radioisotopes. An evaluation of existing resources needs to be performed to ensure coordination and efficient use of any underutilized capacity at accelerators and reactors within the United States. Potential technological solutions as well as efforts to maximize the utilization of existing strategic resources will be required to solve the problem. Diverse options, such as using multipurpose existing facilities versus dedicated new facilities, should be evaluated.

While an enhanced national capability to produce a range of isotopes from domestic sources is desirable, it is likely that the United States will continue to depend upon foreign sources for certain isotopes for the foreseeable future. In this context, enhanced international cooperation and collaboration in isotope development, production, and supply is necessary and should be pursued. The formation of networks or coalitions of research reactors, accelerators, and related facilities for coordinated isotope supply should be encouraged and initiated.

International cooperation should aim to ensure that isotopes acquired from foreign sources meet necessary quality standards and that supply arrangements from foreign sources are robust, reliable, and redundant. Occasionally the quality of the supply may be a problem as the reliance upon foreign facilities with different standards for quality assurance and quality control may pose problems that also need to be addressed.
The absence of competitive domestic suppliers for many isotopes and the devaluation of the American dollar against most foreign currencies have resulted in significantly higher costs to obtain isotopic materials. A domestic back-up supply will provide increased assurances for a reliable isotope supply.

The significant impact that isotopes have on strategic, economic, societal, and public issues needs to be stressed. New models to ensure the development of public-private partnerships should be investigated together with the determination of realistic cost-sharing between the parties. It is particularly important to recognize that certain isotopes can be produced only within and as a result of government-funded facilities and projects. Paths forward should include mechanisms that allow stakeholders (actual users and producers) to provide input to DOE to ensure proper prioritization. Short- and long-range plans for cradle-to-grave infrastructure support and operations needs to be developed to ensure the supply of these and other isotopes.

Significant improvements in training and education programs are also needed in order to supply the professional, academic and technical workforce needed for all aspects of this vital industry.

CONCLUSION

Table 11 summarizes the isotopes identified at the workshop as being in short supply. It includes isotopes identified from the three working groups: Stable and Enriched Isotopes, Radioisotopes for Research and Development, and Radioisotopes for Applications. The list is substantial, and it is clear that the limited resources of the DOE Isotope Program will not be able to address all of these issues. To set priorities for the production of research isotopes, enhanced communication with stakeholders and federal agencies will be necessary, as will setting of priorities. Shortly after this workshop the NP charged NSAC to conduct two activities. The first activity involves the prioritization of research opportunities with isotopes. The second is the generation of a long-term strategic plan for isotope production, as it pertains to DOE and its Isotope Program.

Table 11. Isotopes considered in short supply or unavailable from DOE for research and applications.

Isotope	Half-Life	Workshop GROUP	Status	Examples of Important Applications	Production Options
Stable Isotopes					
Gadolinium-157	Stable	Stables	Not available	Neutron capture therapy of brain tumor	Needs new production facility
Germanium-76	Stable	Stables	Not available in quantity needed	Double beta decay in nuclear physics	Only available from Russia at present
Helium-3	Stable	Stables, Appl.	Limited amount	Homeland security, gyros for missile guidance systems, neutron scattering research, safeguards, oil drilling, low-T physics, medical, DOE NA25, and medical imaging	Decay of H-3 (Tritium), DOE (Savannah River), only one supplier
Lead-204 (high purity)	Stable	Stables	Not available	Environment, toxicology, earth sciences	Needs new production facility
Lead-207 (high purity)	Stable	Stables	Not available	Environment, toxicology, earth sciences	Needs new production facility
Ruthenium-96	Stable	Stables	Not available	Accelerator target, cross-section measurement	Needs new production facility
Samarium-150 (high purity)	Stable	Stables	Not available	Precursor to Sm-151	Needs new production facility
Tantalum-181 (high purity)	Stable	Stables	Not available	Electronic industry research	Needs new production facility
Tungsten-180 (high purity)	Stable	Stables	Not available	Precursor to W-151	Needs new production facility
Vanadium-51	Stable	Stables	Not available	Solid-state NMR	Needs new production facility
Radioisotopes					
Actinium-225	10 d	R&D	Limited amount	Starting material for the Ac-225/bismuth-213 generator. Bi-213 is used for targeted alpha therapy to treat a variety of cancers, including acute myelogenous leukemia	DOE (ORNL) - extract Th-229 from U-233, and recover Ac-225 daughter. Production also possible from reactors or accelerators
Americium-241	432.7 y	Appl.	Not available Requested	Gamma source for well-logging in oil exploration, for analyzing sulfur content in oil, and in home smoke detectors	DOE (LANL/PNNL) - recovery from operations associated with plutonium production or disposal
Americium-243	7370 y	Appl.	Limited	Nuclear Forensics, isotope dilution	DOE (ORNL-HFIR)

			amount	analysis (Need high purity)	
Arsenic-74	17.8 d	R&D	Not available	Dosimetry Check	Needs accelerator process development
Astatine-211	7.2 h	R&D	Limited amount	Cancer therapy	Requires alpha-beam; currently only 2 suppliers
Bismuth-212	1.0 h	R&D	Not available	α-Possibl useful for cander therapy	Obtained from decay of radium-226
Bismuth-213	45.6 m	R&D	Not available	α-Possibly useful for cancer therapy	Obtained from decay of actinium-225
Bromine-76	16 h	R&D	Not available	Dosimetry check	Needs accelerator process development
Bromine-77	2.4 d	R&D	Not available	Biomedical research, molecule labeling	Needs accelerator process development
Californium-252	2.6 y	Appl.	Limited amount	Neutron source for reactor start-up, for detection of presence of nitrogen based chemical explosives, and for analysis of sulfur content of petroleum. Technology being developed for brachytherapeutic treatment of cervical cancer	DOE (ORNL-HFIR) - multiple neutron capture on Cm-244
Cesium-137	30 y	Appl.	Not available	Gamma source for cargo imaging systems, brachytherapy source for intracavitary cancer treatment, calibration source in medical imaging systems and radiation protection instrumentation, gamma source for blood irradiators and sterilizers	Fission product of U-235, recovered from spent nuclear fuels
Copper-64	12.7 h	R&D	Limited amount	Dosimetry check, medical imaging	Material currently available from Trace Life Sciences
Copper-67	2.6 d	R&D	Not available	Therapeutic agent for cell-targeted radioimmunotherapy of cancer	DOE (LANL/BNL) - proton irradiation of zinc oxide targets. Material currently available from Trace Life Sciences
Holmium-166	1.12 d	R&D	Not available	Beta emitting radioisotope studied as a therapeutic agent for rheumatoid arthritis, metastatic liver cancer (microspheres), and hepatoma.	DOE (ORNL-HFIR) - Neutron capture on Ho-165 (natural holmium); domestic production available but high cost
Iron-52	8.3 h	R&D	Not available, Requested	Blood metabolism and blood disease studies	DOE (BLIP/IPF) – proton irradiation of Ni metal
Iridium-192	73.8 d	Appl.	Not available, Requested	Gamma radiography inspection of welds and localized brachytherapy for treating cancer	DOE (ORNL-HFIR) - neutron capture on iridium-191 metal; domestic production available but high cost
Krypton-85	10.8 y	R&D	Not available	Potential isotope for nuclear battery	Reactor production possible

Lutetium-177 (High Specific Activity)	6.7 d	R&D	Being developed	As a therapeutic agent for cell-targeted radioimmunotherapy of cancer	ORNL-HFIR - neutron capture on enriched Lu-176 target; domestic production available but high cost
Molybdenum-99	2.7 d	R&D, Appl.	Not available	Parent for Tc-99m which is used in about 85% of all nuclear medicine procedures	Produced in Canada, South Africa, Europe and soon Australia; reactor upgrades and processing facilities needed for production in US
Neptunium-237	2.14e6y	Appl.	Limited amount	Neutron Dosimetry, isotope dilution analysis	Only one supplier (Russia)
Neptunium-236	1.55e5y	Appl.	Not available	Tracer for Nuclear Forensics, isotope dilution analysis	Could be available: DOE (ORNL-HFIR)
Promethium-147	2.6 y	R&D	Not available	Beta emitter used as a miniature power source for military electronics	Fission product. Reactor production by neutron capture on Nd-146 target
Promethium-149	2.2 d	R&D	Limited amount	No-carrier added radiolanthanide for cancer therapy	Needs accelerator process development
Plutonium-236	2.87 y	Appl.	Limited amount	Tracer for Nuclear Forensics, isotope dilution analysis	DOE (ORNL-HFIR)
Plutonium-242	3.75e5 y	Appl.	Limited amount	Tracer for Nuclear Forensics, isotope dilution analysis	DOE (ORNL-HFIR)
Plutonium-244	8.0 e7 y	Appl.	Limited amount	Tracer for Nuclear Forensics, isotope dilution analysis	DOE (ORNL-HFIR)
Radium-223	11.4 d	R&D	Limited amounts	Radiotherapy of metastatic breast and prostate cancer	Limited supply available
Rhenium-186	3.8 d	R&D	Not available, Requested	Bone cancer therapy	Production at reactor produces low specific activity, needs new accelerator process
Silicon-32	172 y	R&D	Not available	Marine biology and biochemistry	Requires a high energy proton accelerator
Tin-117m	13.6 d	R&D	Limited amount	Bone malignancy therapy, bone pain palliation	Production requires alpha-beam for high yield and purity
Tungsten-188 Rhenium-188	69d / 17h	R&D	Limited amount	Cancer treatment	Only one supplier
Uranium-232	69.8 y	Appl.	Limited amount	Tracer for geochemical research and applications	DOE (ORNL-HFIR)
Yttrium-86	14.7 h	R&D	Being developed	As a photon-emitting surrogate for Y-90 in various cancer treatment applications; dosimetry check	DOE (BNL-BLIP) - proton irradiation on enriched Sr-88 target

Zirconium-89	3.3 d	R&D	Not available, Requested	Diagnostic isotope	Needs accelerator production R&D
Heavy Actinides (e.g. Berkelium etc.)		R&D	Very limited amount	Used for basic nuclear physics research of new/recently found elements	Requires HFIR or similar high intensity reactor; Some available from foreign suppliers

APPENDIX A: Acronyms and Terms

ANL	Argonne National Laboratory
ATLAS	Argonne Tandem Linac Accelerator System
ATR	Advanced Test Reactor
BER	Office of Biological and Environmental Research
BES	Office of Basic Energy Science
BLIP	Brookhaven Linac Isotope Producer
BNL	Brookhaven National Laboratory
cGMP	current Good Manufacturing Practices
Ci	Curie (unit of radiation activity; activity per unit time)
CORAR	Council on Radionuclides and Radiopharmaceuticals
DBD	Double Beta Decay
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FDA	U.S. Food and Drug Administration
FRIB	Facility for Rare Isotope Beams
FY	Fiscal Year
HFIR	High Flux Isotope Reactor
IAEA	International Atomic Energy Agency
INL	Idaho National Laboratory
IPF	Isotope Production Facility
ISO	International Organization for Standardization
ITU	Institute for Transuranium Elements
LANL	Los Alamos National Laboratory
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
MDS	MDS Nordion Inc.
MRI	Magnetic Resonance Imaging
MURR	University of Missouri Research Reactor Center
NCI	National Cancer Institute
NE	Office of Nuclear Energy
NIH	National Institute of Health
NIST	National Institute of Standards and Technology
NMR	Nuclear Magnetic Resonance
NNSA	National Nuclear Security Administration
NP	Office of Nuclear Physics
NSAC	Nuclear Science Advisory Committee
ORNL	Oak Ridge National Laboratory
PET	Positron Emission Tomography
PNNL	Pacific Northwest National Laboratory
R&D	Research and Development
RIMS	Radioisotope Micro-power Source
SHE	Super Heavy Element
SNM	Society of Nuclear Medicine
SNS	Spallation Neutron Source Facility
TRIGA	Training, Research, Isotopes, General Atomics Reactor
TRIUMF	TriUniversity Meson Facility
USDA	U.S. Department of Agriculture

APPENDIX B: List of Elements

The symbolism for an isotope is $^{A}\mathbf{X}$ where X represents the chemistry shorthand for the element; A is the total number of protons and neutrons in the nucleus. The element is determined by the number of protons in the nucleus, while different isotopes of the same element have the same number of protons and a different number of neutrons in their nucleus. Below is a table indicates the name, and the shorthand symbol for all elements. For example ^{12}C has 6 proton and 6 neutrons, while ^{14}C has 6 protons and 8 neutrons. ^{12}C is stable while ^{14}C is radioactive and in all living organisms. Some are not obvious, e.g. Tungsten is not Tu but rather W, iron is not Ir, but rather Fe, for historical reasons.

Actinium - Ac
Aluminum - Al
Americium - Am
Antimony - Sb
Argon - Ar
Arsenic - As
Astatine - At
Barium - Ba
Berkelium - Bk
Beryllium - Be
Bismuth - Bi
Boron - B
Bromine - Br
Cadmium - Cd
Cesium - Cs
Calcium - Ca
Californium – Cf
Carbon - C
Cerium - Ce
Chlorine - Cl
Chromium - Cr
Cobalt - Co
Copper - Cu
Curium - Cm
Dysprosium - Dy
Einsteinium - Es
Erbium - Er
Europium- Eu
Fermium - Fm
Fluorine - F
Francium - Fr
Gadolinium - Gd
Gallium - Ga
Germanium - Ge
Gold - Au
Hafnium - Hf
Helium - He
Holmium - Ho
Hydrogen - H
Indium - In
Iodine - I
Iridium - Ir
Iron - Fe
Krypton - Kr
Lanthanum - La
Lawrencium - Lr
Lead - Pb
Lithium - Li
Lutetium - Lu
Magnesium - Mg
Manganese - Mn
Meitnerium - Mt
Mendelevium - Md
Mercury - Hg
Molybdenum - Mo
Neodymium - Nd
Neon - Ne
Neptunium - Np
Nickel - Ni
Niobium - Nb
Nitrogen - N
Nobelium - No
Osmium - Os
Oxygen - O
Palladium - Pd
Phosphorus - P
Platinum - Pt
Plutonium - Pu
Polonium - Po
Potassium - K
Praseodymium - Pr
Promethium – Pm
Protactinium - Pa
Radium - Ra
Radon - Rn
Rhenium - Re
Rhodium - Rh
Rubidium - Rb
Ruthenium - Ru
Samarium - Sm
Scandium - Sc
Selenium - Se
Silicon - Si
Silver - Ag
Sodium - Na
Strontium - Sr
Sulphur - S
Tantalum - Ta
Technetium - Tc
Tellurium - Te
Terbium - Tb
Thallium - Tl
Thorium - Th
Thulium - Tm
Tin - Sn
Titanium - Ti
Tungsten - W
Uranium - U
Vanadium - V
Xenon - Xe
Ytterbium - Yb
Yttrium - Y
Zinc - Zn
Zirconium - Zr

APPENDIX C: Workshop Agenda

Monday, August 4

19:00 p.m.	Poster Session Room open for mounting posters - Regency Room
19:15 –21:00 p.m.	Meeting of Work Session Chairs - Adam Room

Tuesday August 5 - Plenary Session: Plaza I & II Ballroom

Chair: Jehanne Simon-Gillo

7:30 a.m.	Registration Sign-In and Continental Breakfast (outside Ballroom)
8:30 a.m.	Welcome and Opening Remarks – *Dr. Raymond Orbach*, Under Secretary for Science, Department of Energy
8:45 a.m.	Objectives of Workshop – *Dr. Jehanne Simon-Gillo*, Acting Associate Director, Office of Science for Nuclear Physics, DOE
9:00 a.m.	Perspective at OSTP for Isotopes – *Dr. Jean Cottam*, Assistant Director, Physical Sciences and Engineering, Office of Science and Technology Policy
9:15 a.m.	Nuclear Physics & Strategic Planning of the Isotope Program– *Professor Robert Tribble*, Professor of Physics, Texas A&M and Chair of the Nuclear Science Advisory Committee
9:45 a.m.	Importance and Role of Isotopes in Basic Research – *Dr. Lee Riedinger*, Professor of Physics, University of Tennessee
10:15 a.m.	Break
10:30 a.m.	Importance and Role of Isotopes to the NIH Mission – *Dr. Roderic Pettigrew*, Director, National Institute of Biomedical Imaging and Bioengineering, National Institutes of Health
11:00 a.m.	Importance and Role of Isotopes to the Medical Community – *Dr. Michael Welch*, Professor of Radiology, Washington University School of Medicine
11:30 a.m.	Importance and Role of Isotopes to the Dept. of Homeland Security Mission and National Security – *Dr. Charles Gallaway*, Deputy Director, Domestic Nuclear Detection Office, Department of Homeland Security
12:00 p.m.	Importance and Role of Isotopes to the Agricultural Research and Applications – *Mr. John Jensen*, Director, Radiation Safety Division, Department of Agriculture
12:15 p.m.	Lunch

Chair: John Pantaleo

14:00 p.m.	International Atomic Energy Agency (IAEA) Activities Related to Research Reactor Production of Radioisotopes – *Mr. Ira Goldman*, Project Manager, International Atomic Energy Agency
14:30 p.m.	Importance and Role of Isotopes to the Radiopharmaceutical Industry – *Mr. Roy Brown*, Senior Director of Federal Affairs, Council on Radionuclides and Radiopharmaceuticals
15:00 p.m.	Importance and Role of Isotopes to the Petroleum Industry–*Mr. Eric Rosemann,* Executive Director, Association of Energy Service Co.
15:30 p.m.	Break
15:45 p.m.	Recent and Ongoing National Academy Studies Relevant to Isotope Production – *Dr. Kevin Crowley*, Director, Nuclear and Radiation Studies Board, The National Academies
16:15 p.m.	The Mission of the Nuclear Regulatory Commission and its Role Pertinent to Radioactive Isotopes – *Dr. Donna-Beth Howe*, Office of Federal and State Environmental Management Programs, Division of Materials Safety and State Agreements, Nuclear Regulatory Commission

16:45 p.m. Status of International Isotope Production – *Dr. Tom Ruth*, Senior Research Scientist and Director of the University of British Columbia/Tri-University Meson Facility (TRIUMF) PET Program
17:15 p.m. Isotope Program in the USA – *Mr. John Pantaleo*, Program Director, Isotope Program, Office of Nuclear Energy, DOE
18:00 p.m. Poster Session and Refreshments – Regency Randolph Room
19:30 p.m. Dinner – Executive Dinning Room

Wednesday, August 6 – Working sessions (Invitation only)
8:00 a.m. – 12:00 p.m. Working Sessions

Stable and Enriched Isotopes – Wilson Room (and Truman Room)
Radioisotopes for Research and Development – Roosevelt Room
Radioisotopes for Applications – Plaza I

12:00 p.m. Lunch
13:30 p.m. – 18:00 p.m. Working Sessions

Stable and Enriched Isotopes – Wilson Room (and Truman Room)
Radioisotopes for Research and Development – Roosevelt Room
Radioisotopes for Applications – Plaza I

Thursday, August 7
8:00 a.m. – 10:00 a.m. Working Sessions
Stable and Enriched Isotopes – Wilson Room (and Truman Room)
Radioisotopes for Research and Development – Roosevelt Room
Radioisotopes for Applications – Plaza I

10:00 a.m. Break
10:30 a.m. – 13:00 p.m. Summary of Working Groups and Discussion – Plaza I
Chair: John D'Auria
13:00 p.m. Workshop concludes
14:00 p.m. – 15:00 p.m. Meeting of Work Session Chairs – Wilson Room

APPENDIX D: List of Institutions Attending Plenary Session

Federal
National Institutes of Health
Department of Homeland Security
Department of Agriculture
Nuclear Regulatory Commission
DOE Nuclear Energy
DOE Basic Energy Sciences
DOE Nuclear Physics
DOE Biological and Environmental Research
DOE Chicago Operations Office
DOE Chief Financial Officer
Office of Science and Technology Policy
National Nuclear Security Administration
National Institute of Standards and Technology
National Institute of Child Health and Human Development
Department of State
Federal Bureau of Investigation
Environmental Protection Agency
National Science Foundation
Office of Naval Research
Armed Forces Radiobiology Research Institute

National Laboratories
Argonne National Laboratory
Brookhaven National Laboratory
Lawrence Berkeley National Laboratory
Los Alamos National Laboratory
Oak Ridge National Laboratory
Pacific Northwest National Laboratory
Idaho National Laboratory
Lawrence Livermore National Laboratory
TRIUMF

Universities
Michigan State University
University of Washington
University of Missouri
Texas A&M University
Duke University
Washington University
University of California/Davis
Georgetown University Hospital
University of Buffalo
University of British Columbia
Caltech
University of Tennessee
Research Triangle Institute
North Carolina State University
University of Connecticut
University of San Francisco
Memorial-Sloan Kettering
American College of Radiology

Industrial
Nidnano
General Electric Energy Reuter Stokes
Spectra Gases
Trace Life Sciences, Inc.
Association of Energy Services
SABIA, Inc.
Council of Radionuclides and Radiopharmaceuticals
General Atomics
Techsource, Inc.
Halliburton
Advance Medical Isotope
JUPITER Corp.
Raytheon
NorthStar Medical Radioisotopes
TRIGA Reactor Systems
MDS Nordion Inc.

Other
The National Academies
International Atomic Energy Agency

APPENDIX E: List of Isotope Working Group Attendees

Attendee	Attendees Title	Institution	Email
Stable and Enriched Isotopes			
Jack Faught - CoChair	Vice President	Spectra Gases Inc.	jackf@spectragases.com
Lee Riedinger - CoChair	Professor	University of Tennessee (UT)	lrieding@utk.edu
Scott Aaron	Isotope Development Group Leader, NSTD	ORNL	aaronws@ornl.gov
Thomas Anderson	Product Line Leader	General Electric Energy Reuter Stokes	thomas.anderson1@ge.com
Ercan Alp	Senior Scientist	DOE/BES	eea@aps.anl.gov
Darren Brown	President	Trace Sciences Inter.	darren@tracesciences.com
Abdul Dasti	General Engineer	National Nuclear Security Administration (NNSA) Stock/Stewship	abdul.dasti@nnsa.doe.gov
Brad Keister	Program Director	National Science Foundation	bkeister@nsf.gov
Nanette Founds	Supervisory General Engineer	NNSA Stock/Stewship	nfounds@doeal.gov
John Greene	Target Development Engineer	ANL	greene@anl.gov
Gary Hatch	Chief, Pulmonary Toxicology Branch	EPA	hatch.gary@epamail.epa.gov
Richard Kouzes	Laboratory Fellow	University of Washington	rkouzes@pnl.gov
Molly Kretsch	National Program Leader Human Nutrition	U.S. Department of Agriculture	molly.kretsch@ars.usda.gov
Craig Reynolds	Associate Director, NCI	National Institute of Health	craig.reynolds@nih.hhs.gov
Andreas Stolz	Assistant Prof.& Dept. Head of Operations	Michigan State University	stolz@nscl.msu.edu
Jehanne Gillo	Acting Associate Director	DOE/NP	jehanne.gillo@science.doe.gov
Clifford Unkefer	Director National Stable Isotope Resource	LANL	cju@lanl.gov
Robert Vocke	Research Chemist	NIST	robert.vocke@nist.gov
Alfred Wong	Professor	Nidnano	awong@nidnano.com
Alfred Yergey	Section Chief	NIH Institute of Child Health	yergeya@mail.nih.gov

Radioisotopes for Research and Development

Robert Atcher - Cochair	Team Leader, SNM (President)	LANL	ratcher@lanl.gov
Robert Tribble - Cochair	Professor of Physics and Director	Texas A&M Cyclotron	r-tribble@tamu.edu
Martin Brechbiel	Section Chief	NCI	martinwb@mail.nih.gov
Glenn Young	Division of Physics	ORNL	younggr@ornl.gov
William Courtney	Linac Operation Manager	Trace Life Sciences	bcourtney@thelinac.com
Jill Chitra	Vice-President, Strategic Technologies	MDS Nordion Inc	jill.chitra@mdsinc.com
John D'Auria	Professor Emeritus	DOE - NP	john.d'auria@science.doe.gov
Darrell Fisher	Scientific Director, Office of Nat. Isotope Programs	PNNL	dr.fisher@pnl.gov
Jim Harvey	Chief Science Officer	Northstar Medical Radioisotopes, Inc.	jharvey@northstarnm.com
Calvin Howell	Professor & Director	Duke University	howell@tunl.duke.edu
Randy Hobbs	Experimenter Interface Staff	UT-Battelle/ORNL	hobbsrw@ornl.gov
Michael Hughes	Research Toxicologist	EPA	hughes.michaelf@epa.gov
Lynn Kaczmarek	Director of PET Radiopharmaceutical Production	University of Buffalo	kaczmare@buffalo.edu
Russ Knapp	Manager, Nuclear Medicine Program	ORNL/Nuclear Medicine Program	knappffjr@ornl.gov
Claude Lyneis	Physicist	LBNL	cmlyneis@lbl.gov
Jason Lewis	Chief, Radiochemistry Service	Memorial Sloan-Kettering Cancer Center	lewisj2@mskcc.org
Steve Laflin	CEO	International Isotopes, Inc.	staflin@intisoid.com
Lester Morss	Program Manager	DOE/BES	lester.morss@science.doe.gov
Leonard Mausner	Senior Scientist, Isotope Program Site Manager	BNL	mausner@bnl.gov
Alexandra Miller	Senior Scientist	Uniformed Services University of the Health Sciences/ Armed Forces Radiobiology Research Institute	millera@afrri.usuhs.mil
Roger Moroney	Manager, Radiological Compliance	Siemens	wilham.moroney@siemens.com
Heino Nitsche	Professor of Chemistry	LBNL	hnitsche@lbl.gov
Meiring Nortier	Dr.	LANL	meiring@lanl.gov
Richard Pardo	ATLAS Operations Manager	ANL	pardo@phy.anl.gov
J. David Robertson	Professor and Associate Director	University of Missouri	robertsonjo@missouri.edu

Ram Ramabhadran	Branch Chief, Cellular Molecular Toxicology	NIST	ramabhadran.ram@epa.gov
Prem Srivastava	Program Manager	DOE/BER	prem.srivastava@science.doe.gov
Mark Stoyer	Experimental Nuclear Physics Group Leader	Lawrence Livermore National Laboratory (LLNL)	stoyer1@llnl.gov
John Snyder	Commercialization Manager	INL	john.snyder@inl.gov
Henry VanBrocklin	Professor of Radiology and Biomedical Imaging	University of California	henry.vanbrocklin@radiology.ucsf.edu
Michael Welch	Professor of Radiology	Washington University	welchm@wustl.edu
Brian Zimmerman	Research Chemist	NIST	brian.zimmerman@nist.gov
Radioisotopes for Applications			
Jeff Norenberg - CoChair	Assoc. Prof. & Dir., Radiopharmaceutical Science	University of New Mexico	jpnoren@unm.edu
Parrish Staples - CoChair	Director, GTRI, NA212	NNSA	parrish.staples@nnsa.doe.gov
Zane Bell	Senior Research Scientist	ORNL	bellzw@ornl.gov
Roy Brown	Senior Director Federal Affairs/ CORAR	CORAR	roywbrown@sbcglobal.net
Cathy Cutler	Research Associate Professor	MURR	cutlerc@missouri.edu
Ron Crone	Division Director Research Reactors Division	ORNL	cronera@ornl.gov
Thomas Deforest	Project Manager	PNNL/NNSA	thomas.deforest@nnsa.doe.gov
Hugh Evans	Vice President	QSA-Global Inc	hugh.evans@qsa-global.com
Dan Fenstermacher	Physical Scientist	State Dept./Office of Nuclear Energy, Safety and Security	fensteada@state.gov
Steven Goldberg	Physical Scientist	DOE Chicago Operations Office	steven.goldberg@ch.doe.gov
Ira Goldman	Project Manager	IAEA	i.goldman@iaea.org
Ken Inn	Research Chemist	NIST	Ken.inn@nist.gov
Jennifer Jackson	Assistant Professor of Geophysics	Caltech	jackson@gps.caltech.edu
John Jensen	USDA - Director	Radiation Safety Division	john.jensen@ars.usda.gov
Jerry Klein	ORNL Isotope Program Manager	Isotope Business Office/Federal	kleinja@ornl.gov
Manuel Lagunas-Solar	Research Chemist	University of California, Davis	Solar@crocker.ucdavis.edu
Tracey Lane	VP Marketing	Trace Life Sciences	tlane@thelinac.com
Elly Melamed	Deputy Director, 2nd Line of Defense Program	NNSA	elly.melamed@hq.doe.gov

Frances Marshall	Department Manager, Irradiation Testing	INL	frances.marshall@inl.gov
David Martin	Program Director	DHS/Nuclear	david.w.martin@associates.dhs.gov
Gene Peterson	Div. Head Chem.	LANL	ejp@lanl.gov
John Pantaleo	Isotope Program Director	DOE/NE	john.pantaleo@hq.doe.gov
Michael Pearson	Senior Technical Advisor	NNSA	mwp@lanl.gov
Thomas Ruth	Senior Research Scientist	TRIUMF	truth@triumf.ca
Wolfgang Runde	DOE Isotope Program Manager	LANL	runde@lanl.gov
Robert Reba	Professor	Georgetown University Hospital	rreba@comcast.net
Alan Remen	Chief Operating Officer	SABIA, Inc.	ironn@sabianinc.com
Eric Rosemann	Chair, Radiation, Safety and Security Committee Chair	Association of Energy Service Companies	eric.rosemann@graywireline.com
James Symons	Director, Nuclear Science Division	LBNL	tjsymons@lbl.gov
Jason Shergur	Test Scientist	DHS	jason.shergur@dhs.gov
David Schlyer	Senior Scientist	BNL	schlyer@bnl.gov
Susan Seestrom	Senior Scientist	LANL	seestrom@lanl.gov
Mike Shlesinger	Chief Scientist for Nonlinear Science	Office of Naval Research	mike.shlesinger@navy.mil
James Tatum	Ass. Dir-Div. of Cancer Treatment and Diagnosis	NIH/NCI	tatumj@mail.nih.gov
Anthony Veca	IRIGA Reactor Systems-Director	General Atomics	anthony.veca@gat.com
Bernard Wehring	Professor	North Carolina State University	bwwehrin@ncsu.edu
Jim Wilson	Director of Materials	Ecker & Ziegler Isotope Products	jim.wilson@ezag.com
Michael Zalutsky	Prof. of Radiology & Biomedical Eng.	Duke University	zalut001@mc.duke.edu

APPENDIX F: List of Posters

Titles	Workshop Attendees
Stable and Enriched Isotopes	
ANL Physics Division Accelerator Target Laboratory	John Greene
Separated Isotope Requirements for Double-Beta Decay	Richard Kouzes
Rare Isotope Research at the National Superconducting Cyclotron	Andreas Stolz
Stable Isotope Enhanced Metabolomics	Clifford Unkefer
Isotopic Reference Materials for the 21st Century	Robert Vocke
Nutritional Uses of Stable Isotopes: An example of ion Absorption	Alfred Yergey
Enriched Stable Isotopes and Technical Services at ORNL	Scott Aaron
Mossbauer Spectroscopy: Stable and Radioactive Isotopes	Ercan Alp
Radioisotopes for Research and Development	
Optimizing a pre-labeling approach to synthesize a water-soluble conjugate for therapy with the Ac225 decay chain	Robert Atcher
Overview of HRIBF	Glenn Young
Use of arsenic-73 in research supports US EPA's regulatory decisions on inorganic arsenic in drinking water.	Michael Hughes
Capabilities of High Intensity Gamma-ray Source at TUNL Isotope Requirements for Research at TUNL	Calvin Howell
High Flux Isotope Reactor (HFIR) Radioisotope Production Facilities and Capabilities	Randy Hobbs
Medical Radioisotope Research at ORNL	Russ Knapp
Isotope use and production at LBNL's 88-Inch Cyclotron	Claude Lyneis

Using a Multiple Isotope Aproach to Understand Uranium Cellular	Alexandra Miller
BNL Radioisotope Research and Production Program	Leonard Mausner
Isotope Needs for Physics and Chemistry of the Heaviest Elements	Heino Nitsche
Californium Rare Isotope Beam Upgrade (CARIBU)-Radioactive Beams for Research using 252Cf	Richard Pardo
Isotope Production at the university of Missouri Research Reactor	J. David Robertson
88-Inch Cyclotron	James Symons
Isotopes for Nuclear Science at LLNL	Mark Stoyer
Present and Future Capabilities of the TAMU Cyclotron Institute	Robert Tribble
Producing Maximum Specific Activity Molybdemum-99 with 14MeV neutrons on a Technetium-99 Target	Robert Schenter
Am-241 Production at Los Alamos National Laboratory	Vigil Toby
Non Standard Pet Radioisotopes	Michael Welch
Radioisotopes for Applications	
Radiopharmaceutical Research at the University of Missouri	Cathy Cutler
Geophysical and Planetary Applications of Enriched Stable	Jennifer Jackson
Radioisotope Research Facilities at UC Davis	Manuel Lagunas-Solar
Isotope Science and Production at Los Alamos	Meiring Nortier
Potential for Accelerator Generated Tc-99m and FPEX Display	John Snyder

APPENDIX G: Summary Table of Working Group 1 on Stable and Enriched Isotopes

Legend:

Supply / Demand	Impact: economic / multiple industries / multiple populations
1. Demand > supply	1. Massive
2. Demand = supply	2. Moderate
3. Demand < supply	3. Minimal

Z	Isotope	Use	Producer	Status of Supply	Missing	Current Demand	Future Demand	Impact	Special Considerations	Options for Increased Availability
1	Hydrogen-2	Pharmaceutical, polymers, SNS cooling, moderator for reactors, in Nutrition and Medicine for measuring total body water in humans and obesity (extensively used to measure energy expenditure measurements in the form as doubly-labeled water).	India, Argentina, Canada, Romania, China, Russia (through TENEX), US inventory	Multiple sources from abroad, only current inventory in U.S.	No domestic generator of new inventory	2	2	1	Not currently produced in US; current demand is met through foreign sources which can be erratic and expensive	(1) United States stockpiles of partially enriched Deuterium Oxide exist at Savannah River and other defense related stockpiles which could be re-enriched and purified. Sufficient reserves exist. Private sector production could be used to process the material.
2	Helium-3	Homeland security, gyros for missile guidance systems, neutron scattering research, safeguards, oil drilling, low-T physics, medical, DOE NA25, and medical imaging	Savannah River, Russia (Mayak)	Only two sources, no new domestic production	No domestic generator of new inventory	1	1	1	Demand exceeds current combined capacity of Savannah River and Russia	(1) Current and anticipated demand is not being met. It is possible that alternative strategies could reduce somewhat the large anticipated demand. (2) There is waste of ^{3}He in some applications in other countries, and international agreements could result in new supplies of ^{3}He for our use. (3) Alternate technologies for neutron detection exist and may reduce demand for ^{3}He.

3	Lithium-6,7	Homeland security, neutron scattering research, safeguards, oil drilling, low-T physics, medical, DOE NA25	Oak Ridge Y-12 National Security Center through DOE/ORNL	Existing inventory		3	3	2?	Supply has not been an issue	
5	Boron-10,11	Detector technology, neutron detectors, semiconductor industry, nuclear power industry	Companies in US, Russia, China, Israel, Georgia, Japan	Multiple sources		3	3	2	Private sector supply is good	One private company operates in the United States and a second source is being developed at LANL.
5	Boron-10	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
6	Carbon-12,13	Pharmaceutical, polymers, atmospheric research, accelerator beams	Companies in US, Russia, China, Israel, Georgia, Japan	Multiple sources		3	3	2	Private sector supply is good	N/A
6	Carbon-13	Human nutrition and Agricultural Science uses	Companies in US, Russia, China, Israel, Georgia, Japan	Multiple sources		3	3	2	Private sector supply is good	N/A
7	Nitrogen-14,15	Pharmaceutical, USDA programs, atmospheric research, accelerator beams	Not available domestically, but current demand is met by sources in China and Georgia	No domestic generator of new inventory	No domestic generator of new inventory	2	1	2	Not available domestically	Enrichment systems are operable at LANL, which could be activated if foreign supply is disrupted.
7	Nitrogen-15	Human nutrition and disease prevention	Not available domestically, but current demand is met by sources in China and Georgia	No domestic generator of new inventory	No domestic generator of new inventory	2	1	2	Not available domestically	Enrichment systems are operable at LANL, which could be activated if foreign supply is disrupted.

8	Oxygen-18	Used in PET diagnostics as a target in the cyclotron	Companies in the USA, China, Israel, Georgia, and Russia produce the product in quantities exceeding demand	Excellent		3	3	3		
8	Oxygen-17	Used in MRI as a diagnostic	Limited production in Georgia < 2 kg per year	Demand is being met	No domestic generator of new inventory	2	2	2		
8	Oxygen-16,18	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
8	Oxygen-18	Human nutrition and obesity studies (extensively used to measure energy expenditure in the form of doubly-labeled water).	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
10	Neon-20,21,22	Neon 20 & 22 are used for laser systems; Neon 21 is a cyclotron target	Companies in the USA produce these gases	Demand is being met		2	2	2		
10	Neon-22	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
12	Magnesium-25,26	Human nutrition, disease prevention, and medical imaging - NIH and USDA	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
12	Magnesium-24	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	

14	Silicon	Electronics industry	Only Russia for large quantities			3	1	2	kg quantities	New enrichment techniques such as plasma ion cyclotron resonance separation, acoustic separation, cryogenic distillation, laser ionization, plasma centrifuge
14	Silicon-29	Environment, toxicology, earth sciences	DOE inventory; Russia	Demand is being met		3	3	2	Concern about future supply and cost	
14	Silicon-28	Worldwide weight standard based on pure perfect crystal balls – Avogadro Project	DOE inventory; Russia	Demand is being met		3	3	2	Concern about future supply and cost	
14	Silicon-28	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
16	Sulphur	Tracer-based studies of drug discovery, metabolism, and quantification	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
18	Argon-36,40	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
20	Calcium-42,44	Human nutrition, disease prevention, tracer studies of plant growth, and medical imaging - NIH and USDA	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
20	Caldium-40,48	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
22	Titanium-48	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
24	Chromium	Tracer studies of plant growth, environment, toxicology, earth sciences	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	

26	Iron-56	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
26	Iron-57,58	Human nutrition, disease prevention - NIH and USDA	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
28	Nickel-58,64	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
30	Zinc-67-70	Human nutrition, disease prevention, tracer studies of plant growth - NIH and USDA; environment, toxicology, earth sciences	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
30	Zinc-64	Nuclear energy	DOE inventory; Russia	Demand is being met		3	3	2	Concern about future supply and cost	
32	Germanium-76	Double beta decay	Only Russia for large quantities			3	1	2	100-1200 kg	New enrichment techniques such as plasma ion cyclotron resonance separation, acoustic separation, cryogenic distillation, laser ionization, plasma centrifuge
32	Germanium-74,76	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
34	Selenium-74,76,78,80, 82	Human nutrition, disease prevention, tracer studies of plant growth - NIH and USDA	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
34	Selenium-82	Double beta decay	Only Russia for large quantities			3	1	2	100-1200 kg	New enrichment techniques such as plasma ion cyclotron resonance separation, acoustic separation, cryogenic distillation, laser ionization, plasma centrifuge
34	Selenium-82	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	

35	Bromine	Atmosphere and hydrosphere programs	DOE inventory; Russia	Demand is being met		3	3	2	Concern about future supply and cost	
36	Krypton-85	Lighting Industry	Russia	No domestic generator of new inventory	No domestic generator of new inventory	2	2	2	Demand is met from Russia	
36	Krypton-78,84,86	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
38	Strontium-84	NIST - standards and spike materials	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
40	Zirconium-90,96	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
42	Molybdenum-100	Double beta decay	Only Russia for large quantities			3	1	2	100-1200 kg	New enrichment techniques such as plasma ion cyclotron resonance separation, acoustic separation, cryogenic distillation, laser ionization, plasma centrifuge
42	Molybdenum-92,98	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
44	Ruthenium-96	Accelerator target, crossection measurement	DOE, Russia both sold out	None available	None available	1	1	?		
44	Ruthenium-102	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
48	Cadmium-116	Double beta decay	Only Russia for large quantities			3	1	2	100-1200 kg	New enrichment techniques such as plasma ion cyclotron resonance separation, acoustic separation, cryogenic distillation, laser ionization, plasma centrifuge
48	Cadmium	Environment, toxicology, earth sciences	DOE inventory; Russia	Demand is being met		3	3	2	Concern about future supply and cost	
48	Cadmium-106	Accelerator beam	DOE inventory; Russia	10 yr left in DOE inventory	10 yr left in DOE inventory	3	2	2	Concern about future supply and cost	

49	Indium	Low background detection	Only Russia for large quantities			3	1	2	100 gm quantites	New enrichment techniques such as plasma ion cyclotron resonance separation, acoustic separation, cryogenic distillation, laser ionization, plasma centrifuge
50	Tin-112,118,120,124	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
52	Tellurium-130	Double beta decay	Only Russia for large quantities			3	1	2	100-1200 kg	New enrichment techniques such as plasma ion cyclotron resonance separation, acoustic separation, cryogenic distillation, laser ionization, plasma centrifuge
52	Tellurium-130	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
54	Xenon-124,129,136	Cyclotron target for Iodine 125, MRI diagnostics, and dark matter research	Russia, Holland	No domestic generator of new inventory	No domestic generator of new inventory	3	3	3	Rare gas centrifuges are not operating in the United States. Foreign supply has met demand.	Do we mention the new technology presented at the meeting?
54	Xenon-129	Tracer studies of plant growth, and medical imaging - NIH and USDA	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
54	Xenon-136	Double beta decay	Only Russia for large quantities			3	1	2	100-1200 kg	New enrichment techniques such as plasma ion cyclotron resonance separation, acoustic separation, cryogenic distillation, laser ionization, plasma centrifuge
54	Xenon-124,132,136	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
55	Cesium-133	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	

57	Lanthanum	Detectors	Only Russia for large quantities			3	1	2	kg quantities	New enrichment techniques such as plasma ion cyclotron resonance separation, acoustic separation, cryogenic distillation, laser ionization, plasma centrifuge
60	Neodymium-150	Double beta decay	Only Russia for large quantities	8 yr left in DOE inventory		3	1	2	100-1200 kg	New enrichment techniques such as plasma ion cyclotron resonance separation, acoustic separation, cryogenic distillation, laser ionization, plasma centrifuge
62	Samarium-144	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
64	Gadolinium	Detectors	DOE inventory; Russia	Demand is being met		3	3	2	Concern about future supply and cost; DOE 157Gd supply nearly sold-out, application unknown	
66	Dysprosium-156	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
68	Erbium-162	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
70	Ytterbium-176	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
78	Platinum	Environment, toxicology, earth sciences	DOE inventory; Russia	Demand is being met		3	3	2	Concern about future supply and cost	
80	Mercury	Environment, toxicology, earth sciences	DOE inventory; Russia	Demand is being met		3	3	2	Concern about future supply and cost	
80	Mercury-196	Accelerator beam	DOE inventory; Russia	10 yr left in DOE inventory	10 yr left in DOE inventory	3	2	2	Concern about future supply and cost	
80	Mercury-204	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	

82	Lead-206	NIST - standards and spike materials	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
82	Lead	Environment, toxicology, earth sciences	DOE inventory; Russia	Demand is being met		3	3	2	Concern about future supply and cost	
82	Lead-208	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
83	Bismuth-209	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	
92	Uranium-238	Accelerator beam	DOE inventory; Russia	Demand is being met		3	3	3	Concern about future supply and cost	

APPENDIX H: Summary Table of Working Group 3 on Radioisotopes for Applications

Legend:

Supply / Demand

1. Demand > supply
2. Demand = supply
4. Demand < supply

Impact: economic / multiple industries / multiple populations

1. Massive
2. Moderate
3. Minimal

Nuclides	**Main Applications**	**Producer**	**Status of Supply**	**What is Missing**	**Current Demand**	**Future Demand**	**Impact**	**Special Considerations**	**Options for increased availability**
Actinium-225	Medical	Germany (ITU), DOE (ORNL)	Limited Availability	Need additional stock of Th-229	1	1	If product approved 1, otherwise 2	Needs to be extracted from U-233 weapons waste, or produced on reactor or cyclotron	Congressional ban needs to be lifted to allow recovery of Th-229 from U-233 waste
Silver-105	Weapons physics/ stockpile stewardship	DOE-DP	2		2	2	1	Capability maintenance essential	Specialized production required
Amercium-241	Process control, analysis, well logging, Safety, ANSI standard for certifying radiation detection instruments	Russia	single source, 1	No disposal pathway, Capital investment	1	1	1	linked to foreign weapons reprocessing	Recycle of Am/Be sources at LANL, Activate LANL Am production line
Americium-243	Isotope dilution spikes/nuclear forensics	DOE-DP	1 for highly enriched	High purity required	1	1	1	High purity required	Reestablish mass separator capability for radioactive and stable isotopes.
Astatine-211	Medical	NIH, Duke, Univ of Washington	Limited Availability, Radiochemical grade only	Lack of local structure for scale-up production	1	1	If product approved 1, otherwise 2	Availability of 25 MeV or greater (,2n) on Bi-209 (100%), FDA hurdles, cGMP production	Build Infrastructure for production and commercial scale-up
Gold-195	Weapons physics/ stockpile stewardship	DOE-DP	2		2	2	1	Capability maintenance essential	Specialized production required

Barium-133	Process Control & Security, ANSI standard for certifying radiation detection instruments	Russia (RIAR)	Single Source, 2	Ok	2	2	2	Enriched Ba-132 needed	ORNL could produce – reactor irradiation
Carbon-14	Geochem., Health Physics, Process control	Russia	Multiple Sources	Ok	2	2	3	N/A	ORNL & INL
Cadmium-109	Analysis, Process Control	Multiple cyclotrons	Multiple sources	Ok	2	2	2	N/A	N/A
Californium-252	Process control, analysis, well logging, Safety National Security, Medical, ANSI standard for certifying radiation detection instruments	DOE (ORNL) & RIAR (Russia)	Dual source - capacity problem – all RIAR production sold until 2010, 1	Apparent (6-9 month) gap between current available supply and industry demand, Processing facilities	1	1	1	ORNL – has capacity – Zero funding – current material in the reactor needs funding for the 9 month process exercise, 4 year campaign needs to be examined	Long term planning, Definition of "Full cost recovery" so industry can adjust their business plans to accommodate pricing increases, Reinstate irradiation and processing
Chlorine-36	Health Physics, Geochem.	None	Last produced late 1970s (Canada – Nordion)	No known current production	1	1	3	Processing difficulties after irradiation	Reactor irradiation
Curium-244	Analysis	DOE (ORNL), Russia (RIAR)	OK	Waste disposal pathway	2	2	2	None	Not an issue
Cobalt-57	Process Control, Analysis, NDT, Mineralogy, ANSI standard for certifying radiation detection instruments, Short-lived RDD surrogate	Russia, Europe	Multiple Sources, 3	Reliable source	2	2	2	N/A	Multiple Cyclotrons
Cobalt-60	Calibration standard	DOE, Europe, Canada, Russia	3	Infrastructure and cost effectiveness within U.S.	3	3	3	ANSI standard for certifying radiation detection instruments.	

Cesium-137	Process control, Well logging, Formation evaluation, Agricultural Irradiation, Health Physics	Russia	No current U.S. production, Russian supply at risk	No new fission product separation	1	1	1	Specific activity concerns viz-a-viz feedstock age	US fission product separation
Copper-67	Medical	Trace Life Sciences, BLIP, LANL	DMF, Radiochemical	If FDA drug approved, address capacity	2	If product approved 1, otherwise 2	1	Scale-up production if drug FDA approved	Scale-up for production quantities and backup suppliers
Europium-149	Weapons physics/ stockpile stewardship	DOE	2		2	2	1	Capability maintenance essential	Specialized production required
Iron-55	Analysis, Process Control, Geochem.	DOE (ORNL), MURR	Multiple sources	Ok	3	2	3	N/A	N/A
Gadolinium-153	Health Physics, Process Control	Russia	Sole source	Reliable/available supply	2	2	1		ORNL & INL have produced and could restart production
Germanium-68	Medical	LANL, BLIP, Cyclotron Co, iTHEMBA	Multiple sources, Radiochemical Only	Ok	2	2	1		No issues
Germanium-68/Gallium-68 generator	Medical	The Cyclotron Co., Eckert & Ziegler, Russia	Radiochemical Only	Current generators not sterile or pyrogen-free	2	If product approved 1, otherwise 2	1	FDA hurdles, Long shelf-life generator does not have attractive market potential	Potential work for others DOE Project to develop sterile pyrogen-free generator
Hydrogen-3	Analysis, Light Sources, neutron targets	Russia, DOE, Canada (Ontario Hydro)	Multiple sources	Ok	1	1	1	Safe guard issues	
Helium-3	Homeland security, Detector technology	DOE	1	Purified materials	1	1	1	Detector material. No helium no neutron detectors	Investigate possible release in existing inventories

Iridium-192	Non-destructive testing	EEC reactors + many Russian, Canada (Nordion)	Zero production in U.S.	Infrastructure and cost effectiveness within U.S.	1	1	1	Cost transparency & facility infrastructure	ORNL & INL have produced and could restart production
Krypton-85	Process control, safety	Russia	Single sourced	Fission process, Reliable source	1	1	2	fission product separation – requires isotopic enrichment via centrifuge or thermo diffusion	ORNL could produce
Lutetium-173	Weapons physics/ stockpile stewardship	DOE	2		2	2	1	Capability maintenance essential	Specialized production required
Lutetium-177	Medical	DOE (ORNL), MURR, Petten (Netherlands)	Radiochemical, Specific activity and radionuclide purity is an issue, Radiopharmaceutical purity in the near future	Desire carrier free production	2	2	1	Carrier free and radionuclidic impurities, FDA hurdles	Project to develop and evaluate carrier free projection and scale up
Molybdenum-99	Medical	NRU, Canada, Petten (Netherlands), Safari, South Africa, BR-2 (Belgium)	Medium and long term questionable	Intermediate and long term supply with Maple Project cancellation and license expiration of NRU and HIR	2	1	1	FDA sNDA or CBE filing for existing mfr to convert to LEU, or DMF for new supplier w/ sNDA for generator mfr	MURR and B&W have proposed LEU production techniques
Nickel-63	Analysis, Detector technology	DOE (ORNL), Russia (RIAR)	1 (supply lags demand)	Ok	1	1	2	N/A	N/A

Neptunium-236	Isotope dilution spikes/nuclear forensics	DOE	1 for highly enriched	High purity required	1	1	1	High purity required	Reestablish mass separator capability for radioactive and stable isotopes.
Lead-210	Health physics & Geochem.	None		Reliable source	1	1	3	Decay product of Ra-226	Anybody with a hot cell
Promethium-147	Process control, Safety, Light sources	Russia	Single source	No fission product separation in U.S.	2	1	1	Fission product separation	ORNL & INL reactor irradiation
Polonium-210	Process Control, Safety, Health Physics	Russia	Single supply	Single user in U.S.	3	3	3		ORNL & INL reactor irradiation
Plutonium-236	Isotope dilution spikes/nuclear forensics	DOE	1 for highly enriched	High purity required	1	1	1	High purity required	Reestablish mass separator capability for radioactive and stable isotopes.
Plutonium-242/244	Isotope dilution spikes/nuclear forensics	DOE	1 for highly enriched	High purity required	1	1	1	High purity required	Reestablish mass separator capability for radioactive and stable isotopes.
Radium-226	Process control, Health Physics, Isotope Production	None	None	No available supply	1	3	3	See Lead-210 – required for production	Decay product
Rubidium-83	Weapons physics/ stockpile stewardship	DOE	2		2	2	1	Capability maintenance essential	Specialized production required
Rhodium-101	Weapons physics/ stockpile stewardship	DOE	2		2	2	1	Capability maintenance essential	Specialized production required
Selenium-75	NDT, Health Physics, Medical	DOE (ORNL), Russia (RIAR), MURR	OK	OK	2	2	2		
Silicon-32	Geochem, Ocean Science	None	No availability		1	1	2		ORNL, Canada
Samarium-151	Analysis	Russia	Available	Ok	2	2	3	N/A	N/A
Strontium-85	Short-lived RDD surrogate	DOE	3		3	3	2		

Strontium-90	Process Control, Geochem,	Russia, PNNL	Available	Ok	2	2	1	Minimal availability, ex. PNNL	US fission product separation
Tantalum-179	Weapons physics/ stockpile stewardship	DOE	2		2	2	1	Capability maintenance essential	Specialized production required
Terbium-157	Weapons physics/ stockpile stewardship	DOE	2		2	2	1	Capability maintenance essential	Specialized production required
Thorium-228	Health Physics, ANSI standard for certifying radiation detection instruments	None	Not Available, 1	N/A	1	1	1	Requires U-232	No current efforts for separation
Thorium-229	Isotope dilution spikes/nuclear forensics	DOE	2	High purity required	2	2	1	High purity required	Reestablish mass separator capability for radioactive and stable isotopes
Thorium-230	Health Physics, Geochem.	None	Not Available, 1	N/A	1	1	3	Requires U-232	
Uranium-232	Geochem., Calibration standard	None	Not Available, 1	N/A	1	1	1	Required for processing other isotopes	Isotope separation
Uranium-233	Isotope dilution spikes/nuclear forensics	DOE	2		1	1	1		
Tungsten-181	Weapons physics/ stockpile stewardship	DOE	2		2	2	1	Capability maintenance essential	Specialized production required
Yttrium-88	Weapons physics/ stockpile stewardship	DOE	2		2	2	1	Capability maintenance essential	Available from high-energy accelerators
Zirconium-88	Weapons physics/ stockpile stewardship	DOE	2		2	2	1	Capability maintenance essential	Available from Y-88 generator
Multiple common isotopes	Emergency responder training	Multiple sources	2		2	2	3		
Multiple reactor isotopes	Weapons physics/ stockpile stewardship	DOE	1 or 2		1 or 2	1 or 2	1	Capability maintenance essential	

Multiple isotopes for Nuclear Forensics	Short-lived RDD surrogate	DOE	2		2	2	3		
Ref. materials (multiple isotopes)	Nuclear forensics	DOE	1	Inadequate supplies	1	1	1		
Research Medical Isotopes	Medical	Many	Limited due to lack of funding		1	1		Lack of trained personnel and facilities	Projects to increase funding, training and facilities