Enterprise SRS: Leveraging Ongoing Operations to Advance Nuclear Fuel Cycle Programs – 12579

J.E. Marra, J.C. Griffin, A.M. Murray, and W.R. Wilmarth
Savannah River National Laboratory
Aiken, SC 29802 USA

ABSTRACT

The international leadership in nuclear technology development and deployment long held by the United States has eroded due to the lack of clear national strategies for advanced reactor fuel cycle concepts and for nuclear materials management, as well as to the recent policy decision that halts work on the nuclear fuel repository at Yucca Mountain. Although no national consensus on strategy has yet been reached, a number of recent high-profile reviews and workshops have clearly highlighted a national need for robust research, development and deployment (RD&D) programs in key areas of nuclear technology, especially nuclear separations science and engineering.

Collectively, these reviews and workshops provide a picture of the nuclear separations mission needs for three major program offices: Department of Energy Office of-Environmental Management), DOE Office ofNuclear Energy), and the National Nuclear Security Administration (NNSA). While the individual program needs differ significantly in detail and timing, they share common needs in two critical areas of RD&D:

- The need for access to and use of multi-purpose engineering-scale demonstration test facilities that can support testing with radioactive material, and
- The need for collaborative research enterprises that encompass government research organizations (i.e., national laboratories), commercial industry and the academic community. Such collaborative enterprises effectively integrate theory and modeling with the actual experimental work at all scales, as well as strengthen the technical foundation for research in critical areas.

The arguments for engineering-scale collaborative research facilities are compelling. Processing history has shown that test programs and demonstrations conducted with actual nuclear materials are essential to program success. It is widely recognized, however, that such facilities are expensive to build and maintain; creating an imposing, if not prohibitive, financial burden on an individual sponsoring office. Given that reality, success for the current and future nuclear separations missions is dependent on a concerted effort to develop new, creative, approaches that leverage existing facilities in a manner that supports both near- and long-term needs of national programs.

As a result of this situation, the Savannah River National Laboratory (SRNL) organized the “Nuclear Separations User Facility Strategy Session” in Washington, D.C. on July 29, 2011. This workshop brought together key stakeholders from DOE and the private sector to develop a strategy for using engineering-scale nuclear materials processing facilities to advance our nation’s nuclear separations research needs. In particular, the meeting focused on

recommending how these engineering-scale demonstration facilities, like the Savannah River Site H-Canyon, can be connected with smaller "bench-scale" research activities to form a seamless approach that integrates across the continuum of RD&D of advanced separations technologies. Coming out of this workshop, a new vision has been developed for a collaborative research facility model that centers on H-Canyon. Unique to this approach is the fact that H-Canyon will continue to accomplish DOE's critical nuclear material processing missions, while simultaneously serving as an RD&D resource for the scientific and technical portions of the nuclear separations community. This paper describes the planned operations for H-Canyon in FY2012 and beyond and discusses how these operations fit within the context of a collaborative research facility model and support the ongoing fuel cycle research and development programs of the DOE.

Nuclear Separations Mission Need

The international leadership in nuclear technology development and deployment long held by the United States has eroded due to the lack of clear national strategies for advanced reactor and fuel cycle concepts and for nuclear materials and facilities management. Recent policy decisions forestalling the demonstration of advanced technologies for nuclear fuel recycle for 20 years and halting the opening of the high level waste (HLW) and spent nuclear fuel repository at Yucca Mountain, Nevada have only exacerbated this decline in US nuclear technology leadership. Without near-term actions to recover this technology eminence, the United States not only faces erosion in its nuclear technology competence and capability to deal with its diverse inventory of nuclear materials and to provide energy for the future, but also faces the prospect of becoming irrelevant to the global nuclear technology community, especially in the area of nuclear separations technologies.

Findings of Pertinent Reviews and Workshops

The needs and options to recover the US technology leadership in nuclear separations technologies are clearly highlighted in several recent high-profile reviews.[1,2,3,4,5,6] However, no national consensus strategy has been reached. Yet the recent events at the Fukushima Daiichi nuclear power plant in Japan and increasing international nonproliferation concerns emphasize the urgency for setting an unambiguous national direction in research, development, and demonstration (RD&D)RD&D of nuclear separations technologies. Even as the policy options are evaluated and debated, RD&D lead times and extreme pressures on the national budget make it essential that the technical strategies be carefully selected and highly leveraged across public agencies and private companies to maximize the value provided.

A common conclusion in all of these reviews is the national need for robust, stable RD&D programs in key areas of nuclear technology , with emphasis on nuclear separations science and engineering needs. This outcome is understandable for the simple reason that nuclear separations science represents the foundation for the back-end of the fuel cycle – differences in separations technology literally define advanced fuel cycle and waste management strategies. It is also a fundamental component of the ongoing work in the Department of Energy Office of Environmental Management (DOE-EM) in setting the direction and scope for the treatment and disposition of legacy HLW from defense nuclear activities. Separations science and engineering also plays a critical role in the National Nuclear Security Administration's (NNSA) activities in helping to guide the development of nonproliferation analysis and safeguards technologies. The scope and time frame for specific needs in all of these areas will be discussed in more detail later in this document.

A close study of the results of the various reviews and workshops reveals that there are at least two critical components for the future success of nuclear separations technology RD&D:

- Engineering-scale test facilities and capabilities – There is recognition of a strong need – both near-term and long-term – for engineering-scale (i.e., pilot-scale) demonstration and test facilities capable of supporting testing with radioactive material. As discussed later in this document, these capabilities will be essential for nuclear separations RD&D in support of a variety of national missions in the NNSA and in the DOE-EM and Office of Nuclear Energy (DOE-NE).

  The availability and use of these engineering-scale test facilities (using actual material) was highlighted as an important contributor to RD&D success in the development of waste treatment technologies in the National Academies of Science review of the DOE-EM Cleanup Technology Roadmap.[6] The need for such facilities was also cited in the recommendations of the Massachusetts Institute of Technology study[5] and became a key focus area for a breakout session (Scale-up) in the recent DOE Nuclear Separations Technology Workshop.[3] The Blue Ribbon Commission (BRC) also recognized the importance of these capabilities in its recommendation to fund "well-designed, multipurpose test facilities" that that can enable collaborative research that advances knowledge in multiple areas.[1]

- Collaborative research enterprises - The scientific and technical community that participated in those recent reviews and workshops (who are the ones that "own" these needs and develop the technologies to address these needs) have indicated a strong belief that the full complement of the Nation's nuclear separations experience, expertise, and capabilities must be captured and focused in collaborative enterprises to assure the success of current and future nuclear missions. These collaborative enterprises are envisioned in the broadest way possible, i.e., to include government research organizations, commercial entities, and the academic community. Such collaborative enterprises accelerate the development and deployment of nuclear separations technologies by facilitating effective access to and use of demonstration and testing capabilities and promoting the sharing of knowledge across organizational and programmatic lines - breaking through the stovepipes that currently exist.

  The most influential of these recommendations comes from the BRC.[1] While the BRC was largely focused on broad policy issues, the BRC's draft document made strong statements about the need to increase "federal support for energy-related research, development, demonstration and deployment" and to focus national resources on "key gaps in the US nuclear RD&D infrastructure and to leverage effectively the full range of resources that exist in industry, the national laboratories and the academic community." The March 2011, DOE NE "Evaluation of Potential Nuclear Energy Research Missions at the Savannah River Site" review concluded that "it is in the best interests of the United States to develop a focused expertise in separations technology in support of a variety of national missions through a knowledge center."[4] This same review team went on to recommend that a plan be developed for utilizing a portion of the Savannah River Site (SRS) H-Canyon as a fuel cycle R&D "user facility" and that plans be developed for establishing a facility platform for international collaboration in support of nonproliferation objectives. A recommendation from this same review subsequently led to the Nuclear Separations Technologies Workshop in Bethesda, MD on July 27-28, 2011, which was jointly sponsored by the DOE, specifically DOE-NE, DOE-EM, and Office of Science and NNSA.[3] This workshop had the objectives of establishing the need for a DOE nuclear separations "center of knowledge" and identifying the key program partnerships and requirements needed to advance separations technology in DOE. Results of the workshop are still in development, but the overarching drive for a collaborative approach is clear.

The nuclear industry has also indicated support for a collaborative research focus in nuclear separations science, as well as the availability of facilities where engineering-scale research and testing could be performed with actual nuclear materials. A number of companies have come out strongly in support of engineering-scale research and demonstration facilities – viewing these capabilities as critical to developing and improving fuel separations processes.

Summary of Need

Clearly, there is a broad consensus in the technical community for taking a collaborative research approach, as well as support for establishing engineering-scale research facilities that can serve these research collaborations. In the area of nuclear separations science research to support critical DOE missions, the arguments for engineering-scale collaborative research facilities are very compelling. Processing history has shown that facilities capable of supporting test programs and demonstrations conducted with actual nuclear materials are essential to program success. However, such facilities are expensive to build and maintain, thus creating an imposing, if not prohibitive, financial burden on an individual sponsoring office. In times of strong federal budget pressures, the single-program model of support (i.e., stovepipe model) cannot be sustained for pursuing new nuclear facilities for research and development. Success for the current and future nuclear separations missions is dependent on the concerted effort by all relevant DOE/NNSA offices and programs to leverage and maintain the current facilities in a manner that supports their respective near- and long-term needs. Fiscal realities will force new, creative, approaches that will cause a close look at new directions and uses for existing facilities.

Scale and Cost Challenges

As discussed above, there are clear sets of nuclear separations mission needs within each program office that extend for years into the future. When the mission needs of the program offices are evaluated individually, it is clear that there are significant differences in the separations RD&D timeframes for the DOE-EM, DOE-NE, and NNSA programs. Expressed broadly and generally, the DOE-EM separations RD&D need is focused on cleanup and is thus very large in the near-term to mid-term, before dropping significantly in the long-term; the DOE-

NE separations RD&D need is focused on solutions for the recycle of nuclear fuel, so it is smaller (but not zero) near-term and increases across the mid-term into the long-term; and the NNSA separations RD&D need is related to the development and deployment of advanced nonproliferation technologies, and is thus relatively constant near-term to long-term. Areas of common interest include process equipment design, flowsheet design, analytical/diagnostic equipment development, and advanced modeling and simulation capabilities. Process modeling tools are also being used by DOE-EM, DOE-NE, and NNSA to support flowsheet development and material accountability studies. These mission timeframes are complementary in a way that allows the potential for strong leveraging of collaborative research capabilities and provides maximum national benefit.

DOE-EM Challenges

As noted, DOE-EM's separations RD&D needs are heavily "front-loaded;" the DOE-EM defense waste legacy cleanup mission is well underway and is being driven by aggressive regulatory commitments. The primary needs for DOE-EM separations RD&D are in the area of HLW treatment - aimed at reducing the amount of HLW or reducing the complexity and expense of treatment. Studies in these areas include HLW pretreatment for removal of solids, removal of certain constituents such as aluminum, chromium, and/or sodium, or separations of actinides.

DOE-EM RD&D in these areas is challenged by the complexity and variety (due to many unique streams) of the legacy materials that must be treated and disposed. This complexity and variety of process feed makes process scale-up (often at multiple scales) an essential component of the RD&D program to discover unexpected interactions and to understand fully the impact of the waste properties and physical phenomena such as solids precipitation, multiphase flow, etc. At the same time, the complexity and variety of feed streams often make non-radioactive simulants prohibitively expensive to develop and deploy for the engineering-scale testing needed. And even if a simulant is developed, it may still fail to behave as desired across a broad spectrum of properties exhibited by the actual material during processing. Given the cost and schedule considerations, the DOE-EM RD&D experience has been most effective with a well-integrated program that blends basic science and bench-scale studies with large-scale real waste tests.

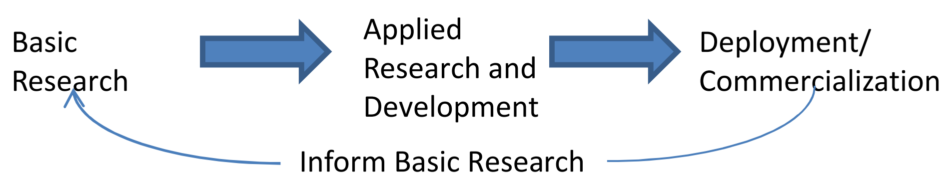
DOE-NE Challenges

DOE-NE's separations RD&D needs are currently focused on fundamental bench-scale testing on potential separations processes that could potentially reduce the cost of alternative advanced fuel cycles. As with the DOE-EM RD&D program, engineering- scale testing will be required to support future fuel cycle testing. The engineering-scale testing also will be required to understand process behavior, equipment performance, and operating windows, as well as to obtain quality data on system performance in prototypical operating conditions. As "new" fuel cycle processes are researched and developed – moving into unfamiliar territory - engineering-scale testing and demonstration activities with actual feed solutions and using real process equipment become even more important.

NNSA Challenges

NNSA's separations RD&D needs primarily revolve around nuclear nonproliferation and safeguards technology development. NNSA activities in this area focus on the detection of clandestine nuclear weapons material production activities, whether through operation of hidden small-scale processes or through diversion of materials or operations in known processing facilities. Consequently, the NNSA program focus is on the development and demonstration of detection capabilities and the understanding of potential "signatures" for different production and processing scenarios. The NNSA RD&D program can strongly leverage active DOE-NE and DOE-EM programs since, by doing so, it gains access to test conditions with engineering-scale operations using real nuclear material. Such tests are essential components of successful nonproliferation testing.

Key to Success – An Integrated RD&D Program
A key component of success for collaborative RD&D programs is effective integration of engineering-scale research and demonstration activities with related basic science and bench-scale research. A collaborative research program that provides an avenue for a full spectrum of research – from basic to applied - and that strongly couples the basic research to the demonstration of the technology enhances the success of the research program and accelerates technology deployment. Feedback from and integration of the technology demonstration establishes a value proposition that makes the overall research program more robust by identifying gaps and unexpected phenomena so that basic and applied research can address those issues in a timely manner (see figure below). This integration can take many forms, but is most effective when it is facilitated by collocation and "shared" researchers, so that there is a shared purpose, constant and open information exchange, and a collective understanding of success.



For example, although the BRC does not recommend deployment of reprocessing flowsheet for the nuclear fuel cycle in the near term, it does strongly support continued RD&**D**, with a special emphasis on deployment.

Strategy for Collaborative Research in Nuclear Separations
As a result of the situation described above, the Savannah River National Laboratory (SRNL) organized the "Nuclear Separations User Facility Strategy Session" in Washington, D.C. on July 29, 2011. This workshop brought together key stakeholders from DOE and the private sector to discuss potential strategies for using demonstration-scale nuclear materials processing facilities to advance our nation's nuclear separations research needs. In particular, the meeting focused on recommending how engineering-scale facilities, like the SRS H-Canyon, can be connected with smaller "bench-scale" research activities to form a seamless approach that integrates across the continuum of RD&D of advanced separations technologies. Coming out of this workshop, a new vision has been developed for a collaborative research facility model that

centers on H-Canyon. Unique to this approach is the fact that H-Canyon will continue to accomplish DOE's critical nuclear material processing missions, while simultaneously serving as an RD&D resource for the scientific and technical portions of the nuclear separations community.

This strategy session was an important first step in defining a model for use and operation of the nuclear separations collaborative research (or user) facilities and in developing a strategy to shift the current paradigm of the sequential RD&D progression to one which integrates engineering-scale demonstrations with laboratory-scale research and modeling in ways that accelerate technology deployment.

Engineering-Scale Collaborative Research in Nuclear Separations at the Savannah River Site

As the last large-scale nuclear reprocessing facility in the United States, the SRS H-Canyon represents a unique value proposition for the DOE. As an already-established, operational facility, H-Canyon has all the attributes and qualities required of an engineering-scale testing and demonstration facility, but does not require the major capital design and construction of a new facility. A vision for the role that H-Canyon can assume in the nuclear separations enterprise has been developed that defines a new approach to the collaborative research facility model. This new approach illustrates how H-Canyon is actually a superior alternative for engineering-scale testing and demonstration of nuclear separations technologies in that it is an alternative that can advance knowledge in several areas at the same time. Unique to this approach for a collaborative research facility is the fact that H-Canyon will continue to accomplish DOE's critical nuclear material processing missions, while simultaneously serving as an RD&D resource for the scientific and technical portions of the nuclear separations community. The following sections provide examples:

- **Nuclear Material Processing**
  In its role as a collaborative research facility, H-Canyon will continue to function in its long-term mission of processing for the disposition of DOE nuclear material according to national schedule requirements. Several metric tons of excess weapons-grade and fuel-grade plutonium exist which have the potential to be used as feed for the Mixed Oxide Fuel Fabrication Facility (MFFF). Some of these materials cannot be used because of impurities while the plutonium in other materials (such as highly-enriched uranium [HEU] materials) needs to be separated from the primary matrix and purified. In addition, there are inventories of impure plutonium-238 which would be invaluable to the DOE NE Space and Defense Power Systems program if they could be purified to meet specifications. Past H-Canyon and HB-Line missions have encompassed all of those desired processing results to provide a usable plutonium product.

  Another critical concern of the United States is to assure the nonproliferation of HEU. For the past seven years, the SRS H-Canyon has been converting HEU from used nuclear fuel (UNF) into low enriched uranium solutions. This same processing can be continued with a variety of HEU materials within the current DOE and NNSA inventories, thus moving the materials from a proliferation risk to an economic advantage. Potential HEU materials range from the Foreign and Domestic Research Reactor UNF being stored (and expected to be stored) at the SRS to HEU weapons components disassembled as part of the Pit Disassembly and Conversion mission.

Any plutonium associated with the HEU processed in H-Canyon can also be purified in parallel in H-Canyon and sent to HB-Line for further purification and then converted to plutonium oxide. Impure plutonium materials, such as the alternate feedstock identified for MFFF, can be dissolved in H-Canyon and purified and converted to oxide in HB Line. It is expected that plutonium oxide from HB Line would, at a minimum, exceed the MFFF Aqueous Polishing feed specification and is likely to exceed the Mixed Oxide Process feed specification. Furthermore, the H-Canyon/HB-Line processing of the alternate feedstock could begin in the near term, thus providing MFFF with an early reserve of feed.

In performing these missions, a key advantage is H-Canyon's modular design; so that the nuclear material disposition processing only occurs in a portion of the H-Canyon sections. Other sections in H-Canyon which remain available for alternative uses, without any impact on the processing operations. The nuclear material disposition mission provides the core operational foundation that supports the maintenance and operation of the canyon while select RD&D activities can be inserted into H Canyon at an incremental cost to the RD&D program.

- **Nuclear Non-proliferation Safeguards Testing and Demonstration**
  Simultaneously with the nuclear material processing operations, the H-Canyon can be instrumented to support real-time testing of advanced safeguard monitoring systems under real-life conditions. By using this approach, researchers can evaluate the performance of this equipment under actual process operating conditions in a secure environment, a circumstance that would be almost impossible to replicate anywhere else. Again, by "piggybacking" onto actual facility processing runs, critical research data can be obtained for an incremental cost compared to the cost of dedicated test runs.

- **Alternative (or Advanced) Used Fuel Separations Technology Development and Demonstration**
  Another feature offered by the collaborative research approach is the ability to perform engineering-scale research and process demonstration on advanced fuel-cycle separations technologies. H-Canyon has a history of processing a wide variety of fuel and target materials in a variety of processing conditions. Many of these historical operations overlap potential with the fuel-cycle RD&D studies envisioned for the future.

  The fuel-cycle RD&D studies can be integrated into normal H-Canyon nuclear material processing operations or conducted non-intrusively and simultaneously on a smaller scale by taking advantage of the flexible Frame Design modular equipment capability that is built into the H-Canyon design. In the Frame Design approach, a complete processing system containing all the necessary components is developed, fabricated, and cold-tested completely outside the H-Canyon facility, then inserted into an available section in H-

Canyon, where it can be instrumented and operated without any impact on other H-Canyon activities.

This operational flexibility also extends to the opportunities for process modeling, process monitoring research and testing and safeguards testing during the fuel cycle process evaluation. Simultaneously, NNSA process monitoring instrumentation and safeguards monitoring systems can be developed and tested under real operating conditions.

- **Engineering-Scale Process Testing and Demonstration**
  H Canyon also presents a possibility of hosting key engineering-scale tests and demonstrations. DOE-EM is engaged in an arduous and expensive campaign to disposition its legacy wastes and facilities. The most daunting challenge facing DOE-EM in this endeavor is the disposition of the HLW primarily at the Hanford and Savannah River Sties. Major impacts to the progress of that disposition could be achieved by reducing the amount HLW that needed treatment or by reducing the complexity and expense of treatment. Various technology approaches have been proposed but require engineering-scale demonstration to assure that there is no degradation in technology performance as the technology scale is increased from the laboratory-scale studies. The ability to perform engineering-scale treatability studies would not only enhance the HLW RD&D efforts by providing the required engineering-scale venue, but allow the behavior of actual HLW to be fed back to the laboratory-scale research effort. The results of that feedback would be a final technology product that is more effective and having far fewer problems upon deployment compared to a technology that had not benefited from an engineering-scale vetting with actual waste.

The ability to perform engineering-scale demonstrations is not limited to processing. Many of the DOE-EM challenges involve decontamination of equipment and its subsequent removal from highly radioactive facilities. Those facilities have complex environments that are not easily simulated. Using SRS facilities, new technologies (e.g., decontamination strategies, robotics) can be tested to see how they perform in a highly radioactive environment that requires robotic capability to execute the task. Disassembling the RD&D equipment from the frames after a demonstration offers an excellent opportunity to test the new decontamination and removal technologies.To support the variety of missions that are emerging for processing and research in the H Canyon, SRNL, working with DOE Savannah River Operations Office and NNSA, is developing a planning roadmap for the utilization of SRS unique resources for processing and for research and development of nuclear materials. This roadmap is a strategic tool for assessing and scheduling multiple missions that could be conducted in the facilities. From this roadmap detailed budget, operation, and staffing plans will be developed.

Stakeholder Return on Investment

Federal Government – In establishing a collaborative research facility such as H Canyon, DOE is creating the kind of visionary, highly flexible capability that today's technical and economic climate demands. This approach brings a high-value operational facility (essentially irreplaceable in today's conditions) into the research community, where it is available to support research and testing. By creating an environment where RD&D and testing can be coupled to facility operations or other research activities, RD&D can be done at only an incremental cost. In taking this approach, the federal government is:

- Utilizing past and current investments in facilities to leverage new, incremental investments in R&D for critical national missions.
- Effectively engaging national laboratories, academia and industry in collaborative research that more effectively links R&D with final deployment or commercialization.
- Establishing a technical foundation for research in critical areas; thus promoting innovation and US competitiveness.
- Creating, through the engagement with academia, a pipeline for the technical workforce of the future.

<u>Research and Educational Community</u> – Recent industry studies have noted that over the next few years, over half of the Nation's nuclear industry workforce will be replaced. The situation in the nuclear sciences in the national labs is similar. If the United States is to regain a leadership position in the development and application of nuclear technologies – for the nuclear fuel cycle and for waste management – it is essential that the nation take positive steps toward increasing the research and educational opportunities in this area. The proposed multi-user collaborative research facility approach will do that - providing a multitude of research opportunities through which the academic community can collaborate with national laboratories and industry to perform research on important national problems. These research opportunities will provide valuable education opportunities to students in fields ranging across the spectrum of chemistry and engineering.

<u>State and Regional Community</u> – Expanding or extending site missions through the implementation of the collaborative research facility approach provides a number of benefits to the state and local community beyond the maintenance of high-paying jobs for citizens of the local communities. Some of the additional anticipated benefits include:

- Growth of the research and educational community in the highly technical areas related to nuclear separations sciences. As a research facility serving several program offices, there will be increased collaboration opportunities for regional, state and local universities covering a variety of technical fields, including chemistry, chemical engineering, nuclear engineering, nuclear physics, electronics, etc.
- Growth in local industry in related technical areas. As the nuclear industry is engaged in the collaborative research efforts, there will be an increased presence of commercial nuclear-related industry in the local area, along with an increase in the supporting industry.
- Establishes the region and state as centers for future-focused work in all aspects of nuclear technology. Establishing a collaborative research facility solidifies SRS and the local area as the true hub of the nation's applied nuclear separations science and technology

development and places the local area in an influential position relative to the nation's future nuclear strategy.

Next Steps

SRNL continues to develop and broaden the concept of a collaborative nuclear research facility. A key component of this concept is the continued maturation of the planning roadmap for processing and research activities, coupled with the development and application of a systems modeling capability that will provide support tools for strategic analysis and decisions.

In addition, as these operations move forward, consideration is being given to expansion of the concept into a true user facility – which will require the development of a new paradigm for operations.

References

[1] Blue Ribbon Commission on America's Nuclear Future, Draft Report, July 29, 2011. (BRC)
[2] DOE Nuclear Separations User Facility Strategy Session, July 29, 2011.
[3] DOE Nuclear Separations Technologies Workshop, July 27-28, 2011.
[4] DOE Office of Nuclear Energy, "Evaluation of Potential Nuclear Energy Research Missions at the Savannah River Site", March 2011.
[5] Massachusetts Institute of Technology, "*The Future of the Nuclear Fuel Cycle - an interdisciplinary MIT Study*", 2010. (MIT Study)
[6] The National Academies of Science "Advice on the Department of Energy's Cleanup Technology Roadmap", 2009. (NAS Review)