CURRENT U.S. DEPARTMENT OF ENERGY NUCLEAR ENERGY RD&D PROGRAMS AND PLANS

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EXECUTIVE SUMMARY

Roadmap

This document summarizes DOE's commercial nuclear energy RD&D program based on a R&D roadmap and on DOE/NE's budget request for fiscal year 2011. The roadmap is written at a high level and is mostly qualitative in terms of activities, milestones and decisions to be made and does not contain budget information. The fiscal year 2011 budget request contains more specific and detailed information on activities, milestones, decisions, and budgets but only for fiscal year 2011 and the two preceding fiscal years. More detailed documents defining long-term program activities, decisions to be made, and budgets do not appear to be available.

The R&D roadmap states four goals for the program:

1. develop technologies that can improve the reliability, sustain the safety, and extend the operating life of current reactors;
2. improve the affordability of new reactors to enable nuclear energy to help meet the Administration's energy security and climate change goals;
3. develop sustainable nuclear fuel cycles, including its waste management; and
4. understand and minimize risks of nuclear proliferation and terrorism. Four research and development objectives to achieve these goals have been identified and are elaborated on and analyzed below.

Nuclear Energy RD&D Budget

A top-level budget breakdown of the DOE Office of Nuclear Energy budget for nuclear energy RD&D is as follows:

Technical Areas	Current	Request
Integrated University Program[1]	5,000	0
RE-ENERGYSE	0	5,000
Nuclear Power 2010	105,000	0
Generation IV Nuclear Energy Systems[2]	220,137	0
Reactor Concepts Research, Development and Demonstration	0	195,000
Fuel Cycle Research and Development	136,000	201,000
Nuclear Energy Enabling Technologies	0	99,300
International Nuclear Energy Cooperation	0	3,000
TOTAL	466,137	503,300

[1] This program has been replaced by the RE-ENERGYSE program.
[2] This program has been replaced by the Reactor Concepts Research, Development and Demonstration program

The RE-ENERGYSE element, renamed from Integrated University Program in previous fiscal years, will provide educational support to bolster nuclear engineering and science programs at U.S. universities.

The Nuclear Power 2010 element is a joint government/industry cost-shared effort established in 2002 to demonstrate untested NRC regulatory and licensing processes. The program accomplished its intended purpose in FY 2010 and is proposed to end as of FY11.

The mission of the Reactor Concepts Research, Development and Demonstration element, renamed from the Generation IV Nuclear Energy Systems program in previous fiscal years, is to develop new and advanced reactor designs and technologies. There are no demonstration activities planned in the immediate future in any of these areas.

The mission of Fuel Cycle Research and Development (FCRD) element is to develop nuclear fuel and waste management technologies. Beginning in FY 2010, the program shifted from a near-term technology development and deployment program to a long-term, science-based RD&D program that will examine three fuel cycle approaches: the current once-through fuel cycle, modified open fuel cycle, and full fuel recycle.

The Nuclear Energy Enabling Technologies element will focus on innovative research relevant to multiple reactor and fuel cycle concepts that offer the promise of dramatically improved performance. Much of the scope of this element resulted from collecting activities scattered among other program elements in previous fiscal years.

The International Nuclear Energy Cooperation element supports the Office of Nuclear Energy (NE) program offices in implementing international cooperative RD&D activities that further NE's mission. Much of the scope of this element resulted from collecting activities scattered among other program elements in previous fiscal years.

Analysis

The FY 2011 budget request provides extensive details (~150 pages) on DOE's planned nuclear energy RD&D activities. The activities proposed in the budget appear to be potentially relevant to developing and supporting both evolutionary and revolutionary advanced nuclear energy systems. However, the very nature of the budget request - providing information on the two previous years and the year of the request - makes it impossible to fully understand how or whether the myriad activities interrelate, how long it will take to yield results, and when and how decisions will be made concerning what to pursue and what to eliminate. There is a long-term goal of deploying used fuel recycle by 2050.

Options

Options for changes to the DOE/NE Roadmap and budget include the following:

1. Endorse the roadmap and the apparent direction of the nuclear energy RD&D budget. This recommendation would indicate support for a protracted and fully integrated RD&D program on alternative nuclear energy technologies and systems in general, and DOE's broadly stated strategy and tactics in particular, by allowing the tasks already underway to proceed as currently planned with deployment being deferred for decades. Within this option, the Commission might consider recommendations on the following:
    a. While avoiding early commitment to any particular nuclear energy system, the absence of deployment would limit participation of U.S. industry in portions of the nuclear marketplace and potentially limit the international influence of the U.S. by not leading from the front.
    b. The RD&D long-term goals and approach of the program should be designed to be based on systems engineering precepts and be stable across administrations.
    c. The magnitude and source of the RD&D budget. The recent MIT study recommended that about $1 B/year is appropriate for supporting the RD&D and infrastructure programs, noting that additional funding would be needed for large-scale government-industry demonstration projects at the appropriate time. The recent PCAST report suggested funding RD&D with a tax on energy producers.
    d. That a robust set of RD&D activities on geologic disposal technologies should be part of the program.
2. Option 1, but recommend that NE develop a resource-loaded nuclear energy RD&D program plan that provides more detail than the roadmap on the nature and interrelationships of R&D activities, and how and when decisions on nuclear strategies and technologies will be made. This option would require DOE to be much more specific on the importance of various technology alternatives as measured by the resources allocated to them, and the process by which the alternatives will be down-selected.
3. Option 1 or 2, but provide strategic recommendations on the direction of the nuclear energy RD&D program. Examples that might be considered include, but are not limited to:
    a. Establish a long-range goal of developing and deploying (a) economic, safe, reliable, and proliferation-resistant fast reactors and recycle technology and (b) nuclear reactors that produce sufficiently high temperatures so as to be useful for process heat while eschewing reprocessing and recycle in thermal reactors.
    b. Establish a long-range goal of deploying economic, safe, reliable, and proliferation-resistant fast reactors and recycle technology while also

recommending pilot/demonstration-scale near-term reprocessing and recycle activities involving thermal reactors. Establish collaborative government-industry demonstration facilities and campaigns supporting the RD&D goals concerning fast reactors.

c. Establish a long-range goal of deploying economic, safe, reliable, and proliferation-resistant fast reactors and recycle technology and endorse near-term commercial reprocessing and recycle in thermal reactors.

d. Recommend that the nuclear energy RD&D program be scaled back to focus primarily or exclusively on the once-through nuclear fuel cycle.

4. Option 1, 2, or 3, but provide tactical recommendations on activities that should or should not be part of the nuclear energy RD&D program and/or the relative priority and funding levels of various activities.

INTRODUCTION

The U.S. Department of Energy (DOE) has an ongoing program for research, development, and demonstration (RD&D) on civilian nuclear energy strategies, technologies, and systems. The current high-level long-range plan for this effort is defined in a roadmap [DOE, 2010b]. Near-term activities to implement the program are identified and described in the DOE Office of Nuclear Energy (NE) budget request for fiscal year (FY) 2011 [DOE, 2010a]. This document summarizes these documents and provides options for the Commission's consideration concerning a civilian nuclear energy RD&D program[3]. More detailed documents defining program activities and budgets do not appear to be available.

NUCLEAR ENERGY R&D ROADMAP

The roadmap has four stated goals: (1) develop technologies that can improve the reliability, sustain the safety, and extend the operating life of current reactors; (2) improve the affordability of new reactors to enable nuclear energy to help meet the Administration's energy security and climate change goals; (3) develop sustainable nuclear fuel cycles, including its waste management; and (4) understand and minimize risks of nuclear proliferation and terrorism. Four research and development objectives to achieve these goals have been identified and are elaborated on and analyzed below.

Roadmap Objectives

RD&D OBJECTIVE 1: Extend the operating lifetimes of current plants beyond sixty years and, where possible, make further improvements in their productivity.

The DOE role in this RD&D objective is to work in conjunction with industry and the Nuclear Regulatory Commission (NRC) to support and conduct the long-term RD&D needed to provide the information necessary for major reactor component refurbishment and replacement strategies, performance enhancements, plant license extensions, and age-related regulatory oversight decisions. DOE-supported activities will focus on aging phenomena and issues that require long-term research and are generic to multiple reactor types, industry activities on nearer-term research on these same issues, and the NRC on confirmatory research.

To achieve Objective 1 DOE will:

1. Support RD&D on nuclear material aging and degradation
2. develop advanced monitoring and non-destructive examination technologies and develop an instrumentation, information, and controls modernization strategy
3. develop long-life, high performance LWR fuel

[3] This paper does not address R&D concerning DOE-managed spent fuel and high-level waste.

4. develop next-generation reactor safety analysis tools and techniques

RD&D OBJECTIVE 2: Develop Improvements in the Affordability of New Reactors to Enable Nuclear Energy to Help Meet the Administration's Energy Security and Climate Change Goals.

More advanced reactor designs, such as small modular reactors (SMRs) and very high-temperature reactors (VHTRs), have characteristics that could make them more desirable than reactors based on today's technology. Some SMR designs, for example, are claimed to have the potential to achieve lower proliferation risks and simplified and cheaper construction than large light-water reactors. The development of these advanced reactors could result in lower capital costs and improved efficiencies. These reactors may be based upon new designs that take advantage of the advances in fuel performance and computing, while also leveraging capabilities afforded by improved structural materials.

To achieve Objective 2 DOE will:

1. Develop advanced reactor concepts, technologies and tools for high-performance plants
2. support research and development of SMR concepts, including cost-shared research related to design certification
3. design and develop safety methods for high-temperature gas-cooled reactors using graphite-based fuels

RD&D OBJECTIVE 3: Develop Sustainable Nuclear Fuel Cycles.

DOE will conduct RD&D to investigate technical challenges associated with three potential fuel cycle strategies for used nuclear fuel (UNF) management:

Once-Through – Develop fuels that would increase the efficient use of uranium resources and reduce the amount of used fuel requiring direct disposal for each megawatt-hour (MWh) of electricity produced. Evaluate the inclusion of non-uranium materials (*e.g.*, thorium) as reactor fuel options.

Modified Open Cycle – Investigate fuel forms and reactors that would increase fuel resource utilization and reduce the quantity of long-lived radiotoxic elements in the used fuel to be disposed (per MWh), with simplified separations steps using technologies that are claimed to have proliferation risks lower than spent fuel recycle.

Full Recycling – Develop techniques that will enable most of the long-lived actinide elements to be recycled rather than disposed. "If actinides can be destroyed in reactors, this simplifies the waste problem in a significant way The ultimate goal is to develop a cost-effective and low-proliferation-risk approach that would dramatically decrease the long-term toxicity of and heat released by the wastes, thereby reducing uncertainties and problems associated with their disposal, while also claiming a higher fraction of the energy potential of the original uranium.

Unlike RD&D Objectives 1 and 2 in which industry and regulators have a substantial role, management of UNF and development of fuel cycle technologies are primarily DOE's responsibility because it is legally responsible for UNF. Thus, the necessary research, development, and demonstration on UNF, if appropriate, will be led primarily by the DOE. However, early and continuous industrial and regulatory involvement is important because any technologies that are developed will ultimately have to be licensed by the regulator and implemented by the commercial entities.

Prior to beginning major RD&D work on the three fuel cycle strategies discussed above, the value of various RD&D activities will be evaluated by performing analyses in the following areas:

1. Fuel Resource Exploration and Mining – The availability of fuel resources for each potential fuel cycle and reactor deployment scenario.
2. Used Fuel Disposition – All radioactive wastes generated by existing and future fuel cycles will need to be safely stored, transported, and disposed.
3. Reduction of Transuranic Element Production In Reactors – One thrust in developing sustainable fuel cycles will be the exploration of nuclear fuels and reactors that significantly reduce the long-lived actinide content of the used fuel per MWh of energy produced.
4. Separation and Partitioning – The development of processes to recycle used fuel is needed, as well as an evaluation of the feasibility and risks associated with alternative recycling processes.
5. Waste Forms – It is necessary to develop understanding of waste form behavior over time in storage and disposal environments to inform decisions on recycle and disposal options.
6. Fuel Forms –A science-based approach will combine theory, experiments, and multiscale modeling and simulation aimed at an improved fundamental understanding of the fuel fabrication processes and fuel and clad performance under irradiation.
7. Material Reuse – The research will focus primarily on recovered uranium for reuse in reactors to obviate the need to dispose of this material once separated from the rest of the used fuel. Reuse of other used fuel constituents such as metal fuel cladding will also be investigated.
8. Transmutation Systems – Transmutation is a process to change the characteristics of waste by turning recycled elements into elements with more desirable disposal characteristics, typically shorter half-lives.

To achieve Objective 3 over the longer term, DOE plans to:

- Perform RD&D to support continuing to increase the burnup of once-through fuels
- Develop technologies involving limited separations for a modified open fuel cycle
- Develop technologies such as reprocessing for full recycle

RD&D OBJECTIVE 4: Understand and Minimize the Risks of Nuclear Proliferation and Terrorism.

DOE plans to pursue an integrated approach that incorporates the simultaneous development of nuclear technologies, including safeguards and security technologies and systems, and the maintenance and strengthening of non-proliferation frameworks and protocols. Technological advances can only provide part of an effective response to proliferation risks; institutional measures such as export controls, management systems and safeguards are also essential to addressing proliferation concerns.

To achieve Objective 4 DOE will:

1. Perform proliferation risk assessments to inform decisions on fuel cycle technology down-selections in the future
2. Develop and test safeguards technology informed by advances in fuel cycle and reactor technology

Nuclear Energy Enabling Technologies

The Department of Energy expects to undertake RD&D in a variety of enabling technology areas that support more than one of the foregoing objectives. Enabling technology areas identified in the roadmap are:

- Structural materials
- Nuclear fuels
- Reactor systems
- Instrumentation and controls
- Power conversion systems
- Process heat transport systems
- Dry heat rejection
- Separations processes
- Waste forms
- Risk assessment methods
- Computational modeling and simulation

Analysis

Aspects of the roadmap that are worthy of note include:

- The nuclear energy RD&D program described in the roadmap contains two major elements: relatively short-term activities to support renewed construction of light-water reactors and typically longer-term activities to develop advanced reactors and fuel cycle technologies.

- The roadmap document is written at a high level: its 60 pages include front material and a significant amount of general background on the U.S. energy landscape.
- Approximate milestones for RD&D activities for each objective are shown for only the minority of activities expected to be completed before 2020. The roadmap does not contain even approximate timelines for activities expected to be completed beyond 2020.
- As RD&D activities continue it is expected that there will be decision points at which fuel cycle strategies (e.g., once-through vs. full or limited recycle) and technologies (e.g., oxide fuel vs. metal fuel, water vs. sodium-cooled reactor) will be evaluated and down selection will occur to allow resources to be focused on the most promising systems as RD&D proceeds to larger-scales that are more costly. When these decision points occur and the process for decision making are not discussed in the roadmap.

NUCLEAR ENERGY RD&D BUDGET

The previous section summarizes DOE's long-range nuclear energy RD&D plans. This section describes how the plan is currently being implemented by summarizing DOE's nuclear energy RD&D budget for the last fiscal year that ended September 30, 2010 (FY 2010) and their budget request for the current fiscal year (FY 2011) on which Congress has not yet acted.

A first level summary of DOE's the nuclear energy RD&D budget in the form of the relevant items from the Office of Nuclear Energy's (DOE/NE's) FY 2011 budget request [DOE, 2010a] is given in Table 1. Second-level budgets and activities within them for each of the lines will be discussed below where appropriate.

Table1. Appropriation Summary by Program (dollars in thousands)

Technical Areas	FY 2010 Current	FY 2011 Request
Integrated University Program[4]	5,000	0
RE-ENERGYSE	0	5,000
Nuclear Power 2010	105,000	0
Generation IV Nuclear Energy Systems[5]	220,137	0
Reactor Concepts Research, Development and Demonstration	0	195,000
Fuel Cycle Research and Development	136,000	201,000
Nuclear Energy Enabling Technologies	0	99,300
International Nuclear Energy Cooperation	0	3,000
TOTAL	466,137	503,300

[4] This program has been replaced by the RE-ENERGYSE program.
[5] This program has been replaced by the Reactor Concepts Research, Development and Demonstration program

Integrated University Program	**FY10**	**FY11**
	5000	0

Commencing in FY 2011, the Department's energy technology education efforts will be focused through its Regaining ENERGY Science and Engineering Edge (RE-ENERGYSE) program.

RE-ENERGYSE	**FY10**	**FY11**
	0	5000

The mission of the RE-ENERGYSE program is to support scientific discovery and innovation at universities across the United States. It is a Presidential initiative to train thousands of young energy scientists and engineers across the U.S. DOE/NE activities under this banner will provide educational support to bolster nuclear engineering and science programs at U.S. universities. In FY 2011 funding is being requested for this program to support the Department's broad educational effort that cuts across DOE programs to coordinate, standardize, and evaluate Science, Technology, Engineering, and Mathematics education programs. The RE-ENERGYSE program plans to fund approximately 88 one-year scholarships and 30 three-year fellowships to students enrolled in nuclear energy-related fields of study at U.S. universities and two-year colleges.

Nuclear Power 2010	**FY10**	**FY11**
	105,000	0

The Nuclear Power 2010 (NP 2010) program is a joint government/industry cost-shared effort established in 2002 to demonstrate untested NRC regulatory and licensing processes. The untested processes include early site permit, the combined construction and operating license, and design certification for advanced, passively safe reactor designs. The program accomplished its intended purpose in FY 2010 and is proposed to end as of FY11.

Generation IV Nuclear Energy Systems	**FY10**	**FY11**
	22,137	0

Beginning in FY 2011, all Generation IV Nuclear Energy Systems (Gen IV) program activities will be carried out under the new Reactor Concepts Research, Development, and Demonstration (RD&D) program, whose broader scope is defined in the next paragraph. The mission of the Gen IV activities has been to address critical unanswered questions about advanced nuclear reactor technologies through RD&D.

Reactor Concepts Research, Development and Demonstration	**FY10**	**FY11**
	0	195,000

The mission of the Reactor Concepts Research, Development and Demonstration program is to develop new and advanced reactor designs and technologies. Activities carried out by the program are designed to address technical, cost, safety, and security issues associated with new reactor concepts, including Small Modular Reactors (SMRs), the Next Generation Nuclear Plant Demonstration Project (NGNP), and other advanced reactor concepts. In addition, the program will develop advanced technologies that will support extending the life of existing Light Water Reactors (LWRs). The second-level budget for this large scope is shown in Table 2. There are no demonstration activities planned in the immediate future in any of these areas.

Table 2. Reactor Concepts Research, Development and Demonstration Budget

	FY 2010 Budget (Thousands)	FY 2011 Request (Thousands)
Small Modular Reactors	0	38,880
Next Generation Nuclear Plant Demonstration Project	0	103,032
Light Water Reactor Sustainability	0	25,758
Advanced Reactor Concepts (formerly Generation IV Nuclear Energy Systems Research and Development)	0	21,870
SBIR/STTR	0	5,460
Total, Reactor Concepts Research, Development and Demonstration	**0**	**195,000**

Small Modular Reactors (SMRs)

The term "modular" in the context of SMRs refers to a single reactor having a capacity up to about 300 megawatts of electricity that can be grouped with additional reactor modules to form a larger nuclear power facility. SMRs are envisioned to embody simplicity of design, economies and uniformly high quality of factory production, more flexibility (financing, siting, sizing, and end-use applications) and lower up-front capital cost compared to large nuclear power plants (1,000+ megawatt capacity).

The SMR program element [DOE, 2010c] supports laboratory/university and industry cost-shared projects to conduct nuclear technology RD&D and to develop advanced computer modeling and simulation tools that demonstrate and validate new design capabilities of innovative SMR designs. These activities focus on demonstrating that SMRs provide an innovative reactor technology that is capable of achieving electricity generation and performance objectives that meet market demands and are comparable, in both safety and economics, to the current set of large base-load nuclear power plants.

Next Generation Nuclear Plant Demonstration Project (NGNP)

The NGNP project was established to demonstrate the generation of electricity and/or hydrogen with a high-temperature nuclear energy source. The NGNP project [DOE, 2010d] includes design, licensing, construction, and RD&D conducted in two phases. Phase 1 consists of pre-conceptual and conceptual design and demonstration activities leading to the selection of a single technology for NGNP. Phase 2 is the preliminary and final design leading to licensing and construction of a demonstration plant. The U.S. Nuclear Regulatory Commission (NRC) is responsible for licensing and regulatory oversight of the demonstration nuclear reactor. Currently there are two major types of high-temperature gas reactor designs under consideration. Both of these reactor designs are graphite-moderated and helium-cooled.

Light Water Reactor Sustainability (LWRS)

LWRS research [INL, 2009] will help provide a technical basis for the long-term safety and reliability of the current nuclear power fleet beyond 60 years. Without this life extension, the current fleet will begin to shut down in 2029 and, therefore, begin to reduce the total amount of GHG-free energy generation from newly constructed nuclear power plants.

Advanced Reactor Concepts

The Advanced Reactor Concepts program is an expanded version of the Generation IV program that sponsors research and development leading to further safety, technical, economical, and environmental advancements of innovative nuclear energy technologies. Both advanced thermal and fast neutron spectrum systems will be investigated. Key focus areas for FY 2011 are fast reactor design, high-temperature reactors cooled by molten salts, turbine technology to generate electricity from gases heated in a nuclear reactor, and development and validation of computer codes to predict the behavior of passively safe reactors.

Fuel Cycle Research and Development

The mission of Fuel Cycle Research and Development (FCRD) program is to develop nuclear fuel and waste management technologies. Beginning in FY 2010, the program shifted from a near-term technology development and deployment program to a long-term, science-based RD&D program which has the potential to produce beneficial changes to the way the fuel cycle, and particularly spent fuel, is managed. The program will examine three fuel cycle approaches: the current once-through fuel cycle, modified open fuel cycle, and full fuel recycle. Second-level funding for elements of the FCRD program are shown in Table 3.

Table 3. Fuel Cycle Technical Areas and Budgets

Technical Areas	FY 2010 Budget, (Thousands)	FY 2011 Request, (Thousands)
Separations and Waste Forms	41,615	31,324
Advanced Fuels	29,651	40,000
Transmutation RD&D	4,288	0
Modeling and Simulation	26,009	15,570
Systems Analysis and Integration	14,783	15,664
Materials Protection, Accounting, and Controls for Transmutation	6,826	7,814
Used Nuclear Fuel Disposition	9,124	45,000
Modified Open Cycle[6]	0	40,000
SBIR/STTR[7]	3704	5,628
Totals	**136,000**	**201,000**

The previous Fuel Cycle Research and Development (FCRD) program underwent significant changes in FY 2010. The previous program direction was based on the assumption of early introduction of a "closed fuel cycle" through construction of major facilities including a large reprocessing plant, a fuel cycle research and development facility, and construction of a fast breeder reactor. These facilities were to be built and operated in the larger context of the previous Administration's Global Nuclear Energy Partnership (GNEP) program that envisioned extensive international partnering arrangements for developing and deploying fuel cycle technologies.

The FCRD program has now dropped the emphasis on construction of major facilities and instead is focusing on RD&D with a new goal of deployment of alternate fuel cycles in 2050. DOE's underlying assumptions for the change in emphasis and direction are that interim storage of used fuel from nuclear power reactors is safe for at least 60 years and that the expanded time allocated for RD&D will lead to new fuel cycle technologies that are "science-based" and "transformational" and will be both beneficial and superior to the more evolutionary technologies that would have been introduced earlier in the GNEP program.

The FCRD program is divided into eight major technical areas (sometimes called "campaigns") in addition to a small business initiative activity. Each of the major technical areas is further subdivided into a number of specific technical areas that reflect new or re-

[6] The Modified Open Cycle includes a range of technology options between fully open and fully closed fuel cycles, thus providing flexibility in fuel cycle deployment technologies.

[7] The FY 2010 and FY 2011 amounts shown are an estimate of the requirement for the continuation of the SBIR and STTR program.

directed research and development initiatives whose goal is to comply with the new DOE directives. Each of the eight technical areas is discussed below.

Separations and waste forms

This technical area has two major subdivisions: *separations* and *waste forms* that are symbiotically related. The separations RD&D emphasis is on evaluation and development of improved, simplified processes to separate uranium and plutonium from fission products in spent fuel and to remove the minor actinides, primarily americium (Am) and curium (Cm), in a separate stream for storage pending eventual subsequent destruction in a fast burner reactor.

Pyroprocessing (reprocessing technology using molten metals and salts to achieve separations) for fast reactor fuels is being pursued along the lines pioneered by ANL, primarily for metallic fast reactor fuels. Improvements are being made in the difficult areas of process control and material accountancy and in recycling the salts used in the process salt to minimize waste production.

The waste form emphasis is on finding improved, durable forms for the fixation of a range of radioactive wastes from reprocessing for permanent disposal. Improvement in vitrified glass waste forms to enable greater fission product fractions is an important goal of the waste form task. Finding a good waste form for iodine is of special interest because ^{129}Iodine is a very long-lived fission product that tends to migrate readily in the environment. A satisfactory waste form for long term storage of ^{85}Krypton (an unreactive gas) is also being sought.

Advanced fuels

The Advanced Fuels technical area has a very broad scope. A major goal is to extend in-reactor fuel lifetimes of both fast reactor and thermal neutron spectrum reactors. The program is mindful of the fact that reactor fuels may be reprocessed and that advanced fuels should not be unnecessarily difficult to reprocess.

This technical area has several tasks: 1) develop improved metallic and ceramic fuel material for several reactor types, 2) irradiate fuels and perform post-irradiation examinations (PIE) of archival and newly developed fuels, 3) develop advanced high-performance "particle" fuels, 4) develop instrumentation and controls for safeguards of nuclear materials during fuel fabrication, 4) analyze and characterize long-term uranium resources, including unconventional resources, and 5) develop improved fuel cladding materials that will enable higher fuel burnups. The fuels irradiation and PIE work is a collaboration among DOE and other countries that have suitable irradiation facilities not currently available in the U.S. The studies include irradiation of reactor fuel cladding materials. Fuel types being studied include several fast reactor fuels (oxides, carbides, nitrides, metal), "deep burn" LWR fuels, and high-temperature graphite-based reactor fuels.

Transmutation RD&D

In FY 2011, DOE transmutation RD&D will focus on separations of fast reactor fuels, transmutation fuels, and systems analysis of fuel cycles employing fast reactors. This work crosscuts other technical areas and will be funded by them.

Modeling and simulation

The mission of Modeling and Simulation area is to create and deploy science-based, verified and validated modeling and simulation capabilities essential for the design, implementation, and operation of all aspects of nuclear energy systems and their nuclear fuel cycles to improve U.S. energy security. Program activities are very broad, encompassing the range of micro-behavior level of fuels and materials in Fuel Cycle RD&D task, to the macro-behavior level of reactor systems (e.g., LWRs and advanced reactors in Reactor Concepts RD&D) and their fuel cycles.

Systems analysis and integration

The systems analysis and integration technical area provides support in the areas of technical integration, project controls, quality assurance, document management, knowledge management, and communications. The basic philosophy is to use a systems engineering approach to conduct systems analyses to define and analyze a broad variety of innovative fuel cycle options including analyzing the effects of a variety of alternative disposal geologies to inform RD&D prioritization and program planning. The program will develop a directory of innovative fuel cycle options that documents key fuel cycle characteristics. This is the first time a system engineering approach is planned to be used by DOE on a sustained basis for such a complex nuclear energy system.

Materials Protection, Accounting, and Controls for Transmutation

MPACT will focus on development of online, real-time, continuous, accountability instruments and techniques that permit at least a ten-fold improvement in the ability to inventory fissile materials in domestic fuel cycle systems in order to detect diversion and prevent misuse. This task will cover both aqueous and pyroprocessing reprocessing methods. Specific goals are: 1) Improve the fundamental understanding of nuclear materials and the physics of detection methods through coupled theory plus the simulations, and experiments necessary to develop next generation nuclear materials management technology, and 2) Develop and demonstrate improved non-destructive assay technologies capable of real-time, high-accuracy quantification of nuclear material content, 3) Create integrated process monitoring and control technologies that provide real time knowledge of facility operations including analytical results, process parameters, video, tags/seals, and personnel movements, and 4) Improve the protection, accountability and control of used fuel separations processes to enable secure, verifiable, and economic implementation of advanced fuel cycles in the United States.

Used nuclear fuel disposition

The mission of the Used Nuclear Fuel Disposition technical area is to identify alternatives, and conduct scientific research and technology development to enable storage, transportation, and disposal of used nuclear fuel and all radioactive wastes generated by existing and future nuclear fuel cycles. Work in this program element supports all three fuel cycle strategies: once-through fuel cycle, modified open fuel cycle, and full fuel recycle.

This technical area will develop an understanding of geologic repository performance; review the extensive technical bases developed in the U.S. and internationally over the past several decades including recent work by SNL and LANL on a generic salt repository; explore a range of potential geologic settings, including granite, salt, clay, and tuff; consider a range of disposal concepts, including shaft-room, ramp-drift and deep borehole designs; investigate storage concepts for UNF and a range of waste streams; and develop an integrated waste management strategy applicable to a range of fuel cycle options.

Modified open cycle

The FY 2011 budget expands the focus of the Fuel Cycle RD&D program to include fuel cycle strategies between the once-through and full recycle strategies. In this cycle limited or no separations steps are applied to used fuel. One example of a potential modified open cycle is the "deep burn" of fuel, a process wherein fuel is fabricated in such a way that it will tolerate very high burnup to the point that recycle is not desirable. Another example is the Direct Use of spent Pressurized-water reactor fuel In a CANDU (Canada Deuterium-Uranium reactor, CANDU), or DUPIC approach, wherein the used fuel from an LWR is reconstituted by (a) heating in air or oxygen to cause it to crumble and release its volatile elements, and (b) fabricating the remaining, but still intensely radioactive, powder into fuel that can be used in existing CANDU reactors, or perhaps in LWRs after more research. The spent CANDU fuel would then be directly disposed of. Elements volatilized during heating (e.g., krypton, iodine, ruthenium, and part of the technetium and cesium) would be captured and solidified into HLW. The intensely radioactive powder (which contains uranium, plutonium, and 40% to 60% of the other fission products) would constitute the new fuel. The DUPIC approach has proceeded to the point where lead test assemblies are being irradiated in CANDU reactors in Canada. CANDU reactors operate in Canada, South Korea, China, India, Romania and Argentina.

SBIR/STTR

Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) are U.S. Government programs in which federal agencies with large RD&D budgets set aside a small fraction of their funding for competition among small businesses only.

Nuclear Energy Enabling Technologies	**FY10**	**FY11**
	0	99,300

The first-level program will focus on innovative research relevant to multiple reactor and fuel cycle concepts that offer the promise of dramatically improved performance. The budgets of second-level areas of work are shown in Table 4.

Table 4. Nuclear Energy Enabling Technologies Funding Profile by Subprogram

	FY 2010 Budget, (Thousands)	FY2011 Request (Thousands)
Crosscutting Technology Development	0	43,332
Transformative Nuclear Concepts Research and Development	0	28,888
Energy Innovation Hub for Modeling and Simulation	0	24,300
SBIR/STTR	0	2,780
Total, Nuclear Energy Enabling Technologies	**0**	**99,300**

Crosscutting Technology Development

Crosscutting areas of inquiry include the development of advanced fuels and reactor materials, research on innovative nuclear manufacturing methods, new sensor technologies for monitoring material, and equipment conditions in existing reactors and creative approaches to further reduce proliferation risks.

Transformative R&D

The Transformative Nuclear Concepts R&D will support, via an open, competitive solicitation process, investigator-initiated projects that relate to any aspect of nuclear energy generation—reactor and power conversion technologies, enrichment, fuels and fuel management, waste disposal, nonproliferation, and so forth—ensuring that good ideas have sufficient outlet for exploration. One goal of this effort is to encourage the identification and development of "outside the box" options in all aspects of the civilian nuclear energy program.

Energy Innovation Hub

NE established the Modeling and Simulation Hub in FY 2010 and will continue to support it in FY 2011. The Hub will apply state-of-the-art computer modeling and simulation of processes from the sub-atomic to the system-integration level.

	FY 2010 Budget, (Thousands)	FY 2011 Request, (Thousands)
International Nuclear Energy Cooperation	0	3000

The objective of International Nuclear Energy Cooperation (INEC) is to support the Office of Nuclear Energy (NE) program offices in implementing international cooperative RD&D activities that further NE's mission; provide technical, policy, and administrative support to carry out the civilian nuclear energy aspects of officially approved international agreements and other relevant U.S. international commitments; provide advice and support to other Department of Energy (DOE) offices and Federal agencies that are planning and/or implementing new agreements and other U.S. commitments having civilian nuclear energy aspects; and serve as advisors to other DOE offices and Federal agencies on general issues related to the international use of civilian nuclear energy.

Analysis

The FY 2011 budget request provides extensive details (~150 pages) on DOE's planned nuclear energy RD&D activities. The activities proposed in the budget appear to be potentially relevant to developing and supporting both evolutionary and revolutionary advanced nuclear energy systems. However, the very nature of the budget request – providing information on the two previous years and the year of the request - makes it impossible to fully understand how or whether the myriad activities interrelate, how long it will take to yield results, and when and how decisions will be made concerning what to pursue and what to eliminate. There is a long-term goal of deploying used fuel recycle by 2050. Difficulty in understanding the program is exacerbated by numerous crosscutting activities that are difficult to relate to the main framework of the program.

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