University Centered Base Technology Program
White Paper

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University Base Technology Program - Specific Proposal

A University base technology program is designed to recognize the unique contributions and operating environment of university research programs. This document first proposes the components of a university base technology program and then provides a detailed rationale for the establishment of such a program.

User facilities

The Department of Energy has already established facilities at universities that can be used for studying radiation performance, corrosion and stress corrosion cracking, and thermal-hydraulics phenomena. These facilities, which will be described in this document, could be made available to the broader university community as user facilities. They would be provided with base support and would be required to then partner with outside university researchers.

The selection of user facilities could be performed via a peer reviewed proposal system. Criteria for running a user facility can be placed into a solicitation. Universities interested in hosting a user facility then propose the services that could be provided and the cost for yearly support. This could be based on existing facilities or a totally new facility. A panel of reviewers from laboratory and industry would select the initial sites and facilities. These facilities would be evaluated over a multi-year period to determine their effectiveness in fomenting collaborations that support DOE research goals. The selection of user facilities must be made in the context of similar facilities being established at national laboratories.

PhD Fellowships

Because research grants are typically three-year awards, shorter than the typical time to finish a Ph.D., a competitive two-year fellowship program should be initiated. Students who are doctoral qualifiers, who have been funded on a DOE NE research project (either NERI or direct laboratory funding from GNEP, Generation IV, or NHI, would apply for a fellowship that pays salary, tuition, and fees. The top doctoral students from around the nation supporting DOE NE mission-oriented R&D work would then be recognized and allowed to finish their doctoral work independent of programmatic decisions on R&D funding. This also allows DOE to recognize superior performance, base on existing work in contrast to the typical fellowship that rewards the promise of good performance.

Secondary Reactor Concept Participation and Leadership

Because of the long-term nature of the Gas-cooled Fast Reactor (GFR), Lead-cooled Fast Reactor (LFR), Molten Salt-cooled Reactor (MSR), and Supercritical Water-cooled Reactor (SCWR) research programs, as well as the necessary national laboratory focus on the Very High

Temperature Reactor (VHTR) and Sodium-cooled Fast Reactor (SFR), the majority of the funding for secondary concepts and crosscutting R&D could be placed into university programs. Because only small amounts of funding are being directed towards the GFR, LFR, MSR, and SCWR, a greater amount of research could be accomplished under the lower cost structure existing at the universities. The leadership for these programs could either remain at the national laboratories or be placed with a collaborating university professor, depending on DOE preferences and the availability of qualified and interested university faculty. The decision on where to place the funding could be based on two criteria: first the existence of ongoing research programs already established via previous DOE NE programs and, if additional funding exists, a special call as part of a routine U-NERI solicitation

International Interfaces

Based on ongoing studies supporting the GFR, SCWR, and LFR, university researchers exist with sufficient expertise to act as interfaces for joint research with international partners. These university researchers could lead the interface or be paired with a national laboratory co-lead. The co-lead arrangement is preferred to ensure continued interface with the national laboratories.

U-NERIs

DOE NE has defined the U-NERI program as the primary vehicle for university participation in the primary concepts (VHTR and SFR, along with GNEP related fuels and recycle research). No changes to this program are suggested.

Base Technology Program- The Concept

A university focused base technology program has the potential for supporting the development of technological innovation and for the development of the research manpower required for the future of nuclear energy. A base technology program has three main goals:

1. Provide a vehicle for long time horizon research that develops trained engineering researchers and provides technological advancements supporting multiple advanced reactor and fuel cycle concepts
2. Maintain a vehicle for international partnerships in long time horizon technologies.
3. Provide a vehicle that provides continuity in research for doctoral students

A base technology program has three main components

1. Establish user facilities to allow a broad range of universities to investigate new ideas in fuels, materials, and thermal hydraulics. These facilities can be based at universities or national laboratories, but some fraction should be located at universities, both to encourage laboratory-university exchange, and to support a robust training pipeline.
2. Establish a competitive fellowship program for outstanding doctoral students, who have been funded on a DOE NE research project (either NERI or direct laboratory funding from GNEP, Generation IV, or NHI, to finish their degrees on mission-oriented research.
3. Ensure universities are integral parts of the primary DOE NE programs (GNEP, VHTR, SFR) and allow them to take the primary leadership roles in the long-range development of secondary Generation IV technologies (GFR, SCWR, LFR, MSR) and crosscutting research.

A base technology program does not replace university participation in the primary DOE NE programs. Universities should still contribute where their strengths lie to support the primary programs being conducted through the national laboratory leadership.

A university centered base technology program has important value, both for developing technological innovation and for developing the research manpower required for the future.

Background

Vision

The goal of the DOE NE research, as typified in the Global Nuclear Energy Partnership (GNEP) program goal statement, is to:

> ***Enable the expanded worldwide use of economical, environmentally responsible nuclear energy to meet growing electricity demand, while virtually eliminating the risk of nuclear material misuse***

The nuclear enterprise is global in nature and is addressing energy and sustainability requirements that must be understood in the context of a time horizon thousands of years long. The university programs that train future generations of nuclear scientists and technicians must also have a global vision and a forward-looking structure. The university structure must provide skilled manpower to design, operate, & maintain an extensive infrastructure of nuclear assets in a global framework.

> ***Tomorrow's nuclear engineers must be both technically <u>and</u> culturally skilled. Additionally, the university programs must provide an infrastructure that continually builds, improves, & innovates with each new generation.***

DOE NE Research Programs

In 2002, the Department of Energy, along with its international partners in the Generation IV International Forum, selected six advanced nuclear energy systems for further research and development. These systems were chosen because of their potential advantages in the areas of reduced capital cost, enhanced nuclear safety, minimal generation of nuclear waste, and further reduction of the risk of weapons materials proliferation. Generation IV systems are intended to be responsive to the needs of a broad range of nations and users. The stated goal of Generation IV is to develop nuclear energy systems that would be available for worldwide deployment by 2030 or earlier.

Since the selection of these concepts, the high priority focus in the United States has been on the Very High Temperature Reactor (VHTR). Limited research has been performed on the Gas-cooled Fast Reactor (GFR), Supercritical Water-cooled Reactor (SCWR), and Lead-cooled Fast Reactor (LFR) concepts. No significant research has been performed on the Sodium-cooled Fast Reactor (SFR) or Molten Salt-cooled Reactor (MSR), although some research on using molten salt as a coolant and process heat transport fluid has been performed in conjunction with the VHTR and the Nuclear Hydrogen Initiative.

The recent announcement of the Global Nuclear Energy Partnership, with a focus on recycle and transmutation of actinides, has increased the need for deployment of a sodium-cooled fast reactor. This had led to more of a focus on the VHTR and SFR, with a possible need to limit research on the GFR, SCWR, MSR, and LFR based on budget constraints.

The concepts selected as part of the Generation IV process were originally proposed in the 1950s through the 1970s. The development of many concepts was deferred because significant R&D is required to make the concepts viable. Currently the VHTR and SFR are primary candidates for Generation IV and GNEP because they are closest to being deployable (partly because they are based on less aggressive environments and partly because of the significant past R&D investment). The other Generation IV concepts (GFR, SCWR, LFR, MSR) are currently being minimally funded, mainly as a mechanism to maintain international collaborations.

The Generation IV Roadmap also identified crosscutting technology issues and areas that would support multiple concepts. These R&D areas include:

High temperature materials
Radiation resistant materials
Complex fluid flow & heat transfer
Tools for coupled thermal hydraulics and neutronics
Instrumentation and NDE

Long-term crosscutting research has not generally been picked up in the R&D plans.

The DOE NE portfolio involves both medium term (VHTR and SFR) and long-term (SCWR, GFR, LFR, MSR, crosscutting) R&D. The research talent of university community can be integrally involved across research the R&D portfolio, for the benefit of both the research effort and the optimal training of students.

Status of Current University Nuclear Engineering Enrollments

Following a large decrease in enrollments from 1992 to 1999, the undergraduate enrollments have increased dramatically, recovering the enrollment loss of the 1990s entirely (figure 1). The large increase in undergraduate enrollment that started in 2001 is now being seen in larger and better qualified graduate student enrollments.

A tremendous new human resource is committing to nuclear engineering and it is important for the university infrastructure to properly train and engage the manpower that will drive the nuclear renaissance.

Locations of Current University Nuclear Engineering Programs

Universities with a nuclear engineering component exist in more than half the states in the U.S. They are distributed throughout the entire U.S. (figure 2) in a similar manner to the national laboratories (figure 3). The Department of Energy relies on assets from multiple laboratories, working collaboratively, to lead and execute technology development programs. This use of distributed assets requires coordination across large geographic regions.

> ***The university resources, distributed in a similar manner to the national laboratory assets, can naturally be woven into national technology development programs, optimizing the university talent and the training and development structure for today's students.***

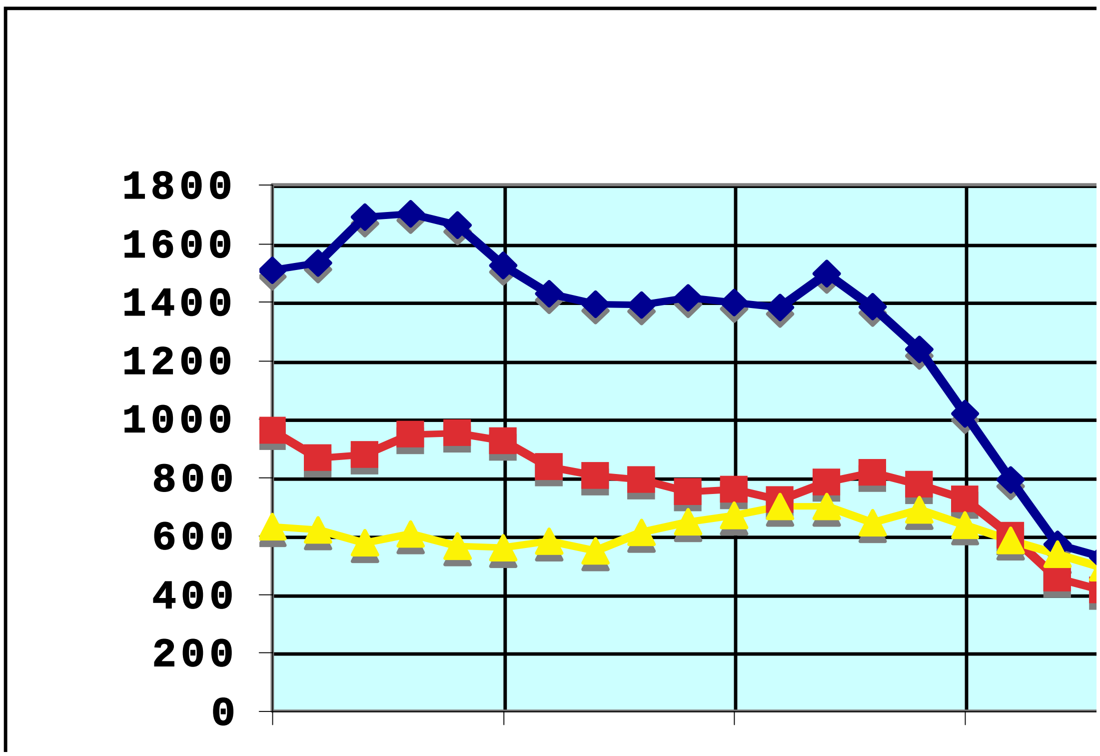

Figure 1. University enrollments over the past quarter century.

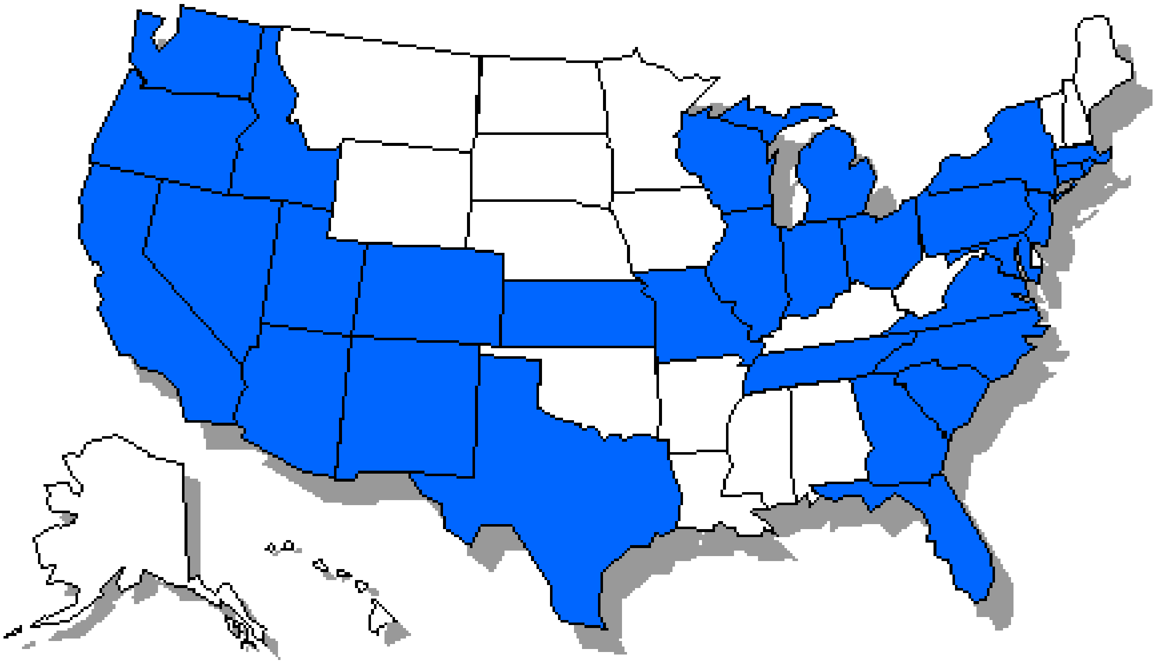

Figure 2. Locations of universities with a nuclear engineering component.

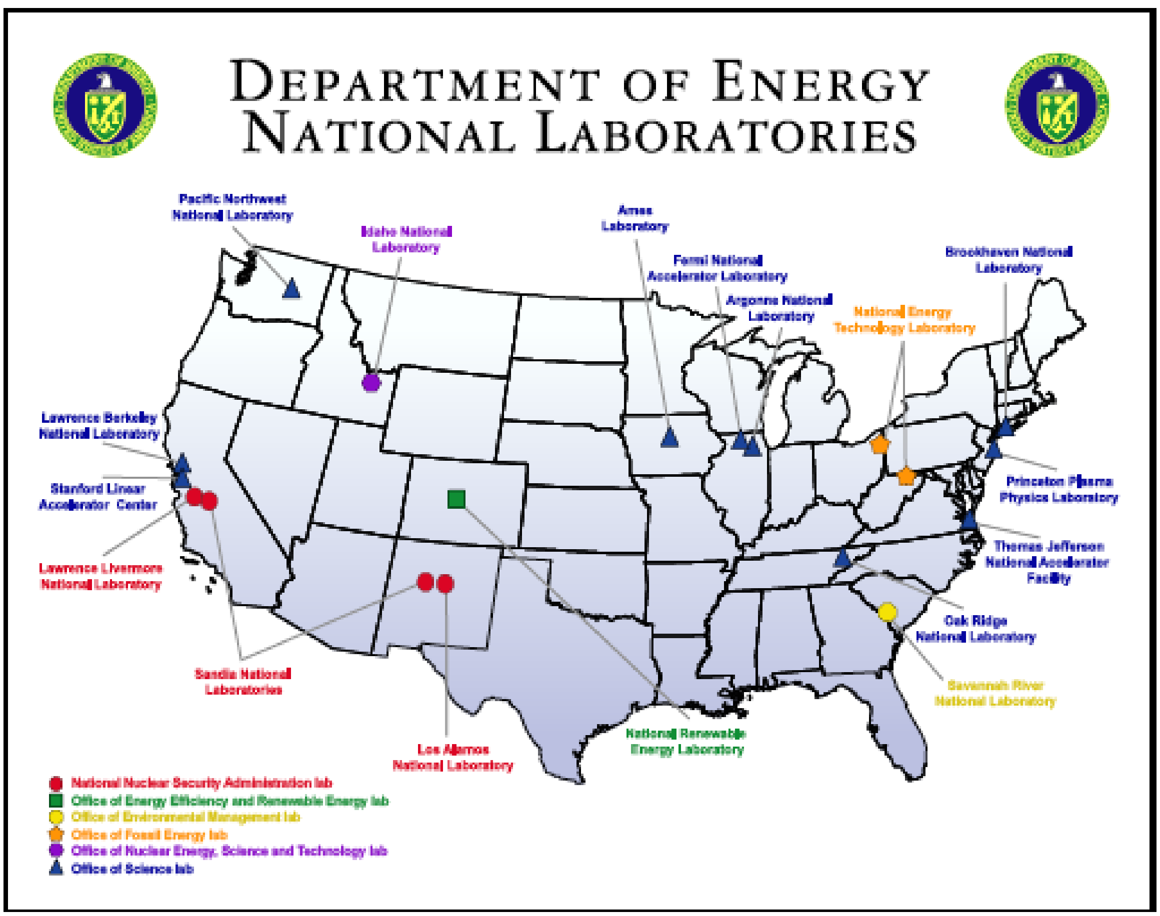

Figure 3. Geographic location of national laboratory infrastructure

Value of university/national laboratory integration in optimizing the educational pipeline

Frequent exchange of personnel between the universities and national laboratories will improve both the national research effort as well as the national educational effort. These exchanges can take the form of laboratory personnel on temporary loan to universities to teach or supplement instructors, laboratory personnel on temporary loan to universities to perform research, and university faculty and students spending time at national laboratories to perform research. Integrating university faculty into the technical leadership of GNEP and Generation IV will help make these exchanges natural.

> ***Natural exchanges will improve the national research programs by both using the available university research talent and producing a better-educated student by integrating the students into the national research programs and the national laboratory staff into the educational programs.***

Support for 30-year horizon research

University's should focus on transformational rather than on incremental research. A typical graduate student doctoral thesis requires 4-6 years of study. Ideal projects focus on open research questions that allow the student to develop a skill set while answering longer time horizon questions. Because of the desire for nearer term development of the VHTR and SFR, these two concepts will naturally focus more on incremental design and development issues. Nonetheless, long-term research still is required to identify technologies that can transform these concepts beyond their current designs; e.g., advanced materials, advance power conversion systems. The base technology research topics as related to GFR, SCWR, and LFR have more basic feasibility issues that would require a sustained base technology research program. The base technology research requirements of these concepts more naturally align with the time horizons of doctoral research, while simultaneously adding value to the nearer-term concepts. If laboratory focus on the VHTR and SFR requires them to defer work on the GFR, SCWR, and LFR, a university focused base technology program would provide an excellent vehicle for continued longer time horizon research.

> ***Because these deferred concepts and crosscutting technology areas exist on a very long research time horizon and have limited funding, they would be good research areas to place under university leadership where manpower costs are lower and projects are more naturally aligned with the longer time horizons required to complete a Ph.D. This leadership focus should not exclude universities from contributing to mainline concepts like VHTR, SFR, and GNEP but recognizes that for small budgets, the lower cost structure of the universities optimizes the use of limited research dollars.***

International Partnerships under Generation IV

While the U.S. focus in on the VHTR and SFR, international partnerships are ongoing related to the GFR, SCWR, and LFR. In some cases, like the SCWR, the international partner (Canada) is primarily interested in the SCWR. The international partners are also researching base technology and access to their research results provides value similar to that described above.

> **Placing significant support for Generation IV funding of secondary concepts at universities maximizes the research contribution to international partnerships based on these concepts.**

The Value of User Facilities

As part of its current mission, the Office of Basic Energy Sciences (BES) plans, constructs, and operates major scientific user facilities (listed in Appendix A) to serve researchers from universities, national laboratories, and industry. These facilities enable the acquisition of new knowledge that often cannot be obtained by any other means. By supporting a large capital cost facility that is open to multiple users, program managers allow a wider cross section of the research community to perform difficult experiments. DOE NE could also support a set of user facilities to underpin GNEP and Generation IV research programs. These facilities could include reactors, hot cells, accelerator facilities, thermal hydraulic test facilities, and corrosion laboratories. User facilities could be located at either national laboratories or universities.

> **Placing user facilities at both laboratories and universities establishes an architecture that encourages university and laboratory personnel to work collaboratively and supports a robust training pipieline.**

User Facility Structure and Operation

The user facilities run by the Office of Basic Energy Sciences range from large, broadly-based facilities such as the Advanced Photon Source and the Spallation Neutron Source to smaller specialized single-purpose centers such as the Materials Preparation Center (MPC) at Ames Laboratory and the Notre Dame Radiation Laboratory. The operational philosophy is similar across facilities, with each having the following components:

1. Facilities are given base funding to cover operations costs and are required to host outside users.

2. Participation is initiated via submission of short proposals from principal investigators. Proposals are submitted for review and approval by an Executive Committee. Approval is based upon scientific excellence of the proposal and relevance to DOE goals.

3. The Executive Committee is composed of representatives from the user facility research staff and external users familiar with the facility. Executive Committee members review proposals, suggesting those that should be given facility time. For those proposals that do not receive facility time, the committee provides constructive comments to aid the principal investigator (PI) in writing a revised proposal.

4. The Executive Committee also acts as an advisory body to the Facility and Program (these Executive Committee functions may be split among more than one committee for the large facilities).

5. Initial proposals may be exploratory, to test the feasibility of a research idea. Exploratory proposals may then lead to extended collaboration between the user facility staff and the external researchers. Typically proposals can be submitted throughout the year.

6. External users are required to provide yearly summaries of the work performed, including publications and patents. This information is summarized in a report to the Department of Energy. Some facilities also require short reports for each visit.

7. All publications based on work funded by DOE to be performed at the user facility are required to acknowledge DOE for supporting the work. A standard acknowledgement is provided for all users.

8. Depending on the level of collaboration, user facility staff may become co-authors on publications.

9. External users are required to complete all facility safety training before performing research at the facility. A plan for performing any experiment requiring special safety precautions will be developed jointly by the facility safety officer and the proposal principal investigator. For facilities located at a national laboratory, participants may *also need to go through security training and clearance.*

10. All user facilities provide experimental support at no cost to the visiting investigator's grants.

11. Travel to the user facility is sometimes funded by the user facility, but more recently this burden has been shifted to the investigator's grants.

A university-based user facility will be operated in a manner conceptually much closer to the smaller specialized single-purpose centers run by DOE BES.

University Based User Facilities

To provide support as a user facility, certain requirements should be met.

1. The facility should be broadly applicable to supporting the DOE NE research portfolio
2. The capital cost of the facility should be large enough that it is cost effective to open the facility to outside users rather than establish similar new facilities across the country
3. The facility must be unique enough from other existing facilities to justify direct support. If a number of similar facilities exist, then a user without such a facility can partner through the general research proposal process.

A study of university web sites was performed to determine broadly the types of large experimental research facilities that exist that could be considered as potential user facilities. The search was restricted to universities with a nuclear engineering component. The facilities were broadly grouped as nuclear reactors, corrosion test facilities, radioactive material analysis facilities, ion irradiation facilities, and thermal hydraulic facilities. In this section, a few select facilities that meet the criteria are described. These examples are not meant to be inclusive, but are provided as examples. Any decision to establish a university based user facility would first require an open solicitation to allow the university community to propose user facilities and justify how they would meet the three criteria.

> **Appendices B through F provide a list of facilities that were identified as part of this study. A notation lists whether they appear to meet the criteria. *The lists are only as accurate as the information that could be gleaned from university web sites.***

Example 1: University of Nevada at Las Vegas Actinide Chemistry Laboratory

UNLV has developed over 1500 square feet of laboratory space of radiochemistry laboratories, including a dedicated laboratory for work with technetium and the higher actinides. The facilities allow researchers to work with radionuclides as chemical reagents, supporting the study of the fundamental chemical behavior of the actinides and technetium for applications ranging from fuel and waste form development to process chemistry to the environmental behavior of the radionuclides.

Within the radiation laboratories, researchers have access to high temperature furnaces, including an arc melter; Ultraviolet-Visible spectroscopy (UV-Vis); Fourier-Transform Infrared Spectroscopy (FTIR); Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES); Inductively Coupled Plasma Mass Spectroscopy (ICP-MS); Time-Resolved Laser Fluorescence (TRLF) Spectroscopy; Laser Raman Spectroscopy; as well as traditional radiochemistry techniques, such as alpha spectroscopy, liquid scintillation spectroscopy, gamma spectroscopy, and proportional counting.

Procedures have been developed to support the analysis of radioactive samples in other analytical facilities on campus, adding X-ray Powder Diffraction; Scanning Electron Microscopy; Electron Microprobe Analysis; Nuclear Magnetic Resonance spectroscopy (NMR); X-ray Photoelectron Spectroscopy (XPS); X-ray Fluorescence Spectroscopy (XRF); and Transmission Electron Microscopy (TEM) to the tools available for the analysis of radioactive samples.

This facility appears to meet the user facility criteria.

Example 2: University of Michigan Irradiated Materials Testing Laboratory

The Irradiated Material Testing Laboratory was designed to provide Constant Extension Rate Tensile (CERT) experiment and Crack Growth Rate (CGR) capabilities of neutron-irradiated specimens in supercritical water, and for specimen analysis by Scanning Electron Microscopy (SEM). The facility was designed to minimize the occupation time of the hot cell by making both the load frame and the SEM column mobile. Hot cell #1 in Phoenix Memorial Laboratory (PML) is adjacent to the irradiated material testing laboratory (IMTL) and is used for specimen loading into the autoclave, autoclave closure and pressure testing in preparation for the experiment, and application of shielding. The autoclave is then rolled into IMTL, a 1000 sq ft laboratory located next to the hotcell, where the CERT or CGR experiment is conducted. Once the experiment is completed, the autoclave is rolled back in the hotcell for specimen unloading. Then, the SEM is installed in the hotcell for post-test analysis of fracture and gage sections.

The SCC facility provides the capability to perform stress corrosion cracking experiments in pure supercritical water, up to 30 MPa of pressure and 600ºC, in a controlled, refreshed environment. The environmental control consists of dissolved oxygen control and monitoring and conductivity monitoring. Oxygen levels below 10 ppb and inlet conductivity of 0.07 μS/cm are obtainable. The make-up and control on the environment is performed in the *water loop*, described in detail below. Constant strain rate, constant load and constant K experiments can be conducted, in addition to fatigue pre-cracking and programmed loading sequences. Those loading modes are applied and controlled by the loading unit described later. The crack propagation measurement technique will also be detailed in this section.

The hot cell facility is provided by PML is the cave No1 presented in figure 2. The cell consists in a 3 meters wide by 1.8 to 2.5 meters deep room. Shielding is provided by 0.9 m of high density concrete and two 35 cm thick iron doors at the rear. The cell contains three leaded glass, viewing widows with a viewing area of 78 cm (tall) by 90 cm (wide). It is negatively pressurized through a HEPA or charcoal (operator selectable) exhaust that can be truncated to provide localized collection of fumes and materials.

The hot cell has two Central Research Model 8 manipulator arms that can transverse left and right across the operating face providing full access to most of the hot cell volume. It contains two half-ton hoists. One is installed on a trolley running along the operating face at the centerline of the hot cell. The other one is located between the manipulator arms.

A JEOL Model JSM-6480 scanning electron microscope is used for post-test analysis. It is equipped with an Everhart Thornley detector for secondary electron imaging and a backscattered electron detector that provides compositional, topographic and shadow images. It also has a Genesis 2000 XMS System 60 Energy Dispersive Spectrometer (EDS) from EDAX. The EDS has a sapphire detector with a resolution of 130 eV. For observation of irradiated specimens, the microscope is installed in the hot cell and connected to the control console outside the hot cell.

This facility appears to meet the user facility criteria.

Example 3: University of Wisconsin Radiation Damage Facility (The Michigan Ion Beam Laboratory has similar capability)

Irradiations are performed using the UW Tandem Accelerator Facility and High Temperature Radiation Stage. This accelerator is a 1.7 MV machine capable of accelerating protons up to 3.4 MeV. Samples can be irradiated in multiple forms including 3 mm diameter disks. These samples are coupled to a metallic stage through a graphite foil that can provide enough compliance to ensure samples of slightly varying thickness are coupled to the stage for adequate temperature control. Samples are irradiated and temperature is monitored and controlled through beam heating and a stage temperature controller. The rastered irradiation beam is centered on the target via an aperture system with total beam current measured to provide a measure of radiation dose. Three K type thermocouples and a Mikron 7302 infrared camera are used to monitor the sample temperatures. During an irradiation the camera can be used to monitor differences in sample temperatures caused by beam irregularities. The beam is rastered as it approaches the stage to achieve an even distribution of current over the sample area. To ensure the beam maintains a centered position throughout the length of an irradiation the current from four electrically isolated aperture plates is monitored.

This facility appears to meet the user facility criteria.

Appendix A: BES User Facilities

SYNCHROTRON RADIATION LIGHT SOURCES

National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory in Upton, NY
Stanford Synchrotron Radiation Laboratory (SSRL) at Stanford Linear Accelerator Center in Stanford, CA
Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory in Berkeley, CA
Advanced Photon Source (APS) at Argonne National Laboratory in Argonne, IL
Linac Coherent Light Source (LCLS)—under construction at Stanford Linear Accelerator Center in Stanford, CA

HIGH-FLUX NEUTRON SOURCES

High Flux Isotope Reactor (HFIR) Center for Neutron Scattering at ORNL in Oak Ridge, TN
Intense Pulsed Neutron Source (IPNS) at Argonne National Laboratory in Argonne, IL
Manuel Lujan Jr. Neutron Scattering Center (Lujan Center) at Los Alamos National Laboratory in Los Alamos, NM
Spallation Neutron Source (SNS) at Oak Ridge National Laboratory in Oak Ridge, TN

ELECTRON BEAM MICROCHARACTERIZATION CENTERS

Electron Microscopy Center for Materials Research (EMCMR) at Argonne National Laboratory in Argonne, IL
National Center for Electron Microscopy (NCEM) at Lawrence Berkeley National Laboratory in Berkeley, CA
Shared Research Equipment (SHaRE) Program at Oak Ridge National Laboratory in Oak Ridge, TN

NANOSCALE SCIENCE RESEARCH CENTERS

Center for Nanophase Materials Sciences at Oak Ridge National Laboratory in Oak Ridge, TN
Molecular Foundry at Lawrence Berkeley National Laboratory in Berkeley, CA
Center for Integrated Nanotechnologies at Sandia National Laboratories and Los Alamos National Laboratory
Center for Functional Nanomaterials at Brookhaven National Laboratory in Upton, NY
Center for Nanoscale Materials at Argonne National Laboratory in Argonne, IL

SPECIALIZED SINGLE-PURPOSE CENTERS

Combustion Research Facility (CRF) at Sandia National Laboratories in Livermore, CA
Materials Preparation Center (MPC) at Ames Laboratory in Ames, IA
Notre Dame Radiation Laboratory at the University of Notre Dame in Notre Dame, IN

Appendix B: University Reactors

A number of universities have operating nuclear reactors on campus. The reactors can be broadly grouped by size as small (less than 1 MW), medium (1MW), or large (greater than 1 MW). The general capabilities to conduct nuclear activation analysis and neutron radiography exist at many reactors across the country. The only facilities that are unique are those that have added some unique capability to their reactor. Examples include MIT and MURR who have high enough fluxes to perform low dose radiation exposure on materials, Wisconsin who has established a water radiolysis facility, and Penn State who are significantly upgrading their neutron science abilities.

Because the DOE already operates materials irradiation and neutron science facilities at national laboratories, establishing user facilities at a university reactor would need to be based on a unique capability or by reduced cost or increased access as compared to the national laboratory facility.

> ***The majority of the existing university reactors do not meet the criteria for user facilities. Consideration of the few unique university reactors as user facilities must be considered in a broader discussion that includes HFIR and ATR.***
>
> ***It is suggested that university reactors not be included further in this discussion of user facilities, but considered separately as part of the development of user facilities at ATR and HFIR.***
>
> ***Support for reactors as training facilities is not included in this discussion. The university based reactors are a vital training asset, but this proposal, which is focused on research, is not addressing their training assets.***

Appendix C: Corrosion and Stress Corrosion Cracking Facilities

Table C.1 lists the established corrosion and stress corrosion cracking facilities that have been established at universities to support the Generation IV and AFCI programs. They all meet criteria #1 in that they are applicable to DOE NE missions and criteria #3 in that they are unique. Most of the facilities are small and were established within the context of a single research grant so they don't meet criteria #2.

The lead testing facilities at the LANL DELTA loop are more extensive than those at universities and are a better candidate as a user facility than the Wisconsin or MIT facilities. The Michigan, which was described as a candidate user facility, is unique in that is has the capability to handle radioactive materials. The Wisconsin facility has the advantage of having a broad cross section of test facilities all in a single location. UNLV is developing a facility for higher temperature lead corrosion testing.

> ***Although none of the isolated university facilities meets the criteria as a user facility, the combination of facilities at Michigan and Wisconsin is an example of facilities that could be grouped into a geographically located center.***

Table C.1. Corrosion and Stress Corrosion Cracking Facilities to Support Generation IV

	Michigan	UNLV	Wisconsin	MIT
Supercritical Water	X		X	
Lead or Lead-Bismuth*		X	X	X
Helium,	X			
Molten Salt			X	
Sodium				
Supercritical Carbon Dioxide				X
Supercritical water radiolysis			X	

*For LBE corrosion studies, the DELTA facility at LANL is already in operation.

Appendix D: Facilities for Testing and Microscopy of Radioactive Material

Table 2 lists universities with capability to examine radioactive materials. The hot cells at Penn State are not currently active but are in good condition and could be used. The SEMs at Michigan and MIT, as well as the UNLV actinide chemistry laboratory meet all three criteria as a user facility.

> ***Similarly to the discussion on university reactors, these facilities must be considered in a broader discussion that includes similar national laboratory facilities.***

Table 2. Testing and Microscopy of Radioactive Materials

	Michigan	UNLV	Penn State	MIT
Scanning Electron Microscopy	X	X		X
Crack Growth and Stress Corrosion Cracking	X			
Actinide Chemistry		X		
Hot Cell	X		X	X
Transmission Electron Microscopy		X		

Appendix E: Ion Irradiation Facilities

Ion irradiation facilities can be used to support both radiation damage studies and surface modification studies. University facilities are listed in Table 3. Although none of the national laboratories are currently supporting DOE NE studies using ion irradiation facilities, both LANL and ANL have accelerators on site. ANL has the IVEM-Tandem that couples an ion irradiation capability with a transmission electron microscope. The ANL IVEM-Tandem is run only part time with support from DOE BES.

All of the ion beam machines are broadly applicable and high cost, thus meeting criteria #1 and #2. The ion beam analysis and implantation capabilities are found at multiple locations and therefore do not meet criteria #3.

> ***The radiation damage facilities meet all three criteria and are logical candidates as user facilities, either alone or as a geographically located center.***

Table 3. Ion Irradiation

	Michigan	ISU	Wisconsin	MIT	TAMU	RPI
Radiation Damage	X		X			
Ion Beam Analysis	X	X	X	X		X
Implantation	X		X		X	

The University of North Carolina currently has ownership of the Ion Beam system previously at ORNL, but the machine is not in active use.

Appendix F: Thermal Hydraulics Facilities

Large-scale thermal hydraulic facilities wee identified at multiple locations. Most were constructed for LWR studies but may be able to support Gen IV studies.

Table 4. Thermal Hydraulics

	Purdue	Penn State	Wisconsin	Oregon State	MIT	NCSU
LWR Loop	X	X		X	X	X
Supercritical Water or SCCO2 Loop			X		X	
Liquid Metal			X			