PNNL-12245, Rev. 1

0051815

Program Scoping Plan for the

Fast Flux Test Facility

A Nuclear Science and Irradiation Services User Facility

August 1999

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Pacific Northwest
National Laboratory

Operated by Battelle for the
U.S. Department of Energy

Executive Summary

The objective of this Program Scoping Plan for the Fast Flux Test Facility (FFTF) is to establish whether a compelling rationale exists for the U.S. Department of Energy (DOE) to consider the restart of this facility, which has been in standby since 1992. The conclusion of the study is that a compelling rationale does exist for pursuing restart. In describing that rationale, this plan asks and then answers a series of questions about need, restart feasibility, life-cycle economics, and management approach for operating the FFTF. Those answers provide, by description, reference, or letters of commitment, both the relevant facts and the basis for confidence.

Is there a clear unequivocal need for the FFTF based on its unique capabilities and user requirements?

The FFTF does have an identified, singular, focused purpose: To produce high-energy, high-fluence neutrons for nuclear science and irradiation services.

Because the FFTF, unique among other available test reactors and accelerators, can produce "fast" neutrons in great quantity, there is a suite of viable missions for which sponsors have identified clear needs. Those missions have the potential to establish the FFTF as a premier nuclear materials testing, isotope production, and plutonium fuels research facility. As demonstrated by the letters received from Japan, South Korea, and France, restart of the FFTF can also broaden and strengthen international nuclear cooperation, which is essential to worldwide nuclear safety. Moreover, transfer of U.S. civilian nuclear technology has been and will continue to be an important contributor to achieving U.S. nonproliferation objectives.

The Fast Flux Test Facility (FFTF) is a 400-megawatt thermal, liquid metal (sodium) cooled reactor. The white dome in the background is the containment building that holds the reactor.

Based on the 90-day study, four mission areas will support FFTF operation at 100 megawatts:

- medical and industrial isotope production
- plutonium-238 production
- non-proliferation programs
- materials testing.

The out-year projections for FFTF use and revenue for these mission areas, as shown in the following table, are more than speculative guesses but obviously less than contractual commitments. As demonstrated in the letters

Mission	Sponsor	Deliverable	Annual Revenue (FY 1999 $M) 2005-2010	2010-2020+
Isotopes (medical & industrial)	Production for Private Companies	10 Specific Isotopes for which FFTF Demonstrates a Pricing Advantage	8.5 Range: 5.3-12	34.0 Range: 23.7-45.8
	Development for DOE-Office for Nuclear Energy, Science and Technology (NE and National Institute of Health (NIH)	Clinical trial quantities of targeted isotopes	1.5	1.0
Plutonium-238 Production	NASA through DOE-NE	2-5 kg/year with a capacity of 5.7kg/year @ 100 MWt	5.0	7.0
Non-Proliferation Technical Programs	International plus DOE-MD (Materials Disposition)	Joint Research Programs involving transmutation, safety, and non-proliferation	10.0	10.0
Materials Testing	International, Industry, and DOE-SC (Office of Science)	Life Extension and Fusion Materials Research	4.0	4.0
	Transmutation Research for DOE-NE	Irradiation test data on candidate fuel and target forms	1.0	3.0
	Nuclear Energy Research Initiative for DOE-NE	Annual competitive research program	1.0	2.0
		Total Annual Offsetting Revenue	31.0	61.0

in Appendix A.1 and as discussed in the body of this report, the private sector is willing to partner with the DOE on improving isotope production and availability, the international community is equally willing to participate financially in the use of the FFTF for various research activities, and elements of the public sector have identified specific applications that can best be performed in the FFTF. Given the current status of the FFTF (i.e., in standby), the prospective users cannot "commit" funds so far into the future, but their intention is very clear—restart the FFTF and they will use it.

Can the FFTF be restarted and operated safely and effectively for those proposed missions?

Based on the FFTF's previous operating history and the facility's current condition, there is high confidence that the FFTF can be safely restarted and operated to effectively carry out a mission based on the nuclear science and irradiation services needs for the next 20 years and beyond. This conclusion is substantiated by the commercial nuclear standards to which the FFTF was originally constructed, the independent safety reviews by the Nuclear Regulatory Commission, the ten years of proven facility operation, recent evaluations of facility condition and readiness, independent concurrence on the adequacy of the restart costs and schedule forecasts, and the level of interest from candidate operating contractors who are willing to risk all fees based on the successful restart and operation of the reactor as well as successful program development.

Are the life-cycle economics for the FFTF credible?

Based on conservative estimates of facility use, an analysis of the life-cycle economics has been performed. The FFTF should be able to recover sufficient revenue from private-sector users over its operating life to offset both the appropriate portion of restart costs (~$100 million) and, from the public and private sectors, the annual operating cost ($55 million). In addition to the revenue received from user fees, the qualitative value of international nuclear technology cooperation is also a positive factor in considering restart and operation of the FFTF.

Could an FFTF management model be developed to satisfy public/private user interests?

The management approach outlined in this plan provides assurance that an organizational structure and set of operational relationships can be established that will ensure the safe and efficient operation of the FFTF. This conclusion is based on the benchmarking of the user facility operating model with other comparable facilities, as well as on extensive discussions with public and private users.

Conclusion

This Program Scoping Plan concludes that the DOE does have a basis to move forward with the National Environmental Policy Act (NEPA) process to evaluate restarting the FFTF as a nuclear science research and irradiation services user facility. Additional motivation to proceed with the NEPA process for the FFTF, independent of this report, may also exist if the Department should (a) decide not to restart the High Flux Beam Reactor; (b) determine that the FFTF is needed to provide national security research support; (c) assign the Advanced Test Reactor to Naval Reactors, which could affect foreign research use of the facility, and/or (d) intend to more aggressively advance its international leadership role in promoting the safe use of nuclear technologies.

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Glossary

ACRR	Annular Core Research Reactor
ACRS	Advisory Committee on Reactor Safeguards
AECL	Atomic Energy of Canada, Limited
ANL	Argonne National Laboratory
ANL-W	Argonne National Laboratory - West
ANMS	Advanced Nuclear and Medical Systems
ANS	Advanced Neutron Source
ASME	American Society of Mechanical Engineers
ATR	Advanced Test Reactor
ATW	Accelerator Transmutation of Waste
B	billion
B&W	Babcock & Wilcox
CANDU	Canada Deuterium Uranium
CDE	Core Demonstration Experiment
CLWR	commercial light-water reactor
CNF	Canadian Neutron Facility
D&D	decontamination and decommissioning
DFA	driver fuel assembly
DNFSB	Defense Nuclear Facilities Safety Board
DOE	U.S. Department of Energy
DOE-RL	U.S. Department of Energy-Richland Operations Office
EBR-II	Experimental Breeder Reactor-II
EIS	environmental impact statement
EMSL	Environmental Molecular Sciences Laboratory
ENSDFB	Evaluated Nuclear Structure Data Files, version B
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ESQ&H	environment, safety, quality, and health
FDA	U.S. Food and Drug Administration
FFTF	Fast Flux Test Facility
FMEF	Fuels & Materials Examination Facility
FSAR	Final Safety Analysis Report
FTE	full-time equivalent
FY	fiscal year
GFM	government-furnished material
HEDL	Hanford Engineering Development Laboratory
HEU	highly enriched uranium
HFBR	High Flux Beam Reactor
HFIR	High Flux Isotope Reactor
IAEA	International Atomic Energy Agency
INEEL	Idaho National Engineering and Environmental Laboratory
ISCP	In Situ Chemical Production
JSC	Johnson Spacecraft Center
LANL	Los Alamos National Laboratory
LIV	long irradiation vehicle
LLFP	long-lived fission product
LMFBR	liquid-metal fast breeder reactor
LTIV	long-term irradiation vehicle
LWR	light-water reactor
M	million
M&O	Management & Operations
MWt	megawatts thermal

MAPLE	Multipurpose Applied Physics Lattice Experiment
MBA	Masters of Business Administration
MD	Materials Disposition
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MOX	mixed oxide
MURR	University of Missouri-Columbia Research Reactor Center
NASA	National Aeronautics and Space Administration
NE	Office of Nuclear Energy, Science and Technology
NEPA	National Environmental Policy Act
NERAC	Nuclear Energy Research Advisory Committee
NERI	Nuclear Energy Research Initiative
NIH	National Institute of Health
NOI	Notice of Intent
NRC	U.S. Nuclear Regulatory Commission
NSNS	National Spallation Neutron Source
O&M	Operations & Maintenance
ORNL	Oak Ridge National Laboratory
ORR	operational readiness review
OTA	open test assembly
PCAST	President's Committee of Advisors on Science and Technology
PHMC	Project Hanford Management Contractor
PNNL	Pacific Northwest National Laboratory
R&D	research and development
ROD	Record of Decision
RTG	radioisotope thermoelectric generator
SAR	Safety Analysis Report
SBK	Schnell-Brueter-Kernkfratwerksgesellschaft
SC	Office of Science
SER	Safety Evaluation Report
SNF	spent nuclear fuel
SNL	Sandia National Laboratories
SPD	surplus plutonium disposition
SRS	Savannah River Site
START	Strategic Arms Reduction Treaty
TPA	Tri-Party Agreement
TREAT	Transient Research and Test [reactor]
USG	User Services Group
WBS	work breakdown structure
WDOE	Washington State Department of Ecology

1.0 Introduction

The FFTF represents a national investment of ~$1 billion, with a replacement cost of ~$2.5 billion.

The United States (U.S.) Department of Energy (DOE) has initiated a two-phased process for finalizing the decision regarding the potential restart of the Fast Flux Test Facility (FFTF), a DOE reactor currently in standby. The first phase is to complete a Program Scoping Plan to establish whether a compelling rationale exists for FFTF restart. The results of this planning effort will be formally presented to the Nuclear Energy Research Advisory Committee (NERAC)[a] in a public meeting on July 29, 1999, in Washington, D.C. At the July 29 meeting, the NERAC will develop a recommendation regarding whether the FFTF should proceed with an environmental impact statement (EIS). NERAC will then forward their recommendation and the study to the Secretary of Energy, Mr. Bill Richardson, by August 2, 1999. The Secretary's decision is expected soon after receipt of the NERAC recommendation.

If the Secretary decides to pursue restart, the second phase will be initiated: development of an EIS. An EIS will be prepared over the next 15 months and the DOE will conduct a highly detailed analysis of all issues associated with the use of the FFTF. This work will be done in full and open cooperation with the affected state, local, and tribal governments, key stakeholders, and the public. With the completion of the EIS (December 2000), the Secretary could issue a positive Record of Decision (ROD), and recovery and restart of the facility could immediately commence. Under such a planning scenario, the FFTF would begin operating in July 2004.

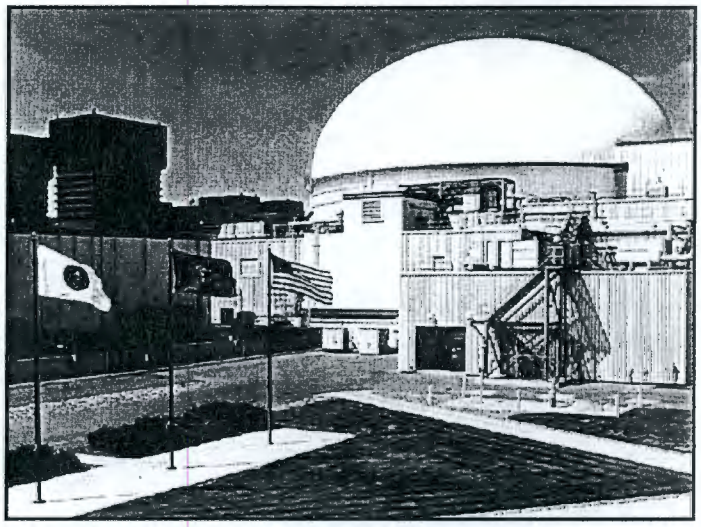

Figure 1.1 Fast Flux Test Facility

1.1 Background on the FFTF

The FFTF (Figure 1.1) is a 400-megawatt, liquid-metal cooled reactor located on the Hanford Site in Washington State (Figure 1.2). This facility, the largest and most modern test and irradiation services reactor within the DOE complex, is described in detail in Appendix A.2 and on the facility's website (http://www.fftf.org/).

The FFTF represents a national investment of ~$1 billion, with a replacement cost of ~ $2.5 billion. That replacement estimate is based on the cost to construct such a facility today, designed and built to commercial industry standards for nuclear and industrial safety, environmental

[a]The NERAC was established on October 1, 1998, to provide independent advice to the DOE and Office of Nuclear Energy, Science and Technology (NE) on complex science and technical issues that arise in the planning, managing, and implementation of DOE's nuclear energy program. The NERAC charter is to periodically review the elements of the NE program and, based on these reviews, provide advice and recommendations on long-range plans, priorities, and strategies to effectively address the scientific and engineering aspects of the research and development efforts. The committee includes representatives from universities, industry, environmental organizations and national laboratories.

protection, and safeguards and security. Constructed in the late 1970s and brought on line in 1980, the FFTF's original mission was to support liquid-metal reactor technology development, large component verification testing, and reactor safety, including fuels and materials irradiation services. From 1983, when this initial mission ended, to April 1992, when the facility shut down for a refueling outage, the FFTF operated successfully as a national research facility to test advanced nuclear fuels, materials, components, systems, nuclear power plant operating and maintenance procedures, and active and passive reactor safety technologies. The facility was also used to produce a large number of different isotopes for medical and industrial users, generate tritium for the U.S. fusion research program, and conduct cooperative, international research work. The reactor was shut down in December 1993 and has been in standby since November 1995, pending the DOE's decision about its future potential use.

The December 1993 decision to shut down the FFTF was based in large part on the conclusions from an independent review led by Mr. John Landis.[b] The Landis review found that "the FFTF is the world's foremost test reactor," having "unsurpassed capacity both for irradiation experiments and for production of plutonium-238 and medical radioisotopes." However, the review concluded that projected revenues could not recover the full cost of operating the FFTF and recommended that the facility be shut down, provided the DOE's existing and planned research reactors were sufficient to meet mission requirements.

The FFTF is the "world's foremost test reactor"

— Landis Review (1993)

The FFTF has been completely defueled. Usable fuel is stored on site in sodium fuel storage pools or in the secure vault at the Plutonium Finishing Plant. Unusable spent fuel has been thoroughly washed to remove all sodium residuals, dried, and placed in approved, 50-year Interim

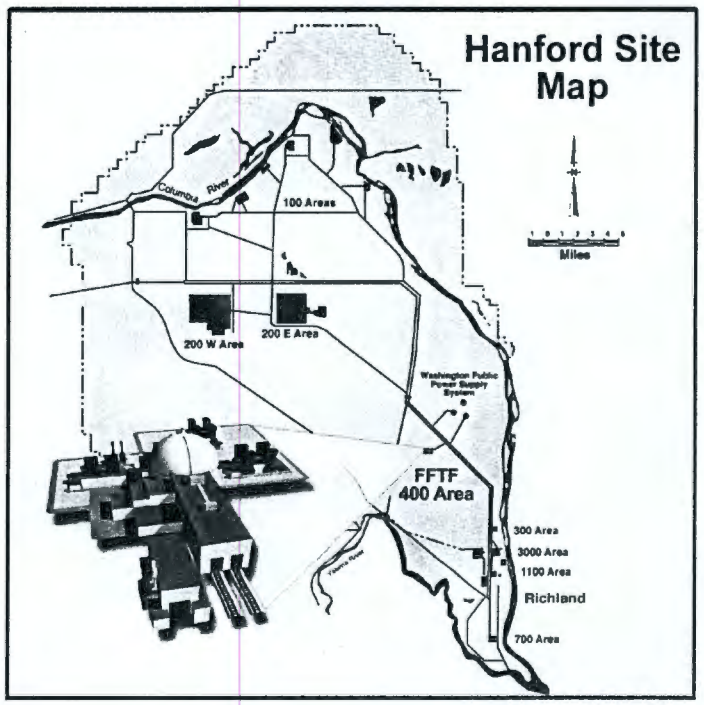

Figure 1.2 Hanford Site Map

Storage Casks. The main cooling system is being operated at ~400°F, thereby keeping the sodium coolant in the reactor liquefied and circulating. Essential systems, staffing, and support services are being maintained in a manner that will support either the rapid deactivation of the reactor or its restart.

In January 1997, as a result of a declining DOE-owned reactor infrastructure,[c] potential increase in demand for reactor-based research and production facilities, and an unsolicited proposal[d] to restart the facility, the Secretary of Energy directed that the FFTF be maintained in a standby condition while an evaluation was conducted of any future role the facility might have in the DOE's tritium production strategy. In December 1998, the Secretary determined that the FFTF would not play a role in the nation's tritium production strategy.

However, recognizing the FFTF's previous contributions to, and future potential for, scientific research, technology development, and isotope production, the Secretary ordered

[b] J. W. Landis et al. 1993 (unpublished). Future Use of the United States Department of Energy's Fast Flux Test Facility. Prepared for the DOE by the Independent Review Team.

[c] Two facilities, the Experimental Breeder Reactor-II (EBR-II) and Transient Research and Test (TREAT) reactor, have been shut down. The High Flux Beam Reactor (HFBR) is in standby, awaiting the results of a National Environmental Policy Act (NEPA) review to determine whether the facility should be returned to operation, and the Advanced Neutron Source (ANS) reactor design project was terminated in 1993.

[d] This proposal was offered by Advanced Nuclear and Medical Systems (ANMS) in November 1995

that analyses be performed as to whether the facility should play a role in supporting various national nuclear science and technology needs. In support of the DOE's decision-making process, the NERAC completed work on the initial phase of its Nuclear Science and Technology Infrastructure Roadmap (NERAC 1999). This roadmap, including an evaluation of the FFTF, assessed the DOE's existing and planned nuclear research infrastructure and compared it to the nation's requirements for the next 20 years. In April 1999, based on technical reviews (see reports at http://www.ne.doe.gov/nerac) and public deliberations,[e] the NERAC recommended to the Secretary that the DOE initiate the preparation of an EIS for the restart of the FFTF. The NERAC's report is available at the DOE-NE website (http://www.ne.doe.gov).

The FFTF has the potential to become the world's premier nuclear materials testing, isotope production, and plutonium fuels research facility.

Of the 20 NERAC members who were present and voted, 11 recommended conducting an EIS as a first step toward restarting the FFTF, 1 recommended shutting down the facility, and 8 indicated that they needed more information to support a decision. Given the investment required to go forward with the EIS process, and the uncertainty on the part of some NERAC members, the Secretary requested this scoping plan be developed to meet this informational need.

On May 4, 1999, Secretary Richardson announced that the DOE would initiate a two-phased process for finalizing the path forward for the FFTF. In the first phase the Secretary asked the Pacific Northwest National Laboratory (PNNL)[f] to complete a 90-day study that would resolve the outstanding informational needs (http://home.doe.gov/news/releases99/maypr/maypr.htm). The study results were to be documented in a program scoping plan for the FFTF. The second phase would be the Secretary's decision to either proceed with the EIS, given a compelling argument for the restart and operation of the FFTF, or absent a sufficiently compelling argument, resume deactivation.

1.2 Purpose of Plan

The purpose of this 90-day Program Scoping Plan is to establish whether a compelling rationale exists for the potential restart of the FFTF. Such a rationale is based on the answers to four questions:

Is there a clear, unequivocal need for the FFTF based on its unique capabilities and user requirements?

Numerous nuclear research and irradiation services activities would benefit from FFTF operation. A specific needs profile based on the demonstrated level of interest from public, private, and international parties in using the FFTF for nuclear science research and irradiation services was assembled. The technical evaluation is presented in Section 2 and the financial evaluation in Section 3 of this report. The intent is to establish not only that individual missions exist that would support the FFTF's operation as a nuclear science and irradiation services user facility, but that through those missions the facility has the potential to become a premier nuclear materials testing, isotope production, and plutonium fuels research facility.

Can the FFTF successfully and safely be restarted and operated?

This is the least controversial of the questions, given the recent evaluations of facility condition and readiness, independent concurrence on the accuracy of the restart costs and schedule forecasts, commitments by candidate operating contractors, and ten years of proven facility operation. The validation required to address this important question is provided in Section 3.3.

Are the life-cycle economics for the FFTF credible?

The expected costs and revenues for operating the FFTF as a user facility are presented in Section 3.2. This section shows that the benefit and the potential revenue exist to warrant and defray both operating and incremental restart costs.

[e]Public meeting, Washington, D.C., March 31, 1999.
[f]Operated for the DOE since 1965 by Battelle Memorial Institute

Could an FFTF management model be developed to satisfy public/private user interests?

A model has been developed that is comparable to the management of other DOE reactor resources. Potential operators were identified, as well as steps to ensure that neither the facility's budgeting nor its operation would interfere with Hanford Site environmental cleanup.

The Program Scoping Plan answers each of these questions, providing by description, reference, or letters of commitment both the relevant facts and the basis for confidence in those answers.

1.3 Description of Plan Development

The scope of the 90-day study was to (a) develop the plan's outline and content; (b) prepare the plan; (c) provide the plan to the NERAC for review on July 20, 1999; (d) present the plan to the NERAC on July 29, 1999, in Washington, D.C.; and (e) forward the plan with NERAC comments to the Secretary on August 2, 1999.

The 90-day study was initiated on May 4, 1999. A project team was assembled, drawing on the expertise of PNNL staff, current and former FFTF staff, and numerous qualified outside consultants. Following DOE approval of the project outline and scope, the team analyzed possible nuclear science and irradiation services missions that could be conducted at the facility, alternatives for meeting those needs, and details regarding the future mission and operation of the facility. The FFTF model was benchmarked against the other major DOE reactor facilities to identify technical capability, available capacity, optimal business model, and appropriate operating methodology. Life-cycle operating costs were developed, and detailed discussions were held with prospective users about the FFTF's role in meeting user mission objectives as well as the users' estimates of funding to support those objectives. Letters of intent were obtained from private-sector users, government agencies, and proponent organizations. A proposed organizational structure for managing the FFTF was developed that accommodates private, public, user community, and facility operations needs. Finally, the plan was documented to serve the informational needs expressed in the March 31, 1999, meeting of the NERAC in their deliberations on the future of the FFTF.

2.0 Technical Analysis

The availability of large reactors for nuclear research is essential to any advanced nation's technology infrastructure.

2.1 Statement of Need

The FFTF reactor can provide high-energy, high-fluence neutrons for nuclear science and irradiation services. This section describes the need for such a facility. The description of that need, relative to other available test reactors and accelerators, is based on an assessment of whether the identified missions can utilize fast neutrons in great quantity. There is a suite of viable missions for which sponsors have been identified.

Fast reactors, as shown in Figure 2.1, are valuable for producing neutrons in the fast and high-energy range. With hydriding (adding materials to slow down the neutrons in specific areas of the core), fast reactors can also produce large quantities of epithermal neutrons and even thermal neutrons. Producing the epithermal neutrons helps in creating isotopes for which there is a high potential for resonance absorption in the precursor target materials.

This section of the report describes the overarching need for a nuclear research and irradiation services infrastructure and a proposed role for the FFTF based on its differentiating physical attributes - one of its premier attributes being the facility's demonstrated ability to simultaneously conduct multiple experiments and production campaigns. The range of missions is described, with reference to the core configuration that the FFTF would employ to address the integrated conduct of those missions. Alternative ways to meet those missions, and their relative merits and drawbacks compared to the FFTF, are presented.

In a 1997 report, Directors of the DOE's National Laboratories made recommendations to the Secretary of Energy for a new nuclear energy research and development (R&D) agenda (USDOE National Laboratory Directors 1997). This report was prompted by the President's Committee of Advisors on Science and Technology (PCAST) who, in their 1997 report, Federal Energy Research and Development

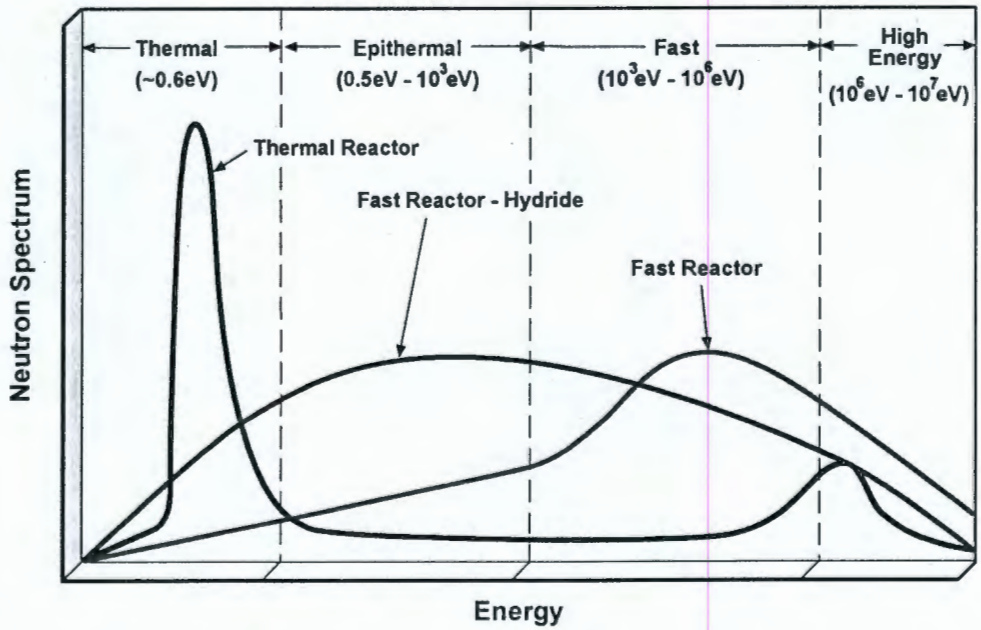

Figure 2.1 Profile of Fast and Thermal Reactor Neutron Spectra

for the Challenges of the Twenty-First Century, concluded that "fission belongs in the R&D portfolio" (PCAST 1997). The Laboratory Directors echoed this conclusion and called for a strong nuclear energy research program. The Directors of the Pacific Northwest National Laboratory (PNNL), Oak Ridge National Laboratory (ORNL), Idaho National Engineering and Environmental Laboratory (INEEL), Argonne National Laboratory (ANL), and Sandia National Laboratories (SNL) have reaffirmed that support for this critical infrastructure (see Appendix A.1) and restated their belief that the needs for those capabilities will grow dramatically over the next twenty years.

The FFTF is capable of producing a larger number of steady-state neutrons over a wider range of energy levels than any other test and research reactor in the world.

The missions and goals reflected in these recommendations, as well as the plans for many different organizations, including other elements of the DOE, the U.S. Nuclear Regulatory Commission (NRC), the National Aeronautics and Space Administration (NASA), and others, depend on the long-term availability of diverse but complementary research reactor facilities. Such facilities[a], according to their design and characteristics, are used to analyze and test a wide range of materials, nuclear fuel, electronic circuits, and other components; to create isotopes required by medical clinicians, researchers, government, and industry for a wide range of applications; and to produce special materials such as fuel required to power deep space probes.

A key factor in the DOE's 1993 decision to shut down the FFTF was that the DOE had other existing and planned research reactors with which to carry out its steady-state neutron research, materials irradiation, isotope production, and national security missions. Since December 1993, however, the DOE's research reactor infrastructure has changed, as has the outlook for nuclear-related missions. Two facilities, the Experimental Breeder Reactor-II (EBR-II) and Transient Research and Test (TREAT) reactor in Idaho, were shut down; the High Flux Beam Reactor (HFBR) in New York is in standby, awaiting the results of a National Environmental Policy Act (NEPA) review to determine whether the facility should be returned to operation; and the Advanced Neutron Source (ANS) reactor design project has been terminated. At the same time, as confirmed by the PCAST, the national need for large research reactor facilities has increased significantly, both for Federal government applications and non-governmental needs.

U.S. universities with research reactors have the challenge to conduct research as well as to adequately educate and train personnel in nuclear sciences and technology. To meet this challenge, these institutions must rely on an aging infrastructure of test and research reactors. The size, configuration, and availability of existing university research reactors is not sufficient to meet the future demand for nuclear science and irradiation services.

A new source of neutrons for basic research may be available early in the 21st century when the National Spallation Neutron Source (NSNS) at the ORNL is completed and operational. The NSNS will be the most advanced accelerator neutron source in the world, and will produce the most powerful pulsed neutron fluxes. The NSNS could give scientists detailed snapshots of the structure of even the smallest samples of physical and biological materials. The FFTF, if restarted, would complement the mission of the NSNS. As discussed in the NSNS Collaboration report (ORNL 1997), "...even though the pulsed sources have high peak fluxes, they lack the integrated neutrons of steady-state sources; and while peak flux is an important parameter for neutron scattering, total flux is needed for such things as isotope production."

2.2 The FFTF's Proposed Role

The FFTF has demonstrated its capability to function successfully as a nuclear science and irradiation services user facility. Within the suite of available DOE-owned research and test reactors, the FFTF has the ability to become the world's premier nuclear materials testing, isotope production, and plutonium fuels research facility.

[a]France plans to build a 100-MWt light-water test reactor, named after reactor physics research pioneer Jules Horowitz. Located in Cadarache, the reactor is being designed to support development of pressurized water reactor technology. France has stated that its existing research reactors of this kind are becoming outdated (Osiris went critical in 1966; Siloe in 1963). Construction is planned to begin in 2001 with operations starting in 2005, at which time it was stated that the Jules Horowitz Reactor will be almost the only research reactor left in Europe (http://info-france-usa.org/america/embassy/nuclear/profile/table.htm).

As one of DOE's major research reactor facilities, the FFTF can provide a significant fraction of the available power capacity and core volume for missions requiring steady-state neutron generation. The FFTF has four distinctive features - size, flux, test evaluation and irradiation capability, and fuel and coolant - which in combination provide a multi-purpose facility that greatly strengthens DOE's diminished research reactor portfolio.

Size. The FFTF is DOE's newest and largest test and irradiation services reactor. It is the largest liquid-metal test reactor in the world. Capable of operating at power levels from 100 to 400 megawatts, the facility has a larger volume to accommodate test and irradiation services than the balance of other operational DOE reactors combined.

Flux. The FFTF is a "fast flux" reactor; that is, one in which the fissioning process occurs using high-energy neutrons. This design feature provides a spectrum of high-energy neutrons as well as a high flux density. Although the FFTF produces neutrons primarily in the fast spectrum (see Figure 2.1), neutron energy levels can be tailored through the use of hydride-moderated targets to produce neutrons across the fast, epithermal, and thermal spectra. Using fast neutrons, the FFTF can conduct specialized testing and resonance absorption production not possible in a thermal reactor, and yet can also specifically tailor or adjust the local neutron flux to provide sample volumes that operate in the epithermal and thermal neutron energy ranges. The FFTF is capable of producing a larger number of steady-state neutrons over a wider range of energy levels than any other test and research reactor in the world.

Test and Irradiation Features. The FFTF was designed and operated as a test and irradiation services facility, with the ability to fully instrument and test in-reactor experiments while varying the conditions experienced in those individual tests. In addition, the FFTF's configuration allows for the addition of a gas loop and up to seven rapid retrieval systems (commonly referred to as "rabbits" - only three of these systems are included in the proposed mission profile).

Fuel and Coolant. The FFTF is the only reactor in the United States operating with liquid-metal (sodium) coolant. The FFTF has demonstrated its ability to use and test plutonium-based fuels, and has an alternative ability to use highly enriched uranium (HEU) fuel.

During its ten years of operation, the FFTF achieved an annual operating availability considerably higher than comparable test reactors. The FFTF even exceeded the operational performance of most commercial nuclear power units at that time. The FFTF's distinctive features and a 97.6% schedule availability in meeting mission performance objectives attract today's users, and it is their sponsorship that results in a performance profile for the facility. Figure 2.2 illustrates how these distinctive features

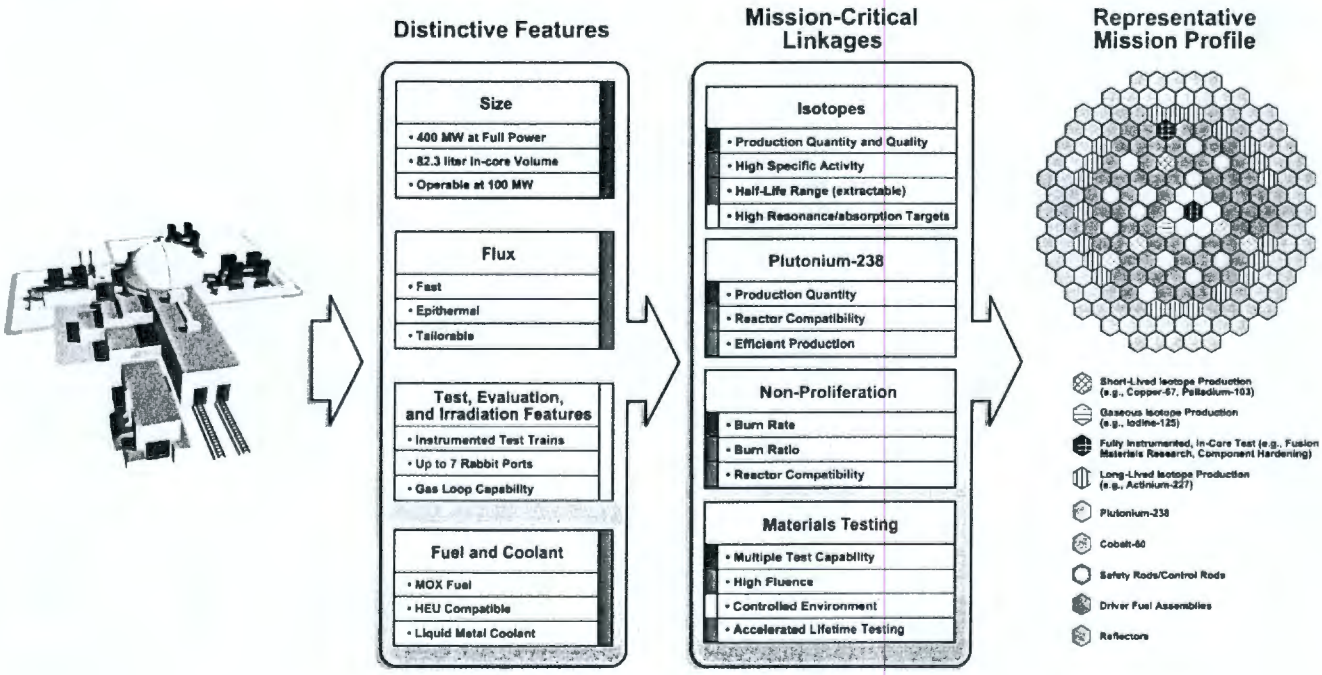

Figure 2.2 Basis for the FFTF Mission Profile

are linked to the mission profile for the FFTF. The next several sections describe how those distinctive features result in the identified sets of committed and emerging missions that support future FFTF operation.

2.2.1 FFTF Missions

The FFTF has a singular, focused purpose: To produce high-energy, high-fluence neutrons for nuclear science and irradiation services. Because the FFTF, unique among other available test reactors and accelerators, can produce fast neutrons in great quantity, there is a suite of viable missions for which sponsors have been identified. Based on the 90-day study, four mission areas will support FFTF operation at 100 megawatts:

- Medical and Industrial Isotopes Production
- Plutonium-238 Production
- Technical Programs Supporting Non-Proliferation
- Materials Testing.

As part of this plan, a list of needs has been compiled based on surveys and contacts with individuals within the DOE, other Federal agencies, commercial enterprises, and international public and private organizations with an interest in nuclear-related work. Given that the facility cannot be restarted immediately, there is a wide range of available customer identification - commitment, expression of interest, and simple identification of possible future need. Basically those areas can be defined as follows:

- Customer commitments - missions for which a clearly identified customer has expressed the need for FFTF services specifically, with both technical scope and an established financial forecast.
- Expressions of interest - missions for which there is a customer who is interested in the FFTF's capability, but where the level and schedule of need may not be clear, or where what the customer really wants is a reliable, alternative (backup) source.
- Potential future needs - missions for which no specific customer exists, but the potential has been identified by agency or expert panel, or may emerge if the mix of production/testing sources changes.

The following sections describe the needs in terms of the overall capabilities of the FFTF and the availability of complementary DOE reactor facilities, then detail specific mission areas where the FFTF is needed to support advances in nuclear science and provide irradiation services.

These missions help maintain an integrated national portfolio that includes the nuclear sciences, provides a viable source of important medical isotopes, encourages the development of proliferation-resistant nuclear fission reactor technologies, and supports the long-term operation of current commercial nuclear power plants.

The FFTF's distinctive features greatly strengthen DOE's research reactor portfolio.

The mission profile for which the FFTF is specially qualified is defined by the need for a fast neutron spectrum, a significant operating power level (a base of 100 megawatts, but expandable to 400 megawatts), potential for supporting many activities at one time, a moderately long operating cycle (~100 days), and high-temperature environments. Such a profile supports the large-scale production of isotopes (particularly those requiring a high specific activity and for which production may require or benefit from a large resonance absorption cross section); cooperative international reactor research; accelerated lifetime testing for reactor fuels and materials; plutonium-238 production for space power systems; and/or testing that requires in-core experiments where performance data can be obtained and retrieved in real time (e.g., temperature, pressure, stress, strain, flow).

As stated earlier, one of the key factors contributing to the FFTF's multi-mission potential is its particular flux characteristics, specifically its fast spectrum and proven ability to tailor that spectrum to produce both epithermal and thermal neutrons, and to be able to do that simultaneously for multiple experiments and production campaigns. Examples of those requirements for a suite of thermal, epithermal, and fast neutron spectra are shown in Table 2.1.

Fast reactors, such as the FFTF, have a higher neutron population outside the core as a result of more neutrons per fission, less parasitic capture (losses) in the core, and a longer neutron mean-free-path. Figure 2.3 shows the smooth and flat radial neutron flux profile for the FFTF 400-megawatt core. Note that reflector rows 7 and 8, which represent a net target production volume of 720 liters, have a flux level between 1×10^{15} n/cm^2/s and 3.5×10^{15} n/cm^2/s. This gives the FFTF the capability to produce significant quantities of plutonium-238 (up to 30 kg/year at 400 MWt, which well exceeds current demand, but provides potential to meet possible future needs) and other relatively long-lived isotopes, while reserving valuable in-core peak flux locations for nuclear research and specialized irradiation services.

Table 2.1 Neutron Flux Requirements for Potential Applied Research and Isotope Production Missions

Mission	Flux Requirements (n/cm^2/s)	Spectrum	Comments
Medical & Industrial Isotopes	$>10^{15}$	Fast	Yttrium hydride-moderated targets would be used in fast reactors to produce thermal and epithermal neutron spectra; a fast spectrum is highly advantageous for production of certain isotopes, such as Cu-67, Cu-64, P-32 P-33, Pt-195m, Sc-47, Sn-117m, and Y-91 (see Figure 4 in Appendix A.3).
	2×10^{14} to 2×10^{15}	Thermal	
	0.5 to 1×10^{14}	Epithermal	
Plutonium-238 Production	10^{14} to 10^{15}	Thermal or Epithermal	Pu-238 can be produced in a wide range of reactors using appropriate target designs. For example, hydride-moderated targets could be used to produce Pu-238 in fast reactors.
Non-Proliferation (Plutonium Fuels & Disposition Research)	Normal FFTF Core Parameters	Normal FFTF Core Parameters	The FFTF operated with mixed-oxide (MOX) (uranium-plutonium) fuel for ten years; while still providing medical isotopes and supporting research programs FFTF can: • conduct fuels testing to support International Programs • develop proliferant-resistant fuels • evaluate alternatives to reprocessing • conduct fuel demonstrations if needed or provide backup to the U.S. Materials Disposition program. At 400 megawatts the FFTF could disposition 1.7 metric tons per year of surplus plutonium using traditional enrichments and a standard core configuration.
Materials Testing	As high as possible	Fast	High fluxes and fluences are used to simulate aging in light-water reactor (LWR) materials at an accelerated rate.
			High-flux irradiations of lithium-containing ceramics in the FFTF can be used to examine the quantity of tritium produced and the release rate of that tritium (for the International Fusion power research program). Tritium would be generated in high-temperature ceramic blanket assemblies in a fusion reactor. Structural materials irradiation of both stainless steel and ferritic steel are of importance to both the U.S. and Japan. At present, experiments are in place or planned for High Flux Isotope Reactor (HFIR) and Advanced Test Reactor (ATR). DOE (Office of Science) has expressed a preference for the FFTF for these experiments were it available and affordable.

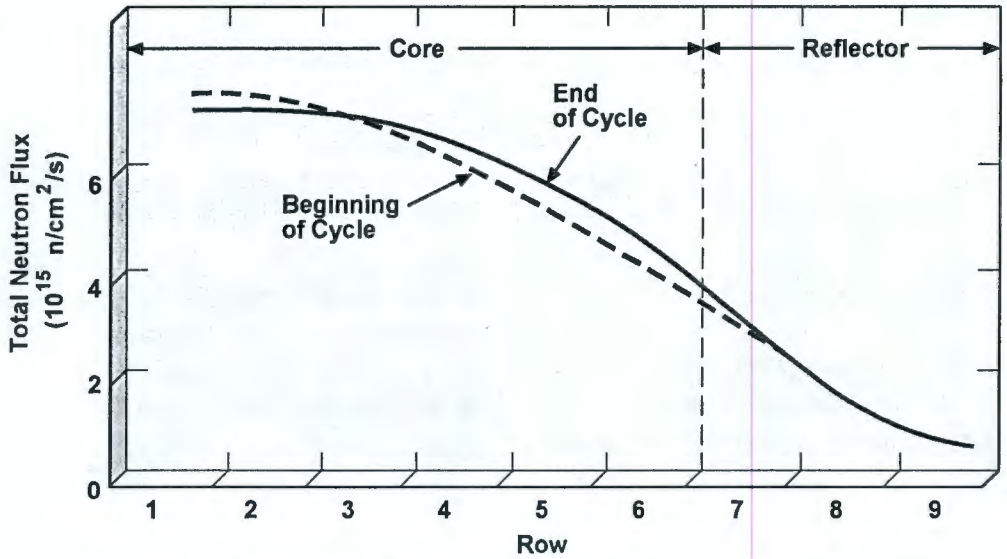

Figure 2.3 Radial Total Flux Profile at Core Midplane at Full Power

The identified commitments or solid expressions of interest, listed by mission area in Table 2.2, make a solid case for the restart of the FFTF. An even stronger case can be made given that, as indicated by the letters in Appendix A.1, the international community, regional universities, radiopharmaceutical companies, and Federal users believe that the FFTF is needed to support not only the individual, currently known missions but also emerging needs. They state that without facilities like the FFTF, many proposed initiatives will take longer, cost more, be cancelled, and/or have to rely on incomplete data and proceed with greater risk.

While the DOE's research reactors are not redundant in their capabilities, given differences in design and experimental support equipment, there are common features that could permit missions from one facility to be transferred to another as a means of optimizing the user communities' access to particular capabilities. Such an integrated mission management strategy could improve the DOE's fuels and materials testing, neutron activation analysis, and isotope production capabilities (see comparative data on research reactors in Table 2.4). For example, should a decision be made to not operate the HFBR, additional beam tube and thermal column physics experiments could be performed at the HFIR by assigning activities involving irradiation services and materials/fuel testing at HFIR to the ATR and the FFTF.

The following sections discuss the primary mission areas identified for which the FFTF offers differentiating attributes: isotopes, plutonium-238, non-proliferation, and materials testing. Three collateral opportunities in the areas of nuclear science, electronic component hardening, and national security are also briefly discussed.

2.2.1.1 Isotopes

The FFTF has important technical advantages for producing medical and industrial isotopes based on its capabilities for flux tailoring and its irradiation volume. Through this combination, the FFTF can meet expected demand for a number of research and production isotopes, and provide additional production margins for all these materials should the demand for these products increase to or beyond the "high"-level projections.

As discussed in Section 3, an iterative process was used to determine the market demand and potential for specific isotopes, then analyze the production capability of the FFTF for the specific isotope, calculate the production cost, and then repeat the assessment against demand at that price. That led to solid estimates for the FFTF's ability to produce iodine-131, cobalt-60, palladium-103, iodine-125, phosphorus-32, and strontium-89 as well as emerging needs for copper-67, actinium-227 (radium-223), gadolinium-153, and rhenium-186.

Medical Isotopes

Leading health care market consultants have concluded that the radioisotope market is likely to experience substantial growth over the next decade (Frost & Sullivan 1997,

Table 2.2 Technical Mission Identification and Commitment (at 100 megawatts)

Mission	Sponsor	Deliverable	Commitment	Facility Use (%)	
				2005-2010	2010-2020
Customer Commitments					
Isotopes (medical & industrial)	Private Radio-pharmaceutical Companies	See Tables 3.2 and 3.3	Forecast of isotope market based on market survey, validated against private company expression of interest (Appendix A.1), and iterative cost-pricing analysis for FFTF production.	27	56
Plutonium-238 Production	NASA (through DOE-NE)	Capacity of 5.7 kg/year @ 100 megawatts	Demand of 2-5 kg/year near-term (Pu-238 EIS) plus potential for expanded growth	17	11
Non-proliferation Technical Programs	International plus Materials Disposition (MD) (through DOE-NE)	Joint Research Program	Letters of Commitment - Japan, France, IAEA, and South Korea	32	16
Materials Testing	DOE-SC (Office of Science)	Fission and Fusion Materials Research	SC, International Commitment Letters (Japan, Korea, France, International Atomic Energy Agency [IAEA]), and cooperative agreement (NRC, Electric Power Research Institute [EPRI])	13	7
Expressions of Interest					
Medical Isotopes (development)	NIH and DOE-NE	Clinical trial quantities of targeted isotopes	Appendix A.1 - Letters from Radiopharmaceutical Companies Appendix A.3 – Hanford Isotopes Program Assessment	5	2
Accelerator Transmutation of Waste (ATW) Research	DOE-NE	Irradiation test data on candidate fuel forms	ATW Roadmap	3	5
Nuclear Energy Research Initiative	DOE-NE	Annual competitive research program	Regional University Letters; PNNL and National Laboratory Directors	3	3
Future Potential Needs					
Electronic Components	Private electronic companies	Irradiation of space-based components	TBD	—	—
Power Technology	TBD	TBD	TBD	—	—
Support for National Security Research	DOE	TBD	TBD	—	—

Spicer et al. 1997). Their conclusions are supported by historic growth curves for therapeutic agents now in widespread use and the results of several early, highly successful clinical trials of new therapeutic agents for cancer treatment. As an example relevant to FFTF (see Appendix A.3 for additional detail), iodine-131 is currently the most widely used therapeutic medical isotope, with applications in the treatment of a wide variety of thyroid disorders such as goiters, Graves' disease, and thyroid carcinoma. It is also a commonly used isotope for the treatment by radioimmunotherapy of several major classes of cancer, such as Hodgkin's and non-Hodgkin's

lymphoma, leukemia, and breast, colorectal, and brain cancer. For these applications, high-specific-activity iodine-131 such as can be produced in the FFTF is particularly desirable since it minimizes the amount of targeting antibody that must be used to deliver the isotope to the tumor tissue. If the growth projections for this and other diagnostic and therapeutic medical isotopes are realized, reactor facilities in North America that are now producing medical radioisotopes will not be able to meet the projected demands, and new isotope production capability will be needed.

The FFTF's advantages for producing medical and industrial isotopes are its capabilities for flux tailoring and its irradiation volume.

The FFTF's target volume and flux-tailoring capabilities could position the facility to meet a significant portion of the developing medical radioisotope market (PNNL and B&W Hanford 1997). A variety of isotope production target assemblies have been demonstrated in the FFTF. Using yttrium hydride targets for moderation, neutron energies can be adjusted to optimize product yield. To make short half-life medical isotopes, mechanical (rabbit) irradiation positions must be designed and installed to provide short duration irradiation and retrieval while the reactor is at power. The rabbits will take advantage of open test positions that allow direct core access through the reactor head. Isotope production could be performed in a 100-megawatt power core configuration using high-flux irradiation positions and consolidating the number of fuel assemblies to increase the core power density. While the DOE would ensure that the FFTF is configured and operated in a manner that encourages isotope production, installation of the hardware and hot cell facilities for processing the medical isotopes would require a co-investment by private industry (see letter, Private Companies, Appendix A.1). If the market grows as projected in the next five to fifteen years (Frost & Sullivan 1997), isotope revenues could then contribute substantially toward offsetting the operating cost of the FFTF.

The possible future demand for medical isotopes and the resulting impact on the need for production resources were described in the recent technical report (Forecast Future Demand for Medical Isotopes) of an expert panel brought together by the DOE (Expert Panel 1999). As shown in Table 2.3, the expert panel identified 28 isotopes the DOE should consider for production.

Based on that listing and independent assessments of the market, the Expert Panel concluded the following:

- Over the next twenty years the diagnostic pharmaceuticals market may grow to a value of between $2.7 billion (7% per year lower limit growth estimate) and $18.7 billion (16% per year higher limit growth estimate), while the therapeutic pharmaceutical market may grow to a value of between $244 million (7% per year) and $1.11 billion (14% per year).

- The potential revenues for the production of isotopes will range from between 17% and 20% of the revenues for the pharmaceutical products that use these isotopes.

The out-year market for medical isotopes is highly dependent on the immediate availability of isotopes for clinical testing, because the poor availability of isotopes for research and clinical trials severely delays the future market growth of those isotopes. But as demonstrated with yttrium-90's growth rate of 1400% from fiscal year (FY) 1996 to FY 1998 and subsequent privatization, availability can have a strong impact on market demand. The projected revenues for production of isotopes at the FFTF are based on those isotopes for which the FFTF has a production advantage. For example: accelerators or existing reactors are not well suited to produce the isotope; accelerators or existing reactors cannot produce the quality (specific activity) desired by researchers and clinicians; and/or accelerators or existing reactors are not able to meet the forecasted market demand. In the last case, the FFTF can supplement other production sources in meeting the demand.

Research Isotopes for Industrial, Medical, and Basic Science Applications

In the United States, over 90 cancer therapy trials are in progress at major hospitals and medical centers to test the safety and therapeutic efficacy of radiolabeled pharmaceuticals, such as monoclonal antibodies, peptides, or phosphates containing yttrium-90, iodine-131, rhenium-186, holmium-166, lutetium-177, samarium-153, and bismuth-213. None of these has yet obtained final U.S. Food and Drug Administration (FDA) approval for general clinical

Table 2.3 Listing of Vital Medical Isotopes (Expert Panel 1999, updated for this report)

Isoptopes with Demonstrated Clinical Efficacy	Isotopes for Research, Medical, and Commercial Applications[d]	Isotopes Showing Promise for Diagnostic and Therapeutic Applications
Reactor-Produced		
molybdenum-99 rhenium-186[c] holmium-166 iodine-131 palladium-103 phosphorus-32 strontium-89[c] yttrium-90[d]	iodine-125[c] samarium-153 tin-117m[c] xenon-127[c]	actinium-227/radium-223[c,e] copper-64 copper-67[c] gadolinium-153[c] lutetium-177 scandium-47[c] thorium-228/bismuth-212[c,e] thorium-229/bismuth-213[c,e] tungsten-188/ rhenium-188[e]
Accelerator-Produced		
indium-111 iodine-123	fluorine-18 krypton-81m	astatine-211 germanium-68 zinc-62

[a]Currently, there are supply and cost concerns for these isotopes.
[b]Clinical use is inhibited by cost and supply.
[c]Previously produced at the FFTF.
[d]Medical-grade yttrium-90 can also be obtained by elution from purified strontium-90 generator material.
[e]The medical isotope (listed second) is obtained as a decay product of the reactor-produced isotope (listed first).

use. More than 30 clinical trials are also underway in the United States to test the efficacy of other isotopes (including phosphorus-32, strontium-90, and iridium-192) for the treatment of arterial restenosis using radioactive stents. Industrial R&D and academic research requirements include numerous reactor-produced isotopes that have applications in nucleonic instrumentation, irradiation and radiation processing, and laboratory-based studies in the biological and medical sciences, in agriculture, in basic nuclear science, and in analysis of the properties of new materials. Many desired isotopes, such as platinum-195m for tracing the biodistribution and metabolism of the chemotherapeutic agent cisplatin, cannot be made in an appreciable quantity in the DOE reactors or commercial U.S. reactors that are currently in operation.

Diagnostic and Therapeutic Isotopes

Today, only a few reactor-produced isotopes are used in large quantities for medical applications (primarily molybdenum-99 [for technetium-99m production] and iodine-131). Many other isotopes are being tested for safety and therapeutic efficacy in early-stage clinical trials. Once FDA approval is obtained for general clinical use of these isotopes, a significant increase in production capacity will be required. Growth forecasts vary somewhat, but consensus places the average growth of the medical isotopes market at about 10% per year. To diagnose and treat the wide variety of diseases currently being studied will require 30 or more different isotopes. Many of these that are reactor-produced will be needed in large quantities. Without a reliable, large-scale production capability, medical R&D efforts will not take place or will be significantly curtailed. Demands currently exceed available supply of copper-67, palladium-103, bismuth-213, high-specific-activity iodine-131, and holmium-166. This shortage has hindered the progress of early-stage clinical trials using these isotopes.

Industrial and Food Safety Isotopes

Industrial applications of radioisotopes fall into three broad categories: (1) nucleonic instrumentation, (2) irradiation and radiation processing, and (3) technologies that use radioactive tracers. Examples of nucleonic instrumentation and the most commonly used isotopes include gauges for measuring physical parameters (carbon-14, krypton-85, strontium-90, cesium-137, thallium-204, americium-241);

detection systems for pollutants, explosives, and drugs; ores, petroleum, and natural gases (carbon-14, nickel-63, promethium-147, iron-55, cobalt-57, cadmium-109, cesium-137, americium-241, californium-252); nondestructive testing by gamma radiography (cobalt-60, ytterbium-169, iridium-192); and smoke detectors (americium-241). Irradiation and radiation processing technologies include radiation sterilization of food and medical products, and the curing of plastics (cobalt-60, cesium-137, europium-152, and europium-154). Recent FDA approval to use irradiation to sterilize red meat will likely increase demand for those needed isotopes beyond existing domestic production sources. Radioactive tracer applications include studies on chemical synthesis reactions; monitoring of mass transfer in industrial plants; analysis of transport and uptake of nutrients, fertilizers, herbicides, and waste materials in plants, soil, and groundwater; and laboratory-based studies on the properties of materials (numerous isotopes are used as tracers in these applications).

2.2.1.2 Plutonium-238

At 100 MWt, the FFTF can produce the maximum amount of plutonium-238 (5 kilograms/year) currently being forecast by the DOE in its EIS planning documents, while still retaining the ability to provide at 400 MWt the much larger quantities (up to 30 kilograms/year) needed if new missions develop.

The FFTF can produce the maximum amount of plutonium-238 currently forecast by the DOE.

The National Aeronautics and Space Administration (NASA) uses radioisotope thermoelectric generators (RTGs), which produce electricity from the heat generated by small amounts of decaying plutonium-238. RTGs, which are often referred to as "space batteries," made possible NASA's celebrated Voyager explorations of Jupiter, Saturn, Uranus, and Neptune; the Pioneer missions to Jupiter and Saturn; the Galileo mission to Jupiter; the Ulysses mission studying the sun's polar regions; and the recent Cassini mission to Saturn. DOE and its predecessor agencies have provided plutonium-238 for spacecraft electrical power for nearly 40 years. Plutonium-238 was produced in the K Reactor at the Savannah River Site (SRS), but that reactor was permanently shut down in the late 1980s. Since then, DOE has used inventory on hand to provide material for the NASA missions, and in 1992 purchased 9 kilograms of plutonium-238 from Russia, under a contract for purchase of up to 40 kilograms at less than $2 million per kilogram. This contract was extended in 1997 for five years. NASA has several new missions that may require the use of plutonium-238-fueled power systems (Europa Orbiter - 2003, Pluto-Kuiper - 2004, and Solar Probe - 2007), and DOE forecasts the need for 2 to 5 kilograms per year for future missions. DOE is currently preparing an environmental impact statement (EIS) related to the development of a U.S. plutonium-238 production capability. Current reactors under consideration are HFIR, ATR, and commercial light-water reactors (CLWRs). The FFTF will be included in that EIS and the schedules for the NEPA reviews synchronized if the decision is made to proceed with an FFTF restart review.

A Radioisotope Facilities Task Force[a] was chartered in November 1991 to evaluate the facilities needed by the DOE to provide plutonium-238-fueled electrical power systems for future NASA space missions. The Task Force determined that the future options for providing plutonium-238 fall into three time frames: near-term (before 2000); mid-term (2000-2015); and long-term (beyond 2015). For near-term missions, the task force recommended purchasing plutonium-238 from foreign sources. For mid-term and long-term requirements, the task force identified the FFTF and the ATR as the technically preferred domestic production facility options. Subsequent analyses also identified the HFIR as a potential source for producing small amounts (< 2 kilograms per year).

Although the projected demand for plutonium-238 falls in the range of 2 kilograms to 5 kilograms per year, production at this level only supports currently projected deep space requirements. NASA is performing mission planning studies to support human exploration of space, with the studies to date primarily focused on Mars. To meet power requirements for the surface of Mars, NASA is examining various technology options including solar

[a]USDOE. 1993 (unpublished). Radioisotope Facilities Task Force Report: Pu-238 Production and Processing and Heat Source/Radioisotope Power System Assembly and Testing.

energy, fission reactors, and radioisotope power systems. Should NASA commit to a human Mars mission in the future, under certain scenarios using radioisotope power systems, the demand for plutonium-238 would increase dramatically (to ~ 70 kilograms total). At these demand levels, higher production rates in the FFTF could enable the delivery of higher power radioisotope power systems on a reasonable schedule. As summarized in Table 2.7, significantly larger volumes would be required to maintain production levels above the 5 kilograms/year level. It is questionable whether HFIR and ATR can concurrently support existing missions and provide the volume necessary to produce quantities in excess of 15 kilograms/year at the desired quality.

The Task Force reported that the FFTF could produce up to 30 kilograms of plutonium-238 each year at 400 megawatts, enabling DOE to meet current and stretch demand (see discussion of 400-MWt operation and fueling in Section 3.2.3), as well as to significantly expand production to meet potential future demand.

Although a decision on human exploration of Mars is not likely to be made in the next few years, NASA's Johnson Space Center (JSC) has tasked PNNL to evaluate the use of significant quantities of plutonium-238 (~70 kilograms) for the In Situ Chemical Production (ISCP) plant proposed as part of the human mission to Mars.

2.2.1.3 Technical Programs Supporting Non-Proliferation

Among the nation's available reactor facilities, the FFTF provides the most comprehensive and applicable capabilities for the study, research, testing, development, and demonstration of technologies necessary to safely convert plutonium-based materials for disposition and use as proliferant-resistant fuels.

Since October 1976, when President Gerald Ford issued a Nuclear Policy Statement prohibiting the export of reprocessing and other nuclear technologies that could contribute to proliferation of fissile materials, all U.S. Administrations have adopted policies aimed at minimizing the prospects that civil plutonium separation would be adopted in other countries. At the same time, the United States itself has refrained from the commercial development of reprocessing and plutonium separation technologies. The Clinton Administration reaffirmed this non-proliferation policy, including refraining from domestic reprocessing and plutonium separation, in a White House Statement issued on September 27, 1993 (White House 1993). However, to accelerate disarmament and the disposition of excess weapons plutonium, both here and in Russia, the Administration has embraced the idea of using the excess plutonium as MOX fuel in commercial reactors, and is encouraging the Russians to do the same. A dual-track program for the 50 tons of plutonium already declared as excess has been adopted. U.S. CLWRs will burn part (33 tons) of the excess weapons plutonium, and the remainder (17 tons) will be immobilized as a ceramic contained in vitrified high-level waste. Implementation of the U.S. program is contingent on execution of a similar comprehensive program in Russia. The DOE has begun several technical cooperation programs with Minatom in Russia to facilitate an early start to the Russian plutonium disposition program.

The FFTF can support a program to reduce proliferation concerns.

Meanwhile, the DOE continues to encourage other countries not now committed to reprocessing to seek other civil nuclear fuel cycles that do not involve reprocessing or the separation of plutonium. The challenge remains: how can the United States help encourage the further use of nuclear energy as a viable, zero-emissions energy source (both here and abroad), while minimizing the likelihood of proliferation of plutonium separations technologies beyond those countries which now employ those technologies? In addition, the United States wants to advance global non-proliferation technology, while at the same time supporting the development of advanced, ultra-high-burnup nuclear fuels [a key element of the Comprehensive National Energy Strategy (USDOE 1998a)]. These goals are not mutually exclusive; in fact, they can be complementary if the United States takes a leadership role in nuclear research, development, and application that is closely partnered with ongoing programs in other countries (most specifically, Russia, Japan, and France).

There are four ways in which the FFTF could contribute:

- **Testing to Support International Programs** - The FFTF's experience with and capability to test MOX and other plutonium fuels, as well as its ability to model irradiation spectra from many types of reactor facilities, means that technical issues associated with alternative fuel and core design, cladding behavior, fuel material characteristics, life extension, safety performance, impact of fuel impurities, transparency assurance, licensing, optimized fuel cycle, neutronic performance and criticality controls, and environmental compliance can be appropriately investigated. Russia is currently exploring two approaches to making MOX fuel for its BN-600 liquid-metal reactor at Beloyarski 3: one that uses the traditional plutonium separation and pelleting approach, and one that does not separate the plutonium and, instead, remotely fabricates the MOX fuel from plutonium, which has not been separated from other actinides and fission products. This latter technique is preferred by the Russians and is of great interest to the Japanese, who are investing in the Russian technology. The FFTF's ability to model the Russian fuel and core design, and through testing to provide assurance regarding the new fuel materials, could be important in evaluating the planned operation of the BN-600 reactor. This mission is not to re-establish breeder technology research or to support such research abroad, but is rather to support plutonium disposition using the FFTF's plutonium fuels research and testing capabilities.

- **Proliferant-Resistant Fuels Development** - Proliferation-resistant fuel technology, due to its innovative features, will require in-reactor testing before implementation in commercial reactors. The FFTF, originally designed as a fuels development and irradiation test facility, serves as an ideal test-bed and is one of the very few available irradiation test facilities that can be used to demonstrate the efficacy of proliferant-resistant fuels. Much of the existing body of scientific and engineering data on the performance of plutonium-based fuel and cladding performance at high burnup and exposure resulted from FFTF experimental data. The technical concepts underlying this research area will also involve nuclear fuel materials and new fuel cycles that reduce plutonium buildup, produce less waste, and be least attractive to a would-be proliferant; for example, the use of thorium-based fuels. Several of the proliferation-resistant fuel concepts involve spiking the fuel with specific actinide or plutonium isotopes during fabrication to reduce the attractiveness of the discharged spent fuel. The FFTF offers a means of demonstrating the use of these "spike" isotopes. Additionally, the DOE-NE created the Nuclear Energy Research Initiative (NERI) in late 1998 to address key technical and scientific obstacles to the future use of nuclear energy in the United States (see the NERI website, http://neri.ne.doe.gov). One of the primary research areas that has been identified under NERI is the development of proliferation-resistant reactor and fuel technologies - half of the 1999 research projects selected under NERI involved advances in nuclear fuels, core designs, or materials.

- **Evaluation of Alternatives to Reprocessing** - Reprocessing and plutonium separation present challenges to non-proliferation and safe fuels conversion. The options are to (1) preclude worldwide reprocessing (extremely difficult); (2) focus on additional controls during reprocessing and for materials reprocessed (difficult); and/or (3) develop alternatives, such as the Korean-Canadian-U.S. State Department-IAEA initiative on dry recycle, that would use already-irradiated LWR fuel converted into components that could be irradiated in the FFTF blanket. Other irradiation burn schemes could be tested. The objective would be to determine whether (through secondary reactor burn, blending, and repackaging) additional energy can be obtained from the existing fuel (thereby avoiding additional fuel contamination), and whether the final disposal configuration could be softened, reducing the challenge to the repository spent fuel standard.

  While Britain, France, and Japan are continuing to pursue reprocessing of LWR fuel, and recycle of plutonium into thermal reactors as MOX fuel, other countries with growing nuclear power programs are not. Korea, Taiwan, and Spain are currently storing their spent fuel, as is the United States, but are seeking an alternative to reprocessing that is advantageous for non-proliferation.

- **Backup to U.S. Plutonium Disposition Program** - While still providing medical isotopes and supporting civilian research programs, operating at 400 megawatts the FFTF could disposition up to 1.7 metric tons per year of surplus plutonium as fuel for the driver core using traditional enrichments and a standard core configuration. At this rate, the FFTF would convert to a safe form the 33 metric tons of surplus

weapons plutonium in 19.4 years, well within the 25-year criterion of the Surplus Plutonium Disposition EIS (USDOE 1996b). A readily available backup provides the DOE with flexibility in planning and encourages competitive pricing by commercial users, who might otherwise feel that the government has no other reasonable option. In addition, the availability of this consumption mechanism could prove valuable to the United States in the future. For example, further disarmament agreements with Russia (e.g., the Strategic Arms Reduction Treaty, START III) may lead to the need to destroy more plutonium than has yet been declared excess.

The FFTF can support a program to reduce proliferation concerns, but that role is highly dependent on (a) complementing existing Departmental programs, most specifically in Materials Disposition (MD); (b) obtaining international agreements for coordinated approaches; (c) developing, funding, and successfully implementing the research programs necessary to provide the technology that ensures safe and efficient fuels utilization; and (d) utilizing the existing Los Alamos National Laboratory (LANL), Idaho National Engineering and Environmental Laboratory (INEEL), Savannah River Site (SRS), and Oak Ridge National Laboratory (ORNL) experimental, fabrication, and processing capabilities. Such a program is a long-term aspiration for both the DOE and the FFTF. Should the DOE make a decision to go forward with the EIS process for the FFTF based on the other mission needs defined in this Plan, a program mission for non-proliferation technology support would be developed as part of the EIS to address mission needs such as those described in this section.

The FFTF has the demonstrated capability to perform extensive fuels and materials testing.

2.2.1.4 Materials Testing

Researchers from many different countries have used the nuclear materials testing and fuels research capabilities of the FFTF (see Appendix A.2). In particular, the FFTF has the demonstrated capability to perform extensive fuels and materials testing related to high-burnup fuels. The attractiveness of using the FFTF for materials testing is largely due to its high fluence which shortens the time needed for such testing, the test devices developed for the facility which allow for real-time control and measurement of multiple tests' thermal-hydraulic along with the neutronics, and the ability to tailor the flux to simulate different reactors and reactor conditions. There is particular interest in materials testing related to four application areas:

Commercial Plant Life Extension

With many CLWRs approaching the end of their current 40-year licenses, utilities are seriously considering extending the lifetimes an additional twenty years or more. Several license extension applications are already pending before the NRC. To support this life extension, and the license applications to the NRC, additional information will be needed on the material properties of the reactor vessel and components as these materials are exposed to more neutrons (fluence). Without this life extension, as many as 27 nuclear units will be out of service by 2020 (EIA 1999). The FFTF can provide a flux level 100 to 1000 times that of a CLWR, providing an aging acceleration factor of ~100 for advanced lifetime testing. Given that it is the fast flux in even a thermal reactor that does the major damage, the FFTF's neutron spectrum provides the best tool for accelerated lifetime testing. Potential research functions that the FFTF could support include the irradiation of components and materials such as instruments, cables, seals, ceramics, and metal alloys used in current or next generation LWRs. Non-U.S. researchers, including those from France and South Korea, have expressed special interest in the irradiation of LWR cabling and structural materials.

Cooperative International Fusion Energy Program

Interest in the use of the FFTF by international researchers is largely focused on its capability to conduct high neutron flux materials irradiations. At the time the FFTF was shut down in 1992, the DOE and Monbusho of Japan were conducting materials irradiations in the FFTF in support of the fusion energy program. This particular irradiation program has been moved to the Advanced Test Reactor in Idaho for completion, but from a technical standpoint (i.e., neutron flux and neutron energy level), the researchers would prefer the environment of the FFTF over other existing DOE reactors (see the letter from DOE-SC, Appendix A.1 - Government Agencies).

Space Technology

DOE has the charter to develop and demonstrate safe nuclear power systems in support of NASA missions. NASA has identified that nuclear energy for propulsion and surface power provide attractive technology options to support human missions to Mars. NASA's current Design Reference Mission for human exploration of Mars identifies a cargo transit to Mars in 2011 and a human transit in 2014. Nuclear Electric Propulsion would require small reactors with a power level up to 5 MWe. Surface power requirements for propellant production and habitation would require up to 150 kWe, which is beyond the capability of non-nuclear sources. The FFTF is an ideal facility for the irradiation demonstration of fuel and core materials that would be employed in the space nuclear power systems. Liquid-metal reactors are capable of meeting both the nuclear propulsion and surface power needs. The FFTF is the only U.S. liquid-metal fast reactor test facility in which a prototypical irradiation environment can be obtained. The scope of fuel and materials testing to support the development of these space nuclear power systems is well within existing FFTF capabilities and is consistent with the original design envelope for the FFTF. This summer, the directors of the major U.S. national laboratories signed a joint letter encouraging the DOE to initiate a technical program for evaluating fission power systems for space applications.

Transmutation of Wastes

The Accelerator Transmutation of Waste (ATW) concept has been proposed by LANL as a means to destroy long-lived isotopes from commercial spent nuclear fuel. The proposed concept employs a proton-spallation neutron source with a subcritical blanket containing transuranic materials and long-lived fission products (LLFPs; i.e., technetium and iodine), which provides for fission of the actinides and transmutation of the LLFPs. The subcritical blanket is envisioned to be a fast-spectrum, liquid-metal-cooled facility that is configured and operated in a manner similar to a fast-spectrum critical reactor.

Although a great deal of relevant experience exists in general on the irradiation performance of dispersion fuels (from research reactors and space reactor development) and metal alloy fuels, the alloys under consideration for use in the ATW system have not been irradiated. The single greatest uncertainty is the irradiation performance of the proposed ATW fuels. It must be demonstrated that the proposed fuels perform acceptably under irradiation to the target burnup. The proposed fuels employ an actinide alloy that is primarily plutonium, and experience shows that fuel performance almost always degrades as the plutonium content of the fuel is increased. Furthermore, the addition of such a large quantity of minor actinides into the fuel alloy has never before been tested.

For ATW, the testing capabilities of the FFTF are unequaled.

The proposed test program (Venneri et al. 1999) has been designed to gain initial irradiation test data on candidate fuel forms as quickly as possible. Relative to ATW the testing capabilities of the FFTF are unequaled, specifically the Open Test Assembly (OTA) positions (Fuels OTA, Materials OTA) that can be used to support this program. The phased fuel testing program ranges from 4 to 8 tests over a period of 6 to 8 years, leading up to fuel qualification testing before operation of a demonstration plant.

The ATW has not yet received authorization from Congress, although the Senate has proposed beginning this research in FY 2000. If the ATW is funded and sustained for several years, the FFTF would be a necessary component of the fuel development activity and has the potential to serve as a component and system test facility.

France, Japan, and other nations have also been studying the use of waste transmutation in nuclear reactors as an adjunct to their current fuel cycles, with the objective of reducing the long-term burden on a repository. This technology also holds promise for domestic (U.S.) application. As one example, studies have been performed on the destruction of minor actinides as well as those few long-lived fission products that dominate repository risk in the far distant time horizons. Fast reactors may offer an efficient way to destroy these isotopes, and hence reduce the toxicity of high-level waste in the far distant time horizon. The FFTF offers a unique facility to examine and test such transmutation technologies.

2.2.1.5 Other Future Potential Needs

Nuclear Science (Nuclear Cross Section and Reaction Rate Data)

With the capability to tailor the flux to the application, the FFTF is uniquely capable of measuring cross sections by the "unfolding" method through the use of several different hydrided locations in the core of the reactor. The U.S. Evaluated Nuclear Structure Data Files, version B[a] nuclear cross section files contain notable omissions of important data, specifically in the resonance integral absorption cross sections and in the absorption cross sections of isomeric states of many isotopes. Single measurements have been performed on certain isotopes, but the variance of the measurement is quite large. For instance, the absorption cross section of europium-152m changed by three orders of magnitude between the 13th and 14th editions of the Chart of the Nuclides. Many cross sections that have not been measured, or cross sections with large variances in their measurement, are important in the production of medical radioisotopes, transmutation of wastes, and other activities key to current DOE missions.

By using a hydride to thermalize the fast flux, the FFTF has demonstrated (see Appendix A.2) that multiple spectra, peaked at almost any energy below the high-energy neutron fission spectrum, can be created in the reactor. An example of using the FFTF neutron energy tailoring capabilities is in the area of transmutation of nuclear wastes where many of the cross sections for actinide isotopes are not well known in certain neutron energy regions. Reaction rate measurements that emphasize these energy regions could be performed in the FFTF to improve our understanding of waste transmutation for both reactor and sub-critical accelerator-driven concepts.

Electronic Component Hardening

The FFTF, with its high-energy spectrum and large irradiation volume, is well configured for use in hardening electronic components for space applications. Today hundreds of communications satellites are being planned for deployment. Unfortunately, the microelectronic components in those satellites can be damaged by exposure to high-energy radiation (cosmic radiation and "secondary" high-energy neutrons). One approach to minimizing the change in circuit characteristics is to "harden" the semi-conductor element before deployment. Hardening the semi-conductor with fast neutrons in a nuclear reactor stabilizes the characteristics of the component so that additional neutron exposure will cause only a small change. Manufacturers of microelectronics who want to harden their components need access to nuclear reactors with a high-energy (fast) neutron spectral component, such as the FFTF[b]. The demand for this type of irradiation service will depend on the future need for communication satellites that are resistant to radiation.

National Security

The FFTF can provide materials irradiation services in support of the national security-related research, including such areas as "stockpile stewardship," which refers to core competencies associated with research, design, development, and testing of nuclear weapons, and the assessment and certification of their safety and reliability under a Comprehensive Test Ban Treaty. If current efforts to identify future needs (USDOE 1996) determine that special materials, testing, or irradiation services are needed, the FFTF has the potential to be a major, reliable, and flexible contributor. Any such analysis would be provided separately from this report.

2.2.2 Physical Plant Configuration

The FFTF has demonstrated in past operations its ability to simultaneously accommodate many different tests and mission objectives (WHC 1993). Virtually any position in the core and reflector region can be used for experiments. Coupled with the eight special, fully instrumented in-core positions, this design feature provides the experimenter and program manager with many options to meet existing or expanded programmatic needs. Based on the expressed or implied interest from the broad user community, both public and private, a preliminary core configuration for the first post-startup testing production run has been developed. The core

[a]Maintained by Brookhaven National Laboratory and available on their website at http //www.nndc.bnl.gov/nndc/ensdf/.
[b]Current key players in this area include NASA's Goddard Space Flight Center, Honeywell's Solid State Electronics Center, and Sandia's Microelectronics Center.

will likely have the following types of mission support and isotope production assemblies assigned:

Position	Type	Function
In-Core	OTA	1 Gaseous Isotope Production
In-Core	OTA	3 Rapid Radioisotope Retrieval (R3)
In-Core	OTA	International Materials Testing (4 positions)
In-Core	DFA	3 to12 Long Irradiation Vehicles (LIVs) for Isotope Production
Ex-Core	Reflector	15 LIVs for Plutonium-238 Production
Ex-Core	Reflector	48 LIVs for Cobalt-60 Production

DFA = driver fuel assembly.

Eight of the in-core positions have the capability to instrument the test article as needed and to access, record and, if desired, adjust the conditions; e.g., temperature, flow, pressure. These positions can also be adapted to provide for convenient installation and removal of targets while at power. The ability to uniquely instrument each test article provides the experimenter with very desirable flexibility. Timely installation and removal of targets is especially important for many short-lived medical isotopes that need to be quickly processed for delivery to the patient.

This core map illustrated in Figure 2.4 provides for production of more than 5 kilograms per year of plutonium-238 in the reflector region, expanded short-lived medical isotope production, and fuels and materials testing. Further increase in production of plutonium-238 up to 30 kilograms per year could be accomplished by increasing the power level to the rated level and placing targets in unused reflector positions. Other missions (medical isotope production, materials testing, etc.) could be supported simultaneously with plutonium-238 production at the 30 kilograms/year level.

The FFTF in its ten years of operation demonstrated the ability to effectively accommodate many different testing and irradiation services scenarios, each with a core load that met the various constraints for reactivity, linear power, and power peaking.

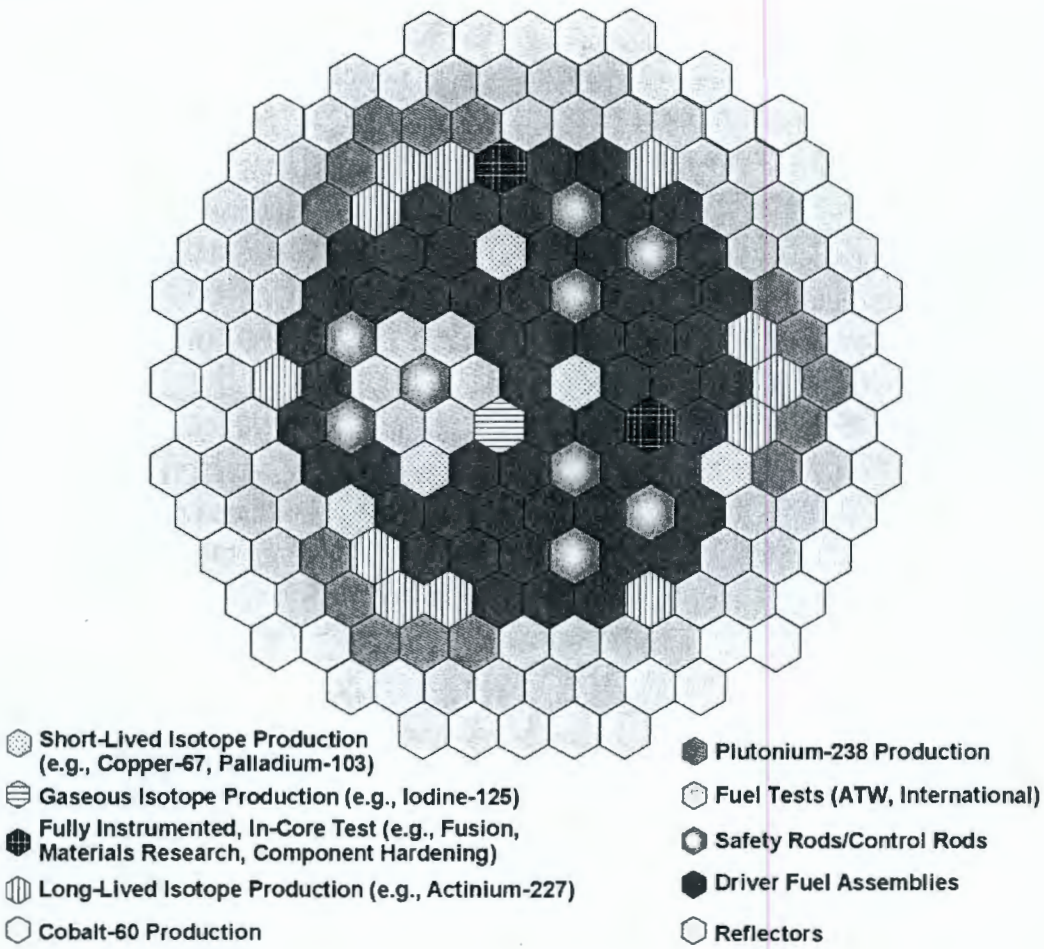

Figure 2.4 Core Map for Multiple FFTF Missions

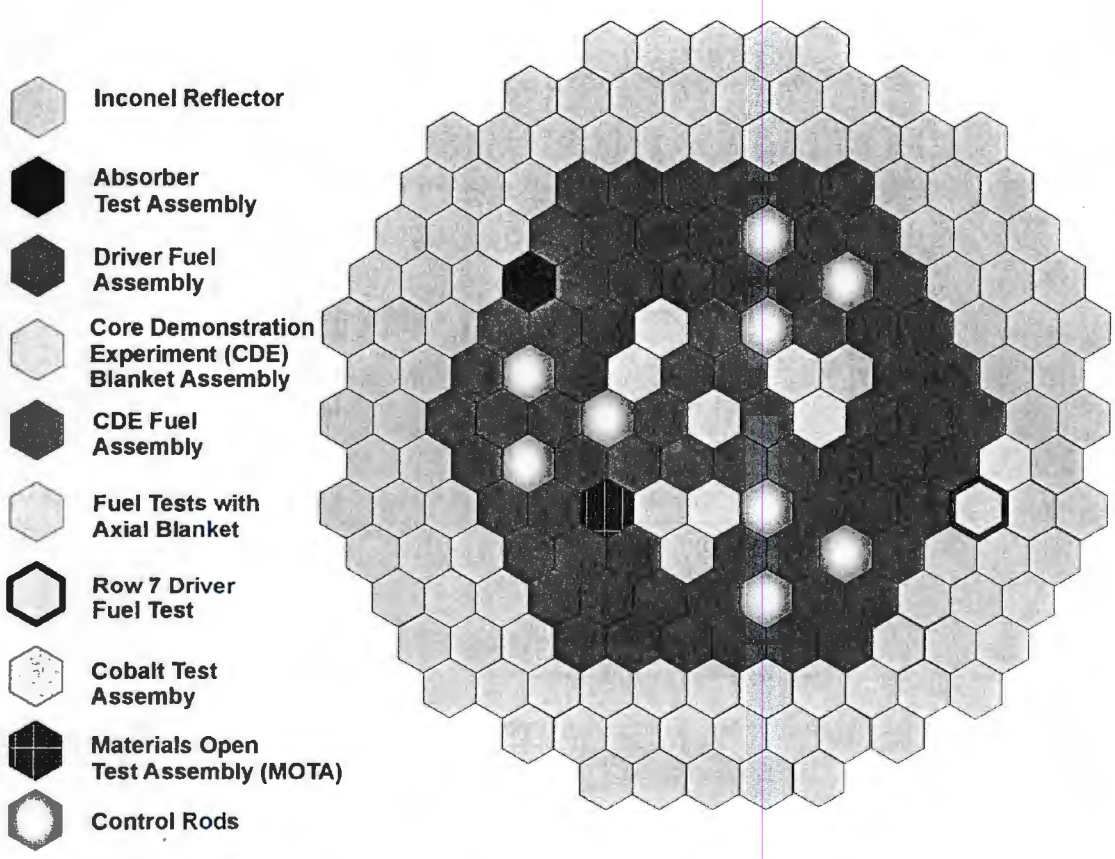

Figure 2.5 Actual Core Configuration for FFTF Cycle 11

2.3 Alternative FFTF Scenarios

The FFTF provides a flexible and robust environment that can accommodate many different nuclear science and irradiation service missions because of its core volume, variable power up to 400 megawatts, relatively flat flux profile with flux tailoring ability, contact-instrumented assemblies, high specific heat capacity and heat removal capability, and large ex-core region with high flux levels. An actual core map (FFTF Cycle 11) showing the diversity available in loading and experimental capability is provided in Figure 2.5.

The FFTF's extensive core performance and modeling information enables accurate prediction and assignment of mission areas within the core and reflector regions. Fuel experiments and some plutonium-based production experiments or missions can be accommodated without penalty to other nuclear science and/or irradiation service missions. Included in this category of multiple, parallel missions are plutonium disposition, actinide burn, proliferation-resistant fuel designs, and some trans-uranium isotope production.

The FFTF is not the only alternative to supply the neutrons for nuclear energy research and irradiation services. However, as discussed below, it represents a unique opportunity to capitalize on an existing facility with a replacement cost estimated at more than $2.5 billion. Restarting the FFTF provides the flexibility and margin to ensure that the United States maintains its lead in the arena of nuclear research, provides for a robust and expandable source of isotopes that support possible human missions to Mars and beyond, and serves as a reliable source of isotopes for medical treatment, research, and diagnostics.

2.3.1 Alternatives to FFTF Use

This section provides a comparative description of the alternatives to using the FFTF, including both U.S. and non-U.S. sources. The primary available U.S. DOE facilities are shown in Table 2.4.

The resultant DOE portfolio of major (> 30 MWt) reactor facilities with a restarted FFTF (and assuming a restarted HFBR) is summarized in Table 2.5.

Table 2.4 Comparative Data on DOE Research Reactors

Facility	Rated Power (MWt)	Peak Neutron Flux ($n/cm^2/s$)		Spectrum		Comments
Fast Flux Test Facility	400	core	7×10^{15} 4.5×10^{15} (avg)	Fast		Flux can be tailored to support a wide range of requirements. For example, yttrium hydride moderator pins can be used to increase the flux of epithermal and thermal neutrons.
		targets	7×10^{14}	< 1 keV	Thermal	
			1.5×10^{14}	<1 eV		
			1.9×10^{15}	Epithermal		
			4.5×10^{15}	Fast		
Advanced Test Reactor	250	1×10^{15}		Thermal		Unique capabilities include water-filled test loops that can be used to simulate LWR conditions.
		5×10^{14}		Fast		
High Flux Beam Reactor	60	core	1.2×10^{15}	Thermal		Unique capabilities include 9 beam tubes. HFBR is in standby awaiting completion of a NEPA review. A restart decision is expected by late 1999. When last in operation, HFBR operated at a lower power level of 30 MWt.
			2.4×10^{15}	Fast		
		beam	1.1×10^{15}	Thermal		
			2×10^{12}	Fast		
High Flux Isotope Reactor	85	core	3.3×10^{15}	Thermal		Unique capabilities include 4 beam tubes.
			1.6×10^{15}	Fast		
		beam	1.4×10^{15}	Thermal		
			3.9×10^{14}	Fast		
Brookhaven Medical Research Reactor	3	core	5×10^{13}	Thermal		Unique capabilities include 3 irradiation ports.
			2.5×10^{13}	Fast		
		beam	6×10^{10}	Thermal		
			2.7×10^{9}	Epithermal		
Annular Core Research Reactor (ACRR)	2	3×10^{13}		Thermal		Lack of private sector interest may impact the utilization of the ACRR for molybdenum-99 commercial production (http://www.ne.doe.gov/).
		4×10^{13}		Fast		
Typical LWR	~3400	3.2×10^{13} (avg)		Thermal		Included for comparative purposes

Available irradiation volume is of significant importance for production of material in quantities greater than that required for research. Table 2.6 and Figure 2.6 provide a comparison of the in-core and ex-core (with flux levels > 10^{13} $n/cm^2/s$) sample irradiation volumes for the DOE reactors with significant, comparable capabilities. These tables also identify the current unused irradiation volume at these facilities.

A first-order estimate of the volume requirements for most of the activities depicted in Table 2.2 and discussed later in this report is provided in Table 2.7. The numbers in the table are based on analyses conducted and completed in other reports (PNNL 1999), and reviewed with potential customers.

It can be noted, from Table 2.7, that there is a significant uncertainty in the requirements for reactor core volume, based on expected and potential needs. Even with the significant volume addition available from a restart of the FFTF, these three facilities alone will not meet the anticipated future demand for medical isotopes. Flexibility in meeting other public-sector needs is also at risk based on

Table 2.5 DOE Research and Test Reactor Portfolio

Facility	Coolant	Core Volume (liters)	Rated Power Max/Typical (MWt)	Annual Operating Cost ($M)
High Flux Beam Reactor (http://www.hfbr.bnl.gov/)	Water	100	60/30	24
High Flux Isotope Reactor (http://www.ornl.gov/hfir/hfirhome.html)	Water	51	85/85	28
Advanced Test Reactor (http://titanic.inel.gov:1025/plan/cflup/html/tra.htm)	Water	275	250/150	45
Fast Flux Test Facility (http://www.fftf.org/)	Liquid sodium	1034	400/100	55[a]

[a]$55 million per year for 20 years at 100 MWt or 5 years at 400 MWt. For costs associated with operations at higher power levels for longer than 5 years, see Section 3.2.3.

Table 2.6 Comparison of Available Sample Irradiation Volumes (liters)

	HFIR		ATR		FFTF	
	In-Core	Ex-Core	In-Core	Ex-Core	In-Core	Ex-Core
Usable Production Volume	4.2	23.2	40	85.8	82.3	925
Current Mission Commitment	1.4	4.0	38	2.8	0	0
Net Available Volume	2.8	19.2	2.0	83.0	82.3	925

flux spectrum differences, volume requirements, and increased demand that would be required to support additional or expanded missions (e.g., possible NASA human mission to Mars).

Based on the volume projections listed in Table 2.7, the potential human missions demand exceeds the net volume availability for the major DOE alternatives (HFIR and ATR). The volume capable of producing an estimated 5 kilograms/year of plutonium-238 (which is less than what could be needed to support NASA's human missions) would require a significant fraction of available high flux volume. However, any current users of that space at the ATR could be re-located within the core. Today, according to INEEL management (DOE and contractor), ATR is 95% utilized (in-core) and has users wait-listed for many of its test ports. ATR and HFIR do not provide for any further growth in plutonium-238 production capacity without impact on other users. Besides the major DOE alternatives, there is the ACRR, located in New Mexico. ACRR is a 4-megawatt LWR, which the DOE has been planning to use to irradiate targets for production of molybdenum-99. While the ACRR is well designed for such a function, the facility, especially with its planned configuration change to pulse mode, has very little expansion capacity for additional missions.

The following non-DOE alternatives are among those that could be considered to meet the mission objectives laid out for the FFTF.

University Test Reactors

Most reactors at U.S. universities date from the 1950s and 1960s. Their primary goal is to educate those interested in working in the nuclear technology industry, nuclear medicine, and fundamental research. The role of

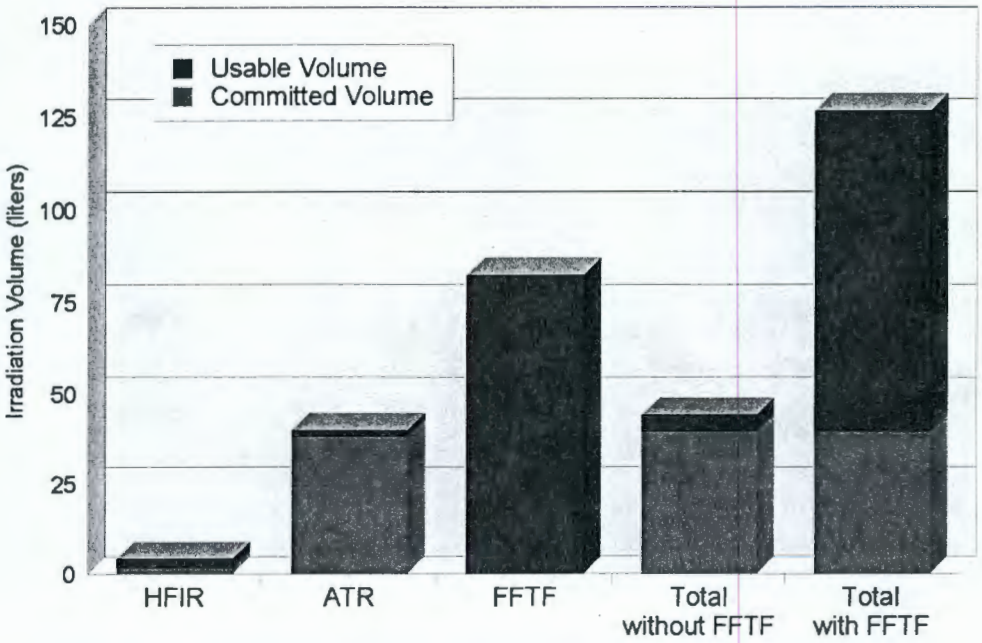

Figure 2.6 Current High-Flux Irradiation Volume Usage/Availability

Table 2.7 Estimate of Volume Requirements to Support Missions (liters)

Mission Area	Low	Medium	High
Plutonium-238[a,b]	45.5	128.4	205.5
Medical Isotopes[c]			
2005 - 2010	5.5	8.3	18.0
2010 - 2020+	7.8	13.4	34.6
International Program Support[e]	8.6		25.8
Fusion Tests[e]	2.9		5.8
ATW[d]	8.6		17.2
Non-Proliferation Programs[d]	0		0
Materials Tests for Future Space Reactor Power Systems, CLWR	8.6		17.2
Industrial and Food Safety Isotopes	8.6		25.8
Electronic Component Hardening	8.6		17.2

[a]Low = 2 kilograms/year; Medium = 5 kilograms/year; High = 20 kilograms/ year; Production above 5.7 kilograms/year will require operation at higher power levels.
[b]Volume projections are for FFTF using hydrided assemblies. Other facilities could produce similar amounts but with higher plutonium-236 impurity.
[c]Based on the report by PNNL (1999) included as Appendix A.3 of this document.
[d]Plutonium disposition and ATW test components of any non-proliferation program may have sufficient fissionable material to substitute for standard driver assemblies and not affect available irradiation volume.
[e]Volume estimates are based on past experience at the FFTF.

university research reactors has evolved from the study of basic reactor physics and nuclear engineering to more diversified programs involving reactor use in basic and applied research as well as technological studies encompassing many disciplines.

There are currently 26 universities operating a total of 28 reactors in 21 states. The 10-megawatt University of Missouri-Columbia Research Reactor Center (MURR)[c] is the most intense neutron source of those university research reactors. MURR is an excellent facility for research, education, and isotope production, and is cited by many radiopharmaceutical companies as the model. No other university test reactor has a production capability comparable to MURR. But even for MURR, as noted in the letter from one of the radiopharmaceutical companies surveyed, the demand for isotopes "...will soon outgrow the capacity of our current arrangement with MURR." The potential overlap in some aspects of isotope production between MURR and the FFTF includes production of rhenium-186, rhenium-188, samarium-153, holmium-166, and lutetium-177. A recent Institute of Medicine report (Institute of Medicine 1995) implied that competition from the FFTF would have a detrimental financial impact on the ability of MURR to survive as a research and production facility. It is not the purpose of the FFTF to compete with MURR in production of these important isotopes. However, both facilities recognize that MURR will not be able to produce rhenium isotopes and other medical isotopes in the quantity needed for the supply of FDA-approved radiopharmaceuticals. Market projections indicate the need for both MURR and the FFTF (quantity and backup).

To strengthen the scientific and technical relationship between PNNL scientists and MURR, and to ensure the continued viability of MURR, discussions have been held with MURR scientists and university administrators on areas of joint collaboration. Areas of discussion for strengthening MURR operations include mechanisms to encourage direct DOE support for MURR operations, research, educational programs, and isotope production; joint MURR-PNNL radiochemistry and radiopharmaceutical research; collaborative target preparation activities; hot-cell radiochemical separations at Hanford for MURR-irradiated targets; and joint study of technical options for minimization/disposal of MURR radioactive wastes.

The overwhelming majority of other university reactors are not production facilities. In concert with the larger U.S. production sources, those test reactors could perform important isotope development work and production for certain target isotopes. The size of these facilities, their access to target processing hot cells, and other logistical factors render use of university test reactor facilities inadequate to meet the expected commercial demand. Another negative factor relative to the use of university reactors is that if demand for isotopes increases as forecasted, use of those facilities could impact the availability of reactor space for research and educational uses. The other identified missions for the FFTF, which depend on a large reactor fluence or temperature/coolant/fuel type, are not compatible with the type of work that can be done at U.S. university test reactors.

Commercial Light-Water Reactors

CLWRs have sufficient core volume, but are neither designed nor licensed for the types of missions identified for the FFTF. It is unlikely that the electric utility industry would be agreeable to pursuing modifications to their NRC operating license to support this activity, nor would they want to make the modification necessary to support target insertion/removal at power, a feature necessary to produce the short-lived isotopes. Additionally, it is equally unlikely that they or their customers would be willing to accommodate the frequent perturbations to their primary mission – production of electricity. CLWRs operate on an 18-month refueling cycle. Optimal medical isotope production cycles, not including the short-lived isotopes that require a "rabbit," are most often in the range of 50 to 100 days. This mode of operation would significantly impact the CLWR's electrical power production capability. Use of the CLWRs for the production of plutonium-238 was included in the list of EIS alternatives, but the impact on utility operations, constraint on optimizing core loading, and licensing issues may create difficulties not experienced with production in the FFTF.

[c]More information is available on the website (http://showme.missouri.edu/~murrwww/mission.html)

Foreign Sources

Letters of support received from the IAEA, Japan, Korea, and France (even with the construction of the Jules Horowitz reactor) indicate that those nations foresee a need for the unique reactor capabilities resident in the FFTF. IAEA specifically cites the disappearing availability of research reactors capable of providing the neutron fields required. Known isotope production capabilities in Belgium, Peru, Argentina, and South Africa all have delivery, reliability, and size limitations.

The IAEA, Japan, Korea, and France foresee a need for the FFTF's unique capabilities.

Canada. Atomic Energy of Canada, Limited (AECL), wholly owned by the government of Canada, has stated that the 125-MWt NRU reactor will not operate beyond 2005. The Canadian National Research Council and the AECL, in partnership with universities and industry, are jointly proposing a new Canadian Neutron Facility (CNF) for Materials Research to support next-generation neutron-based materials research and innovation in Canada (at an estimated cost of $388 million). The stated purpose of the CNF is two-fold: to provide an advanced materials research capability to meet the needs of Canadian universities and industry; and to provide an essential testing facility to advance the CANDU[d] power reactor design and ensure the future competitiveness of the Canadian nuclear industry (http://cu17.aecl.ca/nru.htm).

MDS Nordion (annual sales of $270 million) is investing $140 million in the construction of two small, specialized, pool-type Multipurpose Applied Physics Lattice Experiment (MAPLE) reactors (10 MWt each) and a process facility dedicated to medical isotope production at the AECL Chalk River Laboratories site. The planned facility will produce molybdenum-99, as well as xenon-133, iodine-131 and iodine-125. MAPLE 1 will be the main isotope producer and should begin operations this fall. MAPLE 2 will provide alternate production during shutdowns of the primary reactor, and is scheduled to begin operations a year from now (http://www.mds.nordion.com/home.html).

Nordion provides most of the diagnostic isotopes used for nearly 40,000 medical procedures daily in the United States. In the last three years, two threatened strikes almost brought the supply to a halt (http://www.snm.org/policy/nordn98.html). Relative to price setting, the lack of an alternative U.S. supply can create inflated pricing. For example, Nordion recently increased the price of molybdenum-99 from Canada. Nordion did indicate (see letter in Appendix A.1) support for the FFTF for playing a role in the production of specialized isotopes. And Nordion has stated its intent not to be the sole provider of isotopes, but envisions being part of a global network of companies and technologies linked together. One example may be iodine-131, where FFTF is capable of producing material with a much higher specific activity (minimizing the amount of targeting antibody that must be used to deliver the isotope to the tumor tissue) than the Canadian reactors, which are currently the only sources of this isotope for the United States.

Russia. Russia and other nations of the Former Soviet Union are potential sources for many of the missions proposed for the FFTF, most specifically plutonium-238 and medical isotope production. Table 2.8 lists advantages and disadvantages in relying on the Russian sources.

2.3.2 FFTF Operation - Impacts on Other U.S. Facilities

As shown in Tables 2.6 and 2.7, the available volume requirements to support anticipated needs exceed existing capacity by a large margin. To maximize the benefit to the scientific community and better serve private-sector customers, shifting of activities from one reactor to another may be appropriate. The opportunity exists to establish

[d]CANDU is a registered trademark that stands for Canada Deuterium Uranium. It is a pressurized-heavy-water, natural-uranium power reactor designed in the 1960s by a consortium of Canadian government and private industry.

Table 2.8 Advantages and Disadvantages of Foreign Source (Russia)

Advantages	Disadvantages
• Russia has unused capability. • There would be no need to maintain a U.S. nuclear infrastructure, or deal with the production or processing of wastes. • Russian nuclear organizations could use the financial support. • Initially price for plutionium-238 and isotopes may be cheaper; the U.S. may be able to buy and stockpile large quantities for later use.	• The use of Russian sources creates reliance on the economic and political stability of Russia. • As more isotopes are approved by the FDA for diagnostic and therapeutic applications, U.S. patient treatment could become highly dependent on a stable Russian supply. • There would be minimal availability for joint use (i.e., use isotope production revenue to offset isotope development and basic research). • A pricing vulnerability, absent a competing U.S. source. • Production and processing will occur in Russian facilities that may not meet International safety and environmental standards, but which would continue to be operated to supply U.S. need. • Transport of short-lived isotopes from Russia to the U.S. is not feasible. • No preference given to U.S. customers if new demand or worldwide shortfall in supply occurs. • Russian reactors would not be convenient for commercial research nor capable of conducting national security research.

primary and backup facilities for many activities, especially in the area of isotope production, thereby providing a more reliable and diverse supply of many of these isotopes. With a focused effort to standardize target capsule designs that could be irradiated in any of the DOE reactors, DOE would be able to improve the assurance of supply.

With the FFTF as a major isotope supplier, other reactors should actually see an increase in the demand for isotopes.

During June 1999, a DOE-contractor team from the FFTF toured and met with staff from HFBR, HFIR, and ATR to review capabilities, business models, and capacities to ensure that this Program Scoping Plan reflects a mission and business approach that complements operations at other facilities. The consensus was that a restarted FFTF would not compete, but would greatly support the use of those other facilities for their most appropriate and productive mission profiles.

With isotopes the demand increases when users believe they have an ensured supply, which means that with the FFTF as a major isotope supplier, other smaller reactors should actually experience additional demand for the development and production of isotopes that they can supply to the U.S. market.

2.4 Technical Merits and Drawbacks

Table 2.9 presents a perspective on the relative technical merits and drawbacks of the use of the FFTF for nuclear science and irradiation services.

By focusing its projects and support efforts within its special capabilities of size, flux, test evaluation and irradiation features, and fuel and coolant type, the FFTF can establish an integrated mission as a premier nuclear materials testing, isotope production, and plutonium fuels research facility.

Table 2.9 Technical Merits and Drawbacks

Merits	Drawbacks
• The FFTF has numerous distinctive features: - variable power (100 to 400 megawatts) - large core volume (irradiation volume in core >180% greater than the total of other DOE resources; ex-core irradiation volume with flux > 10^{13} n/cm^2/s >800% greater than total other DOE resources) - fast spectrum, high flux density, and ability to tailor flux high temperature and specific heat removal - eight high-volume, contact-instrumented, in-core assemblies that also provide ability (with modification) for target insertion/removal at power - ability to fully isolate assembly via "closed loop." • The FFTF has a long remaining operating life without required analyses/modifications (especially at 100 MWt). • All in-core and first row of reflector positions have individual temperature and flow instruments. • Highly instrumented test trains provide multiple test capability for evaluating the irradiation behavior of structural materials.	• A moderator would need to be added to slow down neutrons for certain isotope production and materials testing. • The FFTF is not usable as a neutron science tool for physics studies requiring beam-tube facilities. • Compared to older 1950s/60s vintage facilities, the FFTF's modern operating and safety systems are more reliable, but do add cost and in some cases restrict the flexibility of the researcher/user. • The FFTF cannot replicate water coolant corrosion conditions extant in LWRs.

3.0 Financial Analyses

There is a broad range of support and need for a facility such as the FFTF.

This section provides a validated business model, along with a conservative estimate of projected revenue from the identified missions. The life-cycle economics are estimated for the FFTF as a user facility. Estimates of the restart cost and schedule, routine operations cost, and shutdown costs as well as the basis for confidence in these estimates are included. Finally, the financial merits and drawbacks of the approach laid out in this plan are presented.

High confidence exists for all aspects of the financial analysis contained in this plan, including restart costs. This confidence level is based on the following:

- extensive reviews of the restart costs
- routine operations costs, which are based on more than 10 years of operating experience in a nuclear science and irradiation services mode
- application of the requirements of DOE Orders in the operation of DOE-owned user facilities
- benchmarking with other DOE reactor user facilities
- external review of the approach by a recognized expert in the field.

Figure 3.1 depicts these confidence-building elements and how they contribute to the overall assurance that the proposed business model will meet the financial performance objectives.

Figure 3.2 shows the projected revenue breakdown for two time frames: 2005-2010 and 2010-2020+. The stacked bar charts on the left provide a summary-level estimate of the funding sources that offset the $55 million annual operating costs. Detailed information for these sources and assumptions are included in the latter portion of this section. The core maps demonstrate the concurrent mission capability of the FFTF as discussed in detail in Section 2, and depict the shift in mission focus.

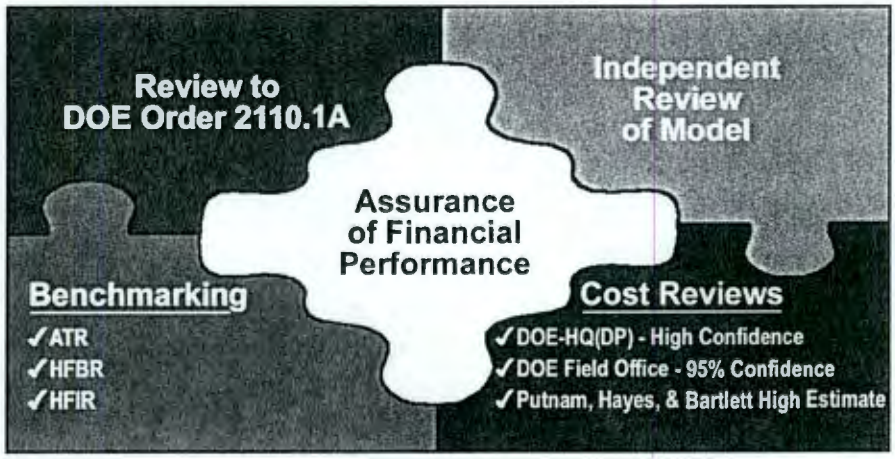

Figure 3.1 Elements of Financial Analysis for the FFTF

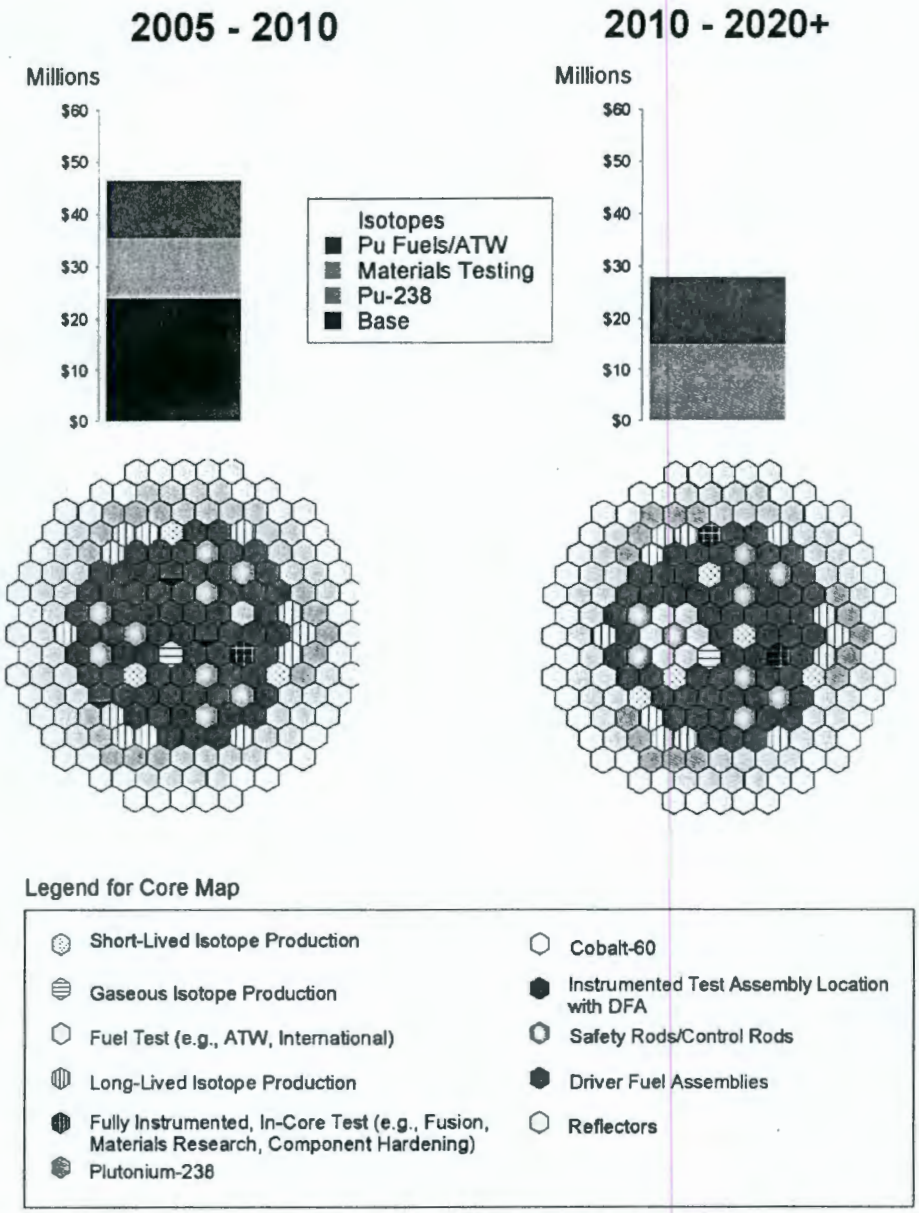

Figure 3.2 FFTF Revenue Profile Forecasted

3.1 Mission Performance

The FFTF, unlike most other DOE user facilities that have a primary mission area and sponsor who provides the majority of the annual funding, will function as a true multi-user facility that serves the needs of the public and private sectors. Although the business model that is proposed for the FFTF was benchmarked against existing models at other DOE-owned reactor facilities, it is evident that future success is closely tied to a larger and more diverse set of prospective users. However, as clearly demonstrated in the numerous letters in Appendix A.1, there is a broad range of support and need for a facility such as the FFTF. Based on these strong statements, the expanding need for reactor-based research and reactor-produced isotopes, and the conservative nature of the financial projections, the confidence level for this project meeting the financial and performance objectives is high.

3.1.1 Business Model

The following business model successfully integrates the DOE requirements and the user needs in a manner similar to other DOE user facilities, and addresses all phases of the facility life cycle.

There are two key factors in evaluating FFTF use:

- identifying the future users of the facility and their objectives
- describing the overall business model for integrating these requests into an effective and efficient use of the FFTF.

Following is a description of the business model envisioned for the FFTF. The model integrates potential uses (and users) of the FFTF and the guiding principles and assumptions by which these activities will be incorporated into the overall FFTF mission. In addition, the business model describes the projected life-cycle cash flow (costs, revenues) associated with various FFTF users and missions.

The FFTF business model has been developed using the guidelines provided in DOE Order 2110.1A, "Pricing of Department Materials and Services" (USDOE 1992). The model has been benchmarked against business models currently in place at other DOE reactor sites[a]. The model assumptions have been reviewed and agreed to by the DOE Chief Financial Officer's office (in meetings on June 15, 1999 and June 23, 1999), and the full model has undergone an independent third-party review[b] to ensure that the details and assumptions within the model are consistent and display sound business and financial fundamentals and practices.

The business model is focused on the re-introduction of the FFTF into DOE's long-term nuclear infrastructure as a National User Facility for the continued advancement of nuclear science and provision of irradiation services. Therefore, the business model assumes that the FFTF is operated under a DOE Management and Operations (M&O) contract subject to DOE Orders and Regulations (see Section 4.1.3).

The provision of reliable and cost-effective in-core testing and irradiation services to both government and commercial users forms the framework for the overall business model. Support services such as research fuel, target, and/or test assembly design and fabrication, and processing are not currently incorporated into the model and are assumed to remain the responsibility of the users. This assumption is consistent with current business models in place at all other DOE reactor sites.

The business model is divided into three time periods: (1) preparations for restart, (2) operations, and (3) deactivation. FFTF costs, expressed in constant FY 1999 dollars, associated with these three phases of the overall business model are shown in Figure 3.3. Specific details and assumptions within each of these periods are described in the following sections.

3.1.2 Preparations for Restart (2000-2004)

The business model assumes a favorable decision in August 1999 to proceed with the development of an Environmental Impact Statement (EIS) for the FFTF. The EIS process would start with the Notice of Intent (NOI) in September 1999 and conclude in December 2000. Assuming a favorable Record of Decision (ROD), restart activities would commence in January 2001 and culminate in FFTF startup in July 2004.

The cost for restart preparation is estimated to be $229 million (see Section 3.3.3). An additional $55 million would be required to maintain the FFTF in standby during preparation of the EIS and to conduct that EIS, bringing the total estimated cost for this phase to ~$284 million.

Baseline funding is anticipated to phase out during the early operational period.

Because the FFTF will become an integral component of DOE's nuclear infrastructure and support DOE's long-term mission as a National User Facility for advancement

[a]The FFTF business model was benchmarked against business models for High Flux Beam Reactor (HFBR), High Flux Isotope Reactor (HFIR) and Advanced Test Reactor (ATR).

[b]Independently reviewed by Dr. Howard Kaufold, Director of Executive MBA Program at Wharton Business School, University of Pennsylvania.

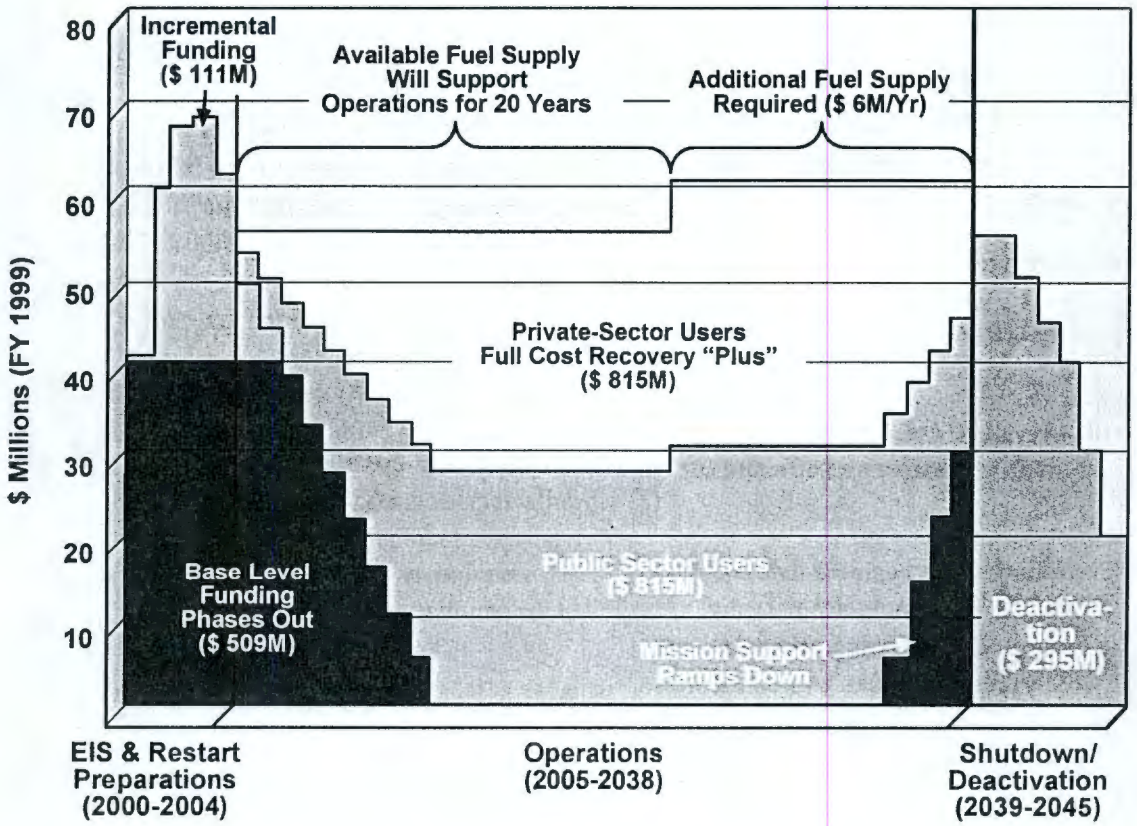

Figure 3.3 Cost Profile for the FFTF Business Model

of nuclear science and provision of irradiation services, the business model assumes that the investment necessary to fund this period of restart preparations will be initially borne by DOE. However, the model recognizes the future importance of the FFTF in providing irradiation services to the private sector, and therefore incorporates a mechanism for the private sector to share in the overall costs for these services (both annual operating and incremental restart). The model has incorporated a "value recovery charge" of ~4% that is applied to all private-sector services during the operational period. This charge recovers an appropriate portion (~$100 million) of the restart preparations.

The business model assumes that the baseline level of standby funding is redirected during this phase to apply toward preparing the FFTF for restart after receipt of a favorable ROD. As shown in Figure 3.3, this level of baseline funding is anticipated to phase out during the early operational period as the reactor becomes fully subscribed with public- and private-sector mission activities.

In addition to this level of annual baseline funding, incremental authorization (authorization above current baseline levels) will be required to achieve operational status by 2004. The total incremental authorization is estimated to be $111 million over a seven-year period (2000-2006). The maximum annual incremental authorization will be $28 million and will occur in fiscal year (FY) 2003.

3.1.3 Operations (2004-2038)

The FFTF will resume operations in July 2004. The reactor is assumed to operate at a power level of 100 megawatts (and at a 75% capacity factor) over a 34-year operational lifetime. An engineering analysis has been completed that supports an additional 22 years of operation at 400 megawatts at a 75% capacity factor. Operation at lower power levels and the use of the reflector region for isotope production (including plutonium-238) reduce the neutron fluence to life-limiting components. Engineering estimates have

shown that reactor integrity can be fully ensured during this operational lifetime at the assumed power and capacity factors.

Although operation at 100 megawatts would normally reduce the flux levels proportionally, the FFTF has the flexibility to adjust core size by reducing the total number of fuel assemblies and replacing them with targets or reflectors. Power density would be maintained near design levels, thereby keeping the in-core flux levels also near design levels (peak reduced from 7×10^{15} n/cm^2/s to ~2×10^{15} n/cm^2/s).

Costs

The estimated annual operating cost in FY 1999 dollars is $55 million per year. All expected operational and ongoing maintenance costs are included in this estimate. The existing, onsite FFTF mixed-oxide (MOX) fuel supply will allow for approximately six years of operation at 100 megawatts. The options for a replacement fuel supply that could be considered and addressed in the EIS include, but are not limited to, the following:

1. Contract with a commercial source for highly enriched uranium (HEU) fuel. While the FFTF was operating in the early 1990s, the DOE conducted tests that demonstrated that HEU fuel would perform well (WHC 1988, 1989). The cost of such fuel, which would comprise 12 to 15 fuel assemblies per year, depending on core configuration and operating power, is estimated at $4 million to $6 million per year. The price is based on a detailed estimate for HEU fuel that was completed in the late 1980s and has been updated to reflect current labor and material costs. This estimate was corroborated by a commercial HEU fuel source, with the assumption that the HEU itself is government-furnished material (GFM).

2. Use the new (currently being renovated) TA-55 MOX fuel production line at Los Alamos National Laboratory (LANL) to produce FFTF driver fuel assemblies after the Materials Disposition (MD) Lead Test Assembly mission is completed in 2006.

3. Obtain fuel from international source(s). In conducting advanced reactor research activities with a broad-based, international application, the potential exists for the FFTF to obtain fuel, materials, plant components, and technical services from collaborating partners as in-kind contribution and support for the programs.

   One potential international source that has expressed interest in providing fuel is the German firm, Schnell-Brueter-Kernkfratwerksgesellschaft (SBK). SBK has, on hand, sufficient SNR-300 fuel for at least 14 years of FFTF operation at 100 megawatts. The unirradiated fuel, enriched to 24.8% to 36% plutonium (with ~20% plutonium-240), would require repackaging in FFTF assemblies.

   Advanced Nuclear and Medical Systems (ANMS), a local Washington-based firm, has negotiated a draft agreement and signed letter of intent with SBK which, subject to DOE and German government approvals, would provide the SNR-300 fuel to serve as a basis for FFTF development. The ANMS concept (see letter in Appendix A.1) is to provide the SNR-300 fuel as in-kind and matching support for the further development of FFTF products such as medical isotopes.

   Previously, the DOE has received expressions of interest from SBK which indicate that the fuel could be provided directly to the DOE for FFTF with funds sufficient to accomplish the repackaging of the fuel into a suitable form for use in the FFTF. SBK's commitment to that offer was confirmed by DOE Office of Nuclear Energy, Science and Technology (NE) in July 1999.

4. Use the FFTF for disposition of surplus weapons-grade plutonium from the military program, which would provide an additional source of fuel (MOX fabricated from excess plutonium stockpiles). However, because such a disposition alternative is not currently planned by the DOE, fuel from this source has not been assumed for this review.

The business model assumes that the onsite FFTF fuel and the SNR-300 fuel (option 3 above) serve as the initial available fuel for the first 20 years of operation. Following this period, the model assumes that additional fuel supplies (HEU, option 1 above) can be obtained for the final 14 years of operation at the previously referenced cost of ~$6 million per year.

Based on these assumptions, the annual cost of operations for the first 20 years of operations is $55 million. Beyond 20 years of operation, the annual operating costs are assumed to increase to $61 million due to the costs associated with purchasing additional fuel supplies. The model assumes that the annual operating costs are funded directly by DOE.

Full subscription of reactor services will be obtained within 10 years of reactor startup.

If the mission needs require the FFTF to operate at a power level greater than 100 megawatts, the assumed fuel supply will not last for the projected 20 years. Figure 3.4 illustrates the relationship of the fuel supplies (FFTF alone and FFTF plus SNR-300) to operating power level.

Operations beyond the existing fuel supply will increase the annual operating costs by $6 to $24 million for replacement fuel, as indicated Table 3.1. This study assumes that HEU will be the operating fuel, as discussed above, after the existing fuel is consumed.

Revenues

At full operation, the FFTF will devote ~50% of its capacity to meet the demands of both the public and private sector for scientific research and provision of irradiation services.

Revenues obtained from private-sector use will be incorporated with DOE operational funding either to reduce out-year DOE funding requirements or to be returned to the U.S. Treasury. A portion of the private-sector revenues will be maintained in a reserve account at the FFTF to ensure available funding for contingency situations. These assumptions are consistent with current models in place at other DOE sites.

The business model assumes that full subscription of reactor services will be obtained within 10 years of startup. The rate of reactor usage, in support of these missions, has been shown to increase at a rate of 10% per year over the first 10 years of operation and then remain revenue-steady through the majority of operational life. The model further assumes that the missions will ramp down at a similar rate during the final four years of operational life. The estimated revenues that have been obtained through the specific letters of interest and more detailed market studies indicate that these assumptions may be conservative. The information obtained through these sources indicate that full subscription may be obtained several years earlier than projected and longer-term revenues may increase above the actual costs of full operation.

Pricing and recovery of funding for both private- and public-sector activities are described in Section 3.2.1.

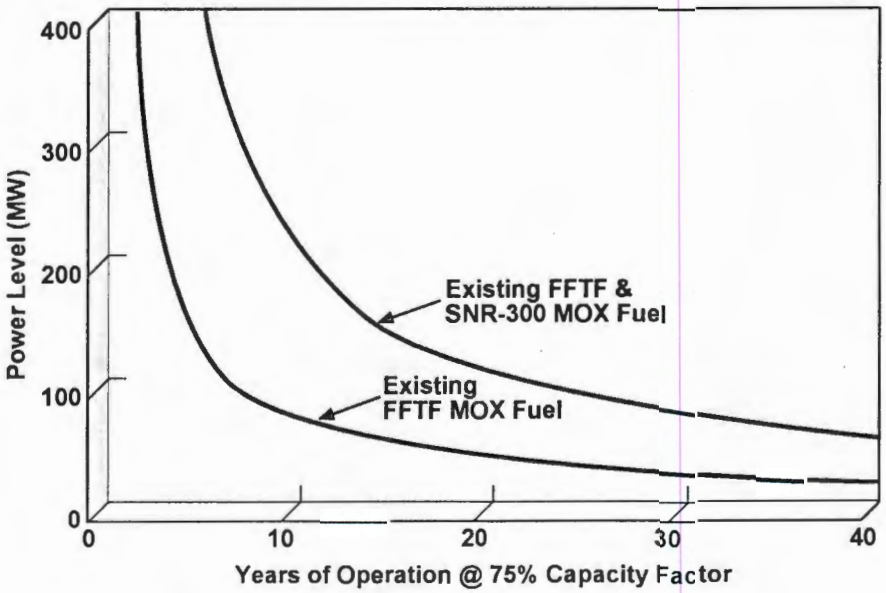

Figure 3.4 Operations with Available Fuel

Table 3.1 Fuel Costs for Different Operating Power Levels (FY 1999 $M)

Operating Power Level (megawatts)	Number of Fuel Assemblies/year	Estimated Fuel Cost	Annual Operating Cost with Replacement Fuel
100	12	6	61
200	24	12	67
400	48	24	79

3.1.4 Deactivation (2039-2045)

After the successful completion of its operational mission, the FFTF will be deactivated over a 7-year period and made ready for subsequent decontamination and decommissioning (D&D) activities (see Section 3.3.6). The cost to complete the deactivation of the FFTF will be $295 million (FY 1999 $). Deactivation will be funded through authorizations from the U.S. Treasury.

3.2 Integrated Revenue Projection

The following section describes the pricing methodology that is used in assessing costs incurred by individual users. These costs are applied using the anticipated mission volumes to arrive at an estimate of annual revenues that will be generated by FFTF. Finally, the present value costs and revenues for the life-cycle operation of FFTF are compared with the shutdown alternative.

3.2.1 Pricing/Recovery Methodology

The FFTF operational mission is anticipated to begin in 2004 and continue through 2038. The costs required to undertake this mission will be $229 million for startup preparations followed by an annual operating cost of $55 to $61 million through the active operational period, and an estimated deactivation cost of $295 million at end of the mission. The business model assumes the following recovery strategy for these expenses.

Recovery of funding for public-sector activities will be coordinated by DOE-NE as the primary DOE sponsoring agent. The current business models in place at similar DOE reactor sites show a variation in potential public-sector recovery mechanisms. In general, the provision of services for the majority of public-sector missions is handled through Financial-Plan transfers or Work-for-Others agreements. However, specific allocations of services on a "subsidized" basis are available for universities and other similar users with the DOE sponsors' approval.

Similar to other DOE business models, private-sector usage costs will be recovered on a "full cost recovery" basis. All annual operating costs associated with private-sector services will be recovered from these users through the application of irradiation service fees. Revenues recovered from private-sector users for such services, (e.g., development of commercial or proprietary products) will be returned to the U.S. Treasury or set aside to offset subsequent operating costs.

Irradiation service fees will be established in a manner consistent with business models in place at other DOE reactor sites. The price will include costs associated with reactor operations in support of experimental testing or isotope production. Irradiation charges will be calculated for each reactor location that will be used or committed to a given customer. Irradiation fees will be reactor-location specific and will incorporate both power level and flux factor variability. In addition, the pricing will be based on the pro-rated portion of the operational costs over the irradiation campaign (currently estimated to be ~100 days per campaign).

In addition to recovery of costs for provision of irradiation services, the FFTF business model will provide for a "value recovery charge" to equitably recover the private-sector portion of reactor startup. This portion of the annual costs recovered from the private sector will be invested in a sinking fund earning a rate assumed to be 5% above inflation. The value recovery charge necessary to recover the private-sector portion of startup is estimated to be 4% of private-sector operational cost per year. The recovery of the private-sector portion of startup costs using this methodology is shown in Figure 3.5.

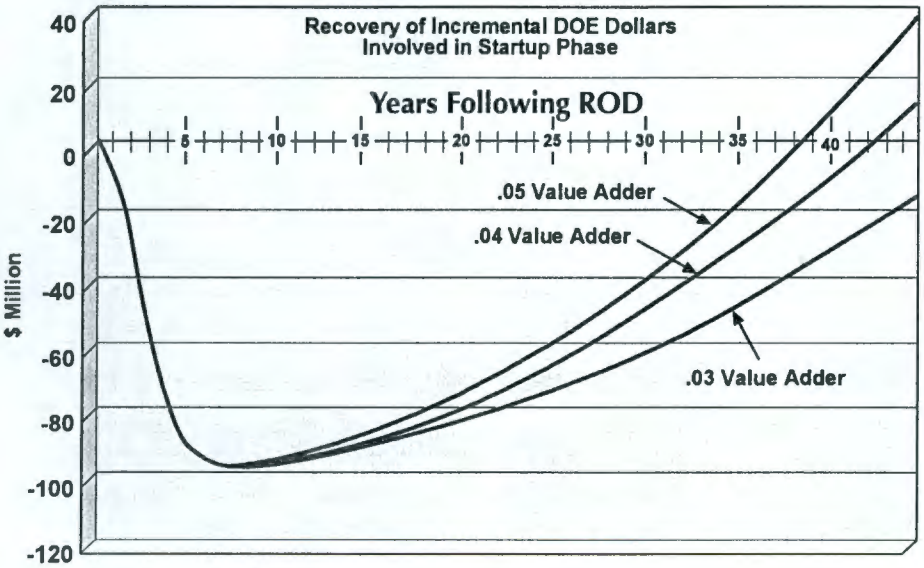

Figure 3.5 Proportional Recovery of Private-Sector Cost

3.2.2 Managing Program-Specific Costs

Additional activities, related to provision of irradiation services, might be requested/required within the missions of the individual FFTF users. Activities might include the following:

- design and construct test/target assemblies
- process test/target assemblies
- distribute/deliver product
- dispose of residual waste.

These additional activities will not be incorporated as a portion of the irradiation services fees within the FFTF user facility. Similar to other DOE business models, the FFTF business model will adopt a separate pricing structure for these activities. All program-specific costs will be borne by the project. The price to the user will be based on receipt of the target or experiment at the FFTF, irradiation at the FFTF, and preparation of the target or experiment for return or shipment to the user.

3.2.3 Estimated Revenue

The various missions analyzed within this plan are assumed to utilize a growing portion of the FFTF's overall core volume. During the first 10 years of reactor operation, the overall revenue from these missions has been estimated in the business model to grow at a rate of approximately $5 million per year, reaching annual operating revenues of $55 million in 2015. The estimates of revenues that have been obtained through the specific letters of interest and more detailed market studies indicate that these assumptions may be conservative and that full subscription may be obtained several years earlier. Beyond 2015, the anticipated revenues from public-sector use are expected to remain steady, while current estimates show the overall net revenue from public- and private-sector production of isotopes may be in excess of operational costs.

Private Sector

The revenues received from private-sector use of the FFTF's irradiation services will be primarily generated through production of isotopes for proprietary use within the medical and industrial sectors. The resultant products are expected to generate profits for the user and therefore provide increased revenues for the FFTF. A series of analyses were performed to establish the potential isotopes of interest and their market potential.

The analyses examined portions of the anticipated market for which the FFTF could produce reasonable quantities of high-demand isotopes with a total production cost at or below market values. In 1997 a research team examined the estimated costs for all additional services (beyond irradiation of the target materials) that would be necessary to generate, market, and distribute various isotopes to the medical sector. The report (PNNL and BWHC 1997) examined the cost to provide these services using staff and resources at the FFTF and PNNL. The costs estimated in this report were updated and added to the estimated cost for provision of irradiation services using the pricing methodology described above. The resultant prices were used to determine specific isotopes for which the FFTF appeared to have an overall cost advantage when compared against current market prices. The overall size and anticipated growth potential for these isotopes were analyzed to estimate potential market sales volume. These data were used to generate overall potential revenues from private-sector isotope production. The data for the time frames 2005-2010 and 2010-2020 are summarized in Tables 3.2 and 3.3.

Table 3.2 Revenue Projections for the Isotope Missions: 2005-2010 (FY 1999 $M)

2005—2010			Letters of Interest	2005	FFTF Revenue	
Isotopes	Current Price			Projected Demand[a]	Market Share	Projected Revenue
	DOE ($/mCi)	Market ($/mCi)	Yes/No (#)	(Ci's)	(%)	($M)
Established						
Co-60	0.01	0.001	Yes (2)	10,000,000	1-5%	0.3 to 1.5
I-125	***	9-20	Yes (3)	650	5-10%	0.06 to 0.3
I-131	***	1.5-15	Yes (4)	14000	1-5%	3.7 to 7.5
P-32	***	25-85	Yes (5)	40	1-5%	005 to .025
Pd-103	***	9-12	Yes (1)	2500	1-5%	0.1 to 0.6
Sr-89	113	***	No	65	5-10%	.05 to .25
Emerging						
Ac-227(Ra-223)	***	***	Yes (2)	30	5-10%	0.5 to 1.0
Cu-67	93	***	Yes (2)	260	5-10%	0.5 to 1.0
Gd-153	***	3	Yes (3)	1100	5-10%	0.1 to 0.2
Ho-166	***	5	Yes (4)	560	1-5%	b
Lu-177	***	5	Yes (4)	5	5-10%	b
Re-186	7.5	7	Yes (4)	730	1-5%	0.1 to 0.2
Sm-153	***	5	Yes (1)	1300	1-5%	b
Sn-117m	***	***	Yes (1)	50	1-5%	c
Th-228(Bi-212)	***	***	Yes (1)	140	1-5%	c
Th-229(Ac-225/Bi-213)	***	***	Yes (1)	0.8	1-5%	c
W-188(Re-188)	4-5	***	Yes (5)	150	5-10%	b
					Total Projected Revenue[d]	***5.3 to 12***

*** Value Not Found

[a]Projected demand for U.S. market in 2005.

[b]FFTF calculated value is above current market price. Revenue not included in total.

[c]Specific projections not included in revenue estimates.

[d]Revenue is the public or private funds received for the irradiation (and any target processing) services provided by the FFTF program.

Table 3.3 Revenue Projections for the Isotope Missions: 2010 - 2020 (FY 1999 $M)

2010—2020 +				2005	FFTF Revenue	
Isotopes	Current Price		Letters of Interest	Projected Demand[a]	Market Share	Projected Revenue
	DOE ($/mCi)	Market ($/mCi)	Yes/No (#)	(Ci's)	(%)	($M)
Ac-227(Ra-223)	***	***	Yes (2)	30	50 to 75	4.5 to 6.9
Co-60	0.01	0.001	Yes (2)	10,000,00	5 to 15	1.5 to 4.5
Cu-67	93	***	Yes (2)	260	50 to 100	4.8 to 9.7
Gd-153	***	3	Yes (3)	1100	20 to 40	0.4 to 0.8
Ho-166	***	5	Yes (4)	560	5 to 15	b
I-125	***	9-20	Yes (3)	650	10 to 20	0.6 to 1.3
I-131	***	1.5-15	Yes (4)	14000	10 to 20	7.5 to 15
Lu-177	***	5	Yes (4)	5	80 to 100	b
P-32	***	25-85	Yes (5)	40	15 to 25	0.1 to 0.15
Pd-103	***	9-12	Yes (1)	2500	10 to 20	1.3 to 2.7
Re-186	7.5	7	Yes (4)	730	20 to 40	0.8 to 1.5
Sm-153	***	5	Yes (1)	1300	5 to 15	b
Sn-117m	***	***	Yes (1)	50	5 to 15	c
Sr-89	113	***	No	65	40 to 60	2.2 to 3.3
Th-228(Bi-212)	***	***	Yes (1)	140	10 to 20	c
Th-229(Ac-225/Bi-213)	***	***	Yes (1)	0.8	20 to 30	c
W-188(Re-188)	4-5	***	Yes (5)	150	30 to 50	b
				Total Projected Revenue		*23.7 to 45.8*

[a]Projected demand for U.S. market in 2005.

[b]FFTF calculated value is above current market price. Revenue not included in total.

[c]Specific projections not included in revenue estimates.

**Projected revenue estimates for 2020 assume conservative market demand equal to 2005 U.S. market demand. Actual markets are projected to expand by 7% to 14% per year.

*** Value Not Found.

These analyses were qualified by close interaction with a number of private enterprises whose business is the production, distribution, and/or application (for research or clinical use) of radiopharmaceuticals. Major radiopharmaceutical companies were contacted by letter, with a follow-up phone call or person-to-person interaction. (See Appendix A.1 for the letter responses from these companies.) Nearly all respondents identified specific isotopes of particular interest which coincided with the isotopes listed in Table 2.3 and, along with the Expert Panel Report (Expert Panel 1999) and current pricing data, formed the basis for isotope selection in Tables 3.2 and 3.3. Most of

the companies had to qualify their growth projections (except one[d]), stating that growth has occurred and will continue to do so, but only with a reliable, consistent, and cost-effective supply[e,f]. Likewise the respondents were unanimous in their conclusion that the existing supply either is, or will be, inadequate in the near future, that reliable sources of high-quality (high-specific-activity[g]) isotopes are needed, and that the lack of supply hinders their research.[h] Many companies expressed an interest in partnering with PNNL in planning for future production.[i,j] Nearly all stated that facilities such as the FFTF should be used to ensure the production of current clinical and promising research isotopes.[k,l,m]

The revenue values shown in these tables are calculated on a conservative basis. The overall demand for individual isotopes is kept constant throughout both time periods at the projected U.S. demand level for 2005. The current estimates of market growth rate for these isotopes have been previously estimated at 7% to 14% per year. The projected market share is estimated on the assumption that increased market share will occur over time as factors such as reliability, quality, and costs are established within the medical/industrial community. In specific cases larger market shares are estimated for isotopes expected to be produced primarily at the FFTF.

Beyond 2020, revenues from isotope production are expected to grow as a function of overall market growth rate. If large market growth rates are realized and the overall size of revenues generated from isotope production increases accordingly, it is anticipated that the FFTF will work closely with private industry to examine the potential of privatizing the facility.

Public Sector

The revenue received from public-sector use of the FFTF's irradiation services will be generated through non-proprietary research testing and production of isotopes for government and/or clinical uses. The resultant products are not expected to generate profits for the user and are therefore not expected to generate additional revenues beyond the actual cost of FFTF-provided services.

International sponsored research, which is one of the public-sector activities, is an important element of this plan. The United States benefits from international

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[d] "We anticipate annual growth rates of more than 20% per year for TheraSeed® palladium-103 brachytherapy seeds for localized prostate cancer," Raymond W. Ruddon, M.D., Corporate Director Science and Technology, Johnson & Johnson Company.

[e] "The growth of therapeutic isotopes depends upon the availability of cost effective isotopes. The industry looks to DOE to prepare for the growth in therapeutics by continue fundamental research in target methodology, processing chemistry and isotope separation both in government laboratories and academic institutions. Industry does not have the facility or expertise to conduct this work," William J. DeLorbe, Executive Vice President, Life Sciences Enterprise, Dupont Pharmaceuticals Company.

[f] "We anticipate that radioisotope consumption will continue to increase, but sales will ultimately depend on reliable production, chemical quality, reasonableness of cost and federal approval of new radioisotope products," Robert M Sharkey, Director Clinical Research, Garden State Cancer Center.

[g] "The standard iodine-131 from Canada is mostly stable (non-radioactive) iodine 127, and these 'cold' and useless atoms tend to occupy the binding sites on the targeting protein that we need for radioactive iodine-131," Eugene A Woltering, MD, Director, Surgical Research, Louisiana State University Medical Center.

[h] "Unfortunately, our research has been severely hampered over the years because the government has so poorly supported a strong isotope production program ...We have had difficulty sustaining some of our research efforts because of a lack of radioisotope availability," Robert M. Sharkey, Director Clinical Research, Garden State Cancer Center, July 5, 1999.

[i] "In the case of our company, we are facing a watershed period in that our existing facilities are at capacity and we will need to build or find extra space in the near future. Hanford is a possibility for our expansion and an isotope program at FFTF might add to the attraction of the area," Len Hendrickson, President, Isotope Production Laboratories, June 30, 1999.

[j] "ABC Laboratories is interested in an alliance with PNNL-FFTF...,We believe we will soon outgrow the capacity of our current arrangement with MURR - but this does provide a useful model of how PNL and ABC could work together," Jake Halliday, President and CEO, ABC Laboratories.

[k] "Hence it is critical to have an additional supply of radionuclides for the medical field. An examination of FFTF indicates that it can supply all of the reactor produced nuclides which are used for restenosis prevention and in several cases, produces them better either in terms of rate of supply, or more importantly, in quality measured by both specific activity and impurities. It is therefore critical that FFTF be brought back on-line to ensure adequate supplies for medical uses," Michael R. Henson, Chairman and CEO, Radiance Medical Systems, Inc.

[l] "The possibility of the reactivation of FFTF with provisions for both facilities for the production of short-lived radioisotopes and extensive core volume for production of long-lived radioisotopes is both interesting and exciting. Failure to reactivate FFTF would be a major waste of a vital resource," J. L. Shepherd, President, JL Shepherd & Associates.

[m] "Given the limited availability of reactors of high flux in the United States, making FFTF available with short term irradiations possible would be important to the support of promising targeted radiotherapies for cancer and other diseases," Alan R. Fritzberg, Chief Scientist and Chairman of the Scientific Advisory Board, NeoRx Corporation.

collaboration at the FFTF in three ways. First, under the Work-for-Others full cost recovery arrangements, the international contribution is a direct source of funds. Second, for cost-sharing arrangements (typically 50/50), the United States acquires valuable data at half the cost, while still offsetting some operating costs. Third, and more importantly, the United States should continue to have a strong role in worldwide nuclear matters, and restart of the FFTF will enhance that role. Agreements to transfer U.S. nuclear technology have improved nuclear safety worldwide and have been an effective negotiating mechanism for encouraging other nations to strengthen their non-proliferation regime. The financial contributions from the first two benefits can be easily quantified, but value cannot be reasonably assigned for the third.

The FFTF will derive revenue by producing a number of special research isotopes for the DOE's medical, industrial, and research isotopes supply service within the DOE Isotope Programs Office (NE-70). For many of the isotopes, the private sector lacks either the capability to produce or the ability to successfully finance a profitable private-side venture (see footnote d on page 3-11). The Isotope Programs Office maintains a revolving fund to support the cost of producing isotopes that have been requested for research activities. These isotopes are made available to government, private, and commercial institutions at prices that support a reasonable return to the revolving fund, but do not over-price and thereby discourage use. This DOE programmatic function helps build new markets for radioisotopes in previously underdeveloped technical areas. The DOE business model for research isotopes assumes that successful research will foster increased demand. Increased demand will lead to increased production and increased sales. These in turn will allow for improvements which reduce the unit costs, further increasing demand. At some point, the process is ready for privatization. As an example, DOE supported the production, radiochemical processing, and marketing of radiochemically pure yttrium-90 at Hanford for several years until the revenue from sales was sufficient to offset the cost of production. As yttrium-90 sales became profitable, the activities were transferred to the private sector.

Table 3.4 summarizes the expected funding from both the private and public sectors. Early operations will require base-level funding at the ~$24 million per year level. As described in the business model analysis, the base-level funding is expected to be eliminated between 2010 and 2020.

The United States benefits from international collaboration at the FFTF.

Present Value Comparison of Alternatives

The costs and revenues for the two options facing DOE (shutdown or restart) are shown in Figure 3.6. The net costs resulting from the two options are compared as present value costs for year 2000 assuming a discount rate of 5% per year over the life cycle of the FFTF.

The present value cost to DOE for a decision requiring immediate shutdown and deactivation of the FFTF is estimated to be $172 million. The present value costs for restart and operation of the facility are shown for two primary revenue cases. The first case assumes that the FFTF builds a market share of approximately 5% to 10% over the first 3 to 5 years of operation while the market demand remains constant, and then maintains this share while the overall market demand grows at a rate of 7%, 10%, and 14% per year. The second case assumes that the FFTF builds a market share of approximately 15% to 20% over the first 10 to 15 years of operation while the market demand remains constant and then maintains this market share while the overall market demand grows at a rate of 7%, 10%, and 14% per year.

The results for the conservative market penetration rate (5% to 10%) combined with an overall small market growth rate (7% to 10%/year) indicate that restarting and running the reactor over its 34-year life (with subsequent deactivation) would cost the government approximately $100 to $250 million more than immediate deactivation in present value over the 40-year project duration. This represents the total cost of the benefits derived from the FFTF

Table 3.4 Revenue Projections for FFTF Operation at 100 Megawatts (FY 1999 $M)

Mission	Sponsor	Deliverable	Revenue* 2005-2010	Revenue 2010-2020+
Isotopes (medical & industrial)	Private Radio-pharmaceutical Companies	See Tables 3.2 and 3.3	8.5**	34**
Plutonium-238 Production	National Aeronautics and Space Administration (NASA) (through DOE- NE)	2-5 kg/year with a capability to produce 5.7 kg/year @ 100 megawatts	5.0	7.0
Non-Proliferation Technical Programs	International plus MD (through DOE-NE)	Joint Research Program	10.0	10.0
Materials Testing	DOE-Office of Science (SC)	Fusion materials research	4.0	4.0
Medical Isotopes (development)	National Institute of Health (NIH) and DOE-NE	Clinical trial quantities of targeted isotopes	1.5	1.0
Accelerator Transmutation of Waste (ATW) Research	DOE-NE	Irradiation test data on candidate fuel forms	1.0	3.0
Nuclear Energy Research Initiative	DOE-NE	Annual competitive research program	1.0	2.0
		Total Annual Revenue	31.0	61

*Revenue is the private or public funds provided for the actual research or specific irradiation services at the FFTF, not the total program or isotope cost.

**Projected revenue estimates for 2020 assume conservative market demand equal to 2005 U.S. market demand. Actual markets are projected to expand by 7% to 16% per year.

***Mid-range of the estimates from Table 3.2 and 3.3

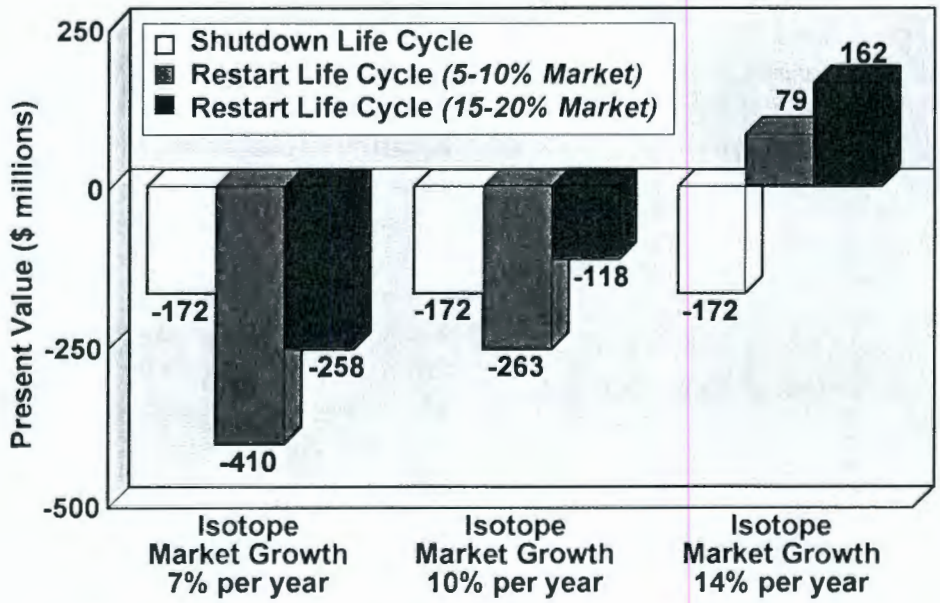


Figure 3.6 Net Present Value Life-Cycle Cost Comparisons

Assuming a more realistic market penetration (15% to 20%), for the same low-end market growth rate, the opportunity costs range from approximately $80 million in additional costs to a present value savings of approximately $50 million compared to immediate deactivation. In either case if the private use demand grows at the upper range of the experts' estimates (14% per year), the facility would actually generate a profit (approaching $100 to $200 million) over its lifetime. If this high growth rate case were to materialize, DOE would need to examine the options for privatization.

In all cases, even with the conservative market penetration (5% to 10%), and low growth (7% per year), the net present value cost to operate for 30+ years then deactivate is not so much larger than the cost to immediately deactivate, that a decision could be based on this comparison alone. This analysis does not consider, or take credit for, any reduction in health care costs from advanced uses of isotopes. These savings would likely result in reduced Medicare costs based on the demographics of the U.S. population.

3.2.4 Basis for Confidence

The projections in this section were based on the following analyses and assumptions:

- **Prior Facility Production and R&D Activity** - During its 10 years of operation, FFTF users conducted a robust program which, while by itself could not cover the entire cost of operation, provided partial reimbursement. Previous sponsors have been contacted to confirm their desire and intent to re-establish a similar level of activity at the facility.

- **Existing DOE Programs** - The potential level of support (e.g., plutonium-238 production) was determined from programs within the DOE that have formally, through appropriate ongoing or completed National Environmental Policy Act (NEPA) reviews, established the specific levels of demand and potential pricing structure.

- **Market Analysis** - The FFTF estimated revenue levels are based on the DOE's Expert Panel report (Expert Panel 1999), selecting only isotopes for which the FFTF, because of size and fast spectrum, is especially well suited for production that complemented other likely sources.

- **Conservative Program Demand Forecasts** - While NASA is reviewing a possible greatly expanded demand for plutonium-238 and/or space reactor development, the assumptions used were the current official forecast for plutonium-238 demand and no reliance on any space-reactor work. Industrial interest in using the FFTF for hardening electronic circuits was considered too preliminary to assign a revenue assumption. Given existing program uncertainty, no revenue was projected from research supporting the DOE's plutonium disposition program even though the FFTF would be a logical option.

The development of isotopes will become the DOE's most important contribution to advancing health care technology.

While the Nuclear Energy Research Advisory Committee (NERAC) continues its work on the Nuclear Science and Technology Infrastructure Roadmap (NERAC 1999), DOE staff, using the available draft, have been able to identify a variety of likely research reactor missions important to the future. While not all these missions would ultimately be performed at the FFTF, it is clear that DOE has few other reactor options to meet the anticipated needs and that the FFTF has the physical capability to do so.

The projected need for medical and other isotopes, as shown previously, has a considerable range and has been controversial for years; however, earlier this year, the DOE brought together a panel of recognized experts (Expert Panel 1999) to help establish the most reliable projection, based on the progress seen across many areas of medical isotope research. These projections, which have been accepted and issued by the NERAC, indicate that the use of isotopes for the treatment of cancer and other illnesses will grow between 7% and 14% each year over the next two decades. Even at the low end of the range, this growth will quickly overwhelm available isotope production reactors, hindering the introduction of many important medical isotopes. The FFTF could serve as the basis for a private-public partnership to support the growth in the application of medical isotopes. Success in

this area would have a beneficial impact in supporting the development of isotopes to become the DOE's most important contribution to advancing health care technology and helping to reduce medical treatment costs nationwide.

The other potential missions (listed in Table 2.2) are the result of the project team's best understanding of the need in each area, based on the current draft of the Nuclear Science and Technology Infrastructure Roadmap and the expressed plans of various organizations. Table 3.4 presents the value or revenue of the FFTF's potential contribution to various missions once it achieves steady-state operation and participation with each mission. The estimated values of these missions are conservative. While they may be significant, potential contributions to some national security research activities are not listed in the table, as the responsible organizations have not yet finalized their plans.

3.3 Plant Recovery, Restart, and Routine Operations

This section outlines the key activities, costs, and schedule associated with the restart and operation of the FFTF, and summarizes the basis for the high degree of confidence in the credibility of the projected cost and schedule.

3.3.1 NEPA Review

Should the Secretary determine that restart of the FFTF is warranted, the DOE would conduct a NEPA review of a proposed restart and operation of the FFTF as a multi-mission facility supporting isotope production, space technology, U.S. and international research activities, and irradiation services. The NEPA review process would involve public scoping and participation, and the preparation of a Notice of Intent (NOI), an EIS, and a ROD. Public scoping and participation would involve formal interactions with potentially affected and/or interested members of the public; Federal, tribal, state, and local governments; and stakeholder groups. The EIS would describe the purpose and need for the restart and operation of the FFTF, the proposed action and reasonable alternatives, and the affected environment, and would fully analyze the potential environmental impacts and mitigation of the affected environment and resources.

Before publication of an NOI to formally initiate the NEPA review process, the DOE would work with the states of Washington and Oregon to publicly present the FFTF's proposed restart activities and multi-mission operations, including rationale; potential resulting environmental impacts, including generation, management, and disposition of waste streams and spent nuclear fuel (SNF); and associated cost estimates.

Table 3.5 outlines a potential schedule for completing the NEPA review process within 15 months.

3.3.2 Required Upgrades for Restart

Because system maintenance and rigorous configuration management have been retained at the FFTF, few major systems and/or equipment upgrades are required to support restart and continued operation. The upgrades are limited to those areas where reliability will be significantly enhanced, maintenance and repair reduced, and operational performance improved. Included in Appendix A.2 is a description of plant modifications and other activities that support restart of the FFTF.

Table 3.5 FFTF NEPA Review Schedule

Date	Activity
September 1999	Notice of Intent (NOI) Published in Federal Register
October 1999 to December 1999	Public Scoping Meetings and Public Comment Period
March 2000	Draft Environmental Impact Statement (EIS) Issued
April 2000 to August 2000	Public Hearings and Public Comment Period
November 2000	Final EIS Issued
December 2000	Record of Decision (ROD) Issued

3.3.3 Cost and Schedule Estimate for Restart

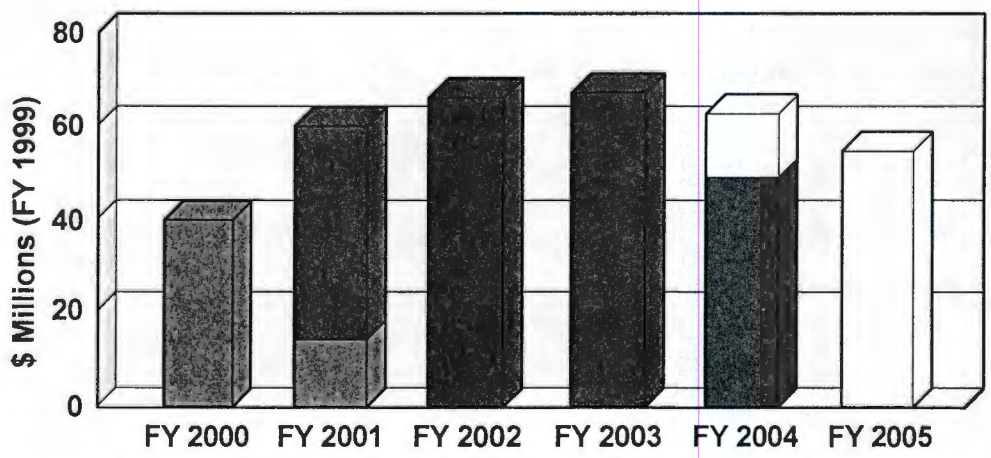
After the January 1997 decision to place the FFTF in standby, increased emphasis was placed on maintaining the "health" of the facility to ensure that operating systems were fully able to support a later decision either to restart or resume deactivation. Preventive maintenance on current operating systems has been increased, the maintenance backlog has been reduced by 36% since January 1997, and key systems and components that support either a restart or shutdown decision have been or are being upgraded (e.g., the Closed Loop Ex-Vessel Refueling Machine, Sodium Removal System, Solid Waste Cask). As a result of these efforts, the FFTF is in excellent condition, requiring minimal upgrades before restart.

Beginning with a restart ROD, the preliminary cost estimate for a 100-megawatt, multi-mission restart is $229 million (in FY 1999 dollars). This includes the cost of recovering all systems, upgrades, modifications, installation of a rapid retrieval system for short-lived isotopes, staff increases, and training. The annual operating costs, once restart was complete, would be $55 million. The funding profiles for major phases associated with restart of the FFTF are shown in Figure 3.7.

Figure 3.8 provides a Level 0 schedule for the major activities that must be accomplished to support restart in July 2004. The underlying assumptions for this cost profile and restart schedule are listed in Table 3.6.

During the planned 42-month restart, more than two-thirds of the anticipated costs are in support of plant engineering and operations staff labor. Any acceleration of schedule saves over $4 million per month off the restart cost estimate.

A preliminary Work Breakdown Structure (WBS) is shown in Figure 3.9. The major tasks required to support the program have been identified and described. These tasks would form the foundation on which a final WBS would be developed once the ROD was issued to authorize reactor restart activities.



	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005
Standby	40	15				
Startup		45	67	68	49	
Operations					14	55

Figure 3.7 EIS/Restart Funding Profile

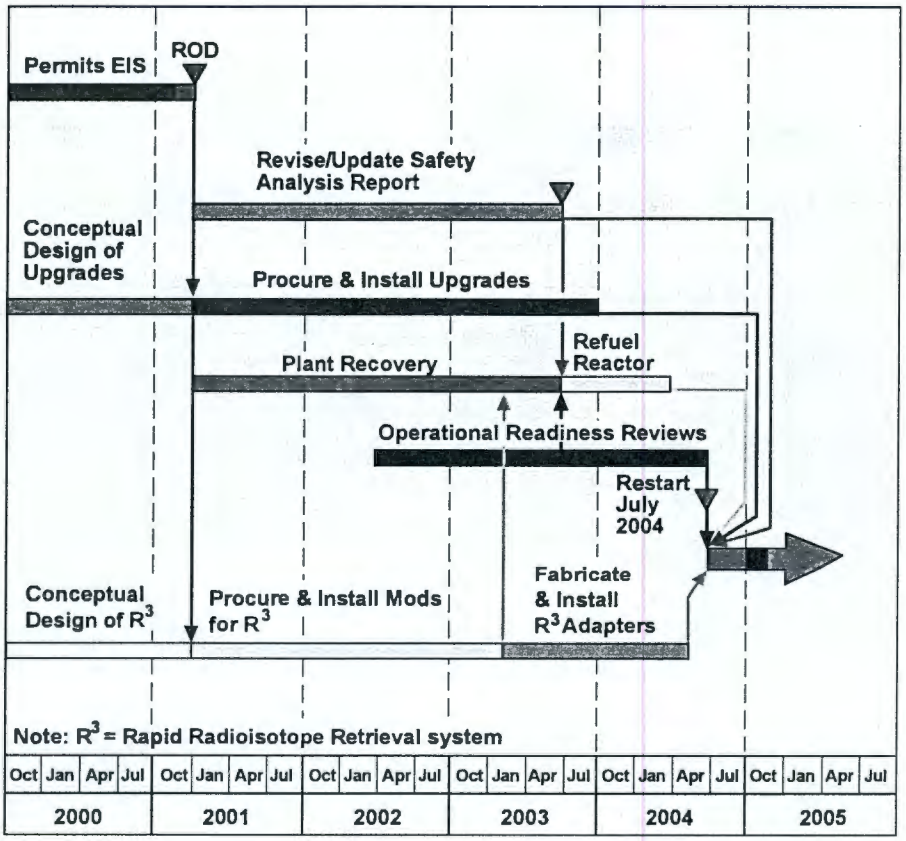


Figure 3.8 Level 0 Restart Schedule

Table 3.6 Restart Cost and Schedule Assumptions

• All cost estimates are in FY 1999 dollars. • Staffing estimates are based on Operations and Health Physics working around the clock and all other organizations continuing their currently defined day shifts. •The operational regulatory authority will be DOE. • DOE-RL and DOE-HQ will support operational restart reviews and safety analysis document reviews within the times shown on the schedule. • The EIS effort will begin no earlier than September 1999, with the ROD issued in December 2000. • Reactor operations will be 100 megawatts with a capacity factor of at least 75%. • Initial operation at 100 megawatts precludes the need for a fuel supply to be available at or near the time of reactor startup. Operation at this power will permit operation for six years following restart without additional fuel.	• Chemical analysis will be provided by a contracted laboratory except for on line cover gas analysis and fuel failure detection. • The design and manufacture of irradiation targets/specimens will be provided by the user in accordance with FFTF procedures. Post-irradiation shipment and processing will be conducted or provided by the users. The cost of irradiation targets will be borne by the users. • Irradiation of targets will begin after completion of initial reactor restart, low-power physics testing, and training. • During any continued period of standby, the material condition of facility equipment will be maintained at least on par with today's plant conditions. • Safeguards and security will be established appropriate to the operational needs and missions.

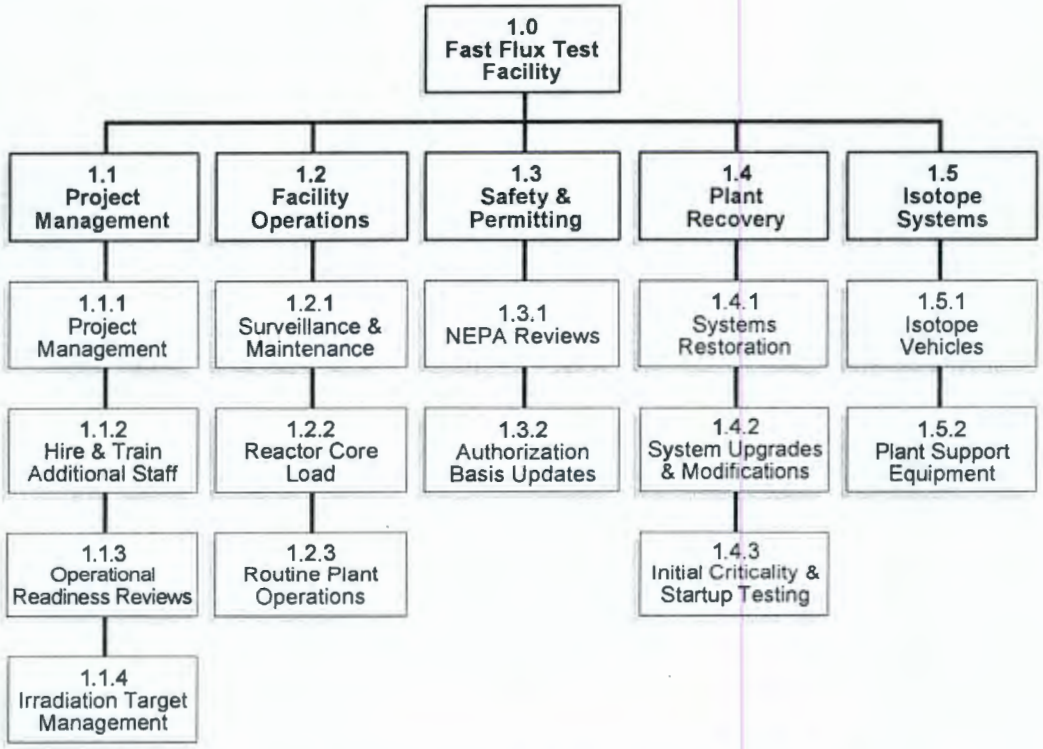


Figure 3.9 Preliminary Work Breakdown Structure

3.3.4 Routine Plant Operations

The annual operating cost for the FFTF (in FY 1999 dollars), with existing fuel, is estimated at $55 million per year. This funding level fully supports all costs associated with the plant operations, including $2 million for ongoing systems and equipment upgrades (Operations Assurance). However, as stated in the assumptions in Table 3.2, the $55 million does not include user program costs, experiment-related design, fabrication, safety analysis and reviews, modifications of authorization basis to allow for irradiation, or post-irradiation processing. Figure 3.10 provides a breakdown of the costs.

Steady-state operating staffing levels are estimated at 410 full time equivalents (FTEs). This staffing level is consistent with the operating levels for the FFTF in the late 1980s and early 1990s. Figure 3.11 shows the distribution of the anticipated staffing for routine operations.

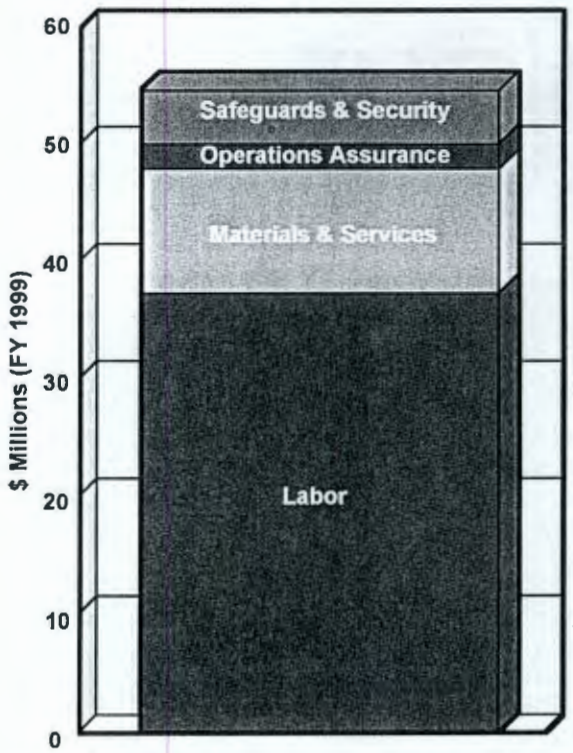


Figure 3.10 Cost Distribution for Steady-State

3.3.5 Basis for Confidence for Restart and Routine Operations

The confidence in the financial estimates is based on four factors: the FFTF's initial design, its current condition, its record of operation, and independent reviews.

Design. As a test reactor supporting advanced reactor development and the next-generation liquid-metal reactor, the FFTF was designed to meet the licensing requirements of a commercial plant. The NRC, at DOE's request, performed a detailed technical review of the FFTF Final Safety Analysis Report (FSAR) and reported to the DOE, via an NRC Safety Evaluation Report (SER), that the FFTF could be operated safely. The standards and controls established during operations have been maintained. Configuration management is excellent.

Current Condition. The FFTF restart primarily consists of system recovery: reintroducing working fluids, reconnecting power supplies, and performing instrument calibrations

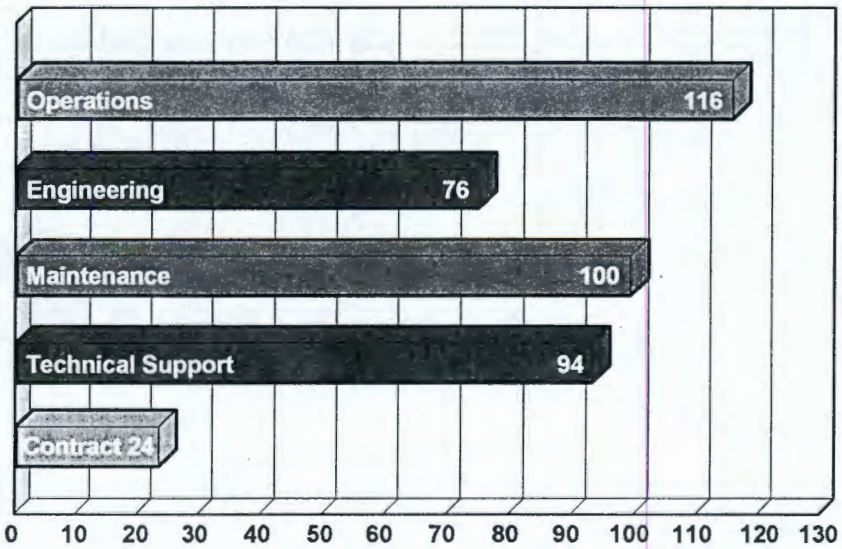


Figure 3.11 Steady-State Staffing Levels for the FFTF

Table 3.7 Cost Comparisons of FFTF Restart and Operations (FY 1999 $M)

	Defense Programs[1]	DOE-RL Independent 95% Confidence	Putnam, Hayes, & Bartlett High Estimate[2]	Current Estimate
Maintain Plant/EIS[3]				$55.0
Restart Costs	$227	$239	$255	$229.0
Annual Operating Costs	$48	$52	$52	$55
Annual Fuel Costs[4]	$4.1	$5.5	$5.2	$5.3
Annual Fuel Storage Costs[5]	$1.0	$0.0	$1.0	$0.0
Deactivation Costs[6]	$269	$215	$269	$296

[1]Defense Programs estimated high confidence in the restart-related costs and schedule.

[2]The Putnam, Hayes & Bartlett high estimate included 138% contingency ($48.26 million) on plant upgrades, security upgrades, reactor refueling plant systems recovery, NEPA, Safety Analysis Report (SAR), and operational readiness review (ORR) activities.

[3] The external reviews assumed that the EIS and plant recovery were completed in parallel. The current estimate is based on completing the EIS in 15 months and proceeding with plant recovery after a positive ROD. The EIS costs estimate from the external reviews varied from $2 million to $4.3 million and are included in the external review restart cost estimates.

[4]If the FFTF uses the SNR-300 fuel, no new fuel would be required to operate the FFTF from restart in 2004 through 2020. The total cost for fuel in this case is $2.8 million. Note that the "current estimate" assumes that new HEU assemblies will be fabricated at a cost of $350 K each.

[5]Fuel storage costs are based on experience with the current system, 15 assemblies per year. Note that the first new additional cask to support fuel offload is not needed for 20 years after FFTF restart and operation begins. Therefore, the "current estimate" of 0 is based on no new cask procurements.

[6]Deactivation costs are based on reinitiating deactivation after the FFTF has operated in a multi-mission role. Estimated deactivation from current plant condition is $199 million.

and preventive maintenance on all plant hardware. All plant changes since the facility last operated have been thoroughly documented via engineering change packages. No irreversible deactivation steps have been performed, nor has there been any cannibalization of systems while the facility has been in standby. The restart estimate includes $20 million as contingency to address component failures, replacements, and upgrades.

Record of Operation. The FFTF is not a "green field" project. The facility and its supporting infrastructure exist and have more than 10 years of operating experience. The FFTF plant is in excellent condition with

- ready access for all significant recovery actions
- existing assembly and laydown areas
- no issues of weather restriction on planned activities
- no need to construct staff support facilities.

Although the total staff has been reduced by nearly 27% since the FFTF last operated, a high percentage of staff in key technical positions are still at the facility. Engineering is at 75% of normal operating levels, and more than 80% of those engineers have experience at power. Operations still has 5 operating crews at >60% of the normal complement on each crew. More than 80% of the operators have experience with the FFTF at power.

The average continuity of service for the current FFTF employees is 19 years. This experience factor reflects in-depth knowledge of systems, processes, and ability to accurately estimate the time (and cost) of work to be performed.

The FFTF staff has consistently met work plan milestones during operation, standby, and deactivation on or ahead of schedule, always with a favorable (positive) cost variance with small (< 5%) schedule variance. During the FFTF's 10 years of operation, adherence to mission objectives averaged 98%.

During deactivation, performance on the Sodium Storage Facility was excellent, demonstrating the ability to successfully coordinate design, construction, and acceptance activities. This major construction project was completed 4 months ahead of schedule and 18% under budget.

Independent Reviews. Extensive external reviews of restart have been conducted by experienced senior management personnel and operations consultants:

- Defense Programs Review 10/95 - 3/96
- Independent Review by DOE-RL team 8/96 - 10/96
- Putnam, Hayes & Bartlett 10/96 - 1/97.

As indicated in Table 3.7, the current estimate is in general agreement with the external, high confidence/with contingency estimates. These cost estimates have been well established by past operations.

3.3.6 Comparison of Restart with Deactivation Costs

The total estimated cost to complete the deactivation is $199 million. If the Department determines that the FFTF is not needed and that a permanent shutdown is required, existing Tri-Party Agreement (TPA) milestones would require timely resumption of deactivation (WDOE, USEPA, USDOE 1998). Based on current plant status, it would take approximately six years to complete all required deactivation activities and transfer the facility to the Environmental Restoration Contractor for long-term surveillance and maintenance. This timeline is based on an optimum funding profile shown in Figure 3.12. Before the FFTF was placed in standby in January 1997, the project team had more than 2 years of deactivation experience. A□detailed shutdown plan (WHC 1996) exists and forms the basis for the above costs and schedule estimates.

The critical path for successful execution of the deactivation activities is the purchase of the remaining Interim Storage Casks, a long-lead equipment purchase estimated at $9 million. This purchase, along with the funding required to maintain the staff and facilities to execute the work, forms the basis for the $50 million required in FY□2000. Should the funding level be less than that shown in Figure 3.12, then the total cost and schedule duration would increase. It is unclear where the FFTF deactivation would fit into the Hanford Environmental Management Integrated Priority List, given the current high-visibility issues; e.g., SNF at the K-Basins, tank waste storage, and the privatization of Hanford Waste Vitrification. Without sufficient funding (~$40 million

per year) to retain key resources who have the specialized knowledge to operate and maintain one-of-a-kind refueling equipment, the ability to execute the deactivation activities in a reasonable time frame is equally uncertain. For example, if in FY 2000 the FFTF standby budget request remained at ~$30 million, the one-year loss of personnel would increase the eventual deactivation cost by an estimated $65 million (total = $264 million) and increase the schedule by 2 years.

3.4 Financial Merits and Drawbacks

If the DOE decides to operate the FFTF, there is sufficient identified need for the facility to justify most, if not all, of its operating cost. The financial merits and drawbacks of FFTF operation are enumerated in Table 3.8.

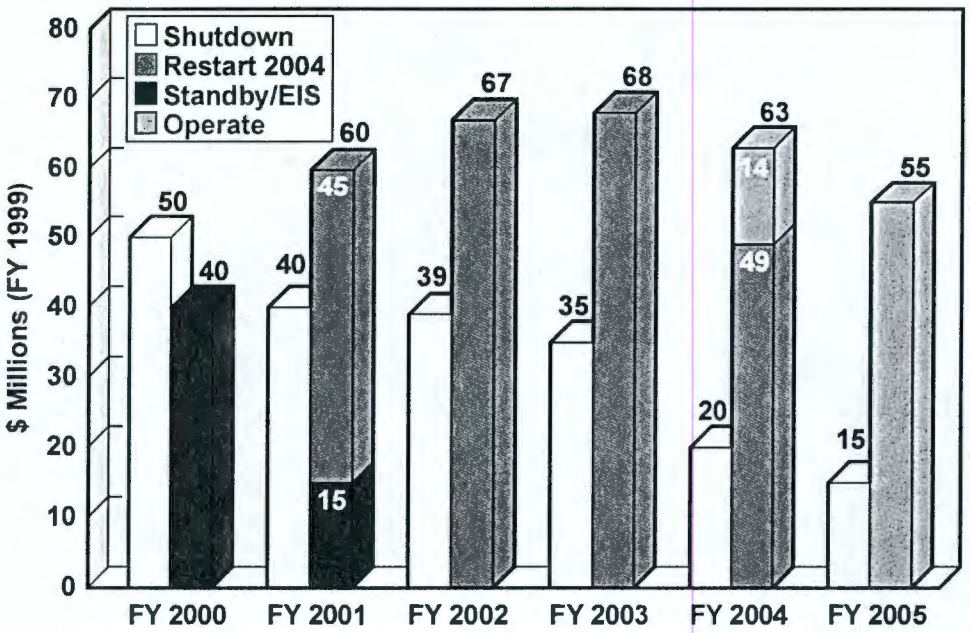


Figure 3.12 Deactivation Versus Restart Cost Profiles

Table 3.8 Financial Merits and Drawbacks

Merits	Drawbacks
• There appears to be a sufficient set of potential missions to warrant the restart, and to allow a proportionate recovery of restart costs associated with future private sector uses of the facility. • Deactivating the FFTF precludes the use of one of the few remaining U.S. reactor research and irradiation services reactors, and there is little likelihood that support and funding could be obtained for designing and constructing a new facility in the foreseeable future. • By providing a potential competitor for nuclear science and irradiation services, restart of the FFTF will compel others to hold down costs for research and irradiation services. • There is high confidence in the credibility of the restart cost estimates. • The business model is straightforward, is comparable to those successfully used at other user facilities, and has been validated by DOE and an independent review.	• Foreign sources for reactor research and irradiation services could be less expensive, and not require infrastructure investment. Other nations (for example, France with the proposed Jules Horowitz reactor) could construct the needed facilities without U.S. investment. • Restart and operation of the FFTF will be perceived by other test and irradiation service reactors in the U.S. as "competing" for limited funding. • There is uncertainty in the revenue projections. • The NEPA process and obtaining the necessary funding add uncertainty to the schedule.

4.0 Management Approach

The management approach presented in this section of the FFTF will resume safe, secure, and efficient operation as a government-owned, contractor-operated nuclear facility in that it

- establishes singular, clearly defined lines of responsibility and authority in the contractor organization and in the DOE-contractor relationship for FFTF project management, restart, operations, and maintenance
- is capable of implementing and managing a viable model for a customer-oriented user facility that ensures scope, cost, and schedule requirements are met
- provides assurance that FFTF staff are knowledgeable, experienced, and proficient in reactor engineering, operations, safeguards and security, technical support, and regulatory compliance
- creates strong partnerships with key public- and private-sector entities
- ensures that FFTF restart and operation will not divert attention or funding from the number one priority at Hanford – cleanup.

The following sections describe the past and proposed management structures for the FFTF, review the expected regulatory approach, lay out the expected user facility model as benchmarked against other U.S. reactors, and discuss the non-financial relationships with the community, universities, and professional organizations.

4.1 Organizational Structure and Reporting

The historical and current management practices employed at the FFTF are described in the next section followed by a proposed management model for facility restart and operations.

4.1.1 Historical Information

Based on a conceptual design developed by PNNL in the 1960s, the FFTF was constructed, started up, and operated as a fuels and materials test reactor facility, managed by a Hanford Site contractor, Westinghouse Hanford Company (WHC), integral with the Hanford Engineering Development Laboratory (HEDL). HEDL was tasked with development of advanced reactor fuels and materials, and liquid-metal technology. HEDL coordinated its reactor engineering development activities with PNNL and the other national laboratories, and with international reactor development programs. FFTF operations were conducted in direct support of these reactor development activities.

The FFTF plant manager, reporting to the HEDL director, was directly responsible for all operations and maintenance (O&M) activities. The plant manager's organization included, along with O&M personnel, plant system engineers and onsite safety and quality assurance engineers.

Closely coordinated with and in support of FFTF operations, the HEDL laboratory functions included the following:

- engineering standards and requirements
- nuclear safety and quality assurance requirements and oversight
- reactor fuel design and procurement
- management and administration of reactor development program activities, including an irradiation test program
- technical support in reactor core physics and engineering, liquid-metal technology, radiation protection, and waste management.

In the late 1980s, the HEDL organization was dissolved. An advanced reactor engineering group was established

within WHC to provide technical support to the FFTF, similar to that which had been provided by HEDL during operations.

The FFTF will cooperatively draw on the expertise of staff at the Argonne National Laboratory

Essential to the FFTF's successful operating history have been effective management and organizational practices:

- rigorous *design and configuration control*, implemented by the in-plant engineering and operations staffs. Cognizant system engineers work closely with the O&M staffs. Configuration control is maintained through rigorous change control procedures.
- a dedicated *technical support staff*, knowledgeable and competent in the reactor, fuel, and plant design, and the underlying fast reactor engineering and liquid-metal technologies
- a highly competent *operations staff*, developed and sustained through adherence to rigorous selection, training, and quality standards
- independent review and oversight of *nuclear safety* aspects of design, operations, and maintenance of reactor, fuel, plant systems, and irradiation/test vehicles. Both the contractor and DOE conducted these activities in close coordination with facility operations.

These essential practices have been sustained during the standby period, and would be reflected in the FFTF restart and return to operations.

4.1.2 Current (Standby) Organization

Standby of the FFTF plant is managed by the Director, FFTF Project as an element of the Babcock & Wilcox Hanford Company (B&W Hanford) Facility Stabilization task within the Project Hanford Management Contractor (PHMC) organization. This organizational arrangement was established to carry out the shutdown and demobilization of the facility, in the event that were to occur. The current FFTF plant staff is made up, in substantial part, of personnel who have prior FFTF operating experience, providing a vital core for resumption of operations.

The site advanced reactor engineering group would need to be reconstituted to provide technical support to the FFTF. While a number of individuals with prior experience, either in O&M or in technical support, are still employed at Hanford in other organizations, the most effective approach to rebuilding this capability would be to ensure that the FFTF will cooperatively draw on the expertise of existing staff at the Argonne National Laboratory – West (ANL-W) facility.

4.1.3 Restart Organizational Relationships and Responsibilities

Safe and efficient conduct of the restart and operation of the FFTF, a complex nuclear reactor plant, requires a technically competent and experienced contractor organization, under contract arrangements that provide for dedicated, single-purpose undertaking of the task.

4.1.3.1 Premises

This management plan can be successfully executed because it is based on the following premises:

- The FFTF would be restarted and operated as a part of the DOE Office of Nuclear Energy, Science and Technology (NE) program. NE currently operates all DOE reactors and has programmatic responsibility for the Advanced Test Reactor (ATR) and the Annular Core Research Reactor (ACRR).
- The FFTF would be restarted and operated as a government-owned, contractor-operated reactor under DOE safety and regulatory cognizance.
- Contractual responsibility for operation and maintenance of the FFTF, and for the nuclear sciences/ irradiation services user facility program, would be undertaken by Battelle under the DOE contract for the operation of PNNL[c]. One of the key benefits of

[c]The PNNL Contract (DE-AC06-76RLO 1830, Section C-3.h) for FY98-02 provides that "If the decision is made to restart the FFTF for production and/or testing mission, then startup and future operational responsibilities may be assigned to the Contractor by the DOE, including direct incorporation of the FFTF facility activities and staff as part of the Laboratory under this Contract."

such a transfer will be to ensure that the FFTF restart and operation does not divert focus away from Hanford cleanup.

- PNNL would be the sponsoring DOE laboratory for FFTF operation and use.

- PNNL would competitively subcontract with a technically competent and experienced reactor plant operations contractor to conduct FFTF plant restart and operation under DOE/PNNL direction and oversight.

- PNNL would, to the greatest degree possible, privatize business operations activities associated with private sector products and services, including target/test preparation and processing (see letters in Appendix A.1 – Private Companies).

4.1.3.2 Functions

The Battelle Memorial Institute (see letter from the Battelle Chief Executive Officer in Appendix A.1 – Operating Contractors), through its operation of PNNL for the Department of Energy, commits to restart the FFTF as a user facility to provide nuclear research and irradiation services supporting the nation's scientific, engineering, and medical communities. Battelle intends to use its strong international and commercial contacts and customer base to ensure that the market for the FFTF's products and services is fully engaged, and that support is obtained to offset the FFTF's operating costs. Battelle is also committed to meeting agreed-upon goals for restart cost and schedule, operational excellence, and revenue offset targets in accordance with performance agreements established with the DOE that place any and all FFTF-related fee at risk. Under this arrangement, the principal organizational functions are outlined in Figure 4.1. Specific PNNL tasks would include the following:

- Provide FFTF/irradiation services program management, including product development, budget, cost and schedule control, in close coordination with the cognizant DOE program managers (DOE-NE and through an established NE program office at the Richland Field Office [RL]).

- Establish and maintain a User Services Group (USG) which, through an Advisory Committee with diverse membership, would coordinate interactions with the user community to promote the growth and mission of the FFTF as an international nuclear science and irradiation services user facility.

- Establish, organize, and train those PNNL staff who would provide technical support, including nuclear safety oversight, to the FFTF subcontractor, and who would develop and manage the FFTF user facility and replacement reactor fuel programs.

- Support development of the EIS and the other NEPA requirements pertaining to FFTF restart.

- Manage the development, review, and approval of the updated Final Safety Analysis Report (FSAR) pertaining to FFTF restart and operation.

Letters of commitment were obtained from three qualified reactor operations organizations.

- Select, provide contract administration, and technically direct the operating subcontractor for the FFTF (as indicated in the current PNNL contract).

  To demonstrate the availability of qualified subcontractors, letters of commitment were obtained from three qualified reactor operations organizations, and a memorandum of understanding (MOU) signed for joint support with the other major fast reactor-experienced U.S. organization:

  - Babcock & Wilcox (incumbent)
  - Duke Engineering
  - Energy Northwest
  - Argonne National Laboratory.

  These companies have committed to operate the facility under the subcontractor arrangement specified in this description, to successfully restart and operate the facility, and to use their corporate resources to promote the FFTF's capability (see letters in Appendix A.1 – Operating Contractors).

- Provide direct technology support as well as Environment, Safety, Quality, and Health (ESQ&H) oversight to the operating subcontractor for the FFTF. This would include coordinating and

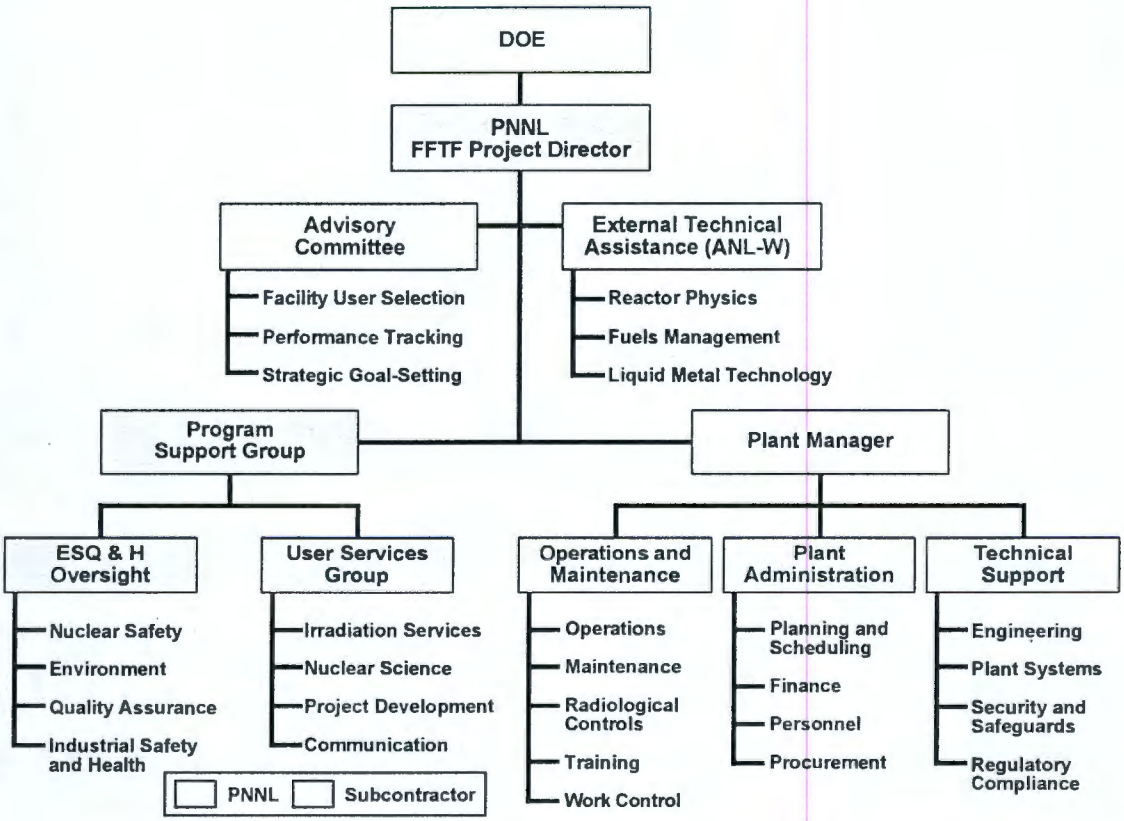


Figure 4.1 Organizational Outline for FFTF Restart and Operation

establishing working agreements with ANL and other DOE laboratories, as required. The DOE and the other identified regulatory groups would provide the independent oversight of ESQ&H at the facility.

- Provide sponsorship, development, technical management, and administration of an irradiation services and nuclear science user facility program for the FFTF, responsive to the developing needs of the users of those services.

- Develop and manage a program to meet needs for FFTF replacement reactor fuel.

The principal subcontractor functions are organizationally outlined in Figure 4.1.

Subcontractor tasks would include the following:

- Establish and maintain effective contractor "ownership" of the FFTF facility.

- Manage the O&M, technical support, and plant administration functions.

- Obtain and utilize the appropriate services from the site Management and Integration contractor to ensure minimal duplication and cost.

- Rebuild, train, and qualify the FFTF O&M staff.

- Restart, operate, and maintain the FFTF reactor plant under DOE/PNNL direction.

- Manage the facilities and equipment ancillary to the FFTF under DOE/PNNL direction.

- Effectively manage and control allocated government resources.

4.1.3.3 Implementation

As indicated in Figure 4.1, PNNL functions and responsibilities related to FFTF operation and its irradiation program would be carried out under the management of an FFTF Project Director. A combination of dedicated and matrixed staff assignments in the laboratory organization would be implemented to fulfill the task requirements.

Continuity and technical capability would be prime considerations in fulfilling these assignments.

The organizational outline of the FFTF plant functions shown in Figure 4.1 generally reflects that which was used during prior operations and has been continued through the standby period. It is clear that as the facility transitions from restart to steady-state operations, the specific organizational structure will be adjusted to most appropriately support the actual mission mix.

The contractor line of responsibility and authority for FFTF operations and for the nuclear safety aspects of the facility and of the irradiation program would flow directly from the Project Director (PNNL) to the plant manager (operating subcontractor).

Privatization options will be evaluated.

Essential to successful operations would be the early establishment of close working relationships (as formally established in a responsibility accountability matrix) between the operating FFTF plant staff and their counterpart PNNL project management and support staffs (ESQ&H Oversight and USG).

In rebuilding the FFTF plant staff and establishing the PNNL support for restart, assistance would be sought from other DOE laboratories and facilities. The extensive fast reactor and liquid-metal engineering and operations experience of the ANL-W staff is the prime example. An MOU between PNNL and ANL highlighting cost- and capability-saving collaboration has been established in the following four areas (see letter in Appendix A.1 – Operating Contractors):

- joint program development and performance of projects utilizing the FFTF's nuclear science and irradiation services capabilities
- specific technical support tasks to be undertaken by ANL, particularly in the areas of fast reactor physics and engineering, liquid-metal technology, nuclear safety review and analysis, and fuels and materials technology
- temporary assignment of ANL operations and technical support personnel to the FFTF
- joint planning for the recruitment and assignment of qualified and experienced personnel within the respective contractor organizations, with any transfers subject to individual staff career aspirations as well as DOE approval.

The FFTF will not only draw on the experience available at ANL-W, but will establish a cooperative relationship with other national laboratories engaged in nuclear activities and reactor operations. Appendix A.1 contains a letter signed by the national laboratory directors pledging their support for cooperatively employing the valuable reactor resources they operate (as well as their endorsement of maintaining this nation's critical nuclear core competencies and infrastructure). As an example of this desire for more cooperative relationships, PNNL has also signed an MOU with the new operators of the Idaho National Engineering and Environmental Laboratory (INEEL) - Bechtel National, Inc. and BWX Technologies, Inc. - to collaborate on nuclear science and technology and to avoid duplication in facility use.

4.1.3.4 Potential for Privatization

For the purposes of this plan, privatization was not considered for FFTF reactor operations. However, there have been expressions of interest in privatizing all operations associated with the FFTF by those believing that if DOE was willing to enter into a mutually acceptable long-term facility lease with a private company, private source funding could be obtained to support the FFTF restart[b]. During the EIS process for an FFTF restart, if initiated, privatization options will be evaluated for alternative management approaches, including

- full privatization of FFTF restart and operations
- alternative contractor relationships (other than with FFTF as part of PNNL)

[b]Advanced Nuclear & Medical Systems (ANMS) submitted an unsolicited proposal, dated September 1996, to the DOE for the privatization of the FFTF. In July 1997 the DOE notified ANMS that it was premature to consider privatization proposals for the FFTF. However, the DOE indicated that it would consider privatizing the facility if a decision were made to restart it.

- economic inducement incentives to attract FFTF users or support facility operators
- leveraging of existing FFTF and ancillary facilities to promote investment and use
- joint initiatives with regional economic development activities.

4.2 Regulatory Approach

The FFTF has established, through its 10 years of operation, an excellent record of providing nuclear science and irradiation services (see Appendix A.2). It has proven to be a safe, reliable, and environmentally benign reactor plant. Bringing the FFTF back into the DOE long-term nuclear infrastructure as a national user facility should entail no significant changes in the design, configuration, or operating mode that would have any appreciable nuclear safety or environmental consequence.

The FFTF continues to be classified as a government-owned reactor, and would be restarted and operated under an incentive-based DOE Management and Operations (M&O) Contract. The facility would be subject to all DOE Orders and Regulations pertaining to the operation of a nuclear facility (USDOE 1995).

The FFTF would also be subject to all applicable state and federal regulations, including NEPA requirements. A restart of the FFTF and the use of its supporting facilities for any proposed missions would be preceded by the preparation of an Environmental Impact Statement (EIS) and would necessitate a positive Record of Decision (ROD) in accordance with the Council on Environmental Quality regulations for implementing the NEPA (40 CFR Parts 1500-1508) and the DOE NEPA regulations (10 CFR Part 1021). The EIS would describe the purpose and need for restart of the FFTF, the proposed action and identification of the reasonable alternatives, and the affected environment, as well as fully analyze the potential impacts and mitigation of the affected environment and resources. Formal and interactive EIS scoping and review participation by other government agencies, the impacted states, tribal nations, stakeholder groups, and the general public would be a major activity during the time between the decision to start an EIS and the expected ROD. The Draft EIS would reflect input from the public scoping process and the Final EIS would reflect public comments on the Draft EIS.

At a minimum, the EIS would analyze the following issues:

- effects on the public and onsite workers from releases of radiological and non-radiological materials during normal operations and reasonably foreseeable accidents
- long-term risks to human populations resulting from waste disposal
- comparison on a technical, economic, and environmental basis of using the FFTF versus the available set of alternatives for supporting the identified suite of missions
- effects on air and water quality from normal operations and reasonably foreseeable accidents. Included will be an assessment of the necessary and appropriate state and federal permitting actions needed, including likely exclusions, modifications to existing agreements, and potential for new submittals.
- cumulative effects, including impacts from other past, present, and reasonably foreseeable actions at the Hanford Site
- effects on endangered species, archaeological/cultural/historical sites, floodplains and wetlands, and priority habitat
- effects from transportation and from reasonably foreseeable transportation accidents
- socioeconomic impacts on surrounding communities
- disproportionately high and adverse effects on low-income and minority populations (Environmental Justice)
- unavoidable adverse environmental effects
- short-term uses of the environment versus long-term productivity
- potential irretrievable and irreversible commitment of resources
- the consumption of natural resources and energy, including water, natural gas, and electricity
- pollution prevention, waste minimization, and potential mitigating measures

- the most appropriate regulatory structure to appropriately ensure a coherent nuclear safety program, including the potential alternative relationships dependent on mission profile with the DOE, Defense Nuclear Facilities Safety Board (DNFSB), the NRC, and the International Atomic Energy Agency (IAEA).

The FFTF has been operated successfully, and information is readily available (Neitzel et al. 1998) on the history and description of the Hanford Site, land resources, visual resources, site infrastructure, air quality and noise, water resources, geology and soils, biological resources, cultural and paleontological resources, socioeconomics, public and occupational health and safety, waste management, etc. The preparation of this EIS is therefore expected to be relatively straightforward, be low in cost, require little new information, and be complete (i.e., ROD issued) in 15 months.

Because the FFTF and its supporting facilities are existing DOE facilities, there would be minimal local land use impact and any changes would be consistent with the *Draft Hanford Remedial Action Environmental Impact Statement and Comprehensive Land Use Plan* (USDOE 1998a). Land use for the FFTF would be in full agreement with the plan established to reflect the positions of the involved tribal nations.

Various waste streams from proposed activities are and would continue to be managed in accordance with the applicable Federal and State regulations. In addition, a "Waste Management and Minimization Plan" will be prepared in concert with the states of Oregon and Washington to ensure that any FFTF waste issues do not negatively impact Hanford Site cleanup.

A "Waste Management and Minimization Plan" will be prepared in concert with the states of Oregon and Washington.

A wide range of postulated reactor accidents were analyzed in the existing FSAR. No substantial environmental or public health and safety impacts were identified in the FSAR or the initial startup EIS (USAEC 1972). However, in addition to the restart EIS analyses, a full Level 1 Probabilistic Risk Assessment and a complete upgrade of the existing FSAR to the most current DOE requirements would be completed before restart.

NRC involvement will be pursued for the FFTF restart.

In preparation for the original startup of the FFTF, the NRC and its Advisory Committee on Reactor Safeguards (ACRS) provided, at DOE's request, a detailed technical review of the nuclear safety aspects of the facility. This included a review of the Safety Analysis Report (SAR) and the writing of a Safety Evaluation Report (SER). The NRC involvement provided added assurance to the DOE and to the public that the plant could be operated safely. A similar NRC involvement will be pursued for the FFTF restart safety review (see NRC letter in Appendix A.1).

DOE also works closely with the IAEA to verify to the international community that all relevant requirements concerning accountability for special nuclear materials are being met under the current Voluntary Agreement. While formal discussions with IAEA regarding the FFTF have not yet been conducted, DOE would, before restart, address IAEA involvement at the FFTF to verify the inventory and characteristics of nuclear materials at the facility. IAEA has a long-standing program with fast reactors and has declared their willingness to help facilitate FFTF's use by the international community (see letter from IAEA Department of Nuclear Energy in Appendix A.1 – International Organizations).

4.3 User Facility Operation

The DOE maintains nearly 80 major user facilities within its complex, including the High Flux Beam Reactor (HFBR) at the Brookhaven National Laboratory, the Advanced Test Reactor (ATR) at the INEEL, and the High Flux Isotope Reactor (HFIR) at the Oak Ridge National Laboratory. The DOE has as part of its charter the planning, construction, and operation of these user facilities, and the responsibility to make them available to serve the research and development (R&D) needs of the nation's

universities, industry, private laboratories, Federal laboratories, and others. As stated by the DOE's Office of Science,

> The nation's scientific and technology enterprise requires and relies upon access to a broad variety of very advanced scientific facilities and laboratories. About 18,000 DOE and non-DOE-sponsored scientists from industry, university and government conduct unique, cutting-edge experiments at the Department's basic research user facilities each year. The construction and operation of major scientific facilities not only sets DOE apart from the other Federal agencies that support science, it ensures that our Nation will maintain its world leadership across a multitude of scientific disciplines. (http://www.er.doe.gov/)

PNNL has demonstrated the ability to successfully bring on line a new national user facility

PNNL has recently demonstrated the ability to successfully bring on line a new national user facility, the Environmental Molecular Sciences Laboratory (EMSL). PNNL intends to model the FFTF as a national user facility after both the EMSL and the other U.S. reactor facilities.

4.3.1 Benchmarking with Other U.S. Reactors

During June 1999, a DOE-contractor team from the FFTF toured and met with staff from HFBR, ATR, and HFIR to review capabilities, business models, and current capacities for new or expanded missions to ensure that this Program Scoping Plan reflects a mission and business approach that build on the success of and complement operations at those other facilities.

The consensus of the benchmark team and the DOE/contractor staff interviewed at the three reactor sites was that a restarted FFTF would not adversely compete with, but could support the use of, these other facilities for their specialized mission profiles. The managers of all the DOE reactor facilities also agreed (see letter from national laboratory directors, Appendix A.1 – Operating Contractors) that the DOE needs to maintain, employ, and operate its nuclear facilities infrastructure as an integrated (rather than site-competitive) system to meet existing and emerging national needs.

FFTF staff also made an earlier visit to the Annular Core Research Reactor (ACRR) at Sandia National Laboratories. The ACRR's small core volume, conversion status, uncertain availability, and lack of private sector interest prohibited comparison with the three larger reactors and, correspondingly, with the FFTF.

Table 4.1 Other Reactors' User Community Approach

Reactor Facility	User Community Approach (reference)
HFBR	"User Coordinator" (http://bnlstb.bio.bnl.gov/biodocs/hfbr/hfbr_contacts.html)
ATR	"New Business Contacts" (http://www.inel.gov/capabilities/nuc-tech/index.html)
	Contract with International Isotopes Idaho Inc. – full rights to market and sell all isotope products manufactured at the ATR as well as exclusive rights to market and sell existing inventories of DOE cobalt-60. (http://www.intisoid.com/corporat.htm)
HFIR	"Research Reactors Division Experiment Coordinator" (http://www.ornl.gov/hfir/hfir8.html)

4.3.2 User Community Input/Interfaces

The DOE and PNNL would promote and manage the use of the FFTF in a manner similar to the central point-of-contact approaches shown in Table 4.1 for the HFBR, ATR, and HFIR.

A key element of that approach would be the establishment of a User Services Group (USG), which would coordinate all interactions with the user community. To enhance those interactions, an Advisory Committee would be established to evaluate and promote the growth and mission of the FFTF as an international nuclear science and irradiation services user facility. The committee, which would include regional stakeholder and university membership as well as representation from professional groups and organizations (e.g., Federal agencies, IAEA, Electric Power Research Institute [EPRI], and international partners), would also

- evaluate the review and selection process for access to all of the FFTF facilities
- advise on the development, modification, and/or acquisition of specialized FFTF support facilities
- advise on appropriate metrics for evaluating the effectiveness of the FFTF as a user facility, and review progress toward goals based on those metrics
- foster the communication of FFTF goals and objectives to the user community, and represent those users as an independent liaison
- provide feedback on new collaborations, progress of present collaborations, and user activities
- have representation, as appropriate, in major reviews of FFTF operations.

The USG would be modeled after the successful program PNNL has established for the EMSL (http://www.emsl.pnl.gov/homes/homepage.html). The USG will be organized to focus on the private and public sectors where there are different objectives and expectations for product results. The charter of this group will be to establish the technical and business ties to both public and private clients. A key product of this group will be the defining of client priorities and requirements, and working with the FFTF operating staff to tailor an irradiation services program and products to fulfill these requirements. As an example of the required technical integration for development and production, the functional steps for a successful medical isotope program include

- preparation of target materials
- fabrication of target materials
- assembly of isotope target components and irradiation vehicles
- irradiation service program
- target processing
- delivery and distribution (production) or testing and redefinition of irradiation or processing program (development).

The integration of steps such as these would be defined in a Product Program Plan approved by the client and the FFTF operations organization. In essence this would be a product business plan to manage all aspects of the client's technical, financial, and interface requirements (to the extent desired). The Product Program Plan would be linked to a formal baseline funding plan for the FFTF, updated annually and maintained to provide a life-cycle financial balance sheet for the facility.

A business plan will be developed for each service or mission area that would provide the objectives, strategies, market analysis, marketing approach, and financial plan. The capabilities of the FFTF would be defined and marketed to public and private clients in an approach tailored to their specific application. This marketing would not be confined to specific FFTF irradiation and testing services, but would integrate DOE complex and other private capabilities with client requirements for delivering the full suite of services (processing, product testing, analysis, transportation).

It is expected that, to the maximum degree possible, performance-based contracting would be used with most clients. This approach would include firm fixed-price and firm unit-price contracts with select clients. Time and material contracts are likely to be used predominantly where there is a strong developmental nature to the work.

4.4 Public/Private Interfaces

4.4.1 Community Relations

The FFTF operating organization has had and would continue to have a strong outreach program, including communications, frequent and open facility tours and briefings, and active involvement with interested stakeholder groups. Several key community relationships would be emphasized:

- **Hanford Advisory Board** - The Board is an independent body consisting of a balanced mix of the diverse interests that are affected by Hanford cleanup issues. The FFTF operating organization would work closely with the Board, especially during the NEPA process, to ensure that any Board concerns regarding a perceived potential interference of FFTF restart with cleanup priority at Hanford, waste generation at the FFTF, or other issues are addressed. Regarding Hanford Advisory Board concerns relative to waste operations, a Waste Minimization and Management Plan will be negotiated with the Oregon Department of Energy and the Washington State Department of Ecology focussed on reducing any impact to the rest of the Hanford Site.

- **Regional Economic Development Organizations** – The FFTF operating organization would work with local groups to appropriately promote the involvement of private organizations with the FFTF project relative to reactor uses, target preparation and processing activities, and facility support (including privatization of select activities, as approved by the DOE).

- **Public Partnerships** – Modeling the approach taken at Brookhaven National Laboratory to respond to problems at the HFBR, as part of the EIS process for the FFTF, a system for communication and involvement that addresses the concerns and interests of local, regional, and national groups and individuals will be established. From membership on the Advisory Committee to regularly scheduled meetings on facility progress and problems, the facility would use the suite of available communication tools and an open process for sharing information to develop and maintain public confidence regarding the facility's contributions and safety.

4.4.2 University Partnerships

Five major Northwest regional universities expressed their level of interest and support for the concept of the FFTF as a user facility:

- Oregon State University
- Oregon Health Sciences University
- Reed College
- University of Idaho
- Washington State University

Each university responded (see letters in Appendix A.1 – Regional Universities) with the clear statement that, with its restart, the FFTF would provide an extremely valuable resource for the nation's faculty and students by providing both research and educational opportunities related to nuclear science, engineering, and medicine.

These universities have, through their ongoing association with PNNL, established a broad range of strong collaborations. The universities believe that the availability of the FFTF's proven research capabilities would enhance and extend collaborations, particularly in the areas of medical isotope development, production, and applications; materials processing; and electronic materials development. These collaborations would also involve training and educational activities, utilizing tours, simulator operation, and joint classroom functions (with faculty, plant staff, and student participation).

Universities believe that the availability of the FFTF would enhance and extend collaborations.

Where appropriate, the universities also state that the FFTF's capabilities and configuration are distinctly different from, and therefore completely complementary to, their own university research reactors. The universities are strongly interested in participating in the use of the FFTF through educational and research programs, most specifically in the recently created Nuclear Energy Research Initiative (NERI) program. The FFTF provides an excellent test-bed for researcher-initiated R&D proposals from the universities, national laboratories, and industry, and the regional universities welcome the opportunity

to participate in the competitive, peer-reviewed, R&D selection process.

PNNL has master agreements for joint technical programs, collaborative agreements, and MOUs with over 100 colleges and universities, as well as arrangements with 180 PNNL Affiliate Staff Scientists from those and other universities and colleges. Special emphasis will be placed in attracting and involving students with backgrounds that are under-represented in the nuclear field, through targeted activities with individual and groups of universities (for example, regional Tribal Colleges and the Historically Black Colleges and Universities). PNNL has also developed software for a prototype collaborative environment that would provide a wide range of communications tools for offsite individuals involved in user research at the FFTF. PNNL has been working with Oregon State University and Washington State University to formulate Nuclear Engineering and Radiation Health Physics graduate degree programs (through Ph.D.) in the Richland, Washington area. These programs would draw upon many of the FFTF's unique capabilities in these academic disciplines. Through joint research, involvement with the user facility advisory committee, and expansion of the existing PNNL educational programs that would bring faculty and students to work at and with the FFTF, a strong affiliation would be established between the DOE, the FFTF, and the university community.

4.4.3 Relationships with Professional Organizations

Major professional societies with related interests in the proposed missions for the FFTF were contacted to gauge their level of interest and support for the concept of the FFTF as a user facility. Positive expressions of support (see letters in Appendix A.1 – Professional Societies) were obtained from organizations such as the American Society of Nuclear Cardiology, Radiological Society of North America, Nuclear Medicine Research Council, National Association of Cancer Patients, and Health Physics Society.

The interest of these societies represents not simply a validation of the facility's potential, but also an opportunity to partner with these organizations to promote potential programs and attract potential users to the facility.

4.5 Management Merits and Drawbacks

The primary advantage in placing the management responsibility for the FFTF under PNNL would be that the facility would then be more closely linked to the expected internal and external customer base for nuclear science and irradiation services. PNNL would be held accountable not just for safe and efficient operation, but also for establishing the facility as a premier nuclear materials testing, isotope production, and plutonium fuels research facility.

By selecting a support contractor with demonstrated expertise and available infrastructure to support reactor facility operations, the DOE can ensure through its management of PNNL that excellence in safety and efficiency receive the same priority as excellence in technical contribution. The only major drawback to this approach is the use of multiple contractors, which if not properly managed through clear roles, responsibilities, authorities, and accountabilities could create operational and program delivery problems at the facility. Table 4.2 summarizes the management merits and drawbacks.

Table 4.2 Management Merits and Drawbacks

Merits	Drawbacks
• The user facility model is accepted within DOE and demonstrated at other reactor facilities. PNNL is experienced in putting together a successful program. • FFTF's prior operation and existing infrastructure should minimize unforeseen technical, cost, schedule, performance, or regulatory "surprises" during restart or operation. • The use of an experienced reactor operations subcontractor in concert with a national laboratory should provide for the best in operations and user interaction. • Regional university and professional organization support is very strong. • Access to the capability of ANL-W (as well as other national laboratories with whom PNNL has established strong, formal relationships) would enhance technical quality and potentially save costs that would be incurred if the FFTF had to locally staff up to support all reactor activities. • Moving the FFTF from the Project Hanford Management Contractor (PHMC) to PNNL would deflect criticism that any operating role for FFTF would distract the PHMC from its #1 priority of cleaning up the Hanford Site.	• The user facility model relies on the joint program development of the facility and the user, and compared to a single-mission facility it is harder to describe the future suite of activities, to conduct the detailed multi-client scheduling, or to avoid the impression that the work to be done is widely variable. • The FFTF's commitment to NRC review, IAEA oversight, and regional approval of its waste program may set a higher standard than required for other comparable DOE facilities (a potential complex-wide drawback, this is actually a merit of using the FFTF). • The multi-contractor model means that clear lines of authority and responsibility need to be established between PNNL, ANL-W and the O &M subcontractor to ensure that the FFTF would be managed safely and efficiently.

5.0 References

10 CFR 1021. Council on Environmental Quality, "National Environmental Policy Act Implementing Procedures." U.S. Code of Federal Regulations. (Available at http://www.access.gpo.gov/nara/cfr/index.html.)

40 CFR 1500-1508. Council on Environmental Quality, "Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act." U.S. Code of Federal Regulations. (Available at http:/www.access.gpo.gov/nara/cfr/index.html.)

Dautel, W.A. 1996. *Potential Role of the Fast Flux Test Facility and the Advanced Test Reactor in the U.S. Tritium Production System.* HNF-SP-1204, U.S. Department of Energy, Washington, D.C. (Available from DOE InfoBridge, http://gpo.osti.gov:901/cgi-bin/newwelcome.pl). – This study concluded that use of the FFTF (alone or together with the Advanced Test Reactor [ATR] at the Idaho National Engineering and Environmental Laboratory) as an integral part of a tritium production system would help (1) ensure supply by 2005, (2) provide additional time to resolve institutional and technical issues associated with the dual-track strategy, and (3) reduce discounted total life-cycle costs and near-term annual expenditures for accelerator-based systems. The FFTF would also provide a way to get an early start on dispositioning surplus weapons-usable plutonium as well as provide a source of medical isotopes.

Drell, S., D. Hammer, J.M. Cornwall, F. Dyson, R. Garwin, W. Happer. 1996. *Use of the Fast Flux Test Facility for Tritium Production.* JASON Panel Report JSR-96-325, Prepared by the MITRE Corporation for the U.S. Department of Energy. (Available at http://www.fftf.org/reports/tritium/.) – This report provides the results of a JASON review of the technical feasibility of using Fast Flux Test Facility to generate tritium needed for the United States' nuclear weapons stockpile. The study concluded that the maximum credible T production rate of FFTF is 2 kg per year if the reactor runs at its full rated power and maximum demonstrated capacity factor.

Energy Information Administration (EIA). 1999. *Annual Energy Outlook 1999*, DOE/EIA-0383(99), U.S. Department of Energy, Washington, D.C. (Available at http://www.eia.doe.gov/oiaf/aeo99/homepage.html.) – "The Annual Energy Outlook 1999 presents midterm forecasts of energy supply, demand, and prices through 2020 prepared by the Energy Information Administration (EIA).The projections are based on results from EIA's National Energy Modeling System (NEMS)."

Expert Panel. 1999. *Forecast Future Demand for Medical Isotopes.* Prepared for the U.S. Department of Energy, Washington, D.C. (Available at http://www.ne.doe.gov/nerac/isotopedemand.pdf.) – The Panel concluded that "the Department of Energy and National Institute of Health must develop the capability to produce a diverse supply of isotopes for medical use in quantities sufficient to support research and clinical activities."

Fast Flux Test Facility (FFTF) Standby Project Office. 1997. Set of three briefing books provided to the U.S. Department of Energy on December 1, 1997. Briefing Book 1: *Summary*; Briefing Book 2: *Draft Technical Information Document*; Briefing Book 3: *Other Key References* (*Medical Isotopes Production at the FFTF*, PNNL-SA-29502, and *FFTF Medical Isotopes Market Study (2001 - 2020)*, PNNL-11774). (Available at http://www.fftf.org/reports/briefing/.) – The recommendation of this report was that the U.S. Department of Energy continue to maintain the FFTF in standby and proceed with preparation of appropriate NEPA documentation to consider the FFTF as an interim supplier of tritium with a secondary mission of medical isotope production.

Frost & Sullivan. 1997. *FFTF Medical Isotopes Market Study (2001 – 2020).* PNNL-11774, prepared for the Pacific Northwest National Laboratory, Richland, Washington. (Available at http://www.fftf.org/reports/briefing/keyrefs.htm.) – This study supports the conclusion that 60% of the operating costs for the FFTF could be offset by revenues from medical isotope production within 10 years of restart.

Institute of Medicine. 1995. *Isotopes for Medicine and the Life Sciences.* Adelstein, J.S., and F.J. Manning, eds. National Academy Press, Washington, D.C. – At DOE's request, the Institute of Medicine undertook this "extensive examination of isotope production and availability, including the education and training of those who will be required to sustain the flow of radioactive and stable materials from their sources to laboratories and bedsides."

Neitzel, D.A., et al., 1998. *Hanford Site National Environmental (NEPA) Characterization.* PNNL-6415, Rev. 10, Pacific Northwest National Laboratory, Richland, Washington. – This document, updated annually, contains descriptions of the physical, climatological, and socioeconomic features of the Hanford Site and the surrounding area. The descriptions are intended for inclusion in environmental assessments, environmental impact statements, and other NEPA documentation.

Nuclear Energy Research Advisory Committee (NERAC). 1999. *Report of the Roadmap Subcommittee*, Draft B, Version 1.2 (Available at http://www.ne.doe.gov/nerac/roadmapdraft.pdf.) – The Subcommittee, recognizing that the cost of maintaining the FFTF in standby is unacceptably high, recommended that the U.S. Department of Energy either identify a compelling set of missions and conduct an EIS or some similar review, or begin the shutdown and dismantlement of the facility.

Oak Ridge National Laboratory (ORNL). 1997. *NSNS/CDR-1 National Spallation Neutron Source Executive Summary: The NSNS Collaboration.* NSNS/CDR-1, Oak Ridge, Tennessee. (Available at http://www.ornl.gov/~nsns/CDRDocuments/ExecSum.pdf.) – This document describes the need, vision, and collaborative approach for the construction of a National Spallation Neutron Source.

Pacific Northwest National Laboratory (PNNL) 1999. *Isotope Production at the Hanford Site in Richland, Washington.* PNNL-12228, prepared by the Hanford Radioisotope Program staff at PNNL, Richland, Washington. (Included as Appendix A.3 of this Program Scoping Plan) – This report was prepared in response to a request from the Nuclear Energy Research Advisory Committee (NERAC) subcommittee on "Long-Term Isotope Research and Production Plans." It concludes that "the FFTF... be reactivated to supply nuclear services and products such as radioisotopes needed by the U.S. medical, industrial, and research communities."

Pacific Northwest National Laboratory and Babcock and Wilcox Hanford Company (PNNL and B&W Hanford). 1997. *Medical Isotope Production at the Fast Flux Test Facility: A Technical and Economic Assessment.* PNNL-SA-29502, Richland, Washington. (Available at http://www.fftf.org/reports/briefing/keyrefs.htm.) – This study confirmed the technical feasibility of producing at least 30 medical isotopes in the FFTF. Assuming a restart in 2002, the study concluded that by 2015 to 2020 the production of isotopes could completely offset the reactor's operating costs.

President's Committee of Advisors on Science and Technology (PCAST). 1997. *Report to the President on Federal Energy Research and Development for the Challenges of the Twenty-First Century.* Washington, D.C. (Available at http://www.whitehouse.gov/WH/EOP/OSTP/Energy/.) – The Panel's primary recommendation was to strengthen the U.S. Department of Energy - applied energy technology portfolio by increasing funding for four of its major elements (energy end-use efficiency, nuclear fission, nuclear fusion, and renewable energy technologies) and restructuring part of the fifth (fossil fuel technology).

Scott, S.W. 1996. *Scoping Assessment on Medical Isotope Production at the Fast Flux Test Facility.* HNF-SD-FF-RPT-010, Revision 0. Prepared by Babcock & Wilcox Hanford Company for the U.S. Department of Energy. (Available at http://www.fftf.org/reports/medical/.) – This assessment concluded that the FFTF could produce large quantities of a variety of radioisotopes concurrently with a tritium production mission. then transition its role to a supplementary/backup tritium source and shift its focus to radioisotope production. Over the next 30 years, the FFTF could increase U.S. market share to at least 50% of the rapidly expanding radioisotope market.

Spicer, K.M., et al. 1997. *Evaluation of Medical Radionuclide Production with the Accelerator Production of Tritium (APT) Facility.* Prepared for the U.S. Department of Energy by the Medical University of South Carolina, the University of South Carolina, and Westinghouse Savannah River Company, Aiken, South Carolina.

United States Atomic Energy Commission (USAEC). 1972. *Environmental Statement FAST FLUX TEST FACILITY Richland, Washington.* WASH-1510, Richland, Washington. – This document is the EIS that was prepared for the original construction and startup of the FFTF.

U.S. Department of Energy (USDOE). 1999a. *Revised Draft Hanford Remedial Action Environmental Impact Statement and Comprehensive Land Use Plan.* DOE/EIS-0222D, Richland, Washington. (Available at http://www.hanford.gov/eis/hraeis/hraeis.htm.) – "The DOE's Preferred Alternative anticipates multiple uses of the Hanford Site, including: consolidating waste management operations in the Central Plateau, allowing industrial development in the eastern and southern portions of the site, increasing recreational access to the Columbia River, and expanding the Saddle Mountain National Wildlife Refuge to include all of the Wahluke Slope (managed by the U.S. Fish and Wildlife Service)."

U.S. Department of Energy (USDOE). 1999b. *Surplus Plutonium Disposition Draft Environmental Impact Statement.* DOE/EIS-0283-D, Washington, DC. (Available from DOE InfoBridge, http://gpo.osti.gov:901/cgi-bin/newwelcome.pl) – This EIS "analyzes alternatives that would use the immobilization approach (for some of the surplus plutonium) and the MOX fuel approach (for some of the surplus plutonium); alternatives that would immobilize all of the surplus plutonium; and the No Action Alternative."

U.S. Department of Energy (USDOE). 1998a. *Comprehensive National Energy Strategy.* DOE/S-0124, Richland, Washington, D.C. (Available from DOE InfoBridge, http://gpo.osti.gov:901/cgi-bin/newwelcome.pl.) – This strategy document establishes a set of five goals for national energy policy: (1) improve the efficiency of the energy system, (2) ensure against energy disruptions, (3) promote energy production and use in ways that respect health and environmental values, (4) expand future energy choices, and (5) cooperate internationally on global issues. The goals, objectives, and strategies form a blueprint for the specific programs, projects, initiatives, investments, and other actions that will be developed and undertaken by the Federal Government, with significant emphasis on the importance of the scientific and technological advancements that will allow implementation of this Strategy.

U.S. Department of Energy (USDOE). 1996. *Draft Programmatic Environmental Impact Statement for Stockpile Stewardship and Management.* DOE/EIS-0236, Washington, D.C. – "The US nuclear weapons program is reducing the size of the nuclear stockpile by dismantling existing weapons. DOE has been directed to maintain the safety and reliability of the reduced nuclear weapons stockpile in the absence of underground testing. Therefore, DOE has developed a stewardship and management program to provide a single highly integrated technical program. The stockpile stewardship portion of the PEIS evaluates the potential impacts of three proposed facilities: the National Ignition Facility, the Contained Firing facility, and the Atlas Facility."

U.S. Department of Energy (USDOE). 1995. "Startup and Restart of Nuclear Facilities." DOE Order 425.1A, Washington, D.C. (Available at http://www.explorer. doe.gov: 1776/pdfs/doe/doetext/neword/425/o4251.pdf.)

U.S. Department of Energy (USDOE). 1992. "Pricing of Departmental Materials and Services." DOE Order 2110.1A, Washington, D.C.

U.S. Department of Energy National Laboratory Directors. 1997. *Recommendations for a Department of Energy Nuclear Energy R&D Agenda.* UCRL-ID-129209 (2 volumes), prepared for the U.S. Department of Energy, Washington, D.C. (Available at http://www.llnl.gov/tid/lof/.) – This report describes the challenges associated with nuclear energy in the U.S. and "the need and role for a strong and comprehensive nuclear energy effort by the federal government."

Venneri, F., et al. 1999. *The Roadmap for the Development of Accelerator Transmutation of Waste: Target and Blanket System.* LA-UR-99-3022, DRAFT, Los Alamos National Laboratory, Los Alamos, New Mexico.

Washington State Department of Ecology (WSDOE), U.S. Environmental Protection Agency (USEPA), U.S. Department of Energy (USDOE). 1998. *Hanford Federal Facility Agreement and Consent Order, As Amended Through December 31, 1998.* 89-10 REV. 5, Richland, Washington. (Available at http://www.llnl.gov/tid/lof/. http://www.hanford.gov/tpa/tpahome.htm .) – This document, usually referred to as the Tri-Party Agreement, "ensure[s] that the environmental impacts associated with past and present activities at the Hanford Site are thoroughly investigated

and appropriate response action taken as necessary to protect the public health, welfare and the environment."

Westinghouse Hanford Company (WHC). 1996. *Fast Flux Test Facility Stabilization Project Plan.* WHC-SD-FF-SSP-0004, Revision 3, Richland, Washington.

Westinghouse Hanford Company (WHC). 1993. *A Fast Flux Test Facility Outage and Operations Report, Cycle 11, March 14, 1989 - March 19, 1991.* WHC-SP-0521-2, Richland, Washington.

Westinghouse Hanford Company (WHC). 1989. *Test Design Description Volume IA: Enriched Uranium Oxide Fuel Test UO-2.* WHC-SD-FF-TTD-0020, Richland, Washington.

Westinghouse Hanford Company (WHC). 1988. *Test Design Description: Enriched U-10Zr Metal Fuel Test MFF-4.* WHC-SP-0392, Richland, Washington.

White House. September 1993. "Fact Sheet: Nonproliferation and Export Control Policy." Office of the Press Secretary, Washington, D.C. (Available at http://www.td.anl.gov/RERTR/REFDOCS/PRES93NP.html.)

PNNL-12245, Rev. 1
Appendices

Program Scoping Plan for the

Fast Flux Test Facility

A Nuclear Science and Irradiation Services User Facility

August 1999

Pacific Northwest
National Laboratory

Operated by Battelle for the
U.S. Department of Energy

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1999-07-08

Dear Dr. Madia,

I am aware that the U.S. Secretary of Energy has asked you, as Director of the Pacific Northwest National Laboratory in Richland, Washington, to conduct a 90-day study regarding the future of the Fast Flux Test Facility (FFTF) to establish whether a compelling rationale exists for the restart of this 400 MWth reactor.

The International Atomic Energy Agency (IAEA) has a long-standing programme on Fast Reactors to which an eventual restart of the FFTF could make important contributions. The scientific and technical bases for a FFTF restart are mainly linked, in my opinion, to the increasing awareness that sustainable development of nuclear energy in the next century requires, on the one hand, continuous safety enhancement efforts, and, on the other hand, a sound strategy for natural resource utilization and waste management.

Waste management provides one very specific rationale for an eventual restart of FFTF: namely, development and testing advanced transmutation concepts. World-wide, the current studies addressing the potential of partitioning and transmutation to reduce the volume and toxicity of long-lived radioactive waste clearly indicate the need for irradiation tools for the fuel and target developments required to establish transmutation as a viable concept. Research reactors that provide suitable fast neutron fields for transmutation are disappearing throughout the world, and therefore the unique capabilities of the FFTF should be maintained.

Dr. William J. Madia
Director
Pacific Northwest National Laboratory
P.O. Box 999
Richland, WA 99352
United States of America

The IAEA's established International Working Group on Fast Reactors (IWGFR) is certainly willing to play a co-ordination role for timely exchanges of information with interested users of the FFTF among the international nuclear energy community.

Yours sincerely,

V.M. Mourogov
Deputy Director General
Head of the Department of Nuclear Energy

COMMISSARIAT A L'ENERGIE ATOMIQUE

ADMINISTRATEUR GENERAL

SRT /99 . 256

Paris, July 12, 1999

Mr. William B. RICHARDSON
Secretary of Energy
US Department Of Energy
Headquarters Forrestal
1000 Independence Avenue, S.W.
WASHINGTON DC 20585

Dear Mr. Richardson,

Members of the French Atomic Energy Commission have noted with great interest the US Department of Energy press release of May 4, 1999 regarding your plans to make a decision by August 2 regarding the restart of the Fast Flux Test Facility.

Our interest in the FFTF and its unique testing capability go back several decades when both France and US nuclear energy planners considered the capabilities of such test facilities so important that we developed similar national research and development capabilities.

Every time it developed between our two countries, cooperation in nuclear energy Research and Development proved to be important and mutually beneficial. Now, as funding limitations are affecting both our countries, there is an even greater need to identify and engage in nuclear R&D cooperation based on our common priorities.

In particular, we believe that the FFTF has most interesting characteristics in terms of power level, flux profile, testing capability, fuel usage, advanced safety features and operating experience which cannot be easily replaced. Recent visits by senior French government, industry and R & D officials, including myself, to the FFTF site have reconfirmed our favorable impression of the facility's capabilities. Furthermore, once France will have retired its last liquid metal fast flux test reactor facility (at the end of 2004, Phenix will have reached the end of its life), the US FFTF will be a high fluence liquid metal test facility that could well complement our Phenix phase out, in particular for R & D on the transmutation of long life high level waste.

We are planning to continue reactor oriented research and development in France with non liquid metal test facilities : we will rely on existing capabilities such as those in Osiris and hot cells laboratories, while preparing the future construction, scheduled to begin in 2002 in our Cadarache Center, of the new Jules Horowitz 100 MW test reactor which could be, when in operation, of a great interest for your own R & D programs.

31-33, RUE DE LA FEDERATION - 75752 PARIS CEDEX 15
TEL. 01 40 56 10 00 - FAX 01 40 56 11 99

To help achieve better coordination of our advanced reactor R & D programs, we are pleased to be in the process of reestablishing more formal ties with the DOE office of Nuclear Energy, Science and Technology. We look forward to effecting new cooperation agreement in the not too distant future. This agreement anticipates cooperation involving the FFTF and other facilities such as those mentioned above. Such cooperation could involve financial or other in-kind forms.

We therefore urge a positive decision on your part on the next phase of the FFTF reactivation program and strongly support your efforts to identify a set of sustaining missions to retain FFTF testing capability.

Sincerely,

with my best personal regards,

Yannick d'ESCATHA

Korea Atomic Energy Research Institute

P.O. BOX 105, YUSONG, TAEJÖN, 305-600, KOREA
TEL.(042)868-2000/TLX.KAERI K45553/FAX.(042)868-2702

Dr. William J. Madia, Director
Pacific Northwest National Laboratory
PO Box 999
Richland, WA 99352

July 13, 1999

Dear Dr. Madia:

I have been advised that you have been requested by the Secretary of the United States (U.S.) Department of Energy to prepare a program plan to analyze the possible application of the Fast Flux Test Facility (FFTF) as a user facility. As I understand, the plan is to be presented to the Nuclear Energy Research Advisory Committee (NERAC) on July 29, 1999 in Washington, D.C.

In an earlier letter to Mr. William D. Magwood, IV, Director, Office of Nuclear Energy, Science and Technology, I stated my belief that the restart of the FFTF would be a significant contribution to future nuclear research and development in the U.S. as well as in the world.

In view of the uncertain status of FFTF, KAERI has no current plans for use of this facility. However, if the U.S. decides to restart this facility, we can envision possible uses for fuels and materials research and isotope development.

We would be prepared to negotiate in the future a possible long-term agreement for using FFTF that would be mutually beneficial. Our possible support for this unique facility could reach several million dollars depending on our future program priorities and resources and subject to detailed negotiations.

I hope this letter is useful in developing a program plan for the future of FFTF and we will try to send a representative to the NERAC meeting to communicate our position on this important matter.

Yours sincerely,

C. K. Park

Chang K. Park, Ph. D
Senior Vice President
KAERI

JAPAN
ATOMIC ENERGY COMMISSION
2-2-1 Kasumigaseki, Chiyoda-ku, Tokyo

July 23,1999

Mr. William D. Magwood. IV
Director
Office of Nuclear Energy, Science and Technology
Department of Energy, USA

Dear Mr. Magwood,

I am writing in reference to your letter, dated June 17th, which pertained to the possible restart of FFTF. I was very happy to learn that the restart of operation is being seriously considered by the United States.

When I visited the DOE last April. I had the opportunity to give a presentation on a wide variety of joint research proposals which included FFTF utilization programs within the framework of Japan - US cooperation.

We strongly hope for the successful restart of this facility, as long as FFTF will be used for peaceful, not military, purposes.

Restarting FFTF would certainly assure that the US, already possessing vast technological knowledge in fast reactor related fields, would contribute towards the technological progress of 21st century's peaceful use of atomic energy. Japan will feel reassured in that case.

As potential programs at FFTF, we are now considering the pursuit of two areas of research in the field of the fast reactor: 1) a passive reactor safety demonstration test and 2) a TRU burning and long-lived fission products transmuration study.

Because FFTF also has an important and useful characteristic for nuclear fusion test material research requiring high radiation exposure, we would like to consider pursuing research in this field.

The utilization of FFTF would be very effective for Japan in developing efficient R&D programs in the fields of the fast reactor and in nuclear fusion. Therefore, we would like to be in closer cooperation with the United States in possible future utilization of FFTF.

The Director of the Research and Technology Division, Nuclear Energy Bureau of the Science and Technology Agency of Japan, Shinichi Kawarada will participate in the NERAC meeting on July 29th and will express Japan's interests in the utilization of FFTF. With him, Dr. Kiyoto Aizawa, Executive Director of the Japan Nuclear Cycle Development Institute, will also participate in this meeting to give an expected presentation on research programs that would make use of FFTF.

Finally, we thank you for arranging Japan's participation in the important NERAC meeting.

We are looking forward to the success of the NERAC meeting and are hoping for a positive outcome regarding the utilization of FFTF.

Sincerely, yours

藤家洋一

Yoichi Fuji-ie
Vice Chairman
Atomic Energy Commission

Department of Energy
Germantown, MD 20874-1290

June 25, 1999

Dr. William J. Madia, Director
Pacific Northwest National Laboratory
P.O. Box 999
Richland, Washington 99352

Dear ~~Dr. Madia~~: Bill

As the Department of Energy prepares to make a decision in August regarding the future of the Fast Flux Test Facility (FFTF), and in support of the effort you are currently leading to help establish the potential mission profile for that facility, the Office of Fusion Energy Sciences wants to re-affirm that the US and international fusion programs need the capabilities of the FFTF reactor as an important tool in the research to develop and test the materials needed for fusion power systems.

Until an irradiation facility designed specifically to meet the needs of simulating a fusion environment can be built, with neutron energies near 14 MeV and flux comparable to FFTF, the Materials Open Test Assembly (MOTA) facility in FFTF would be the preferred vehicle for fusion program irradiations. The irradiation volumes, temperature control, neutron spectrum and flexibility of specimen bonding method (Na, Li, He, etc) are all highly desirable features. The FFTF high neutron flux combined with the simplicity of experiment reconstitution with previously irradiated specimens would allow the achievement of potential end-of-life neutron fluence levels that cannot be achieved in facilities anywhere else. If the FFTF again becomes available, we would hope to be able to add it to the few other facilities (especially HFIR) used by the U.S. and international programs for fusion materials research. Informal and unofficial communications with members of the fusion materials user communities in Japan and Europe have confirmed their interest in and need for FFTF irradiation experiment capabilities.

The types of needed Fusion Materials Irradiation Experiments that could advantageously be conducted in the FFTF include:

- Instrumented, high-fluence irradiation of candidate structural materials at a range of controlled elevated temperatures. These would include alloy and ceramic specimens; either exposed to reactor sodium or separately contained. These experiments would be similar to the MOTA experiments previously conducted in the FFTF.

- The production and off-gas collection of tritium during irradiation of lithium-containing ceramics at high fluences and a range of temperatures. Experiments would be similar to the BEATRIX II experiments conducted in MOTA.

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- Integrated effect experiments, involving simulated subsystems with combinations of metals, ceramics, coatings, and /or liquid metals or molten salts. These would be new types of experiments, for which not even the concepts have been developed.

We understand that much of the capability (hardware, software, and personnel) to support design, fabrication, operation, disassembly, reconstitution, and post-irradiation examination of MOTAs and BEATRIX II type experiments still exists at Hanford. Fabrication equipment is still available. Disassembly and reconstitution was and will be part of the Interim Examination and Maintenance hot cell at the FFTF. It is understood that the majority of the installed "in-plant" equipment that supported the Fusion MOTA (glove boxes, computer data acquisition and control systems) has not been disturbed since last used in the early 1990's. However, reuse of this equipment will require reviews to confirm operability. Equipment renovation and upgrades in computer systems to address research needs may be required, which will require additional programmatic funding.

All fusion experiments in the FFTF were the product of international collaborations. These teams have all moved on to substitute other facilities for the FFTF, so time will be required to rebuild that user base at the FFTF. The best prospects are (a) collaborations with the European Union (EU) and Japan for the irradiation of structural materials and/or integrated effects experiments, and (b) collaboration with EU and Japan for the irradiation of tritium-breeding ceramic materials. The US could possibly be an equal partner in the first of these, but would likely be only a minor partner in the tritium breeding experiments.

While U.S. fusion budget projections do not allow the commitment of significant funding to the operating costs of the FFTF, it is possible that collaboration with interested fusion partners in Europe and Japan could fund use of the FFTF (neutron charges) in the range of $1 to 3M per year. Any international agreements to use the FFTF for irradiation experiments, however, will require some kind of assurances on the availability of the reactor for the planned irradiation schedule. Our potential partners are now quite concerned about the reliability of future operation of US facilities.

If requested, we will send a representative to the July 29, 1999 public meeting of the Department's Nuclear Energy Research Advisory Committee (NERAC) to further communicate our support.

Sincerely,

N. Anne Davies
Associate Director,
for Fusion Energy Sciences
Office of Science

cc:
W. Magwood, IV – NE-1

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

COMMISSIONER

July 15, 1998

Mr. William D. Magwood, IV
Director, Office of Nuclear Energy, Science & Technology
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Mr. Magwood:

As the Department of Energy prepares to make a decision in August regarding the future of the Fast Flux Test Facility (FFTF), I am taking this opportunity to reaffirm the facility's past and potential usefulness to the U.S. Nuclear Regulatory Commission (NRC). I am writing in my individual capacity, based on my long time involvement with advanced reactors research and development, including fast flux reactors.

From its conceptual origins both as a licensing demonstration for liquid metal reactors in the United States and as a major nuclear science and irradiation services facility, the FFTF has had strong and important associations with the NRC:

- The design was reviewed by the NRC staff and independently reviewed by the Advisory Committee for Reactor Safeguards. These reviews, along with a number of recommendations, were documented in a Safety Evaluation Report prepared by the Commission to confirm the acceptable licensing potential of the facility. The FFTF's highly successful operating history is certainly reflective of the sound standards established in its design, construction, and operations.

- The construction to commercial nuclear standards, including the N-stamped containment, and configuration control maintained for the facility clearly reflected a continuing effort at the FFTF to apply NRC standards.

- The demonstration of advanced reactor technology and safety, including enhanced safety features at the facility (such as passive heat removal through natural circulation), were very important to facilitating the Commission's review of the advanced reactor designs.

- Finally, the FFTF conducted research that has advanced the nuclear field in important areas of safety, isotope production, advanced materials, and improved fuels.

The FFTF has a well-recognized potential to conduct important research and development activities, and to contribute to expanding missions such as isotope production. Given that very few irradiation facilities remain in the United States, and the unique capabilities of FFTF, it would be in the national interest to keep this resource available. If the department decides to prepare an Environmental Impact Statement as the first step toward restart of the FFTF, I believe the

DOE/NRC Memorandum of Understanding (MOU) should accommodate assistance for conducting the startup safety review.

As you already know, the NRC expects to send a representative to the July 29, 1999, public meeting of the Nuclear Energy Research Advisory Committee (NERAC) in Washington, DC.

Sincerely,

Nils J. Diaz

cc: Chairman Dicus
Commissioner McGaffigan
Commissioner Merrifield
EDO

NJD542

POWERING PROGRESS THROUGH
SCIENCE AND TECHNOLOGY

EPRI

June 8, 1999

Dr. William J. Madia, Director
Battelle, Pacific Northwest National Laboratory
P.O. Box 999
Richland, WA 99352

Dear Dr. Madia:

I am aware that you are conducting a 90-day study for the Secretary of Energy, who will be making a decision in early August 1999, regarding the future of the Fast Flux Test Facility (FFTF) and am taking the liberty of writing to you to communicate EPRI's views on this matter.

In our opinion, the FFTF has served as one of the premier test reactors in the world. It achieved a superb reputation during its years of operation as a national research facility, testing advanced nuclear fuels, materials and components. The facility was also used to produce a large number of different isotopes for medical and industrial users, to generate tritium for the U.S. fusion research program, and to conduct cooperative, international research work.

The FFTF represents a major national investment, and EPRI hopes that your study will identify one or more high-value future missions for the facility. If one of the missions identified and approved for the FFTF is to serve as a commercial reactor research facility, then EPRI would welcome the opportunity to work cooperatively with the DOE to define R&D programs of value to current and future commercial nuclear power plants.

Sincerely,

Robin L. Jones
Vice President, S&T Development &
Chief Nuclear Officer

RLJ/bjr/9780L

c: William Magwood, Director, DOE-NE

CORPORATE HEADQUARTERS
3412 Hillview Avenue | Palo Alto CA 94304-1395 USA | 650.855.2000 | Customer Service 800.313.3774 | www.epri.com

Mr. William D. Magwood, IV
Director, Office of Nuclear Energy
US Department of Energy
1000 Independence Avenue, S.W.
Washington, DC 20585

February 5, 1999

Subject: FFTF Public/Private Partnership Proposal

Dear Mr. Magwood:

I wish to express my appreciation for your courtesy in our last conversation and for the opportunity to introduce our thoughts and concepts for an FFTF public/private operational plan. Since our last conversation, our team has reassessed its position in this initiative and drawn three precepts as our forward planning basis:

- The FFTF is a national asset that betters the quality of American life through cancer treatment, materials development, and possibly food irradiation,
- In addition to the human condition benefit, there is a positive return on investment to the government when avoided costs of cancer treatment are considered,
- Optimizing the value and return on investment in FFTF requires an alliance between the DOE and the private sector. Neither the DOE nor the private sector can alone deliver the optimum return from FFTF.

ANMS believes that we have developed an innovative proposal that forges such a public/private partnership, fits within the political realm of "doable", and fuels the mission that garnered such widespread political support at the initiative's outset.

To date, contracting limitations and funding challenges have inhibited private sector investment in federal privatization projects. This has been an issue within DOE's privatization efforts and the FFTF commercialization initiative.

As we discussed in our last conversation and disclosed in our December 22, 1998 letter to Secretary Richardson, ANMS has secured rights with Schnell-Brueter-Kernkraftwerksgesellschaft (SBK) of Essen, Germany to the surplus SNR-300 reactor fuel. This fuel is the only fabricated fuel in the world suitable for use in the FFTF.

ANMS is prepared to utilize this asset as a solution to the private sector investment issue for the development and commercialization of FFTF products.

Advanced Nuclear & Medical Systems
1933 Jadwin Ave., Suite 210, Richland, WA 99352 Phone (509) 627-3399 Fax (509) 627-3388

ANMS offers a creative partnership, outlined below, between DOE and the private sector, which we believe to be supportable under current contracting authority.

- FFTF operations remain with the DOE and are contracted to a qualified M&O contractor, such as B&W, through traditional contracting vehicles,
- ANMS will sell the SNR-300 fuel to the DOE at a discount to an agreed upon asset valuation [redacted]
- ANMS will form a Joint Venture with a National Laboratory. The Joint Venture will contract directly with DOE and establish a Trust Fund for the management of the fuel sale proceeds,
- The fuel sale payments will be made annually [redacted], subject to appropriation, and be used exclusively for research and development by the National Laboratory, and for product and business development by ANMS,
- ANMS will consider the balance of the fuel asset value as private sector's investment in FFTF operations, and
- Government investment through breakeven is recouped through participation in proceeds from licenses and royalties.

Under the ANMS plan, the Joint Venture is completely self-funded. The plan also offers significant "value-added" to the overall medical/commercial isotope mission.

- The arrangement provides a defined fuel supply source for 15 years of commercial operation,
- Use of the ANMS fuel allows the FFTF restart EIS to eliminate secondary waste streams from new fuel fabrication lines at Hanford or elsewhere,
- The ANMS plan provides private sector resources to advance the commercial utilization of FFTF, federal funds are only used for reactor operations, and
- The DOE, through its ownership of FFTF, can provide a disciplined Conduct of Operations for the safe and efficient management of FFTF.

I look forward to the opportunity for discussion during your trip next week. Please forward any questions to me for discussion preparation or formal response. Thank you for your courtesy and consideration.

Sincerely,

William J. Stokes

William J. Stokes
President and CEO

Advanced Nuclear & Medical Systems
1933 Jadwin Ave., Suite 210, Richland, WA 99352 Phone (509) 627-3399 Fax (509) 627-3388

LOUISIANA STATE UNIVERSITY MEDICAL CENTER
1542 Tulane Avenue
New Orleans, LA 70112-2822
Telephone: (504) 568-4750
FAX: (504) 568-4633

LSUMC

Department of Surgery

March 5, 1999

The Honorable Bill Richardson
Secretary of Energy
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

Dear Secretary Richardson,

SHORTAGE OF CERTAIN MEDICAL ISOTOPES AND OUR NEED FOR THE FAST FLUX TEST FACILITY

In March of 1996, I wrote to Senator John Breaux and Senator Patty Murray about our need for high-specific-activity iodine-131. This high-purity radioisotope is *not currently available* from any source anywhere in the world. We understand that it could be produced under a high neutron flux with the high neutron energies available in the core of the Fast Flux Test Facility, near Richland, Washington.

We need high specific activity iodine-131 because we are developing a cancer-targeting peptide that has four binding sites for radioiodine. The standard iodine-131 from Canada is mostly stable (non-radioactive) iodine-127, and these "cold" and useless atoms tend to occupy the binding sites on the targeting protein that we need for radioactive iodine-131. Our new approach will be able to treat patients with cancer cells that express the receptors that bind somatostatin. These cancers include certain lung, brain, colon, neuroendocrine, and pancreatic cancers.

As I previously wrote to Senators Breaux and Murray, one of our greatest challenges in developing new cancer treatments is the acute shortage of the necessary type, quality, and activity of radioisotopes for special applications. We believe that our approach will offer significant new hope to cancer patients who have no other recourses for successful treatment.

For these reasons, I encourage you to support the restart of the Fast Flux Test Facility.

Sincerely yours,

EA Woltering

EUGENE A. WOLTERING, M.D., F.A.C.S.
The James D. Rives Professor of Surgery
and Neuroscience
Chief, Section of Surgical Endocrinology
Director, Surgical Research

EAW/cao

JLSHEPHERD & ASSOCIATES
1010 ARROYO AVE., SAN FERNANDO, CALIFORNIA 91340-1822
818-898-2361 FAX 818-361-8095

June 8, 1999

Pacific Northwest National Laboratory

Attn: William J. Madia
Director

FAX: 509 375 6844

Ref: your communication of June 2 re FFTF

Dear Mr. Madia,

The possibility of the reactivation of FFTF with provisions for both facilities for the production of short lived radioisotopes and extensive core volumes for production of long lived radioisotopes is both interesting and exciting. Failure to reactivate FFTF would be a major waste of a vital resource.

The principle area in which JLS&A operates is in the medical and industrial use of sealed sources. We are developing process irradiators utilizing Co-60 for both food irradiation and product sterilization.

With the emergence of the food irradiation industry the requirements for Co-60 production, now $\approx 40 \times e^{16}$ Ci./year worldwide, will dramatically increase. The lack of a USA Co-60 production facility could seriously hinder development of this industry in the USA, both for designers/fabricators of these facilities such as ourselves and for the owners/operators.

Normally we prepare Co-60 targets for irradiation which, after activation, are processed and the Co-60 encapsulated by others. We have both the technology and personnel to process these targets and encapsulate the sources, but lack the facility to do so. Consequently we would be most interested in a cooperative effort to do this in Hot Cells on the Hanford Reservation.

In the medical/clinical area we have a unique type of equipment under development which also is designed to use Co-60 sources. If Eu-152/Eu-154 of the specific activity attainable in the FFTF were available on a competitive cost basis it would be the radioisotope of choice in this equipment. The potential market is thousands of Ci./year.

Another program in the development stages utilizes Gd-153. The potential market for this material is hundreds to thousands of Ci./year.

Although not related to FFTF but specific to the Hanford Reservation is the utilization of the WESF and other Cs-137 now in storage. JLS&A is the primary (and probably the only major) USA manufacturer of both Biological and Blood Product Irradiators which utilize Cs-137 sources.

Since the demise of the USDOE Cs-137 production program, these sources are only available from a single foreign (Russian) manufacturer. The pricing policies of this manufacturer and its distributor favor manufacturers of this type of equipment in countries other than the USA to the extent that no USA manufacturer of Blood Product Irradiators can compete in either the US or the world market.

In the Biological Research Irradiator market our proprietary units are the choice of most researchers, but budget constraints by both the National Cancer Institute and the National Institute of Health (the typical funding agencies) limits the researchers ability to purchase units with the Ci. loadings required because of the inordinately high cost of the Cs-137 sources in these units.

JLS&A would be most interested in developing a cooperative effort with PNNL for chemically purifying WESF Cs-137 and encapsulating Cs-137 sources in facilities (Hot Cells) at Hanford. As with the Co-60 program we have the technological expertise and personnel to undertake such a program. For many reasons Hanford is the only site at which such a program can be undertaken on an economically viable basis.

If I can provide additional information, please call or FAX at any time. We wish you success in reactivating FFTF.

Best regards,

J. L. Shepherd
President

Diatide, Inc.

9 Delta Drive • Londonderry, New Hampshire 03053
(603) 437-8970 • FAX (603) 437-8977

June 14, 1999

Mr. William J. Madia
Pacific Northwest National Laboratory
902 Battelle Blvd.
P.O. Box 999
Richland, Washington 99352

E-mail - madia@pnl.gov

Dear Mr. Madia:

Diatide is in receipt of your letter dated June 2, 1999. Diatide is on the leading edge of new diagnostic and therapeutic imaging agents using peptides combined with various radioisotopes to produce either an imaging or a therapeutic agent for use in the nuclear medicine field. You state in your letter that the DOE is mandated by Congress to be a major contributor to the development of isotope use, and in the development of business relationships. Some of us have been in this field for twenty-five years or more and have seen the ebbs and flows of the DOE support to this industry. It has been stated at each of the last several meetings held by the DOE that the DOE is aware of the failings of the ORNL group in supporting this industry, and that efforts are being made to improve that relationship. Perhaps this is the reason for your involvement.

It is important in today's business world to utilize resources as effectively as possible. Towards that goal, it has been realized by many companies in the private sector that each company creating a microcosm of its own to produce the necessary components may be inefficient. Thus, the world of contract manufacturing has evolved and is expanding at a significant rate. We believe there is a need for the DOE to provide a new line of services through facilities such as yours in the area of reactor produced isotopes and leased facilities for use in the nuclear medical field.

Currently there is only ORNL in the US with capabilities to support new isotope irradiation and development. The ATR site in Idaho has a cycle schedule in support of the Navy that is too long at too low of a power level to produce most medical isotopes. ORNL is aging to the point that the reactor needs significant refitting. The labs available to handle the irradiated targets would require significant revamping if they were to be used in support of the medical community. It is our understanding that the FFTF reactor site has lab space available that is more up to date than the labs at ORNL. If this is true then FFTF should give consideration to the concept of renting lab space to public sector companies in which research and development using new and diverse isotopes could be conducted.

Diatide has investigated the use of diverse isotopes such as Sn-117m, Y-90, and W-188/Re-188, & Ac-227/Ra-223. The field of therapeutic isotopes is just opening up and has tremendous potential for the future. However, this future will be heavily impacted by availability of not only these new isotopes at costs that basic research can afford, but also by the availability of lab space in which the development of these isotopes into final product preparations for use in humans can evolve.

Thus your letter of inquiry has many avenues open that commercial companies such as Diatide would be interested in using. We would be interested in discussing lease of not only irradiation space and target processing facilities, but also space in which to develop the pharmaceutical model for patient treatment at some point in the future after you reach a decision as to the future use of this site.

Target design, construction of targets and encapsulation of target isotope as well as irradiation services are all programs used by Diatide at the ORNL facility. Rocky Cline and Saeid Mirzadeh have both been extremely cooperative and supportive to past efforts within the guideline constraints provided to them by the DOE.

Diatide has discussed enriched isotope production with ORNL. We have been told the Calutrons are not economically efficient to compete with foreign supplies. ORNL has discussed the construction of newer enrichment systems such as centrifugation. I am sure you have also had these discussions with ORNL. There will be a need for enriched isotope in the future. You will have to do something to compete with foreign competition or lose the US leadership in this area. The costs vs the returns are hard to determine at this stage.

Specialized radiolabeling, packaging and distribution services for most industrial applications are not as rigorously defined as in the pharmaceutical industry. The cost to set up, qualify and validate pharmaceutical grade facilities is not a trivial exercise. Thus, I am not sure your group will be able to pursue this as a government installation. However, we would be pleased to discuss the needs and options for these types of services with you.

There are several sources of cyclotron produced isotope available. These can be prohibitively expensive in today's health market and nuclear medicine looks to reactor produced isotopes as a lower cost alternative. The medical community needs a reliable and economically sensitive source of these reactor-produced isotopes. The DOE needs to know and understand these cost restraints on companies developing the next generation of treatments and be able to support the pharmaceutical industry by providing these isotopes at a reasonable cost. The current philosophy of trying to make each program self-sufficient has not been successful in meeting the public sectors needs.

We would be happy to discuss options with you, should you so desire. I hope this input proves of use to you.

Sincerely,

Victor J. Becker
Sr. Director – Operations

VJB/pp

Telephone: 603-437-8970
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E-mail: v_becker@diatide.com

abc®
laboratories

Columbia, Missouri

June 21, 1999

Dr. William J. Madia, Director
Pacific Northwest National Laboratory
P.O. Box 999
Richland, WA 99352

Dear Bill:

FAST FLUX TEST FACILITY

ABC Laboratories is a life sciences testing and technology company. One of our important areas is the development and manufacture of radiopharmaceuticals and medical devices that deploy radioisotopes. Our business in this segment depends on a domestic supply of high quality isotopes on a reliable and cost effective basis. Further development of successful therapies for life threatening conditions also hinges on such supply. Our company has taken steps to associate with the University of Missouri Research Reactor and presently leases two laboratories inside the reactor facility at which we provide post irradiation processing and low run manufacturing of finished radiopharmaceuticals under FDA's cGMP and QS requirements respectively for distribution for use in patients. The capacity of the MURR is really rather modest relative to the demand anticipated in the developing nuclear medicine market. We feel it is important for the FFTF to be available to meet the demand for medical and industrial isotopes.

Our company's expertise in this field lies in the translation of intended new technologies into viable products that can be manufactured and meet applicable FDA requirements. Our core competencies are in pharmaceutical biochemistry and regulatory compliance. Most of our clients need significant process improvement R&D and even formulation development. We come into our own in the synthesis of the radioisotope constituent into organic carrier molecules. ABC Laboratories is interested in an alliance with PNL - FFTR in which we provide the cGMP driven development, testing and manufacture of value-added isotopic molecules. We have the regulatory and laboratory staff and project experience to contribute effectively to such an alliance. We have project experience with the following isotopes: C-14; H-3; Ho-166; I-125; I-131; Mo-99; P-32; Sm-153; Re-186; Y-90.

We believe we will soon outgrow the capacity of our current arrangement with MURR -- but this does provide a useful model of how PNL and ABC could work together. MURR provides all of the irradiation services, including special facilities, safety program, NRC license umbrella and waste management. ABC provides the marketing, project management, project design, analytical chemistry, GMP testing (stability, purity, etc) and packaging and distribution services. Our MURR relationship is particularly suitable for short-life isotopes and it is our understanding that the FFTF is well suited to long-life isotopes.

ABC Laboratories California
32380 Avenue 10
Madera, CA 93638 USA
Tel: 209/675-0889 Fax: 209/675-0884

ABC Laboratories Missouri
7200 E. ABC Lane
Columbia, MO 65202 USA
Tel: 573/474-8579 Fax: 573/443-9033

ABC Laboratories Europe
38 Castleroe Road
Coleraine, N. Ireland BT51 3RL
Tel: 44 (01265) 320639 Fax: 44 (01265) 320653

We would be interested to participate in further business-planning discussions to make it possible for FFTF to continue operations and produce medical isotopes.

While this letter does not represent a contractual commitment, it does represent strong interest in activities that depend on continuance of FFTF as an isotope production facility. I enjoyed and benefited greatly from my tenure at Battelle from 1984 to 1993 and would welcome the opportunity to work together with Battelle in such an important mission as assuring the ready availability in this country of critical isotopes for treating cancer and other diseases.

Yours sincerely,

Jake Halliday, Ph.D.
President & Chief Executive Officer

BWX Technologies, Inc.
Babcock & Wilcox, a McDermott company

E. Allen Womack, Jr.
President

Rt. 726, Mt. Athos Road
Lynchburg, VA 24504

P.O. Box 11165
Lynchburg, VA 24506-1165
(804) 522-6178
Fax: (804) 522-6963

June 21, 1999

William J. Madia, Ph. D.
Director
Pacific Northwest National Laboratory
902 Battelle Boulevard, P.O. Box 999
Richland, WA 99352

Re: Your Letter of June 2, 1999 – Fast Flux Test Facility (FFTF) Reactor

Dear Dr. Madia:

Thank you for the opportunity to discuss the benefits of retaining in operation the Fast Flux Test Facility (FFTF) reactor, which is currently being maintained on a stand-by basis at the Hanford Site. While we are very aware that FFTF is slated for shut-down and decommissioning, we also believe that FFTF is a valuable asset and consider the national interest better served by keeping the reactor in service to provide the tool for the medical, commercial and defense research and products that FFTF can play a role in producing. Our experience and success in the nuclear engineering field leads us to this conclusion.

For many years, BWX Technologies, Inc. (BWXT) has led the nation in various R&D, design and manufacturing projects related to nuclear systems and fuel. For some time BWXT has been the sole source provider to the U.S. Navy of its nuclear fuel. We supply today nearly all of the reload cores for research and test reactors in the United States. Moreover, we supply some of these products to other parts of the world, including but not limited to Japan. We long have owned and operated research and test reactors and continue to have operational hot cells capable of handling a broad range of radioactive materials. These cells include some large enough to accept a full-sized commercial reactor fuel assembly.

Our longstanding experience in nuclear research, development, design and manufacturing also includes substantial hands-on experience with isotope technology and production. We use americium, cobalt and iridium sealed sources in our manufacturing processes and operations. Our hot cells provide services for radioisotope separation and packaging. We have developed and patented a small, homogeneous aqueous reactor for isotope production for use in medical applications, e.g. Mo-99. In support of operations in Canada, we now supply high-enriched uranium targets to Nordian for its production of Mo-99 isotope. Our corporate R&D organization, McDermott Technology Incorporated, located in Alliance, Ohio, has produced specialized targets for ORNL's Holifield Radioactive Ion Beam Faci

Mound, Ohio, we are responsible for integration of Pu-238 heat sources into the RTG's. Pu-238 is in short supply and purchases have been made from Russia to partially alleviate this situation. However, the Russians do not permit us to use their material for certain applications. Using the FFTF to provide an indigenous supply of this material would clearly have significant benefits to the nation.

For years we have considered the business potential in a number of isotope related markets. In general, we see the market and potential for demand and growth in the need for medical and industrial isotopes. BWXT has heretofore declined to make a full-scale entry into these markets because it lacks the requisite sales and marketing infrastructure needed for such an endeavor. We have discussed collaboration with others possessing the requisite sales and marketing structure; one of these initiatives continues but is too embryonic to predict a final outcome. At this time, however, we have no plan to become a broad-scale supplier of isotopes. Nevertheless, we have little doubt that the market for isotope production and sale would be a viable commercial venture. In that regard, we could clearly fill the role of operator of FFTF and would have considerable interest in collaborating with PNNL and other commercial firms to develop the facilities and provide the support to manufacture targets and fuel and process isotopes for the market that we believe will expand in the near term.

We believe that FFTF is a national asset that should play a key role in many future projects, some of which will have broad national security implications. For example, FFTF could be instrumental in the development of proliferation resistant fuels and advanced reactor technology. Such basic research and development should not be ignored as a means to address the demand for environmentally acceptable power generation for the future. Moreover, deep space exploration can only be accomplished with nuclear energy. FFTF could and should play a role in this very important work that impacts directly the national interest. These kinds of uses of FFTF are in addition to the production of isotopes for medical, commercial and industrial application. BWXT would welcome the opportunity to work with PNNL and other national laboratories and utilities to design programs for the full and beneficial use of FFTF.

We look forward to talking with you and becoming an integral member of the team to prepare the Environmental Impact Statement and to make the reactor ready for restart.

Sincerely,

Allen /(R)

E. Allen Womack, Jr.

H:\...\womack\...\99096-eaw

NEORx

NeoRx Corporation
410 West Harrison
Seattle, WA 98119-4007
206-281-7001
Fax 206-284-7112

June 22, 1999

Via Fax 509 375-6844

William J. Madia, Director
Pacific Northwest National Laboratory
902 Battelle Boulevard
P. O. Box 999
Richland, WA 99352

Dear Mr. Madia:

Thanks you for including NeoRx Corporation in your survey for information on use of the FFTF reactor. Our company's efforts have been largely based on the development of radiopharmaceuticals for imaging and radiotherapy and we have current efforts that are relevant to potential supply by FFTF.

Current development efforts involve Holmium-166 for bone marrow ablation via chelation by the bone seeking agent, DOTMP, and Yttrium-90 for the treatment of cancer via antibody pretargeting. The Holmium-166 is reactor produced and thus directly relevant to FFTF. We are injecting large multicurie doses to achieve marrow ablation in multiple myeloma. For support of product we anticipate needing a minimum of 300 Ci/week. Because of the 26.8 hour half life, double the amount of the large doses is needed to compensate for radioactivity decay between production and arrival in the hospital. We also would want it available at least weekly and preferably 2-3 times/week in order to facilitate use by bone marrow/stem cell transplantation facilities. We are currently obtaining the Ho-166 from MURR and specific activity is adequate, although we do not want to obtain it much lower than the 2 Ci/mg levels being obtained now. It is important to have a reliable additional supplier with capacity and flexibility being prime needs. We are currently in Phase I/II dose escalation studies at M.D. Anderson Cancer Center in Houston and the Fred Hutchinson Cancer Research Center in Seattle. We anticipate approval in a few years. Broader indications are possible and we expect the needs to rise beyond what is listed above further in the future.

We also have development activities in antibody pretargeting (see Invited Commentary in Newsline of J. Nucl. Med., A. Fritzberg, "Antibody Pretargeted Radiotherapy: A new Approach and a Second Chance" 39: 20N, 1998). As

mentioned above, Yttrium-90 is currently being used. However, for small volume, adjuvant disease in which the potential for cure or significant impact on course of disease is possible, radiotherapy emitters of weaker energy such as Lutetium-177 or alpha emitters such as Bismuth-212 via pretargeted Lead-212 are possible. We have results supporting feasibility of pretargeted delivery of the "in vivo" generator Lead-212. Unfortunately, supply of this generator from Radium-224 has been problematic and the potential of FFTF to aid in production of Thorium-228 as a generator precursor would be important in the feasibility of such a targeted alpha radiotherapy product.

We have a major technology base for Rhenium-186, another reactor produced radionuclide with good radiotherapy properties. One of its limitations has been specific activity. This limits its use with some antibodies, antibody pretargeting in general and with tumor receptor binding peptides. For this example, the potential of FFTF to increase specific activity of Re-186 could be important for potential applications. Rhenium-188 has potential as well, but its 17 hour half life can be limiting. The Tungsten-188 generator solves the supply issue on site, but reactor production capacity for many large generators to support a product requiring large amounts of Re-188 is a concern. Again, the capacity of FFTF could be helpful as well as increased efficiency in the low yield, double neutron conversion of W-186 to W-188.

The above examples cover radionuclides of interest to NeoRx. I would be happy to discuss them further or to discuss other aspects in general. Given the limited availability of reactors of high flux in the United States, making FFTF available with short term irradiations possible would be important to the support of promising targeted radiotherapies for cancer and other diseases. We have had a significant number of patients who have benefited from treatment with pretargeted Y-90 DOTA-biotin in prostate cancer and other solid tumors and lymphoma as well as promising results in multiple myeloma with Ho-166. Remarkably, these patients experience minimal side effects compared to other cancer therapies and such results strongly encourage the effort to improve the delivery of promising therapeutic radionuclides.

Sincerely,

Alan R. Fritzberg

Alan R. Fritzberg, Ph.D.
Chief Scientist and
Chairman of the Scientific Advisory Board

cc. Paul Abrams, MD, JD,
Chief Executive Officer

NEORX

For Immediate Release

CONTACT:
Melinda Kile
Controller
(206) 286-2508

NeoRx Corporation
410 West Harrison Street
Seattle, WA 98119-4007
206-281-7001
Fax 206-284-7112

NeoRx Announces Clinical Progress at Annual Meeting

-Positive data, including complete tumor regressions, shown in two cancer Phase I clinical trials-

Seattle, WA, – May 18, 1999 –Updating shareholders at its annual meeting, NeoRx Corporation (NASDAQ:NERX) presented information on its Skeletal Targeted Radiotherapy ("STR") trial in multiple myeloma patients and Pretarget® Lymphoma trial in Non-Hodgkin's lymphoma. The company announced that complete tumor regressions have been achieved in some of the patients in both of its Phase I cancer therapy clinical trials and that the maximum tolerated doses in the cancer studies have not yet been determined.

NeoRx also announced its lead anti-inflammatory agent Chemotides™ demonstrated positive preclinical results in animal models of allergic inflammation and stroke.

"One of the challenges in treating multiple myeloma is that the patients' tolerance for radiation therapy decreases as the dose of chemotherapy increases", said Paul G. Abrams, M.D., J.D., NeoRx's CEO. "Skeletal Targeted Radiotherapy ("STR") is designed to deposit radiation in the bone where the tumor cells have lodged, while avoiding radiation to non-target organs. Although patient numbers are too small to predict a response rate, preliminary Phase I data indicate that adding the therapeutic radiation of STR to chemotherapy has produced complete tumor responses in a sizable fraction of patients without increasing toxicity." These data will be formally presented at an international scientific meeting in July.

NeoRx's Pretarget® technology involves the separate injections of antibody (to target tumor tissue) and radiation (to kill the tumor) that then join at the tumor site. This approach reduces the exposure of normal organs, such as the sensitive bone marrow, while maintaining the dose to tumor. "Proof that this concept works has now been demonstrated in lymphoma patients with a commercially available antibody," said Dr. Abrams. "The tumor to whole body ratio of radiation that can be delivered using our technology is considerably better than has been reported by others. This has allowed us to treat seven patients at radiation dose levels that some of them probably could not have tolerated otherwise. Substantial tumor regressions have occurred in most of these patients including documented complete responses. NeoRx is currently in the process of developing its own lead antibody to bring to the clinic for this indication. We believe a

major patient need exists, and we intend to address it as rapidly as biology and regulatory authorities permit."

Although not yet in clinical testing, NeoRx's Chemotides™ technology has made substantial progress in preclinical development in the emerging field of chemokine research. Evidence of efficacy has been demonstrated in several animal disease models of inflammation including airway inflammation, dermal inflammation and, most recently, stroke.

NeoRx Corporation is developing innovative products designed to provide improved, cost-effective treatments for patients with cancer and inflammatory diseases.

This release contains forward-looking statements relating to the development of the Company's products and future operating results that are subject to certain risks and uncertainties that could cause actual results to differ materially from those projected. The words "believe," "expect," "intend," "anticipate," variations of such words, and similar expressions identify forward-looking statements, but their absence does not mean that the statement is not forward-looking. These statements are not guarantees of future performance and are subject to certain risks, uncertainties and assumptions that are difficult to predict. Factors that could affect the Company's actual results include the progress and costs of clinical trials and the timing of regulatory approvals. Reference is made to the Company's latest Annual Report on Form 10 - K filed with the Securities and Exchange Commission for a more detailed description of such factors. Readers are cautioned not to place undue reliance on these forward-looking statements that speak only as of the date of this release. The Company undertakes no obligation to publicly update any forward-looking statement to reflect new information, events or circumstances after the date of this release or to reflect the occurrence of unanticipated events.

Visit NeoRx at www.neorx.com.
To receive NeoRx news releases via email, register at www.neorx.com/news/pr.html.

447 March Road
Kanata, Ontario
Canada K2K 1X8
Tel: 613 592-2790

MDS Nordion

Science Advancing Health

1999 June 28

William J. Madia
Director, Pacific Northwest
National Laboratory
902 Battelle Boulevard
P>O> Box 999
Richland, WA 99352

Dear Dr. Madia,

Our president, Mr. Morrison, has requested that I reply to your letter of June 2 regarding isotope production at the DOE's Fast Flux Test Facility (FFTF).

We believe that the FFTF can play a useful role in the production of reactor radioisotopes for research applications and the research community in the United States is best positioned to be able to provide input into their needs. However, MDS Nordion would be reluctant to reply on the use of the FFTF for high level commercial production of radio-isotopes. For such products we use commercial facilities such as those at MURR or our own reactors at Chalk River.

I would like to thank you for requesting our input into your plans.

Sincerely,

Iain C. Trevena
Senior Vice-President
Nuclear Medicine

c.c.: Chris Critch

ISOTOPE PRODUCTS LABORATORIES

June 30, 1999

Dr. William J Madia
Director
Pacific Northwest National Laboratory
902 Battelle Boulevard
PO Box 999
Richland, WA 99352

Dear Dr. Madia:

Thank you for your letter of June 2, I am sorry we were not able to meet at the SNM meeting in Los Angeles.

We are quite interested in new reactor capacity. As you know almost all of the world's research reactors are aging and it is likely that their missions will change in the next decade. While there is satisfactory reactor capacity today, this is unlikely to continue if there are more facility closures.

To maximize funding for a reactor a primary mission outside of medical isotopes needs to be defined. There is not the revenue to justify medical isotope production as the main raison d'etre for such a large facility. Within the field of medical isotopes, however, there are three large revenue streams possible. They are Mo-99, Co-60, and an irradiation program aimed at producing a wide variety of isotopes that includes many of those that your colleagues at Hanford have very effectively publicized. Again, it is unlikely that the revenue from any one of these prospective medical products individually will generate enough revenue to impact the FFTF operating budget, but as a whole there could well be a case for a program at FFTF. It would be subsidiary to the main mission, but as a whole, a substantial program.

Each of the three streams I mention above could generate $5 to 10 million annually to the reactor operator, but there are obstacles to each. For the case of Mo-99, DOE has already spent considerable funds at Sandia to begin a program, how would such a program at Hanford work within DOE? For the case of co-60 there are commercial distribution questions that include breaking into a market with 2 established suppliers with their own long term reactor relationships. For a general irradiation program it will need some intense publicity and an experienced team to bring the promise of such a program to fruition.

In the case of our company, we are facing a watershed period in that our existing facilities are at capacity, and we will need to build or find extra space in the near future. Hanford is a possibility for our expansion, and an isotope program at FFTF might add to the attraction of the area. Perhaps of interest, it is feasible for us, with an expansion in the Hanford region, to bring an experienced team to support isotope irradiation and separation at FFTF.

In any case, we will watch your progress with interest as the industry in general needs the extra capacity in the future, and Isotope Products specifically would be a customer for FFTF irradiations wherever we are located. We wish you the best success with your efforts to understand the private sector's requirements for reactor isotopes and the subsequent preparation of the case to restart FFTF.

Please call me if you need further information.

Sincerely,

Len Hendrickson
President

Corporate and
Main Laboratory
1800 N. Keystone Street
Burbank, California
91504

818•843-7000
Fax 818•843-6168

Immunex Corporation
Susan K. Erb, *Vice President, Operations*

IMMUNEX®

July 2, 1999

William J. Madia
Director
Pacific Northwest National Laboratory
902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352

Dear Mr. Madia:

Mr. Ed Fritzky forwarded your letter requesting Immunex's assistance in your endeavor to better understand both the public and private sectors' requirements, plans, and potential business relationships related to isotope production at the DOE's Fast Flux Test Facility (FFTF) reactor.

Mr. James (Jeff) Palmer is the Immunex Radiation Safety Officer and will act as your primary contact at Immunex. Jeff, along with some of our key scientists, will be able to provide you information on the future use of isotopes at all Immunex facilities. Jeff can be reached directly at 206-389-4365 or at his e-mail address palmer@immunex.com.

Please call me if I can be of any further assistance.

Sincerely,

Susan K. Erb
SKE:vp

Cc: E. Fritzky
J. Palmer
D. Williams

51 University Street, Seattle, Washington 98101-2936
206.389.4365, Fax 206.587.0606
Internet: erb@immunex.com

Garden State Cancer Center

520 Belleville Avenue, Belleville, NJ 07109-0023

Tel:(973) 844-7100 Fax:(973) 844-7120

July 5, 1999

Dr. William J. Madia, Director
Pacific Northwest National Laboratory
P.O. Box 999
Richland, WA 99352

FAST FLUX TEST FACILITY

Dear Dr. Madia:

Garden State Cancer Center is a not-for profit research center that is focused on the development of diagnostic imaging and therapeutic products for the detection and treatment of cancer. We have been engaged in this research for over 20 years, principally highly specific monoclonal antibodies and fragments designed to deliver radioisotopes, chemotherapeutic agents, or toxins to tumors.

I attended a portion of the DOE's presentation in Los Angeles during the Nuclear Medicine meetings. During this meeting it became very evident that scientists like myself need to convey to the Department the importance of maintaining a strong program to develop and distribute medically useful isotopes. I understand that the Fast Flux Test Facility (FFTF) represents a significant source of medical and industrial radioisotopes, and I would encourage your Laboratory and the Department of Energy to restart this facility so that it might continue to provide quality isotopes for medical research.

As one of the leaders in the development of therapeutic radiopharmaceuticals, our facility purchases large amounts of yttrium-90, indium-111, and iodine-131. Unfortunately, our research has been severely hampered over the years because the government has so poorly supported a strong isotope production program. Alpha-emitters have long been an interest, but the supply of certain isotopes, such as actinium-225 and radium-223 (from actinium-227), have not been forthcoming. We have had difficulty sustaining some of our research efforts because of a lack of radioisotope availability, and grant applications to investigate new agents are impossible without an adequate supply that is reasonably priced. Our program is highly translational, focusing on agents that can move quickly from preclinical to clinical studies. However, with the uncertainly of isotope supply and an expensive front-end in the development, the research program has fallen back on isotopes with more reliable supply and reasonable cost per dose. We would be interested in Lu-177, high-specific-activity I-131, P-32, Re-188 from tungsten-188, to mention a few, if reliability and high quality were guaranteed and pricing was reasonable. The future demand for the agents that we develop will depend on successful clinical trial outcomes and FDA approval.

We were a major customer of DOE's yttrium-90 production at PNWL. We were pleased with the quality and reliability, but the current high price is going to make it difficult to maintain a substantial clinical program that could lead to Phase III trials and the approval of an isotope-based, biologic therapy. The current pricing schedule for many DOE radioisotope products is overpriced, and we recommend downward adjustment of the costs for Y-90 and Re-188 generators since at least could become clinical-based products in the near future.

We anticipate that radioisotope consumption will continue to increase, but sales will ultimately depend on reliable production, chemical quality, reasonableness of cost and federal approval of new radioisotope products. We believe that FFTF should be restarted to help meet projected needs for many isotopes that not only we would like to explore in the future, but I know that my colleagues in this field would also like to develop.

Yours sincerely,

Robert M. Sharkey, Ph.D.
Member and Director Clinical Research

Radiance
MEDICAL SYSTEMS, INC.

July 9, 1999

William J. Madia
Director, Pacific Northwest National Laboratory
902 Battelle Boulevard
PO Box 999
Richland, WA 99352

Dear Mr. Madia:

Radiance Medical Systems is dependent upon an adequate and continuing supply of radionuclides for the production of our main product lines, radioactive balloon catheters for prevention of restenosis following angioplasty. As you know, the field of restenosis prevention is new, with no FDA approved medical devices but with more than nine companies in clinical trials. All of these medical devices require radioactive materials, so beyond what Radiance requires, the industry itself is dependent upon an adequate nuclide supply.

The range of nuclides which are required for the current approaches includes P-32, W-188/Re-188, Re-186, Y-90, Sr-90/Y-90, Ir-192, with R&D investigations also using Gd-153, Eu-155, I-125, Pd-103, among others. As is readily apparent, this list exclusive of Sr-90 is entirely reactor produced. Currently, the nuclides are for these devices are made at HFIR, MURR, Petten and various reactors in Russia, which would seem like a significant supply. However, the availability of nuclides has limited the research in the field.

Y-90, because of its very short half-life, must be produced in very high specific activity. At present, the only reactor of sufficient neutron flux in the US is HFIR. Given the problems of supply at HFIR, either inconsistent operation or the downtime for refitting, the field has already moved elsewhere to find adequate Y-90. For both Gd-153 and Eu-155, the only significant supply currently is Russia, with uncertain supply links with consistently changing government regulations. Although HFIR supplies W-188, it will be insufficient if the medical devices become available.

Hence, it is critical to have an additional supply of radionuclides for the medical field. An examination of FFTF indicates that it can supply all of the reactor produced nuclides which are used for restenosis prevention and in several cases, produces them better either in terms of rate of supply or, more importantly, in quality measured by both specific activity and impurities. It is therefore critical that FFTF be brought back on-line to ensure adequate supplies for medical uses.

If you should have any questions concerning this letter, please feel free to contact me.

Sincerely,

Michael R. Henson.
Chairman and CEO

Radiance Medical Systems, Inc.
13700 Alton Parkway, Suite 160
Irvine, CA 92618 USA
Tel: 800-983-2284 / 949-457-9546
Fax: 949-457-9561

CVD

Life Sciences Enterprise
DuPont Pharmaceuticals Company

William J. DeLorbe, Ph.D.
Executive Vice President
Medical Imaging

July 15, 1999

William J. Madia
Director
Pacific Northwest National Laboratory
902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352

Dear Mr. Madia:

DuPont Pharmaceuticals welcomes the opportunity to comment on the possibilities of the FFTF for commercial isotope supply. The unique attributes of FFTF: high neutron flux, large target irradiation capabilities, and high energy flux, position this reactor to meet the needs of the radiopharmaceutical industry in the coming decades.

As the leading supplier of Radiopharmaeucticals in North America, DuPont's isotope requirements are likely to reflect the requirements of the industry as a whole. The radiopharmacuetical industry is evolving from its traditional diagnostic basis into therapeutic applications. Molybdenum-99 for which there are already excellent supply options has been the workhorse of the industry not only because of its favorable imaging characteristics, but because supply has been reliable, consistent and relatively cost effective. Expansion into therapeutic isotopes e.g. Lu-177, Ru-106, W-188, Y-90 will require the same supply characteristics: timely, cost effective delivery.

As the industry expands into therapeutics, isotope costs will be critical, both for clinical development as well as routine commercial supply. Parenteral therapeutics for oncology, compounds in which the lethality of the radioisotope is targeted by a ligand of high specificity to the tumor site, will be expensive to develop and manufacture. Clinical trials will be more extensive than for diagnostics. The effects of radiolysis on the targeting agent pose formidable development efforts. Isotope costs must be proportional to comparable "cold" components for labeled drugs to be competitive with traditional treatments. The growth of therapeutic isotopes depends upon the availability of cost effective isotopes.

The industry looks to DOE to prepare for the growth in therapeutics by continued fundamental research in target methodology, processing chemistry and isotope separation both in government laboratories and academic institutions. Industry does not have the facility or expertise to conduct this work. The expectations for commercial supply are high. Physician acceptance depends upon availability. Any isotope that will be incorporated into a parenteral therapeutic will of necessity be short-lived. A radioactive therapeutic has to be ready to be administered when the patient and

331 Treble Cove Road • N. Billerica, MA 01862 • (978) 671-8500

physician are ready. Such a demanding supply chain requires frequent, repetitive production of small lots of material, both by the isotope supplier and the pharmaceutical manufacturer. The barriers to success in the therapeutic arena are high, but so are the rewards. FFTF could and should play an important role in partnering with industry to develop this market. To do so, the FFTF will need to be capable of operating under the principles of providing materials at low cost, with fast turnaround and extremely high reliability. If this is achieved, the FFTF could play a very significant role in health care in the United States.

Sincerely,

William J. DeLorbe

WJD/boh

Johnson & Johnson

CORPORATE OFFICE
SCIENCE AND TECHNOLOGY

410 GEORGE STREET
NEW BRUNSWICK, N.J. 08901-2021

July 16, 1999

Dr. William J. Madia
Director
Pacific Northwest National Laboratory
902 Battells Boulevard
P.O. Box 999
Richland, WA 99352

SUBJECT: Fast Flux Test Facility

Dear Dr. Madia:

Thank you for your recent letter seeking expressions of interest in preserving the Fast Flux Test Facility as a reliable producer of radioisotopes for medical and industrial purposes. As you know, Johnson & Johnson is the world's most comprehensive and broadly-based manufacturer of health care products. It is a leading provider of related services, for the consumer, pharmaceutical, and professional markets. Johnson & Johnson has more than 94,000 employees, and operates 188 companies in 52 countries around the world.

Johnson & Johnson companies use cobalt-60 for product sterilization, market and distribute palladium-103 brachytherapy seeds for prostate cancer, and are developing stents using phosphorous-32 for cardiovascular radiation therapy for prevention of restenosis after balloon angioplasty. We anticipate annual growth rates of more than 20% per year for TheraSeed® palladium-103 brachytherapy seeds for localized prostate cancer. Johnson & Johnson also uses a wide variety of research isotopes for labeled organic compounds in drug metabolism research, such as tritium, carbon-14, and P-32. Other isotopes of potential interest to us include iodine-125, yttrium-90, iriduim-192, and molybdenum-99.

As a potential customer of FFTF-produced medical isotopes, Johnson & Johnson is interested in reliable supplies of low-cost, high-purity radioisotopes. We applaud your ongoing efforts to preserve the FFTF for cost-effective isotope production. While this letter does not represent a contractual commitment, we believe that FFTF can fill an important need for the future demand for medical isotopes.

Sincerely,

Raymond W. Ruddon, M.D., Ph.D.
Corporate Director, Science & Technology

cc: M. Chuisano
R. Gussin
R. Morrissey

RWR/kmc

Syncor®
The Service Difference®

Syncor International Corporation

July 17, 1999

Dr. William J. Madia, Director
Pacific Northwest National Laboratory
P.O. Box 999
Richland, Washington 99352

Dear Dr. Madia:

I enjoyed having the opportunity to speak with you last week. This letter is a summary of our conversation.

Syncor provides radiopharmaceuticals and comprehensive nuclear pharmacy services, as well as medical imaging services, to nuclear medicine departments in hospitals and out-patient clinics worldwide. Our company depends on consistent, reliable, and cost-competitive sources of high-purity medical isotopes for diagnostic and therapeutic purposes. Consequently, we are very interested in any possible restart of the Fast Flux Test Facility (FFTF) for, among other missions, the production of isotopes.

As we discussed, there are a number of key issues in developing an alternative source of isotopes:

- It must be a reliable source that can consistently produce isotopes, given the limited amounts of product that we can effectively carry in inventory.
- It must be cost effective compared to other readily available sources of supply.
- It must be scalable to support the expected growth in demand for diagnostic and therapeutic medical isotopes.

We would be interested in collaborating in a business-planning process to help minimize potential supply shortfalls or disruptions as well as enable fuller use of the available capabilities, including the Fast Flux Test Facility, for isotope production and processing.

Obviously, the types, quantities, and schedule of isotopes we expect to require from sources such as the Fast Flux Test Facility depend upon a number of key assumptions:

- The federal government (National Institutes of Health and the Department of Energy) continues to support research in the use and application of medical isotopes.

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- Current and future clinical trials continue to be highly successful, and these results lead to deployable diagnostic and therapeutic isotope products.
- Reimbursement for diagnosis and treatment keeps pace with approvals and market demand.
- Public acceptance of nuclear medicine procedures develops as expected.
- The Department of Energy establishes itself as a reliable, competitive source as the medical isotope market expands.

Dr. Madia, we applaud your ongoing efforts to support the burgeoning development of medical isotope applications, which is so contingent on assurance of an available supply. While this letter does not represent a contractual commitment, we believe strongly that isotope utilization will grow and we welcome the potential availability of a demonstrated, reliable facility such as the Fast Flux Test Facility that can meet the projected demand for high-quality products and services at an acceptable cost.

Sincerely,

Robert G. Funari
President & CEO

July 23, 1999

Dr. Bill Madia, Director
Pacific Northwest National Laboratory
902 Battelle Blvd.
Richland, WA 99352

Dear Dr. Madia,

I wish to offer any support I may provide you in your efforts to restart the Fast Flux Test Facility. During my past work experience, I assisted in the engineering completion of Union Carbides 5 MW reactor. I then loaded the core and (with help form Oak Ridge) took the new reactor critical. I then achieved an operator's license and then a senior operator's license. For some 10 years we produced thousands of curies of various radiochemicals for the radiopharmaceutical industry.

I then moved to the IRL nuclear reactor in Princeton, New Jersey and continued those same efforts and entered the radiopharmaceutical business supplying isotopes from John Hopkins in Baltimore to major hospitals in New York City and Boston. I then moved my business to Texas and those activities are described in the enclosed catalog.

Our main efforts currently are addressed to custom labeling of monoclonal antibodies and peptides. We now produce radiopharmaceuticals for four corporations, and these drugs are in phase I, II, and III clinical trials, with our goal of FDA approval of these radioactive therapy products.

We have some 100 terminal cancer patients now in these different studies, surviving and returning to their families. The descriptions of the programs are also enclosed including some of the numerous letters from appreciative patients.

I am currently purchasing from foreign suppliers, multi curie quantities of I-131, I-125, I-123, Y-90, Mo-99 and In-111.

I have a pressing need for Sr-90/Y-90, Copper 64, Copper 67, Ho-166, I-125, I-131, Mo-99, P-32, and Pt-195m.

I believe our nuclear medicine/research programs are in great jeopardy as our isotopes are now only available from foreign suppliers and at their take or leave price program. I do know that these prices increase 10 to 40% annually.

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I have also reviewed a Mo-99 / Tc generator from Australia and will license that device through the FDA and perhaps assemble same at your location, with your reactor supplying the Mo-99.

In Texas I have a multi curie isotope license and we are a FDA licensed manufacturer of radioactive sterile, nonpyrogenic injectable diagnostic and therapy drugs.

I have enclosed information on a lab I am constructing at the University of Rhode Island Nuclear Reactor in Providence, Rhode Island.

If your reactor is operational I would be most willing to build a lab and produce and ship products from your location. Please inform me if you wish to explore this concept.

I also believe it urgent that the Society of Nuclear Medicine discusses your problem in great detail. If I can be of any help in this matter, I do know the Editor personally. A fact sheet should be produced and it should go out to all isotope users and be placed in all shipping boxes from NEN, Squibb, Amersham, Syncor, Medi-Physics, Mallinckrodt, and all other producers in every box for a one-week period. If you can supply the information, I can have it printed and sent to all producers. If you think a lobbying group would help, just give me the directions and I will secure the help and funding.

In conclusion, I will tell you that it was a sad day for me when I was informed that my Union Carbide Nuclear Facility was to be shut down and decommissioned.

I sincerely hope you do not have to experience these feelings.

If there is anyway that I can assist you in your major task, please call.

Good Luck and Best regards,

T. Maloney

Thomas Maloney
President

ISO-TEX DIAGNOSTICS

P. O. Box 909 • FRIENDSWOOD, TEXAS 77546 • 713/482-1231 • FAX 713/482-1070

Advanced Nuclear & Medical Systems
. . . an isotope production & development company

1933 Jadwin Avenue, Suite 210
Richland, Washington 99352
(509) 946-9900
fax (509) 946-9500

Mr. William D. Magwood, IV
Director, Office of Nuclear Energy
US Department of Energy
1000 Independence Avenue, S.W.
Washington, DC 20585

July 25, 1999

Reference: *ANMS Privatization Proposal, September 1996, DOE No. P9700006*
ANMS Letter Stokes/Root to Richardson, December 22, 1998
ANMS Letter Stokes to Magwood, December 28, 1998
ANMS Letter Stokes to Magwood, February 5, 1999
ANMS Letter Stokes to Richardson, June 13, 1999
Compass Letter Hardin to Stokes, July 20, 1999 (attached)
IPL Letter Hendrickson to Stokes July 23, 1999 (attached)

Subject: FFTF EIS and Public/Private Partnerships

Dear Mr. Magwood:

ANMS has supported the restart and operation of the FFTF for the past five years. We have invested private funds in the effort to maintain the FFTF option as an asset for the DOE and the American people. Our vision continues to be that the FFTF will be allowed to achieve its potential of providing the isotopes to save thousands of lives each year. In addition, there are other side benefits that will accrue to the DOE and the nation from additional nuclear and materials testing conducted in parallel with this production of life-saving isotopes. To this end, ANMS provides our unqualified endorsement and support for the conduct of an Environmental Impact Study for the restart of the FFTF as a multi-purpose isotope production and materials test center facility.

In November 1995, ANMS presented a proposal to privatize the FFTF operations, product development and production. This presentation initiated the re-evaluation of FFTF mission options. ANMS formalized the proposal in our September 1996 submittal. ANMS had sufficient capital identified for the venture, however, DOE determined that the timing for such a proposal was inappropriate. Our December 1998 letter to Secretary Richardson reaffirmed our interest in a public/private partnership for FFTF restart.

ANMS continues to have access to the necessary capital to privatize the FFTF operations and the ancillary isotope processing and distribution facilities, as evidenced by the attached letter from the Compass Group indicating the availability of $200M subject to appropriate due diligence. The privatization or development of adjunct processing facilities under a federal operations approach for the FFTF will require additional security for construction loans to protect the investors from a premature shutdown of the FFTF. In our February 5, 1999 letter, ANMS proposed an innovative approach to create a trust fund, which could be used to secure the required investment notes.

ANMS and Schnell-Brueter-Kernkraftwerksgesellschaft (SBK) have signed a Letter of Intent to execute a previously negotiated contract for the transfer of ownership of the SNR-300 fuel. The Letter of Intent imposed two conditions for contract execution: the first is the restart of the FFTF and the second is the approval from the DOE for the importation of the fuel. The second condition is satisfied by correspondence from DOE in 1996. The SNR fuel will provide the FFTF fuel needs for an additional 15 years over current inventories and is valued at $125-$150M.

This asset value of the fuel can provide the necessary security for isotope processing facility investment and, with the privatization capital, represents a private sector investment of at least $325M towards the privatization of FFTF operations and isotope production.

ANMS has secured the interest of Isotope Products Laboratories in joining the ANMS and Compass team to establish and commercialize the FFTF's isotope production capability (see attached letter Hendrickson to Stokes). ANMS is prepared to utilize the asset value of the SNR-300 fuel to guarantee investment loans for development of new processing facilities adjacent to the FFTF. Isotope Products is prepared to develop business plans and complete due diligence analyses for the relocation of existing product lines to be co-located with the FFTF product processing lines.

This teaming represents a sincere and financially sound interest by the private sector in supporting privatization of the FFTF or formulating an innovative approach to commercializing FFTF products and services under the operational plan proposed in the PNNL report.

The ANMS privatization proposal of 1996 attempted to offer the DOE an alternative approach to dependency on federal funding. Privatization is commonly defined as any process aimed at shifting functions, responsibilities, and risk from the government to the private sector. It has been the policy of this administration to promote private enterprise in preference to new federal programs. The ANMS proposal of 1996 left ownership of the facilities in the hands of the DOE by proposing a facility lease, addressed the questions of licensing and qualification of the operator, and provided adequate funding to support restart and operations. ANMS is prepared to submit an amended privatization proposal within four weeks should you determine that this course of action could support the advancement of nuclear science and continue the process of saving American lives through the use of medical isotopes produced at the FFTF.

Thank you for your attention and courtesy. Please contact me if you would like further discussion or detail regarding the opportunities discussed above.

Sincerely,

William J. Stokes

William J. Stokes
President

cc: Secretary Richardson, USDOE
Dr. Walter Apley, PNNL

Advanced Nuclear & Medical Systems
1933 Jadwin Ave. Suite 210. Richland, WA 99352 Phone (509) 946-9900 Fax (509) 946-9800

23 July 1999

Mr. William J Stokes
President
Advanced Nuclear and Medical Systems
1933 Jadwin Ave., Suite 210
Richland, WA 99352

Dear Mr. Stokes:

Following our discussions I am writing to express our interest to establish an isotope processing and distribution facility adjacent to the FFTF, should it once again become operational. As we discussed there is a concern in the isotope community, from both the nuclear medicine and industrial perspectives, that reactor capacity will become inadequate as facilities now operating are shut down. The FFTF would be an important addition to the industry's capacity.

Further, the timing of the FFTF decision coincides with facility decisions we need to make. Our current capacity is filled. We are considering several interesting opportunities for development of new therapeutics. We will need more space for expansion and should we establish an operation near FFTF we are certain that other production lines would be relocated there.

However, the financial case that justifies the commitment for such a facility indicates a long operating time required to meet net present value and other investment return criteria. As we discussed, we would need some type of assurances that shifting priorities within Federal or DOE budgets would not affect the FFTF operation. You raised the possibility of an indemnity, but whatever the mechanism, this is an important issue for us and would need a resolution.

You proposed a plan which would include financing and security for construction loans as well as development and financing of the operations, this is indeed interesting. We hope that with further information this approach could be incorporated into our business plans.

Before funds could be committed by either one of our organizations, we need a full market assessment of the portfolio of products available from FFTF. We are anxious to proceed on this. Additionally, before funds can be committed from our firm, the full financial performance assessment of these facilities must be completed. Of course, you will need to perform a due

diligence review for commitment of funds. This would also require board approval from our firm.

While there are a number of analysis that need to be performed by all involved parties we believe there is a good potential for medical isotope production to be integrated with the FFTF operation.

We look forward to further discussion of this opportunity.

Sincerely,

Leonard M. Hendrickson

Len Hendrickson
President

Compass Group POST OFFICE BOX 3806 • SPOKANE, WA 99220-3806 • (509) 353-7993 • FAX (509) 353-7818

July 20,1999

Bill Stokes, President
Advanced Nuclear and Medical Systems
1933 Jadwin Ave. Suite 210
Richland, Washington 99352

Subject: FFTF Expression Of Interest

Gentleman,

Compass Group is interested in your request for financing of $200,000,000 for the Fast Flux Test Facility. But as I have indicated to you previously, Compass can not commit until such time we have had an opportunity to review and underwrite the financial statements, appraisals, construction plans, business plans, construction contractors, costs breakdown of the project, and expense statements. This is not intended to be a commitment, only a expression of interest to finance.

We are aware that the Department of Energy is considering the restart of the facility, our concern as a lender, will be, how much control and involvement they will have. Compass Group is only interested in moving forward if the government allows for privatization of the facility.

Should the Department of Energy's decision be to go forward with an Environmental Impact Statement looking at FFTF restart, we would welcome the opportunity to meet with you and further explore this project.

Sincerely,
Rich Hardan
Rich Hardan, President
Compass Group

COMPASS GROUP

Was founded over 30 years ago. It serves as an investment advisory firm to union building trade pension trust funds.

Typically, we finance small to medium sized projects throughout the northwest. Included are, retail stores, motels, medical office buildings and clinics, hospitals, supermarkets, banks, credit union facilities, restaurants, warehouses, federal agency facilities, and retail centers.

ASSETS OF THE COMPANY

Total assets $1.3 billion invested in stocks bonds and real estate:

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Stocks	$ 320 Million
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SIEMENS

July 27, 1999

William J. Madia, Ph.D., Director
Pacific Northwest National Laboratory
902 Battelle Boulevard, P. O. Box 999
Richland, WA 99352

RE: **Your letter of June 7, 1999 – Fast Flux Test Facility (FFTF) Reactor**

Dear Dr. Madia:

Siemens Medical Systems, Inc. can respond to your referenced letter concerning the use of FFT the supply of important research and production quantities of medical isotopes and for nuclear s and irradiation services missions. Siemens Medical systems, Inc. develops and markets an ext range of products for nuclear medicine worldwide.

Growth in many of our products and services are to a large extent coupled with the growth in die and therapeutic nuclear medicine. Consequently, while we do not produce or market radiopharmaceuticals, we are very familiar with the need to have an abundant and reliable supp such isotopes. Nuclear medicine, from research to full-scale deployment of approved, reimbure and validated radiopharmaceuticals, requires diverse, reliable, high-quality and competitive sou medical isotopes. For reactor-produced isotopes, FFTF appears to fit this need and is particula timely given the aging and cost-to-maintain government reactor infrastructure.

Our recent experience with PET (Positron Emission Tomography) suggest that if one can over regulatory and reimbursement issues with products and/or services having a large benefit-to-co then large growth rates in demand will occur. A decision to terminate the operation of DOE's n and largest isotope-producing reactor could become self-fulfilling in reducing the growth of high to-cost ratio radiopharmaceuticals that depend on reactor-produced isotopes. In our opinion, F large volume, relatively young age, and unique nuclear and design characteristics, make it an i U.S. facility for reactor-produced medical isotopes. FFTF has the potential to become an impo of the federal user facility infrastructure that must be present if nuclear medicine, especially the nuclear medicine, is to reach its full potential.

As you know, Siemens Power Corporation has been a major part of the Tri-Cities infrastructur number of years. We are familiar with the "nuclear-friendly" community environment there and many other physical and human attributes you have to support nuclear endeavors in your area providing Siemens Power a copy of this letter so that we may jointly explore with you potential opportunities relative to FFTF and related activities for any of our Siemens affiliates.

Sincerely,
SIEMENS MEDICAL SYSTEMS, INC.
NUCLEAR MEDICINE GROUP

Barbara D. Franciose

Barbara D. Franciose - Group Vice President

BDF/jz
cc: James H. Nordahl & Mark D. Weiss - Siemens Power Corporation

Siemens Medical Systems, Inc.

Nuclear Medicine Group

2501 North Barrington Road
Hoffman Estates, IL 60195-5203

Tel: (847) 304-7700
Fax: (847) 304-7707

MALLINCKRODT

Improving Healthcare and Chemistry

Mallinckrodt Inc.
675 McDonnell Boulevard
PO Box 5840
St. Louis MO 63134
Phone: 314.654.2000

July 28, 1999

Dr. William J. Madia, Director
Pacific Northwest National Laboratory
P.O. Box 999
Richland, WA 99352

Dear Dr. Madia:

Mallinckrodt Inc. is one of the world's leading suppliers of radiopharmaceuticals to the medical community. Our products are used for the early detection of cancer, heart disease, stroke and other illnesses. We also have several therapeutic products that save lives. In the U.S. alone more than 14 million nuclear medicine procedures are performed each year. Our products rely on the availability of medical radionuclides. Although many of these radionuclides we manufacture in our own facilities in St. Louis and Petten, Holland, we must also rely on outside nuclear reactors for the production of byproduct materials. For that reason we are interested in the medical radionuclide capabilities and future of the Fast Flux Test Reactor (FFTF). To that end we wanted to provide you with some information that may help in your study of the facility.

Mallinckrodt views nuclear medicine as a very healthy industry. We have witnessed a double digit growth rate for the last several years. We have also seen market predictions by Frost & Sullivan and the DOE *Expert Panel* of 7-15% annual growth rates for both the diagnostic and therapeutic markets for the next few years. There are several new peptides and monoclonal antibody products that are under development by Mallinckrodt and our competitors that will fuel this growth. We need to be assured that the radionuclides needed to produce these new radiopharmaceuticals are available in the necessary quantities, on a reliable basis.

We are very aware of the high neutron flux and large target volume advantages available in the FFTF. The medical isotope capabilities of the FFTF can provide many of the radionuclides that have been examined for new products from Mallinckrodt. These include Gd-153, Ho-166, Lu-177 and Re-86. The FFTF also has the capability to produce many of the radionuclides we are using for current products including I-131, Mo-99 and P-32. We are aware that the DOE has created the Nuclear Energy Research Advisory Committee (NERAC) to look at the available sites for medical radionuclide production. We know the FFTF has the capabilities to handle many of our medical isotopes needs, however, the NERAC is in a much better position than Mallinckrodt to judge the adequacy of each facility. We feel the advisory committee is comprised of true experts in their field, and we welcome the findings of their detailed study.

We would like to thank you for the opportunity to provide you some of our thoughts on the capability and value of the FFTF to the medical community. If you have any specific questions, you may direct them to me at (314)654-7204 or Roy Brown at (314)654-7914.

Sincerely,

Michael J. Bronowicz

Michael Bronowicz
Vice President
Nuclear Medicine

cc: Roy Brown

STERIS®

July 28, 1999

CONFIDENTIAL

Dr. William J. Madia
Pacific Northwest National Laboratory
902 Battelle Blvd.
P.O. Box 999
MSIN: K1-46
Richland, WA 99352

Dear Dr. Madia,

[The contents of this letter are Confidential. However, the STERIS Corporation has authorized Pacific Northwest National Laboratory to quote them as foreseeing a significant prospective growth in the demand for medical and industrial isotopes.]

Very truly yours,

STERIS Corporation

Thomas J. Magulski
President
Scientific and Industrial Group

National Association of Cancer Patients

July 12, 1999

Dr. William J. Madia
Pacific Northwest National Laboratory
902 Battelle Blvd.
PO Box 999, MSIN: K1-46
Richland, WA 99352

Dear Dr. Madia:

I am writing to express the support of the National Association of Cancer Patients for the use of the Fast Flux Text Facility (FFTF) for the production of medical isotopes. The use of isotopes is absolutely essential to developing new treatments for cancer, and in some cases the isotopes themselves can be used to treat the disease more effectively and with fewer devastating side effects than other currently available treatments. They are a weapon in the war against cancer that must be available to patients and physicians.

Unfortunately, that is not the case today. Research and clinical trials are being hampered by the lack of a reliable supply of isotopes, and some isotopes that have been shown to be efficacious in treating cancer in other countries are not available in the U.S., a truly shameful state of affairs for the world's richest and most technologically advanced nation.

The urgency is apparent when you consider that more than 1,500 people die from cancer every single day in the U.S.—the equivalent of a fully-loaded 747 crashing, killing all on board. Every year, more people die from cancer than have died in all the wars we have fought in this century. Isotope availability has real-life consequences for cancer patients and their families, and those who will be diagnosed with cancer in the future. Incredibly, experts estimate that by the year 2025, two million new cases of cancer will be diagnosed each year, reflecting the aging of the U.S. population. The need for isotopes is already great, and growing by leaps and bounds.

Full consideration should be given to restarting the FFTF, which could produce a reliable supply of critically needed medical isotopes. The FFTF is a valuable national resource from many perspectives, but for cancer patients it offers the hope of life and relief from pain. We urge you to do everything in your power to make it available for medical isotope production.

Sincerely,

Nicki Hobson

Nicki Hobson
Executive Director

6119 Vista de la Mesa • La Jolla, CA 92037 • (619) 459-9344 or (760) 598-8289

HEALTH PHYSICS SOCIETY

Specialists in Radiation Safety

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FAX: (301) 990-9878
E-Mail: rjohnson@radtrain.com

July 14, 1999

Dr. William J. Madia, Director
Pacific Northwest National Laboratory
P.O. Box 999, K1-46
Richland, WA 99352

Dear Dr. Madia:

SUPPORT FOR RESTART OF THE FAST FLUX TEST FACILITY

We have learned that your Laboratory is conducting a study, at the request of the Secretary of Energy, on the future need for the Fast Flux Test Facility (FFTF), and that results from this study will be presented to the Department of Energy's Nuclear Energy Research Advisory Committee in a public meeting on July 29, 1999, in Washington, DC.

The Health Physics Society's Board of Directors met on June 27, 1999, and voted unanimously to support the restart of the FFTF. The Society directed its President to write a statement in support of continued operation of the FFTF for medical radionuclide production and for other missions. The Society encourages the Secretary of Energy to proceed with an environmental impact statement and to resume medical radionuclide production at the earliest possible date.

The Health Physics Society is a professional organization of more than 6,000 engineers, scientists, physicians, administrators, and educators, whose mission is to promote the practice of radiation safety. The Society and its members encourage research in the basic radiation sciences, development of technically based radiation safety standards, and the dissemination of radiation safety information. Society members are also involved in understanding, evaluating, and controlling the potential risks from radiation relative to the potential benefits derived from radiation-producing activities (such as operation of the FFTF reactor).

One of the major benefits to public health from radiation is the use of radionuclides in nuclear medicine for diagnosis and treatment of disease. The Society encourages production and use of medical radionuclides, so long as production can be accomplished safely in state-of-the-art facilities, and with negligible impact on human health or the environment.

Members of the Health Physics Society consider the FFTF to be a state-of-the-art facility that can produce several unique and important radionuclides, in quantity and quality, for

the benefit of mankind. We note that the FFTF operated safely for more than ten years with very small worker exposures to radiation and negligible releases of radioactive material to air, soil, or groundwater. Given the many years of safe reactor operations, the high quality of plant engineering design, and the exceptional capabilities of FFTF staff, we believe that the FFTF can be expected to continue to operate safely for many years into the future.

The Society believes that the demand for medical radionuclides will greatly increase in the future, particularly for cancer therapy. The Society also believes that the FFTF should be a major provider of medical radionuclides now and in the future, and that radionuclide production at FFTF can also be cost-effective.
However, the Society believes that the continued production of essential medical radionuclides in the U.S. is at risk. A report presented in January, 1999, at the Society's 32nd Midyear Topical Meeting on *Isotope Production, Applications, and Consumption* found that beneficial use of medical radionuclides and growth in the number of medical radionuclide applications are severely impeded by

- reduced federal funding for medical radionuclide production
- reactor shut-downs, and
- decreased radionuclide availability

Together, these factors contribute to a decrease in the number of reliable suppliers who will be able to provide diagnostic and therapeutic radionuclides for medical applications. The potential reduction in or loss of this major public health benefit is of great concern to the Society.

Therefore, the Health Physics Society strongly supports the restart of the Fast Flux Text Facility for the purpose of producing radionuclides for the health benefit of the public and for other scientific research endeavors. The Health Physics Society urges the Department of Energy's Nuclear Energy Research Advisory Committee to recommend to the Secretary of Energy that the preparation of an Environmental Impact Statement on the restart of the Fast Flux Test Facility be initiated as soon as possible.

Sincerely,

Ray Johnson

Raymond H. Johnson, Jr., C.H.P., P.E.
President

cc: Mr. William D. Magwood, Director
Office of Nuclear Energy, Science and Technology
U.S. Department of Energy

NUCLEAR MEDICINE RESEARCH COUNCIL

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nmrc@owt.com • www.cbvcp.com/nmrc

July 15, 1999

Dr. William J. Madia, Director
Pacific Northwest National Laboratory
P.O. Box 999
Richland, WA 99352

Dear Dr. Madia,

The Nuclear Medicine Research Council strongly supports the development of an Environmental Impact Statement for the restart of the Fast Flux Test Facility. Our support was expressed in the enclosed letter sent to Secretary Richardson on March 6, 1999, outlining the critical shortage of medical isotopes. The attachment to the enclosed letter contains the statement of twenty two medical physicians and medical scientists (including two Nobel Laureates) that "Nuclear medicine offers more effective, less costly, and less debilitating forms of treatment for many diseases, greatly increasing the health care and quality of life of patients." These experts agree that there is a critical shortage of isotopes to meet the needs of nuclear medicine and additional production capacity is needed. The restart of the Fast Flux Test Facility will provide sufficient isotopes to meet research needs and provide isotopes for the nuclear medicine treatment of many more patients than our present capabilities will permit.

Very truly yours,

David H. Jones

David H. Jones
President

Enclosure (1)

NUCLEAR MEDICINE RESEARCH COUNCIL

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Maynard J. Plahuta

Robert E. Schenter, Ph.D.

Stanley W. Scott

Donald R. Segna

Thomas S. Tenforde, Ph.D.

March 6, 1999

Mr. William Richardson, Secretary of Energy
United States Department of Energy
Forrestal Building 7A-257
1000 Independence Avenue
Washington, DC 20585

Dear Secretary Richardson:

The United States today has a shortage of radioisotopes for medical research and treatment. Future, larger shortages are certain to occur if our country does not have additional production capability.

In November, 1997, the Nuclear Medicine Research Council sent the attached letter to then-Secretary Pena signed by 22 medical physicians and medical scientists including two Nobel Laureates advising him of the then-current shortage of isotopes--including patients denied treatment because of the shortage--and warning of the consequences of a lack of supply of medical isotopes. This letter stated that restart of the FFTF for an interim tritium production mission would supply the needed medical isotopes.

Since the time the attached letter was written, the tritium mission has been assigned elsewhere. However, even though the FFTF is no longer involved in that mission, it can still produce a wide variety of isotopes for medical and other purposes, as well as conduct many programs of national and international significance.

Although some researchers are able to obtain sufficient quantities of the isotopes required for their specific work, the statement advanced by some that "There is no shortage of medical isotopes" is simply not true. A more appropriate view is that research into new medical treatments using currently unavailable isotopes such as some alpha emitters cannot even be considered without an expansion of medical isotope supply.

Since the date of the attached letter, the shortage of isotopes has grown larger. Researchers at the National Institutes of Health have been unable to obtain high specific activity platinum-195m for effectively monitoring the chemotherapy agent Cisplatin;

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Thomas S. Tenforde, Ph.D.

further, doctors at MD Anderson Hospital cannot obtain holmium-166 for bone marrow ablation prior to bone marrow transplant recently used in the treatment of multiple myeloma.

We in the Nuclear Medicine Research Council ask that you carefully consider these matters as you make decisions how the Department of Energy fulfills its mission of providing our country with isotopes for research and treatment of diseases such as cancer, arthritis, heart and others. We urge you to order an Environmental Impact Statement for the Fast Flux Test Facility.

By separate cover, I am transmitting this material to Governor Locke of the state of Washington.

Very truly yours,

David H. Jones

David H. Jones, Co-Chairman
Nuclear Medicine Research Council

Attachment
cc: Honorable Slade Gorton
Honorable Patty Murray
Honorable Richard (Doc) Hastings
Honorable Norm Dicks
Honorable George Nethercutt
Honorable Jay Inslee
William Magwood IV, USDOE

NUCLEAR MEDICINE RESEARCH COUNCIL

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Robert E. Schenter, Ph.D.

Stanley W. Scott

Donald R. Segna

Thomas S. Tenforde, Ph.D.

Ann O. Worcester

November 26, 1997

The Honorable Federico F. Peña
Secretary of Energy
1000 Independence Avenue SW
Washington, DC 20585

Dear Mr. Secretary:

Nuclear medicine offers more effective, less costly, and less debilitating forms of treatment for many diseases, greatly increasing the health care and quality of life of patients. During the past decade, major advances have been made in the use of radioisotopes for the effective diagnosis and treatment of cancer, cardiovascular disease, arthritis, and other diseases. It has been demonstrated, for example, that the use of radiolabeled antibodies for the selective destruction of cancer cells provides an increased probability of long-term survival with fewer debilitating side effects than chemotherapy or external beam irradiation.

The widespread use of these new nuclear medicine techniques will not be possible, however, unless sufficient quantities of radioisotopes are readily available. There is currently a shortage of isotopes for medical research and for FDA-approved medical applications. Several clinical trials involving the treatment of cancer using radiolabeled antibodies have been curtailed due to a shortage of isotopes such as copper-67 and rhenium-186. Prostate cancer patients have been denied treatment with radioactive seed implants due to an insufficient supply of palladium-103. Without an adequate supply of medical isotopes to carry out clinical trials, medical research will also decline as a result of the lack of motivation to develop innovative new radioisotope procedures for treating disease.

On September 19-20, ten leading nuclear medicine physicians and researchers from throughout the United States participated in a conference held in Richland, WA, on "The Future Role of the Fast Flux Test Facility (FFTF) as a Supplier of Diagnostic and Therapeutic Medical Isotopes." These experts unanimously agreed that the United States is facing a critical shortage of radioisotopes for medical diagnostic and therapeutic applications by the early part of the twenty-first century, and that new accelerator and reactor sources are needed to fill this need. At the Richland conference, representatives of the Department of Energy described the proposal to restart FFTF for the mission of producing tritium for national defense applications, while simultaneously producing medical isotopes that are not available in sufficient quantities from existing U.S. sources.

In December, 1996, over sixty physicians and distinguished researchers requested Secretary O'Leary to review and strongly consider the potential for future FFTF operation, including isotope production. We have been very pleased and encouraged by the Department's steps this year to do just that. Restart of the FFTF for an interim tritium production mission would also provide critically needed medical isotope production capabilities, unmatched by any other reactor in the Western hemisphere.

Much work remains to be done to enhance health care through nuclear medicine techniques. The medical community is doing its share, despite the shortage of existing isotope supplies for clinical trials and the uncertainties that are faced in the future supplies of isotopes for medical research and therapeutic applications. To that end, it is critically important that the Department make available its unique resources, such as the FFTF, to sustain and enhance its partnership with the nuclear medicine community — a partnership that can do so much to save lives and improve the quality of life for critically ill patients.

We strongly encourage the Department to maintain its long-term commitment to the production of medical isotopes and continue its consideration of restarting the FFTF.

Sincerely,

Marc A. Garland
President

Susan L. Golladay
Board Co-Chair

Darrell R. Fisher, Ph.D.
Board Member

Robert E. Schenter, Ph.D.
Board Member

Thomas S. Tenforde, Ph.D.
Board Member

We, the undersigned, concur with this letter prepared by the Nuclear Medicine Research Council.

S. James Adelstein, M.D., Ph.D.
Daniel C. Tosteson University Professor,
Harvard University
Past-President, Society of Nuclear Medicine

A. Bertrand Brill, M.D., Ph.D.
Professor of Radiology,
Vanderbilt University School of Medicine
Professor of Radiology,
University of Massachusetts

Robert F. Carretta, M.D.
Director, Department of Nuclear Medicine,
Roseville Hospital, Roseville, CA
Vice-President-Elect, Society of Nuclear Medicine
Past-President, American College of
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Professor of Internal Medicine and Radiology,
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Chief Scientist and Chairman of the
Scientific Advisory Board,
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Elissa L. Kramer, M.D.
Associate Professor of Clinical Radiology,
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Assistant Medical Director,
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Nobel Laureate in Chemistry
University Professor of Chemistry,
University of California at Berkeley
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Professor of Medicine and Radiology,
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University of Cincinnati College of Medicine
Board of Trustees, Society of Nuclear Medicine

Huibert M. Vriesendorp, M.D., Ph.D.
Radiation Oncologist,
Arlington Cancer Center, Arlington, TX

Rosalyn S. Yalow, Ph.D.
Nobel Laureate in Physiology and Medicine

cc: Congressional Delegation of Washington
Congressional Delegation of Oregon
Congressional Delegation of Idaho
The Honorable Gary Locke, Governor of Washington
The Honorable John Kitzhaber, Governor of Oregon
The Honorable Phil Batt, Governor of Idaho

ASNC

American Society of Nuclear Cardiology

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DAWN M. EDGERTON

July 20, 1999

Dr. William J. Madia
Pacific Northwest National Laboratory
902 Battelle Blvd.
PO Box 99
MISN: K1-46
Richland WA 99352

Dear Dr. Madia:

I am writing to you to express our strong support for a full and open consideration of the restart of the Fast Flux Test Facility (FFTF) and its renewed operation as a user facility to provide irradiation services for the nation's medical community.

With its restart, FFTF could provide an extremely valuable resource for the nation's medical faculty and students by providing both research and educational opportunities related to nuclear science and especially nuclear medicine. The availability of FFTF's proven research capabilities would enhance and extend those efforts, especially in the areas of medical isotope development, production and applications for heart patients.

The FFTF has the ability to produce large quantities of a variety of medical isotopes. Many of these promising isotopes are currently either unavailable or available in such small quantities from other sometimes unreliable production facilities that it is difficult to conduct cardiac studies with even very small numbers of patients. Research is being hampered or removed from consideration by a lack of these isotopes. Medical isotope therapy is generally more effective against disease such as coronary restenosis, at lower cost. It is crucial that we receive a wide variety of isotopes, including those with high specific activity, appropriate to diagnose and treat heart disease.

It is vital that an adequate supply of medical isotopes be available to our members for research, diagnosis and treatment of coronary disease. We fully support the effort behind the FFTF restart.

Sincerely,

Timothy M. Bateman

Timothy M. Bateman, MD
President

RSNA
Radiological Society of North America
Founded in 1915

820 Jorie Boulevard
Oak Brook, Illinois 60523-2251
630/571-2670
FAX: 630/571-7837
www.rsna.org

July 21, 1999

Dr. William J. Madia
Pacific Northwest National Laboratory
902 Battelle Blvd
PO Box 99
MISN: K1-46
Richland, WA 99352

Dear Dr. Madia:

Our organization represents over 30,000 practicing radiologists. We are writing to you to express our strong support for a full and open consideration of the restart of the Fast Flux Test Facility (FFTF) and its renewed operation as a user facility to provide irradiation services for the nation's medical, science, and engineering communities.

With its restart, FFTF would provide an extremely valuable resource for the nation's faculty and students by supplying research and educational opportunities related to nuclear medicine, engineering, and nuclear science. The availability of FFTF's proven research capabilities would enhance and extend those efforts, especially in the areas of medical isotope development, production and applications, and materials processing.

The FFTF has the ability to produce large quantities of a variety of medical isotopes. Many of these promising isotopes are currently either unavailable or available in such small quantities from other production facilities that it is difficult to conduct clinical studies with even very small numbers of patients. Research is being hampered or removed from consideration by a lack of these isotopes. Medical isotopes are often the only effective way to properly diagnose and treat serious disease. It is crucial that we, as radiologists, have access to a wide variety of isotopes, including those with high specific activity, appropriate to diagnose, prevent and treat heart disease, cancer, arthritis, and more recently, infectious disease.

The FFTF is a unique facility with capabilities that no other device in the world can match. It also has an outstanding record of research, operational excellence, and environmental stewardship. A reactor like FFTF might never be built again. Thus, I hope that the decision on its future will fully weigh its considerable merits and many prospective contributions to the nations health and welfare.

Sincerely,

Jerry P. Petasnick, MD
Chairman of the Board

Board of Directors
Jerry P. Petasnick, MD
Chairman
Seymour H. Levitt, MD
President

C. Douglas Maynard, MD
R. Nick Bryan, MD, PhD
Peggy J. Fritzsche, MD
Brian C. Lentle, MD

David H. Hussey, MD
Robert R. Hattery, MD
Delmar J. Stauffer
Executive Director

OREGON HEALTH
SCIENCES UNIVERSITY

MANUEL MARTINEZ-MALDONADO, M.D.
VICE PROVOST FOR RESEARCH
3181 S.W. SAM JACKSON PARK RD.
MAIL CODE L106
PORTLAND, OR 97201-3098
TEL: 503-494-1085
FAX: 503-494-1099

June 21, 1999

Dr. William J. Madia, Director
Pacific Northwest National Laboratory
P.O. Box 999
Richland, WA 99352

Dear Dr. Madia:

I am writing to express my strong support for a full and open consideration of the restart of the Fast Flux Test Facility (FFTF) and its renewed operation as a user facility to provide irradiation services for the nation's science, engineering, and medical communities.

With its restart, FFTF could provide an extremely valuable resource for the nation's faculty and students by providing both research and educational opportunities related to nuclear science, engineering, and medicine. Through our ongoing association with the Pacific Northwest National Laboratory, we have established a broad range of strong collaborations. The availability of FFTF's proven research capabilities would enhance and extend those efforts, particularly in the areas of medical isotope development, production and applications, materials processing, electronic materials development, and others.

The FFTF is a unique facility with capabilities that no other device in the world can match. It also has an outstanding record of research, operational excellence, and environmental stewardship. A reactor like FFTF might never be built again. Thus, I hope that the decision on its future will fully weigh its considerable merits and many prospective contributions to the nation's health and welfare.

Sincerely,

Manuel Martinez-Maldonado, M. D.

cc: Mr. William D. Magwood, IV, Director
Office of Nuclear Energy, Science & Technology (US DOE)

WILSON C. "Toby" HAYES

VICE PROVOST FOR
RESEARCH

June 25, 1999

OREGON
STATE
UNIVERSITY

312 Kerr Administration
Building
Corvallis, Oregon
97331-2140

Dr. William J. Madia, Director
Pacific Northwest National Laboratory
P.O. Box 999
Richland, WA 99352

Dear Dr. Madia:

I am writing to express my strong support for a full and open consideration of the restart of the Fast Flux Test Facility (FFTF) and its renewed operation as a user facility to provide irradiation services for the nation's science, engineering, and medical communities.

With its restart, FFTF would provide an extremely valuable resource for the nation's faculty and students by providing both research and educational opportunities related to nuclear science, engineering, and medicine. Through our ongoing association with the Pacific Northwest National Laboratory, we have established a broad range of strong collaborations in these areas. The availability of FFTF's proven research capabilities would enhance and extend those efforts, particularly in the areas of medical isotope development, production and applications; materials processing; electronic materials development; and others.

Several of our faculty here at Oregon State, including Dr. Andrew Klein, Department Head of Nuclear Engineering, and Dr. Stephen Binney, Director, Radiation Center, have worked on FFTF-related projects in the past and are very interested in and concerned about the FFTF being available for future missions.

Telephone
541-737-3467

Fax
541-737-3093

Internet
wilson.hayes@orst.edu

Washington State University
Office of the Vice Provost for Research
PO Box 641030

The FFTF is a unique facility with capabilities, such as its hard neutron spectrum, that no other device in the world can match. It also has an outstanding record of research, operational excellence, safety, and environmental stewardship. A reactor with the capabilities of the FFTF might never be built again. Its unique capabilities and configuration are complementary to our own TRIGA thermal neutron research reactor. Thus, I hope that the decision on its future will fully weigh its considerable merits and many prospective contributions to the nation's health and welfare.

Oregon State University

Sincerely yours,

Wilson C. Hayes

Wilson C. "Toby" Hayes
Vice Provost for Research

WCH:nm

cc: Mr. William D. Magwood, IV, Director
Office of Nuclear Energy, Science & Technology (US DOE)

R. Eric Leber, Ph.D.
Manager, College and University Relations

RADIATION CENTER

Dr. William J. Madia, Director
Pacific Northwest National Laboratory
P.O. Box 999
Richland, WA 99352

Dear Dr. Madia:

I am a strong advocate of the Fast Flux Test Facility (FFTF). I view the FFTF as a unique national facility that has demonstrated its capabilities very well in the past. As the nation's priorities have shifted, so has the scope of opportunity for the FFTF. This is a tribute to the flexible and multi-faceted nature of the FFTF and its outstanding record of research and operational safety.

I encourage a decision for restart of the FFTF. I would hope this decision would be made based on scientific merit and not political expediency.

The FFTF is a unique facility, especially in terms of its very hard neutron spectrum. As such, it has the capability of producing many high specific activity radioisotopes that cannot be produced at any other facility in the world. There is much research that is hampered by the lack of certain medical isotopes. It's a "chicken and egg" situation in which the lack of isotopes leads to less research from which USDOE deduces that these isotopes aren't needed. Furthermore, because of the low use rate of these research isotopes, they tend to be very expensive. In my opinion significant advances in nuclear medicine diagnostics and therapy could be accomplished if an expanded suite of radioisotopes were available. The FFTF would be an invaluable contribution to this effort. With expanded research studies the price of producing these isotopes would also decrease.

Oregon State University has had many valuable collaborative research relationships with the Pacific Northwest National Laboratory and other Hanford contractors over the years, especially in the nuclear area. We are very interested in and concerned about the FFTF being available for future projects. Thus, I hope that the decision on its future will fully weigh its considerable merits and many prospective contributions to the nation's health and welfare.

Sincerely,

Stephen E. Binney
Director

c: Mr. William D. Magwood, IV, Director
Office of Nuclear Energy, Science & Technology (USDOE)

OREGON
STATE
UNIVERSITY

100 Radiation Center
Corvallis, Oregon
97331-5903

Telephone
541-737-2341

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541-737-0480

Washington State University
Office of the Vice Provost for Research

PO Box 641030
Pullman, WA 99164-1030
509-335-3535
FAX 509-335-1949

July 21, 1999

Dr. William J. Madia, Director
Pacific Northwest National Laboratory
P.O. Box 999
Richland, WA 99352

Dear Dr. Madia:

I am writing to comment on your upcoming consideration of the restart of the Fast Flux Test Facility (FFTF) and its renewed operation as a user facility to provide irradiation services for the nation's science, engineering, and medical communities.

Over the years, Washington State University and Pacific Northwest National Laboratory have engaged in joint research across a broad spectrum of science and technology. This relationship, as reviewed through a recent series of summit meetings, has brought considerable value to all parties. Accordingly, the University is interested in sustaining those interactions and, as new opportunities emerge, examining them as prospects to expand and enhance the productive collaborations between our two institutions. We are particularly interested in biomedical and agricultural applications that will enrich the scholarly work of our faculty and students.

Sincerely,

George A. Hedge
Vice Provost for Research

pc: Mr. William D. Magwood, IV, Director
Office of Nuclear Energy, Science and Technology (US DOE)

University of Idaho
University Research Office
Moscow, Idaho 83844-3010
Phone: 208-885-6651
FAX: 208-885-6198

June 22, 1999

Dr. William J. Madia, Director
Pacific Northwest National Laboratory
P.O. Box 999
Richland, WA 99352

Dear Dr. Madia:

I am writing to express my support for the restart of the Fast Flux Test Facility (FFTF) and its renewed operation as a science and engineering user facility.

The University of Idaho has over the years established many strong collaborations with the Pacific Northwest National Laboratory, and the research capabilities offered by the FFTF could not only strengthen existing collaborations but help build new ones as well. UI scientists and engineers would welcome such enhanced opportunities, particularly in the areas of materials processing and development.

With its restart, FFTF could provide an extremely valuable resource for the nation's research universities by providing both research and educational opportunities related to nuclear science, engineering, and medicine. A positive decision to restart this unique facility would be an important step in retaining our nation's position as the world's top scientific enterprise.

Sincerely yours,

Jean'ne M. Shreeve

Jean'ne M. Shreeve
Vice President for Research and Graduate Studies
Professor of Chemistry

JMS:cm
cc: Mr. William D. Magwood, IV, Director
Office of Nuclear Energy, Science & Technology (US DOE)

The University of Idaho is an equal opportunity/affirmative action employer and educational institution.

REED COLLEGE Portland, Oregon 97202

REACTOR FACILITY

June 23, 1999

Dr. William J. Madia, Director
Pacific Northwest National Laboratory
P.O. Box 999
Richland, WA 99352

Dear Dr. Madia:

I am writing in support of the restart of the Fast Flux Test Facility (FFTF). Upon restart, it will provide an unparalleled source for neutron irradiation services to our nation's science and medical communities.

The Reed College Reactor has a strong collaboration with the Pacific Northwest National Laboratory. The availability of FFTF's research capabilities would extend our efforts, particularly in the area of medical isotope development. Its capabilities are distinctly different from our own research reactor, and therefore provide complementary capabilities.

I hope that the decision on FFTF's future will fully weigh its considerable merits and many prospective contributions to our nation's health and welfare.

Sincerely,

Stephen G. Frantz
Director, Reed College Reactor

cc: Mr. William D. Magwood, IV, Director
Office of Nuclear Energy, Science & Technology
U.S. Department of Energy
Washington, D.C. 20585

3203 SE Woodstock Blvd., Portland, OR 97202-8199 Tel: (503) 777-7222 Fax: (503) 777-7274 reactor@reed.edu

ENERGY NORTHWEST

P.O. Box 968 ■ Richland, Washington 99352-0968

June 24, 1999

Mr. William D. Magwood, IV, Director
Office of Nuclear Energy, Science & Technology
U.S. Department of Energy
1000 Independence Avenue, S.W.
Washington, DC 20585

Dear Mr. Magwood:

Subject: **OPERATING CONTRACT AT THE FFTF**

We are aware that the Department of Energy is considering the restart of the Fast Flux Test Facility (FFTF) for a variety of government and private-sector missions related to nuclear science and irradiation services. With this letter, we are expressing interest in being considered a candidate for the operating contractor at the FFTF.

Energy Northwest, formerly Washington Public Power Supply System, has a proven track record of operating a commercial nuclear reactor on the Hanford site since 1984. Its current leadership team has a proven track record of operating to the highest standards of safety, reliability, and cost effectiveness. Energy Northwest's commitment to nuclear operating excellence, community stewardship, and onsite/infrastructure support make it well positioned to carry out this mission.

As a measure of our confidence in the FFTF and our capabilities, we would be willing to place any and all fee at risk conditional on meeting restart cost and schedule goals. Furthermore, as a measure of our confidence in the market for the FFTF's products and services, once the FFTF is operational, Energy Northwest would not only put all fee at risk for meeting goals related to operational excellence, we would also put at risk all fee based on meeting agreed-upon operating revenue offset targets.

The FFTF is a world-class facility that can make important contributions to our nation for years to come. We believe that as the operating contractor we can help the Department leverage this reactor to its full advantage. We hope to send a representative to the July 29, 1999 public meeting of the Department's Nuclear Energy Research Advisory Committee (NERAC) to further communicate our support. We look forward to the opportunity. Feel free to contact Jack Baker, Vice President of Resource Development at (509) 377-8322, for more information.

Respectfully,

J.W. Parrish, CEO
Energy Northwest (MD 1035)

cc: Dr. William J. Madia, Director
Pacific Northwest National Laboratory

Douglas E. Olesen
President and
Chief Executive Officer

Battelle
. . . Putting Technology To Work
505 King Avenue
Columbus, Ohio 43201-2693
Telephone 614•424•6562
Fax 614•424•3260

June 30, 1999

Mr. William D. Magwood, IV, Director
Office of Nuclear Energy, Science & Technology
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, D.C. 20585

Dear Mr. Magwood:

As the Department of Energy prepares to make a decision regarding the future of the Fast Flux Test Facility (FFTF), I am writing to affirm the support of the Battelle Memorial Institute for the restart of the FFTF and its operation as a user facility to provide nuclear research and irradiation services supporting this nation's scientific, engineering, and medical communities.

Battelle is committed to:

- Ensuring, through its operation of the Pacific Northwest National Laboratory (PNNL), the safe and productive restart and operation of the FFTF as an essential element of this nation's nuclear science and irradiation services infrastructure.

- Using the strong international and commercial contacts and customer base of this Institute to ensure that the market for the FFTF's products and services is fully engaged, and that support is obtained to offset the FFTF's operating costs.

- Meeting agreed-upon goals for restart cost and schedule, operational excellence, and revenue offset targets in accordance with performance agreements established with the Department that place any and all FFTF-related fee at risk.

We believe that through PNNL we can help the Department leverage this reactor to its full advantage and potential. When Dr. Bill Madia presents the results of the 90-day study on the FFTF at the July 29, 1999, public meeting of the Department's Nuclear Energy Research Advisory Committee (NERAC), he will be representing all of Battelle in confirming our support for this world-class facility. We know FFTF can make important contributions to our nation for years to come.

I was a member of the PNNL staff when Battelle had responsibility for the initial concept and design of FFTF. I watched its construction and initial operation with a great deal of pride. We have always believed that this facility had great potential to make contributions on a broad scale to

improve the quality of life. I look forward to the opportunity to have Battelle once again assume responsibility for this fine facility and guide its utilization in the service of the nation.

If you have any questions, please do not hesitate to call me on (614) 424-6562.

Sincerely,

D. E. Olesen
President and
Chief Executive Officer

DEO:bjc

cc: W. J. Madia, Director
Pacific Northwest National Laboratory

Pacific Northwest National Laboratory
Operated by Battelle for the
U.S. Department of Energy

July 12, 1999

Mr. William D. Magwood, IV, Director
Office of Nuclear Energy, Science & Technology
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, D.C. 20585

Dear Mr. Magwood:

As the U.S. Department of Energy prepares to make decisions regarding the future of the Department's reactor facilities, we are writing to reaffirm our joint support for retaining the essential elements of this nation's nuclear science and irradiation services infrastructure. As we indicated in the report to Secretary Peña (*Recommendations for a Department of Energy Nuclear Energy R&D Agenda*, UCRL-ID-129209, December 1997), to achieve the energy and safety goals of this nation, we must maintain our critical nuclear technical competencies and its vital infrastructure.

Our Laboratories are the stewards of most of the reactor-related capabilities within the U.S. Department of Energy. We believe that the need for those capabilities will grow dramatically over the next 20 years given the demand for radioisotopes, the development of proliferation-resistant technologies, and the lack of replacement construction. Your efforts and those of the Nuclear Energy Research Advisory Committee to roadmap the needs and infrastructure support related to nuclear technology are extremely important. Together we can sustain a supportive national program that meets those needs, maintains that infrastructure, and cooperatively employs all of our valuable reactor resources.

Sincerely,

William J. Madia
Director
Pacific Northwest National Laboratory

Alvin W. Trivelpiece
Director
Oak Ridge National Laboratory

Barton Krawetz
Director
Idaho National Engineering and Environmental Laboratory

Frank Y. Fradin
Interim Director
Argonne National Laboratory

C. Paul Robinson
Director
Sandia National Laboratories

902 Battelle Boulevard • P.O. Box 999 • Richland, WA 99352

Telephone (509) 375-6600 ■ Email madia@pnl.gov ■ Fax (509) 375-6844

MEMORANDUM OF UNDERSTANDING

SUBJECT: Technical Support for restart and operation of the Fast Flux Test Facility (FFTF)

This memorandum outlines our intent and understanding about potential Argonne National Laboratory (ANL) collaboration with Pacific Northwest National Laboratory (Pacific Northwest), in support of the proposed restart and operation of FFTF under Pacific Northwest sponsorship.

Any FFTF restart will require augmentation of the current facility operations and maintenance cadre, and reconstitution of a technical support organization. Knowledge and experience in reactor physics, fast reactor engineering, reactor safety, and liquid metal technology will be essential to timely and efficient restart and operation of the facility. The ANL staff include a substantial increment with that knowledge and experience, derived from prior conduct of fast reactor development work and design and operation of EBR-II.

The timing of EBR-II stand down and the proposed schedule for FFTF restart appear to be compatible, in that the prospective need for technical support for FFTF would seem to dove-tail quite well with the EBR-II stand down schedule.

Argonne National Laboratory's collaboration in the proposed FFTF restart is anticipated to take several different forms, including:

- Joint program development and the performance of projects which utilize the FFTF nuclear science and irradiation services capabilities

- Specific technical support tasks to be undertaken by ANL, such as developing and/or confirming reactor core calculations

- Loan of ANL operations and technical support personnel to Pacific Northwest and its operations and maintenance subcontractor, under terms and conditions compatible with the needs of the two organizations.

Specific working agreements for collaboration, as outlined herein, will be developed between the two organizations if the decision is made to restart FFTF.

Yoon I. Chang, Associate Laboratory Director
Argonne National Laboratory

Date July 14, 1999

Walter J. Apley, Director
FFTF Standby Project Office
Pacific Northwest National Laboratory

Date July 13, 1999

BWX Technologies, Inc.
Babcock & Wilcox, a McDermott company
John A. Fees
President, B&W Services, Inc.

Rt. 726, Mt. Athos Road
Lynchburg, VA 24504

P.O. Box 11165
Lynchburg, VA 24506-1165
(804) 522-6178
Fax: (804) 522-6963

July 16, 1999

William J. Madia, Ph.D.
Director
Pacific Northwest National Laboratory
Post Office Box 999, MSIN: K1-46
Richland, Washington 99352

RE: Fast Flux Test Facility - B&W Hanford Company

Dear Mr. Madia:

For the past several years, B&W Hanford Company (BWHC) has operated the Fast Flux Test Facility (FFTF) for the U.S. Department of Energy (DOE) under a subcontract with Fluor Daniel Hanford, Inc. (FDH) with programmatic direction by the joint Pacific Northwest National Laboratory (PNNL)/FDH Project Office. We have continued the tradition of FFTF operational excellence that has earned the FFTF the reputation as the best operating reactor in the DOE complex.

BWX Technologies, Inc. (BWXT) has a long and proud history as a designer and supplier of reactor systems and fuel to the U.S. Government and the utility industry. We have supplied plutonium fuel to the FFTF and many highly enriched cores for the U.S. Navy and for research and test reactors. We are currently the sole supplier of reactor system components and nuclear fuel for the Naval Nuclear Program.

We are committed to continue this record of operational excellence should the DOE decide to proceed with the environmental impact statement (EIS) process and ultimate restart of the FFTF. BWHC is committed to support DOE, PNNL, and FDH in developing an optimum arrangement for completing the work necessary for the EIS process and prepare the FFTF and the operating staff for restart of critical operation. We are prepared to dedicate the experienced resources necessary for this important task.

We believe we have developed a high confidence restart cost and schedule plan based on our detailed involvement with the FFTF Standby Project Office in the planning process. As a measure of our confidence in the FFTF, the FFTF staff and our corporate

resources and capabilities, we would be willing to place all fee at risk based upon meeting restart cost and schedule goals.

Once the FFTF is operational, BWXT would also place all fee at risk for meeting goals related to operational excellence and performance. In addition, we commit to use our FFTF and corporate resources to support meeting the agreed-upon operating revenue offset targets.

The FFTF is a world-class facility and an important national asset. Dr. Allen Womack, President, BWXT, and I plan to attend the July 29, 1999, public meeting of the Nuclear Energy Research Advisory (NERAC) to reinforce our support and commitment for the FFTF restart.

Sincerely,

John A. Fees
President
B&W Services, Inc.

bjk

Duke Engineering & Services
A Duke Energy Company

400 South Tryon Street
P.O. Box 1004
Charlotte, NC 28201-1004

R.F. GREEN
President & Chief Executive Officer
704 373-3384
Fax 704 382-7969

July 16, 1999

Mr. William D. Magwood, IV, Director
Office of Nuclear Energy, Science & Technology
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Dear Mr. Magwood:

We are aware that the Department of Energy is considering the restart of the Fast Flux Test Facility (FFTF) for a variety of government and private-sector missions related to nuclear science and irradiation services. With this letter, we are expressing interest in being considered a candidate for the operating contractor at the FFTF.

DE&S possesses the management and technical expertise and resources gained by more than 40 years of nuclear facility design, licensing, construction, and operations experience. Our personnel have had the responsibility of operating nine commercial and DOE reactors efficiently and cost-effectively. We currently provide operations consulting and management and technical services to 95 percent of the commercial reactors in the U.S.

The FFTF is a world-class facility that can make important contributions to our nation for years to come. We believe that as the operating contractor we can help the Department leverage this reactor to its full advantage. As a measure of our confidence in the FFTF and our capabilities, we would be willing to enter into a performance based contract related to start-up and operations of the reactor. We feel this will lead to a "win-win" arrangement for all parties—the Nation, DOE and ourselves.

We plan to send a representative to the July 29, 1999 public meeting of the Department's Nuclear Energy Research Advisory Committee (NERAC) to further communicate our support. We look forward to the opportunity.

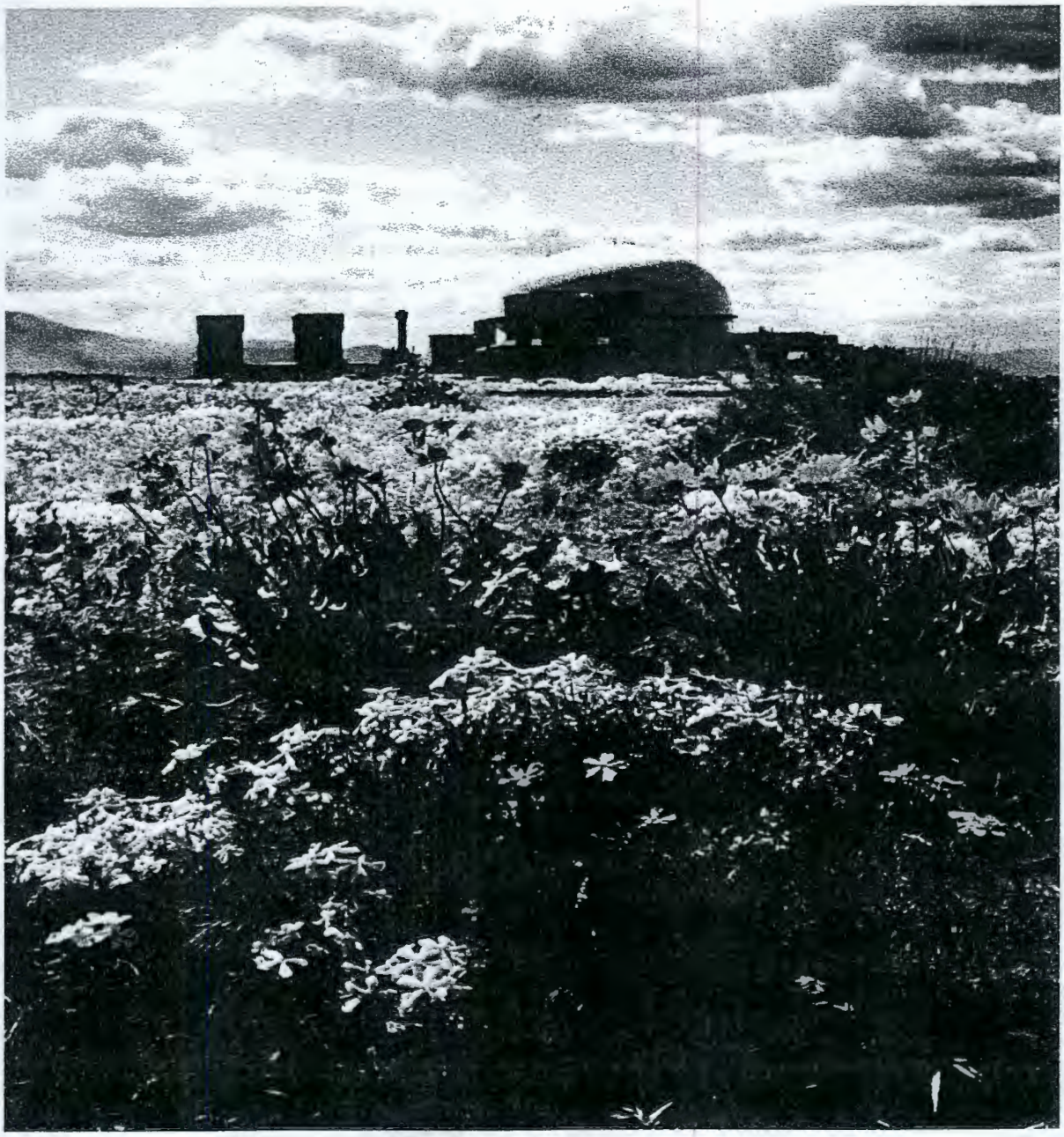
Sincerely,

R. F. Green
President & CEO

cc: Dr. William J. Madia, Director
Pacific Northwest National Laboratory

Appendix A-2

Plant Description/
Research and Isotope Production Capabilities



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Plant Description/ Research and Isotope Production Capabilities

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Plant Description/ Research and Isotope Production Capabilities

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Appendix A-2

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1.0 Introduction

This appendix provides a physical description of the Fast Flux Test Facility (FFTF), with particular emphasis on the reactor features that enable the facility to support a wide range of isotope production and research missions. In addition, a current status of the facility is provided as well as a discussion of plant dependability and estimated facility life.

2.0 Background

The FFTF is a 400-megawatt, sodium-cooled, fast neutron flux reactor (Figure 1) owned by the U.S. Department of Energy (DOE) at the Hanford Site in southeastern Washington State near Richland, Washington (Figure 2). The FFTF was designed and built to be the Nation's leading test reactor for development of the next generation of commercial power reactors and is the newest, largest, and most versatile test reactor in the DOE complex. Although the FFTF was constructed to support the development and testing of materials and equipment for the Liquid Metal Fast Breeder Reactor (LMFBR) program, it was not designed nor was it ever operated as a breeder reactor itself. Furthermore, there is no expectation that it would be used for that purpose in any new mission.

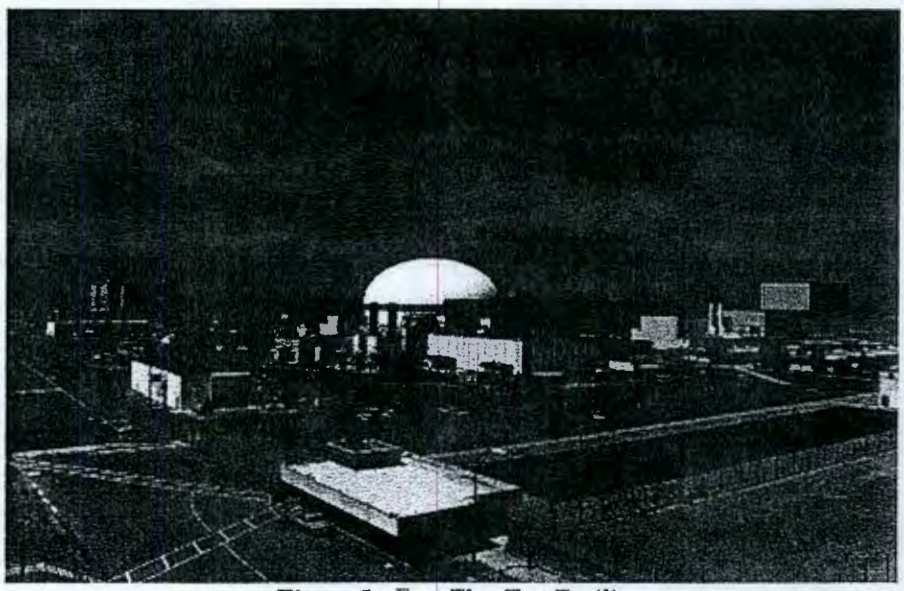


Figure 1. Fast Flux Test Facility

The major difference between the FFTF and a breeder reactor is that the active core region in a breeder is surrounded by blanket assemblies, typically containing natural uranium that is converted to plutonium by absorbing neutrons; in the FFTF, the core is surrounded by metal reflector assemblies that "reflect" excess neutrons back into the active core region, thus increasing the efficiency of the reactor for irradiation/testing purposes.

Construction was completed on the FFTF in 1978. Following extensive testing, the reactor was started up in 1982. Because of its size and core design, the FFTF can simultaneously carry out a significant array of missions. For approximately 10 years, the FFTF operated successfully as a national research facility testing advanced nuclear fuels, materials, components, active and passive reactor safety technologies, and gaining operating experience for the next generation of nuclear reactors. The FFTF also produced a wide variety of medical isotopes and made tritium for the U.S. fusion research program. Attachment 1 highlights the FFTF's significant events and accomplishments since initial nuclear criticality was achieved in February 1980. The list includes several record-breaking milestones.

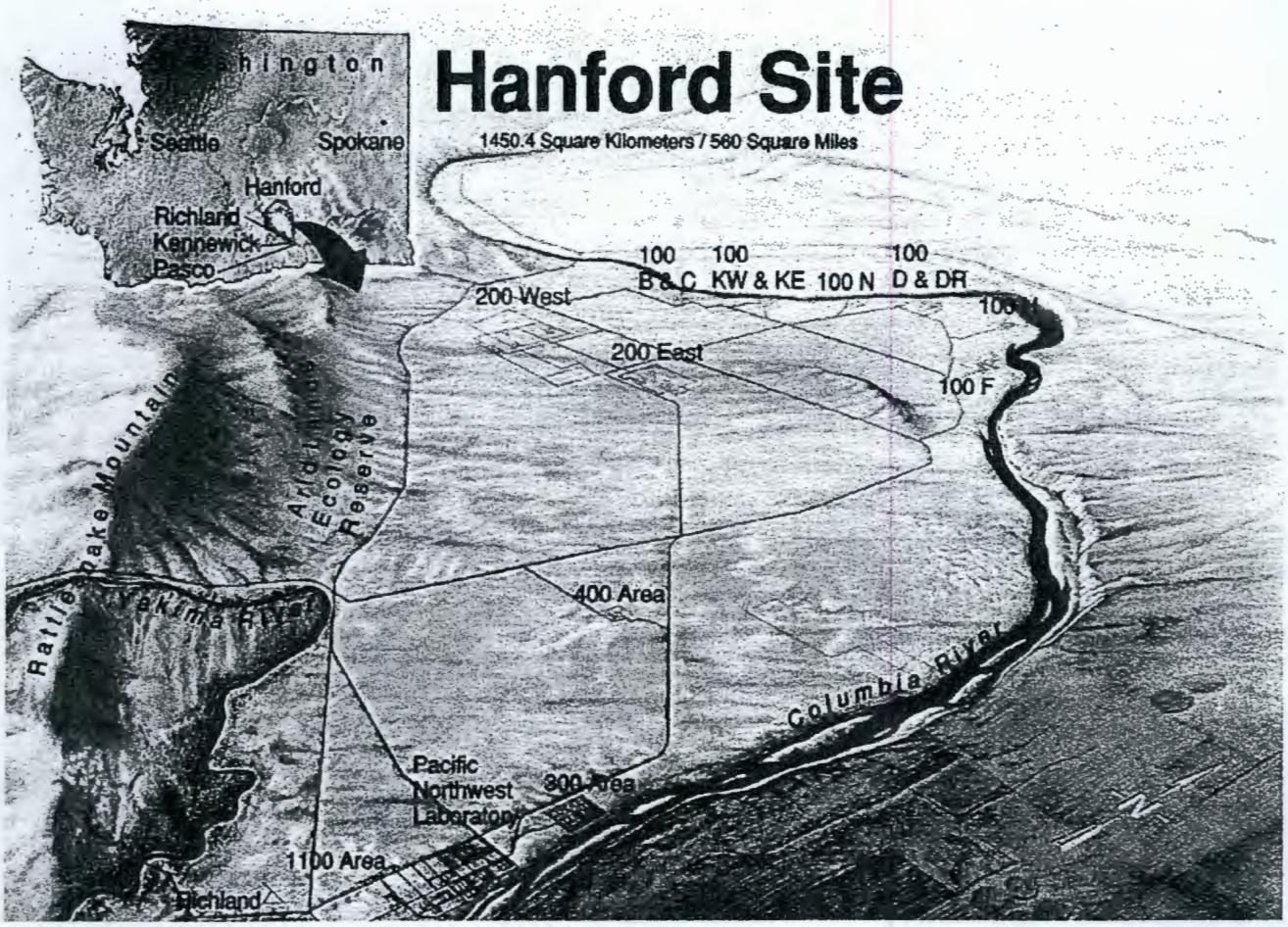


Figure 2. Hanford Site

The FFTF is currently defueled and being maintained in a standby condition pending a decision by the DOE on its future. The FFTF could play a pivotal role in the nation's nuclear research infrastructure, as it is ideally suited to support multiple missions requiring steady-state neutron generation such as isotope production, space technology, U.S. and international research activities, and irradiation services. Projected mission needs could be met with operation at a nominal 100 megawatts rather than the maximum power rating of 400 megawatts. This has the added advantages of increasing the lifetime of the reactor and reducing the demand for replacement fuel.

3.0 Plant Description

This section provides an orientation to the physical layout and significant design features of the FFTF complex. A more detailed technical description of the FFTF is available (HEDL 1980). The FFTF complex includes the reactor, as well as equipment and structures for heat removal, containment, core component handling and examination, fuel offload and storage, and supplying utilities and other essential services. The central feature of the FFTF is the reactor containment building, an all-welded cylindrical steel structure 135 ft. in diameter and 187 ft. high (115 ft. of which is above grade). The array of buildings and equipment surrounding the containment building and comprising the FFTF complex is depicted in Figure 3.

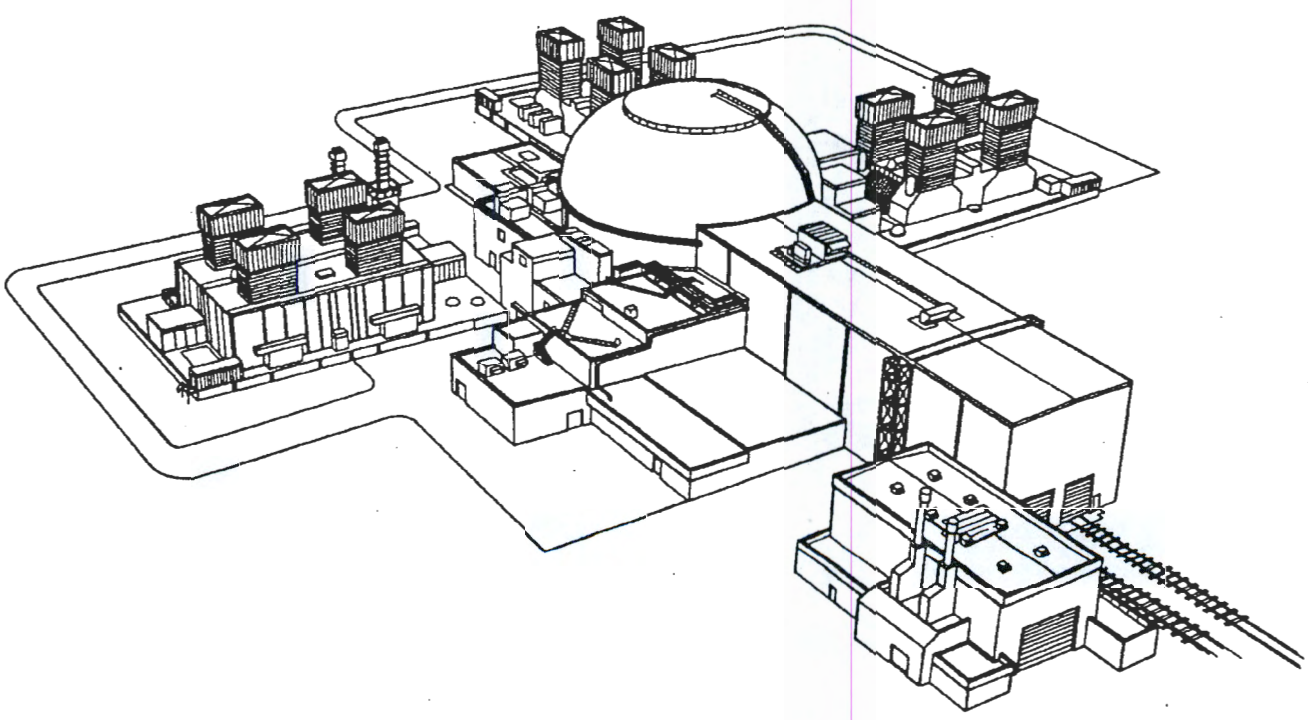


Figure 3. FFTF Complex

3.1 Reactor and Main Heat Transport System

The reactor (Figure 4) is located in a shielded cell in the center of the containment. Heat is removed from the reactor by liquid sodium circulated under low pressure through three separate closed primary piping systems, referred to as loops, which include pumps, piping, and intermediate heat exchangers. These loops are located within cells in containment. Figure 5 is a cutaway of the containment building showing the location of the reactor, primary pumps, and intermediate heat exchangers. Three secondary sodium loops transport the reactor heat from the intermediate heat exchangers to the air-cooled tubes of the dump heat exchangers for dissipation to the atmosphere (the FFTF does not generate electricity). Figure 6 depicts one of the three cooling loops.

The design of the FFTF has proven to be extremely robust and flexible, allowing it to be used for a variety of purposes beyond its original mission. For example, the extensive instrumentation and characterization of the reactor and heat transport system have led to the ability to perform a wide variety of tests to demonstrate the safety characteristics of Liquid Metal Reactors (LMRs). In addition to the instrumentation found in a typical nuclear reactor facility (e.g., neutron flux, coolant loop temperature, flow and pressure), the FFTF includes instrumentation to measure the coolant flow and temperature at the exit of each of the core subassemblies. Furthermore, the capability exists, and has been used, to install specially instrumented assemblies within the core region to provide even more detailed core operating data (see Section 4.0). These capabilities were used during the early operation of the facility to confirm that the reactor was operating as expected and to verify many of the safety characteristics discussed below. For example, fueled open test assemblies (FOTAs) were used to place many thermocouples within the core region during verification of the natural circulation decay heat removal process. These capabilities were also used during later testing performed to provide additional detailed information on the reactivity feedback characteristics of the reactor and during demonstration testing of devices designed to further enhance the inherent safety of LMRs.

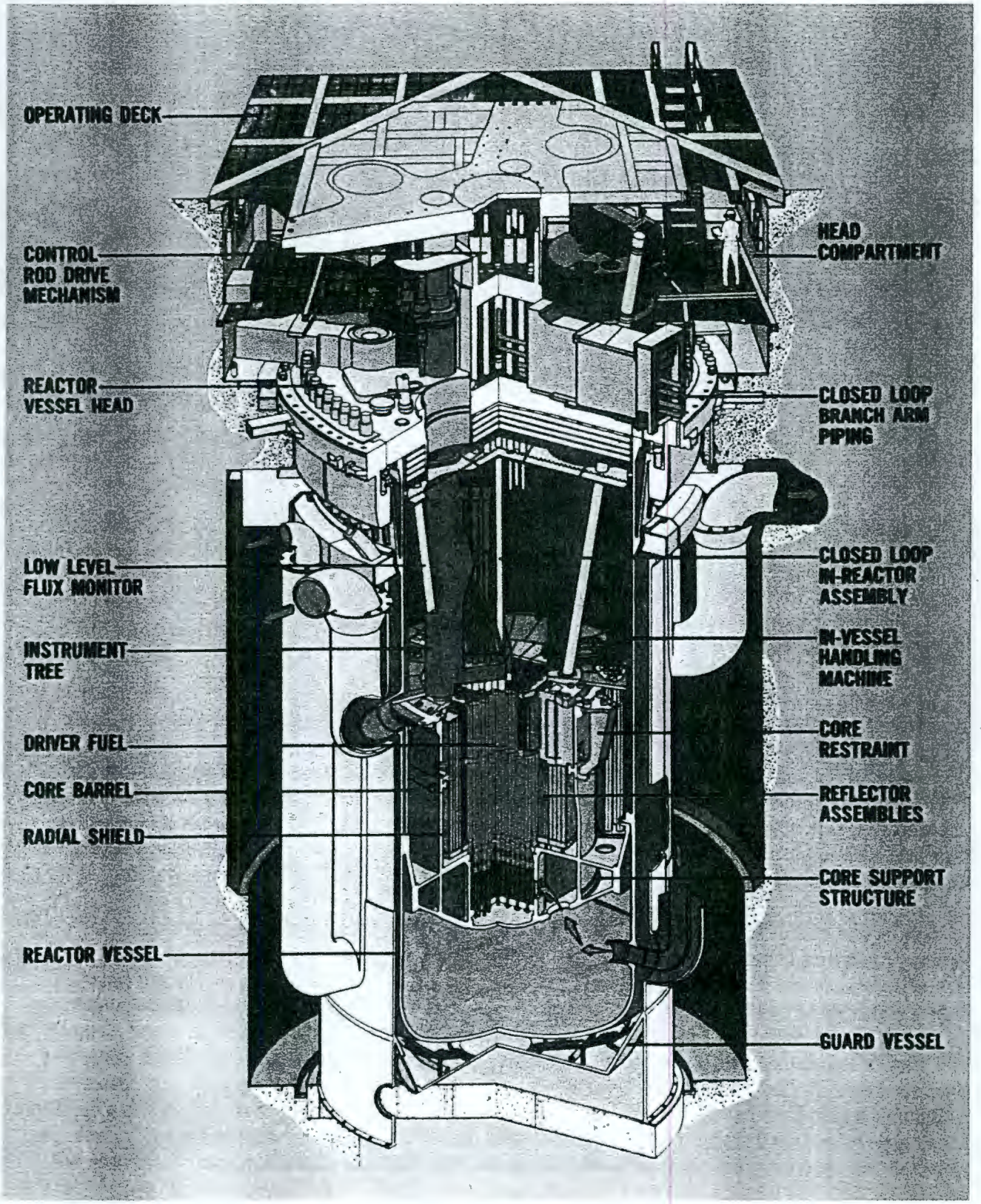


Figure 4. FFTF Reactor

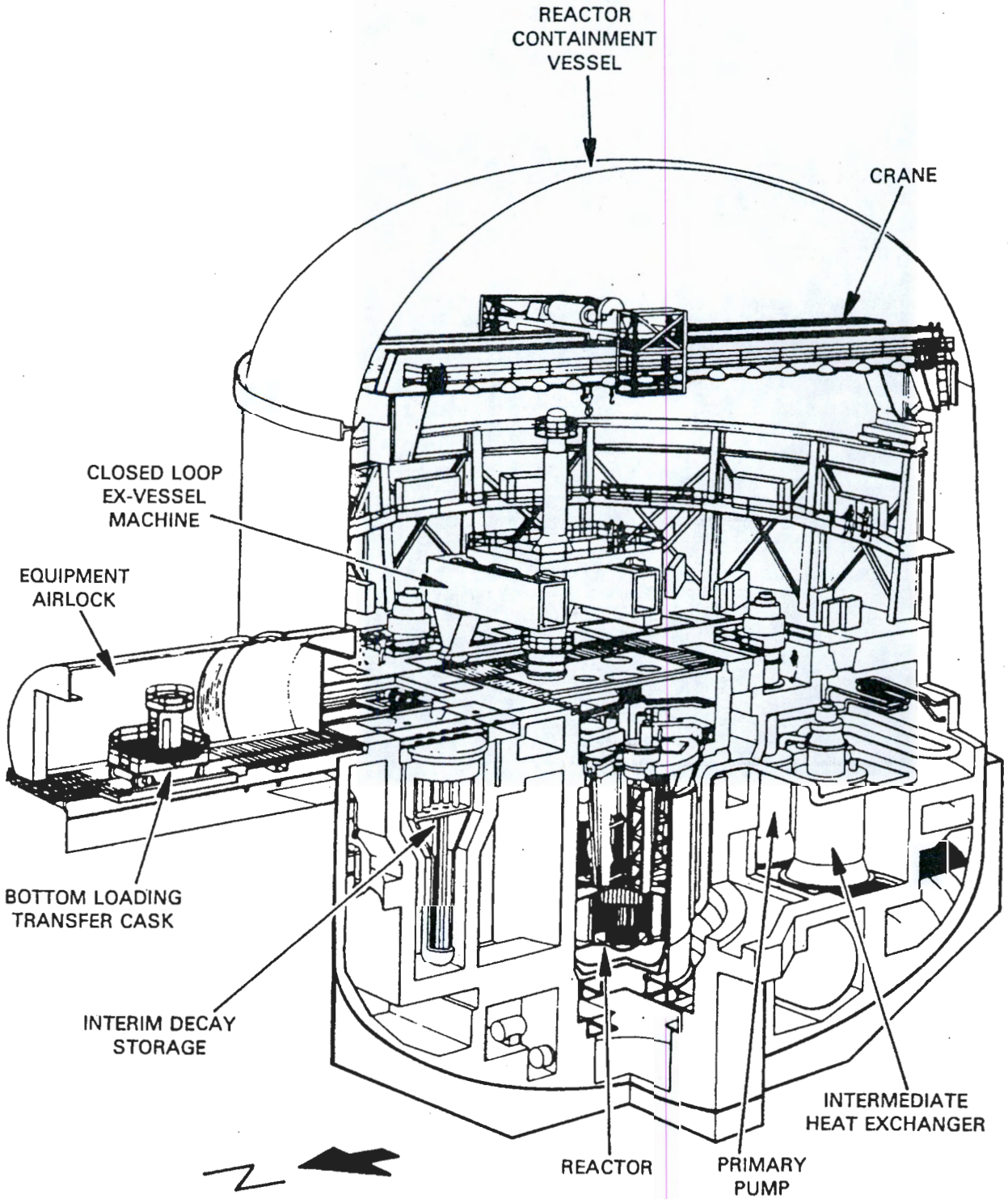


Figure 5. Cutaway of the Reactor Containment Building

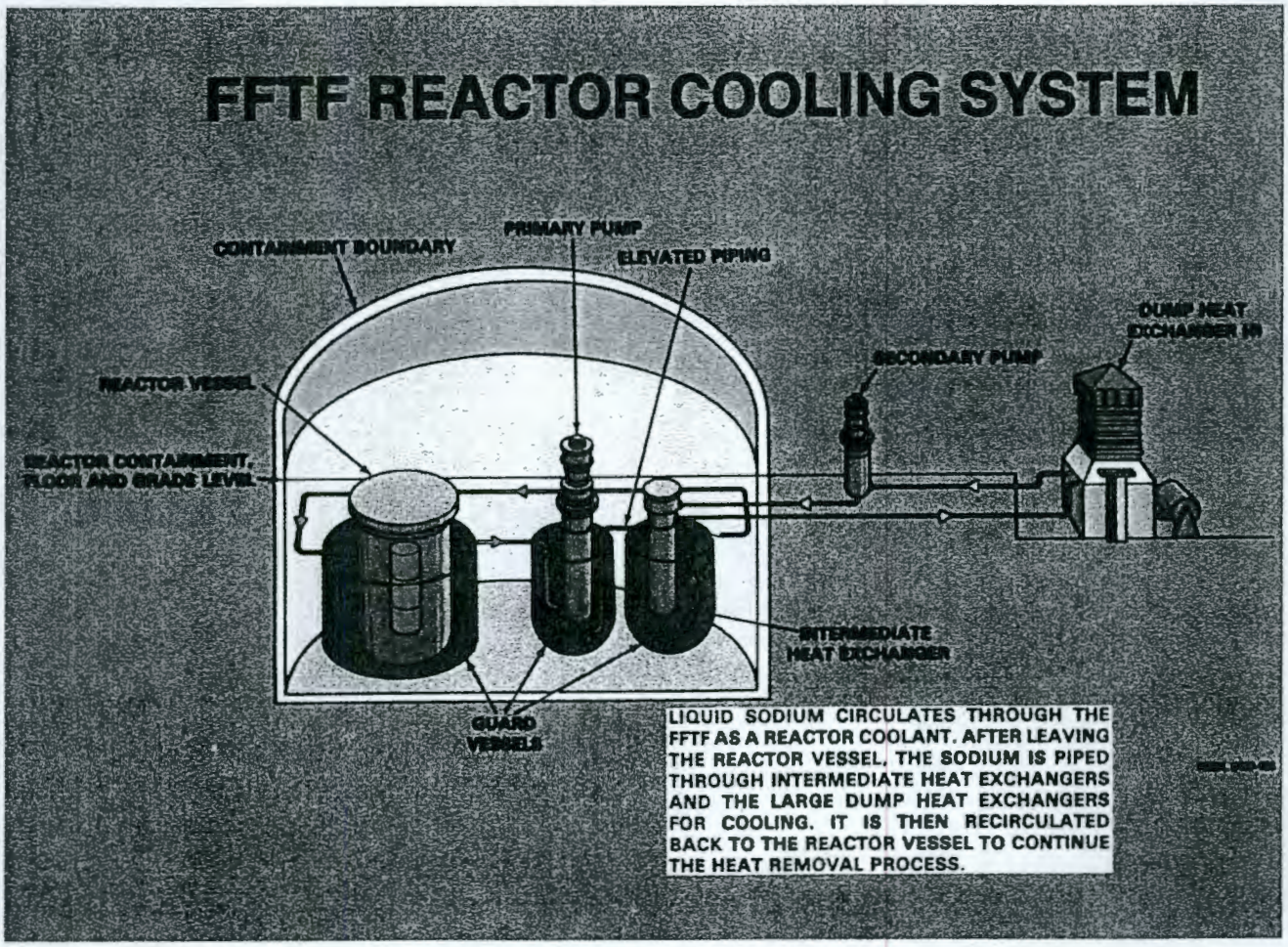


Figure 6. Representation of One of Three FFTF Cooling Loops

3.2 Inherent Safety Characteristics

Liquid-metal-cooled reactors in general and the FFTF in particular have a number of important safety characteristics inherent in their design. Some of the key characteristics leading to this inherent safety are described below.

- Excellent Coolant Heat Transfer Characteristics

The sodium coolant used in the FFTF has a very high thermal conductivity (approximately one hundred times higher than water). Therefore, during normal operation, and even under most accident conditions, the fuel cladding operates only a few degrees above the temperature of the coolant.

- High Boiling Point/Low Operating Pressure

The boiling point of sodium at atmospheric pressure is approximately 880°C (1620°F). Therefore, for almost all accident scenarios, there is no concern about boiling away the coolant, and thus overheating the fuel. Furthermore, because of the high boiling point, the reactor and associated heat removal systems operate at essentially atmospheric pressure. This not only results in a very low probability that coolant leakage will occur, but also leads to a low leak rate if leakage does occur.

- "LOCA-Proof"

A major concern for water-cooled reactors is the loss-of-coolant accident (LOCA). The possibility of this type of an event has been virtually eliminated in the FFTF and most other liquid-metal reactor designs. A major reason for this is the use of the high-boiling-point sodium coolant. When combined with the incorporation of guard vessels around each major component of the primary heat transport system and the use of elevated piping outside of the guard vessels, multiple independent, and highly unlikely, failures would be required to lose the coolant from the core.

- Reliable Reactor Shutdown System

The FFTF has an extremely reliable Reactor Shutdown System that meets modern commercial reactor design standards. Many key operating parameters are monitored and automatic reactor shutdown (scram) is initiated when any of the key parameters exceed established values. Both redundancy and diversity are incorporated into the design of the Reactor Shutdown System.

- Desirable Nuclear Feedback Characteristics

The FFTF core is designed to ensure that the overall power coefficient is negative throughout the operating range. This means that any perturbation to the reactivity of the core tends to be self-correcting and self-limiting. In addition, heating of the core reduces the reactivity of the core, thus driving it to a lower power level.

- Passive Decay Heat Removal System

The FFTF is designed for essentially passive decay heat removal; no active equipment is required once the reactor is shut down. Decay heat removal is accomplished by natural circulation of the sodium through the reactor and heat transport system and natural draft cooling of sodium-to-air heat exchangers. The only electrical power required to perform decay heat removal is that provided by safety grade batteries which power instruments to monitor critical operating parameters.

- Containment Building for Added Safety Margin

Although there are no credible accident scenarios identified for the FFTF that would require a containment building, one is included to provide additional assurance that the public is protected from unforeseen events. The containment building is designed, tested, and maintained to the requirements of the American Society of Mechanical Engineers (ASME).

3.3 Interim Examination and Maintenance Cell (IEM Cell)

The IEM Cell (Figure 7) is a large shielded hot-cell complex located inside containment that provides a reliable means of conducting nondestructive examinations of test assemblies and core components under controlled argon atmosphere conditions. Four levels of operating galleries provide visual access for remotely operating the in-cell equipment. This highly shielded hot cell has a significant number of remote tools and equipment for diverse examination and disassembly needs. It contains two cranes and two very large electro-mechanical manipulators as well as multiple pairs of smaller master-slave type manipulators for component and equipment handling. A sodium cleaning station is available to wash irradiated components of all external sodium residues after removal from the reactor. This sodium removal system has been used extensively to wash all fuel and experimental test assemblies processed in the IEM Cell , as well as a large number of the FFTF spent fuel assemblies.

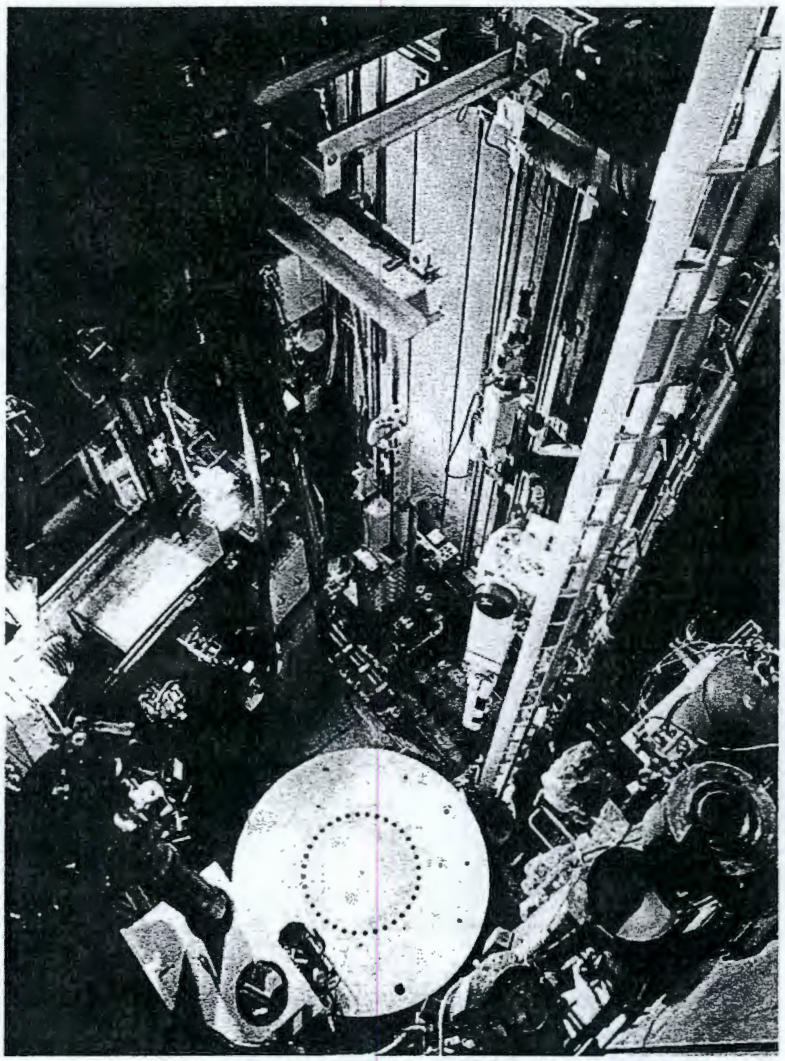


Figure 7. Interim Examination and Maintenance Cell

3.4 Reactor Component Handling/Spent Fuel Offload

The FFTF includes areas for receiving, conditioning, storing, installing, and removing from the reactor core all routinely removable core components. There are also areas for washing and storing irradiated fuel. Test and component examination and packaging capabilities are also provided.

Reactor Component Handling. The FFTF uses state-of-the-art computer-controlled shielded transfer machines to perform reactor refueling operations as well as component and experiment transfers into and out of the reactor, IEM Cell, and shipping/transfer casks. Figure 8 is a schematic of the equipment and transfer locations. The transfer machines are designed and operated with safety features and redundant systems to ensure safe transfer of irradiated materials. They are maintained reactor-grade clean; all internal surfaces are made of stainless steel and are maintained inert with argon.

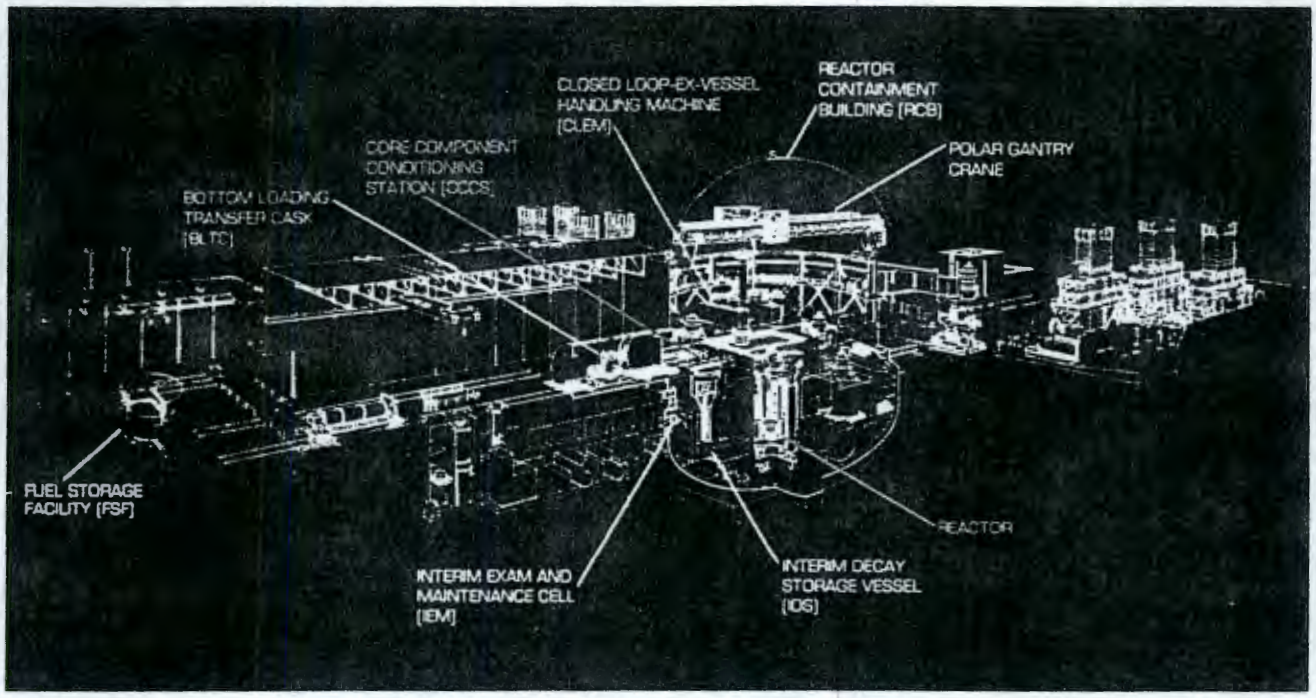


Figure 8. Core Component Transfers

The Closed Loop Ex-vessel Machine (CLEM), Figure 9, is used to handle both standard length reactor components (i.e., 12-feet long) and longer test assemblies such as OTAs which are described in Section 4.1. CLEM is used for inserting all components into the reactor vessel directly in the case of the OTA or into In-vessel Storage for the standard length component. The CLEM is also used for the transfer of irradiated components from the reactor vessel to either Interim Decay Storage or to the IEM Cell depending on whether it will undergo examination or storage for later disposition. The standard length assemblies are then handled by one of the three In-Vessel Handling Machines (Figure 10) for installation into or removal from the core.

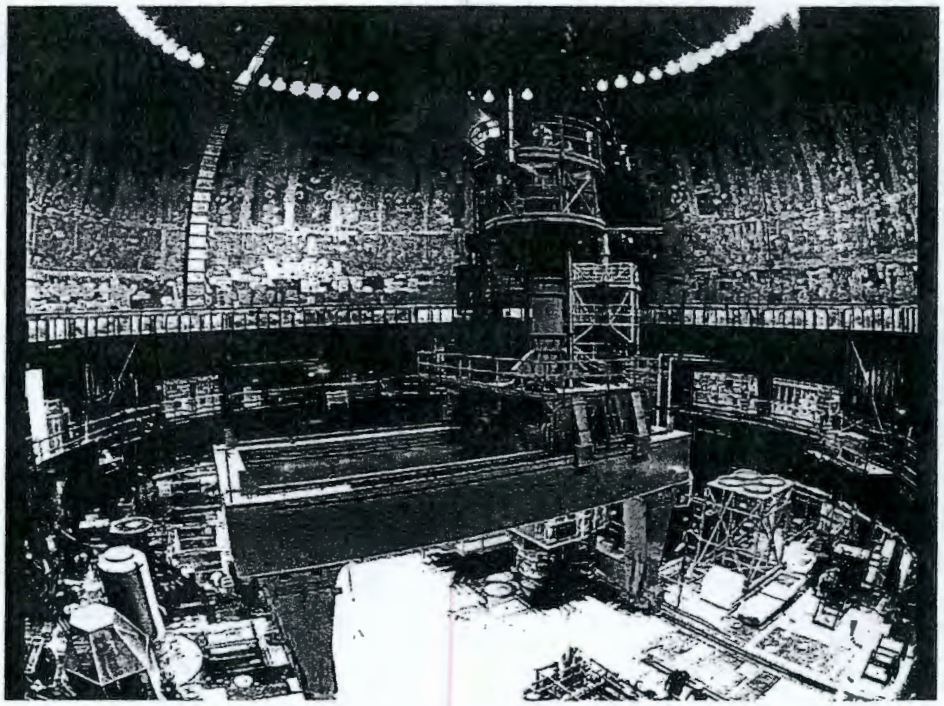


Figure 9. Closed Loop Ex-Vessel Machine

Figure 10. Two In-Vessel Handling Machines Rotated Over the Core (taken during construction)

Following sodium removal and drying, irradiated components can be remotely disassembled using the manipulators, fixtures, and special tooling. The IEM Cell contains equipment for profilometry, weight, gamma scan, visual exam/photography, disassembly, and packaging for shipment. The IEM Cell was also used for interim examination of tests and complex reassembly and qualification to allow a test to be returned to the reactor for further irradiation.

The Bottom Loading Transfer Cask (BLTC), Figure 11, is used to transfer test articles, standard length components, and specimen containers from the IEM Cell to the cask loading station for transfer to offsite facilities for further examination, or to the Fuel Storage Facility for subsequent storage.

Test assemblies can be transferred from the IEM Cell to the cask loading station for placement into shipping casks for transport to offsite locations for testing, destructive examination or other testing or processing. The cask loading facility is a very versatile facility with the capability to handle large spent fuel casks weighing up to 75 tons for vertical loading and unloading.

Spent Fuel Offload. Spent fuel is washed in the IEM Cell, dried, and loaded into a Core Component Container that can hold up to seven assemblies. The Core Component Container is inerted, sealed, and transferred to the cask loading station for placement into an Interim Storage Cask (Figure 12). The ISC is then transferred to aboveground dry cask interim storage at the Interim Storage Area, which is located adjacent to the FFTF complex.

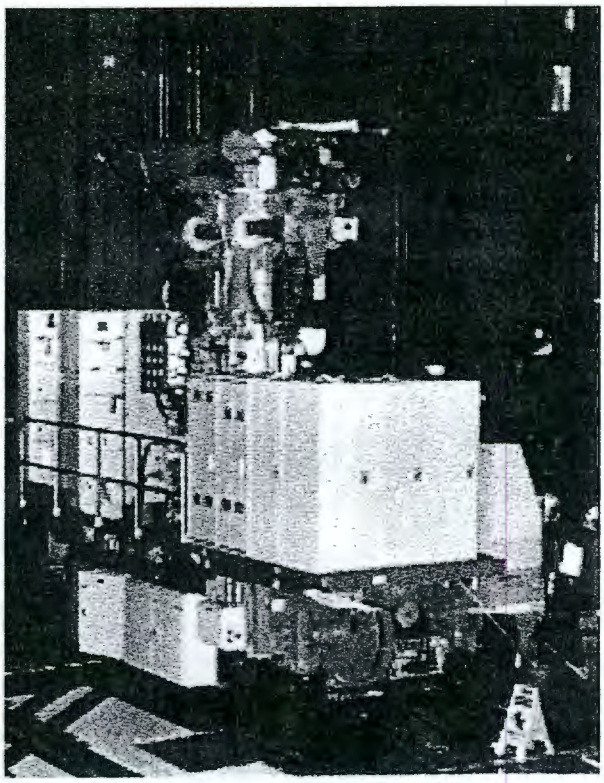


Figure 11. Bottom Loading Transfer Cask (BLTC)

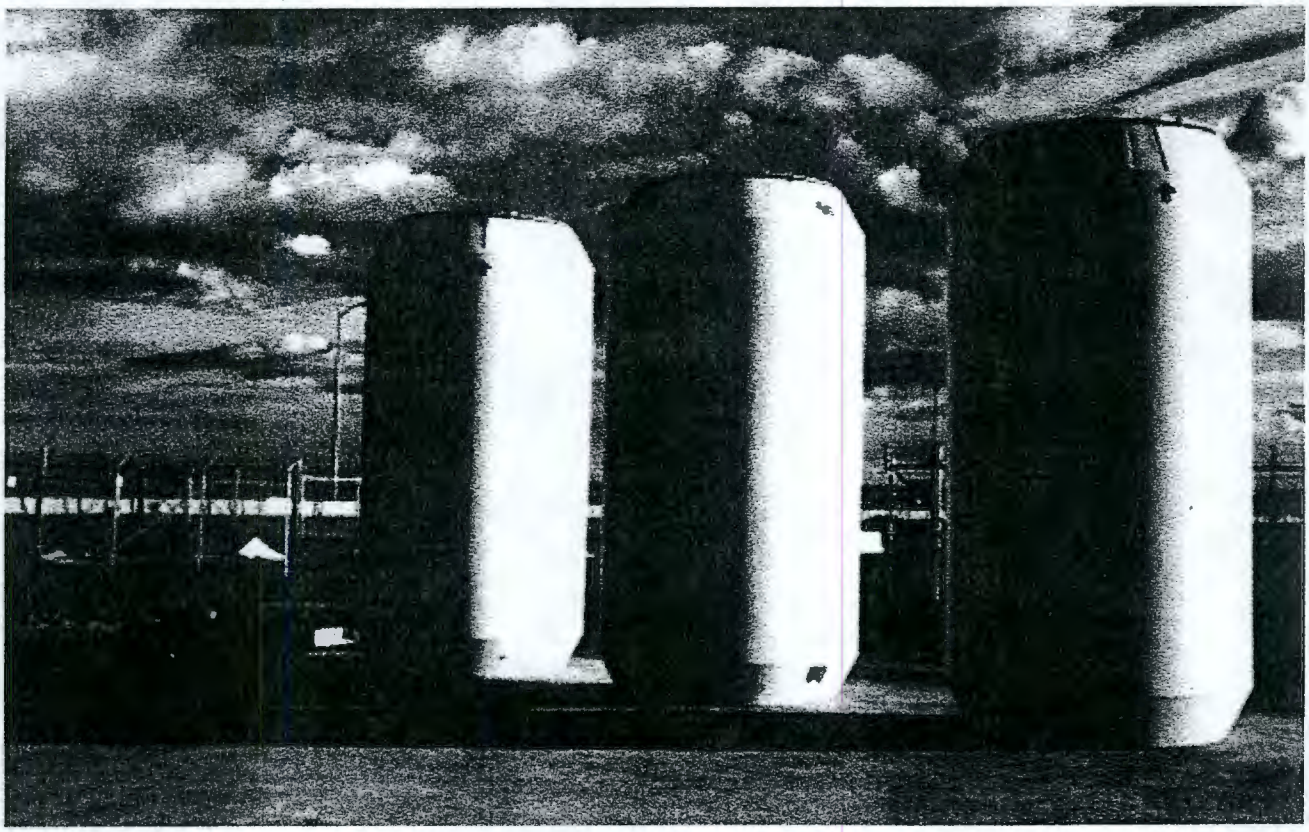


Figure 12. Interim Storage Casks

3.5 Maintenance and Storage Facility (MASF)

MASF (Figure 13), co-located in the 400 Area with the FFTF, was designed as a multipurpose service center to support the specialized maintenance and storage requirements of the 400 Area facilities. MASF provides the capability for residual sodium removal from large sodium-wetted components and non-fuel core components, decontamination, repair, and storage of non-fuel components and hardware for the FFTF and other 400 Area facilities.

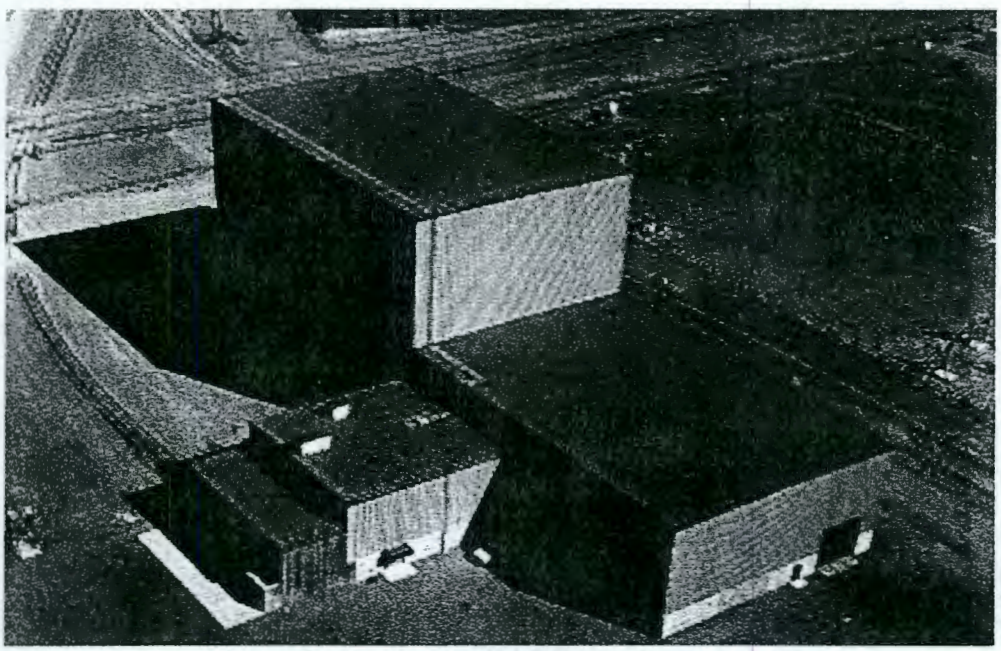


Figure 13. Maintenance and Storage Facility (MASF)

3.6 Safety Review and Regulation

FFTF has established an excellent operational record in support of nuclear science and technology development. It has proven to be a safe, stable, reliable, and environmentally benign reactor plant. Authorization to restart FFTF for research, isotope production, and to provide irradiation services will require reconfirmation of the adequacy of the nuclear safety and environmental protection aspects of the facility.

Nuclear Safety. Licensing of the FFTF under the regulations for commercial reactors was not a regulatory requirement. However, the Energy Research and Development Administration (a predecessor to DOE) requested a technical review by the Nuclear Regulatory Commission (NRC). As a result, the FFTF underwent a technical safety review by the NRC before initial operation. The Final Safety Analysis Report (FSAR) for the FFTF, issued in 1975, was reviewed by the NRC and the Advisory Committee on Reactor Safeguards. The NRC safety evaluation report and recommendations were issued in 1979 and all open issues were addressed before the start of operation in 1982.

NRC advisory involvement at the time of initial startup served the purposes of:

- Re-enforcing and adding credibility to the DOE determination that this developmental reactor was safe to start up and operate,

- Contributing to the determination that commercial reactor plants of similar design would be licensable, and

- Aiding in the development of the NRC staff capability to provide licensing review and approvals for fast reactor liquid metal cooled power plants then under consideration.

The FFTF SAR was prepared and approved per the requirements of DOE Order 5480.6. Throughout the life of the FFTF, the FSAR has been maintained via approved change control and engineering change notices. All updates and revisions have had the required reviews and approvals. No deficiencies in the FFTF design, analysis, facility condition, or operations have been identified that would prevent the FFTF from meeting the safety objectives and intent of commercial nuclear safety regulations for equivalent facilities.

SAR requirements are now provided in DOE Order 5480.23. Update of the FFTF SAR in accordance with these current requirements would be required prior to the reactor restart. The update would involve a substantial rewrite to reflect changes in the plant, format requirements, and added emphasis on safety related organizational matters and human factors. The update would address the multi-mission role of the facility. The following assumptions are being used for planning:

- FFTF will be restarted and operated as a government owned, contractor operated research reactor under continuing DOE safety and regulatory cognizance. Licensing is not required nor intended.

- The basis for DOE authorization to restart the reactor will include DOE review of the contractor updated SAR and issue of a revised SER, along with the conduct of appropriate operational readiness reviews.

- DOE may seek NRC advisory assistance in review of the safety and readiness aspects of the reactor restart.

- FFTF would be restarted and operated under a DOE Management and Operations (M&O) Contract that is subject to all DOE Orders and Regulations pertaining to the operation of a Nuclear Facility (See DOE Order 425.1A, *Startup and Restart of Nuclear Facilities*.)

Early identification of the responsible DOE and/or NRC staff responsible for reviewing the revised SAR is essential to provide an effective and efficient working team. Good communications between this oversight team and contractor staff will improve the SAR update process.

Special Nuclear Materials Accountability. DOE works closely with the International Atomic Energy Agency (IAEA) to verify to the international community that all relevant requirements concerning accountability for special nuclear materials are being met under the current Voluntary Agreement. While discussions with IAEA regarding FFTF have not yet been undertaken, DOE will, prior to restart, consider IAEA involvement at FFTF to verify the inventory and characteristics of nuclear materials at the facility.

Environmental Requirements and Performance. FFTF startup and operations were addressed in accordance with the National Environmental Policy Act of 1969 (NEPA) in environmental statements (WASH-1972 and WASH-1510). Deactivation activities were later addressed in an environmental assessment (DOE/EA-0993). FFTF continues to be maintained in compliance with other applicable regulatory requirements, including

(but not limited to): Clean Air Act and Amendments of 1990, Resource Conservation and Recovery Act of 1976, Toxic Substances Control Act of 1976, National Historic Preservation Act of 1966, Washington State Environmental Policy Act, and Washington State Waste Discharge Permit Program. Required operating permits are maintained current.

The FFTF's record of superior safety and environmental performance during its construction and operation is well documented (PNNL 1982-1998). As a result of the plant's defense-in-depth design, environmental and radiological releases during its ten years of operation were all well within applicable regulatory guidelines and/or standards. For example, routine radiation exposure to facility workers was and continues to be at least one hundred times less than at comparable commercial nuclear plants (PNNL 1985), and the maximum background exposure to a member of the public was at least 500,000 times less than background radiation (DOE-RL 1990).

If DOE pursues restart of the FFTF, an environmental impact statement will be prepared to evaluate the multi-mission use of the facility. The NEPA review process would involve formal participation with potentially affected and interested members of the public; Federal, tribal, state and local governments; and stakeholder groups. None of the missions currently proposed for FFTF present a unique or unacceptably challenging safety or environmental compliance issue. Because of the facility's long operating history (1982-1992) and the fact that none of the proposed missions represent a major departure from earlier activities conducted at the facility, the formal NEPA review process will be relatively straight-forward.

However, the FFTF's location on the Hanford Site requires that special consideration be given to ensure that the impact of restarting FFTF neither distracts from nor adds to the major cleanup challenges at Hanford. In parallel with the public scoping and draft EIS preparation, DOE would generate a *Waste Minimization and Management Plan* in concert with the States of Washington and Oregon. This plan would address all of the potential waste streams, evaluate best available treatment technologies, and evaluate alternate disposition paths. The goal of the plan would be to ensure that any concerns about waste streams generated from operation of FFTF and support facilities are fully understood and addressed and that there is no adverse impact on the ongoing Hanford Site cleanup. Appropriate information from the plan would be incorporated into and/or referenced in the Draft EIS.

4.0 Multiple Testing Capabilities

The FFTF is a highly versatile reactor capable of supporting multiple testing missions and production of high quality isotopes. Due to the reactor size, number of available test locations, and the instrumentation capabilities for monitoring each test location, a wide variety of tests can be irradiated in the reactor concurrently. Figure 14 shows the core loading for Cycle 11B demonstrating the capability of managing a multi-test core configuration. The reactor features, coupled with the high fast neutron environment (up to 7 x 10^{15} n/cm^2/s), allow significant irradiation testing to occur over shorter periods of time. These high-energy neutrons, coupled with the FFTF's relatively large power output, enable the FFTF to test a variety of materials and produce many isotopes in amounts and purity levels not attainable in other reactors. To accomplish multiple testing missions, there are several testing modes available to both optimize the testing and allow, to the maximum extent possible, an economical test vehicle configuration. These various testing modes are described in the following subsections.

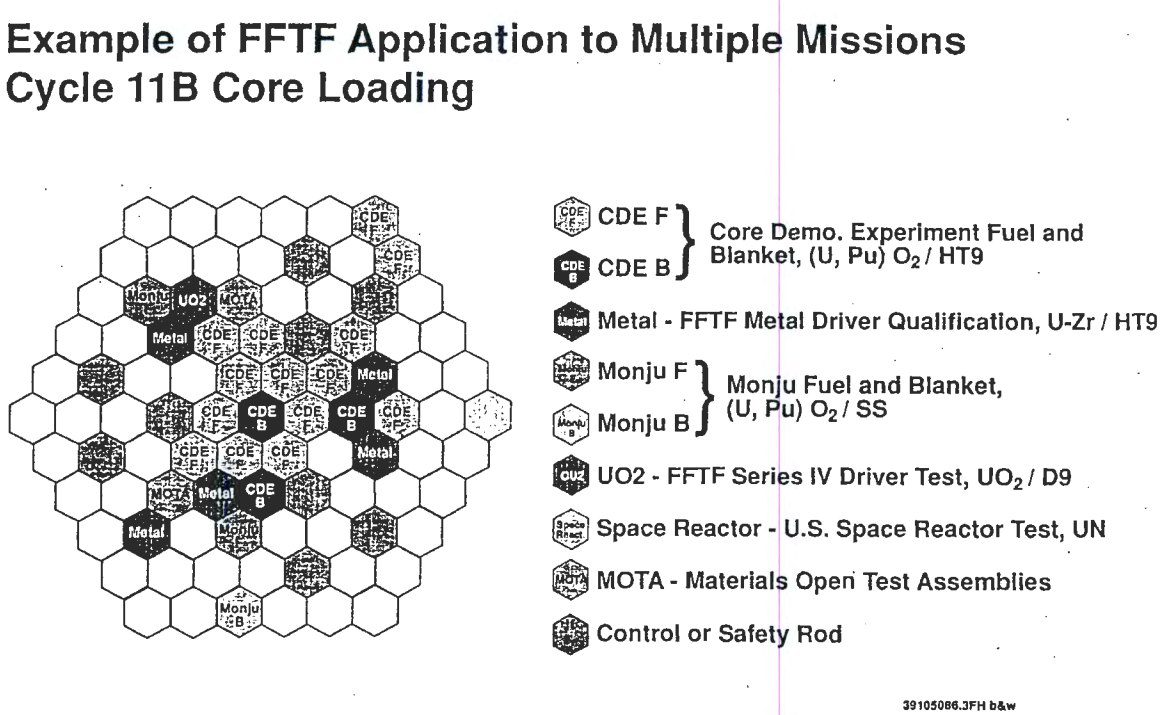


Figure 14. Multiple Mission Core Load for Cycle 11B

4.1 Reactor Core

There are eight locations available in the reactor that are termed open test assembly (OTA) positions. These eight locations are unique from the rest of the reactor in that they allow for direct, contact instrumentation for remote monitoring during reactor operation. They are termed "open" because they are directly cooled and exposed to the reactor sodium environment within the reactor, as are most of the in-vessel components. What makes these locations unique is the provisions to have instrument stalks attached to them that communicate with and extend above the reactor head for routing of various instrumentation packages (Figure 15). They are also positioned so that they allow for inner (core row 2), middle (row 4), and outer (row 6) reactor fluence environments.

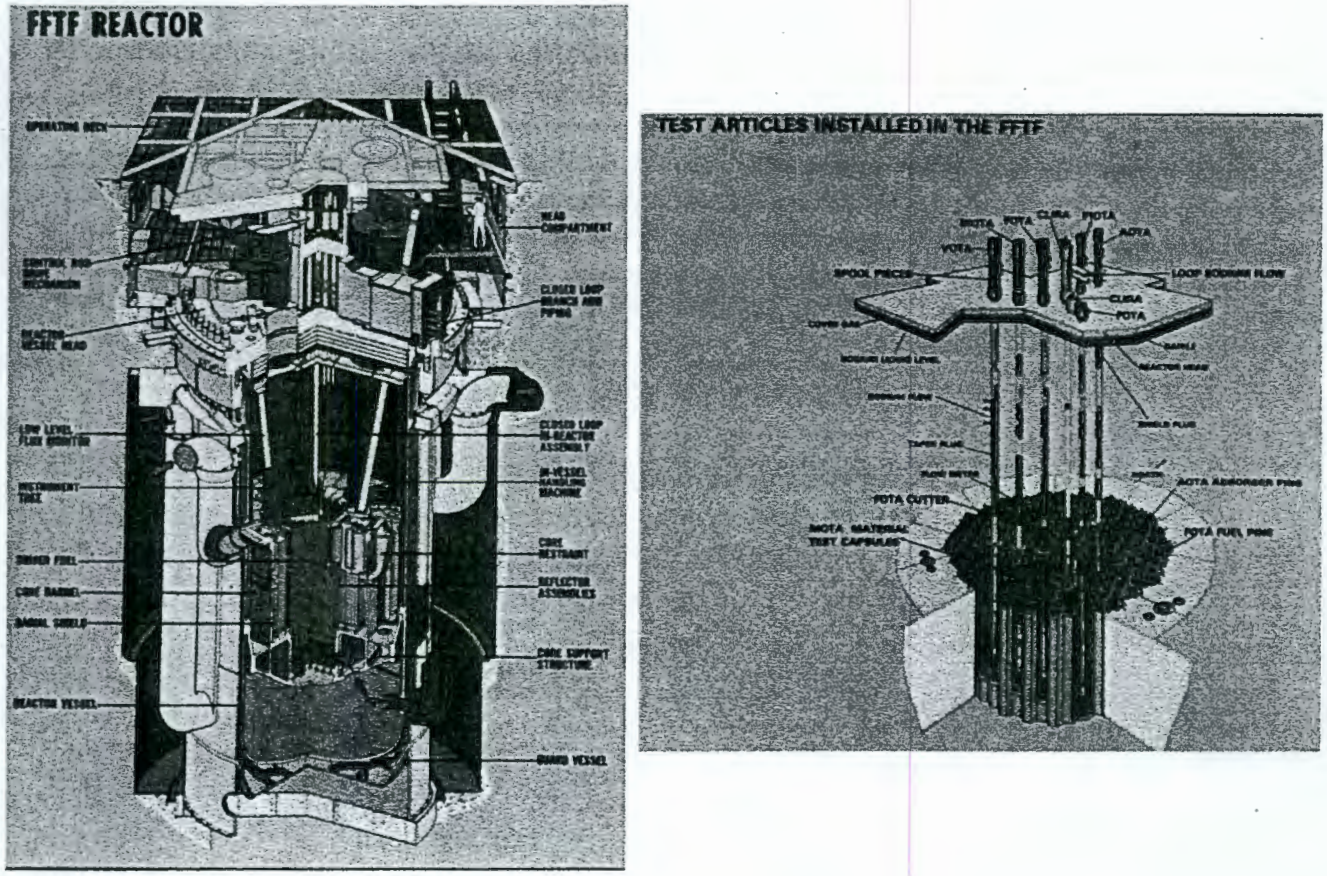


Figure 15. Test Articles Installed in Reactor

Within the 82 active core locations, there are up to 20 or more additional locations (Figure 15) that could contain a standard length (12-foot) test assembly within the active core region (Figure 16). These locations also have specific on-line outlet temperature and flow measurements from installed plant instrumentation in the reactor core instrument trees.

In addition to these test locations within the active fueled region of the core, there are 108 locations available in the surrounding reflector region where other tests could be inserted. These three basic testing configurations enable large quantity and very diverse testing capabilities.

4.2 Test Handling Capabilities

The FFTF is an excellent test reactor due to the well characterized irradiation testing environment. During the 10 years the FFTF was in operation (1982 to 1992), a wide variety of tests were run which supported various domestic, federal, and international test needs. The FFTF has demonstrated the following attributes:

- ability to accurately model the neutron environment in complex assembly designs
- ability to produce tailored neutron environments, including intense epithermal fluxes
- highly instrumented testing capabilities
- capabilities for onsite interim and post-irradiation examination
- capability to reconstitute test vehicles and qualify them for return to the reactor
- capability to properly handle and store radioactive waste
- infrastructure to support fabrication, shipping, and additional post-irradiation examination needs.

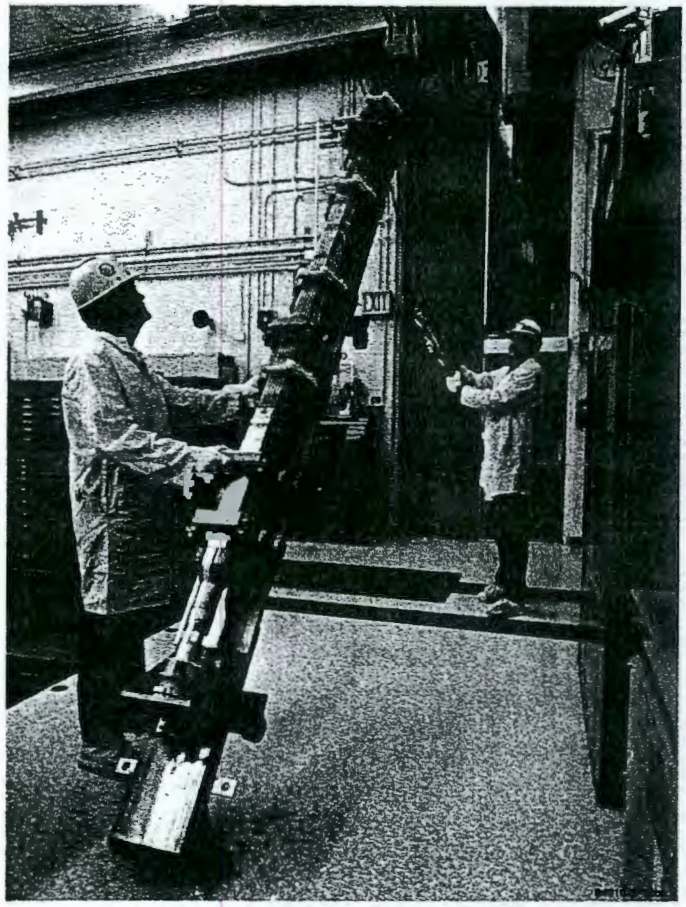


Figure 16. Standard Length (12-foot) Irradiation Vehicle

4.3 Previous Testing Program

During its 10 years of operation, the FFTF supported a large and varied test program for industrial, nuclear energy (domestic and international), nuclear defense, and medical research and treatment. Many of the nuclear energy tests were directly applicable to the commercial nuclear industry as well as to the LMR program. The testing focused primarily on reactor fuel and different fuel assembly material evaluations but also provided significant testing for many other programs. See Table A-1 for a summarized listing of tests performed at the FFTF.

The strengths of the FFTF for testing are well recognized in the international community. Tests were conducted for Canada, Japan, France, Germany, United Kingdom, and Switzerland. These researchers were attracted by the ability to test multiple target and fuel designs simultaneously as specimens, partial assemblies, or full size components with a tailored neutron environment. The FFTF irradiation services were also desired

because of the well understood core performance, the large amount of in-core instrumentation, the capability for pin or container failure detection, and the versatile hot cell and support facilities for post-irradiation examination and handling needs.

The following is a brief description of the major types of tests performed at the FFTF.

Open Test Assemblies (OTAs). Several types of OTAs were used to conduct numerous and varied test programs:

♦ **Materials Open Test Assembly (MOTA).** MOTA (Figure 17) provided multiple containers capable of irradiating multiple material specimens. Each container was individually temperature controlled by the on-line mixing of argon and helium gases in the container annulus. This provides varying heat transfer from the container to the reactor sodium coolant. The support system for this test vehicle included multiple gas lines, temperature control loops, and an on-line control and monitoring system.

Figure 17. Materials Open Test Assembly (MOTA)

♦ **Fusion Materials Open Test Assembly (FMOTA).** The reactor portion of this test vehicle was essentially identical to the MOTA assembly and included many material test specimens as well as the two canisters that were part of the fusion testing program. This test series was a joint venture for the United States, Canada, and Japan to evaluate tritium production by the irradiation of lithium oxide (Li_2O), which is proposed as a solid breeder material for tritium production in a fusion facility. The purpose of the experiment was to measure tritium release characteristics and thermal stability of Li_2O as a function of neutron exposure, temperature, gas composition, and sweep gas flow rates. This equipment also included the instrumentation and controls for tritium measurement, analysis, and recovery.

♦ **Absorber Open Test Assembly (AOTA).** AOTA provided for on-line instrumentation (temperature and pressure) of standard boron carbide absorber pins used in reactor control and safety rods.

♦ **Fuel Open Test Assembly (FOTA).** FOTA provided direct measurement during reactor operation of temperatures and pressures of individual fuel pins allowing monitoring of fuel assembly performance during the entire irradiation phase.

♦ **Vibration Open Test Assembly (VOTA).** VOTA provided temperature and flow measurements within the core as well as multiple accelerometers for measuring flow and component vibration characteristics during operation.

Standard Test Assembly. These tests assemblies are similar to standard 12-ft-long reactor components.

♦ **Fuel.** Testing of fueled assemblies benefited all aspects of reactor fuel performance to extend the life of fuel components. Substantial testing was conducted to allow core designs to proceed from a one-year core to a three-year core. Specific testing was performed to evaluate variations in fuel fabrication, fuel performance tests, fuel cladding tests, fuel spacer tests, and fuel assembly duct tests.

♦ **Non-Fuel.** Non-fuel tests were used to evaluate long-life components for reactor material and surveillance tests, reactor lifetime extension evaluation, control rod hardware and absorber material performance testing, and advanced absorber testing.

♦ **Isotope Production.** Isotope production tests were used to demonstrate significant quantities of commercial and strategic radioactive isotopes could be produced in the FFTF. A cobalt-60 test contained yttrium hydride moderator pins with target pins for the production of cobalt-60 and gadolinium-153. This was a standard length core component that was cleaned and disassembled in the IEM Cell after irradiation with the three pin types shipped offsite for further examination. In 1986, the FFTF produced the highest purity gadolinium-153 ever made. This material, which is used for the diagnosis of osteoporosis, was made by the FFTF to avert a world shortage.

♦ A multi-isotope production (MIP) assembly provided physics data on plutonium-238 isotope production with targets irradiated in an FFTF epithermal neutron environment and demonstrated the capability of the FFTF to produce more than 20 other radioisotopes important for medical, industrial, and defense needs (see Table A-2). This test used yttrium hydride pins as the moderating material surrounding the various capsules of differing target materials. During the late 1980s, the FFTF produced other isotopes, which were delivered to physicians and hospitals for cancer treatment, diagnostic research, and cardiovascular and brain studies.

Closed Loop Tests. In addition to the testing methods discussed above, there is a complete testing system with the ability for an irradiation test vehicle that is completely isolated from the reactor coolant system with its own subsystems to provide cooling. This complex test arrangement would allow for transient and high temperature testing in much more severe environments with essentially no impact to the reactor systems. This system, although installed, has never been placed on-line and would require a major facility effort to put it into operation.

4.4 Proposed Isotope Production Modes

In addition to the test capabilities described in Section 4.3, the following systems would be used for isotope production.

Rapid Radioisotope Retrieval System. The rapid retrieval system would be used for the production of short-lived isotopes at the FFTF. This system would allow target materials to be inserted and withdrawn from the reactor core region with the reactor operating at full power. Systems for routinely inserting and removing irradiation targets, nuclear instrumentation, and research hardware at an operating reactor have been in use at various research reactors throughout the world for years. Most of these systems use either a pneumatic rabbit-type system or a mechanical cable-type system for insertion and retrieval.

Initially, up to two rapid retrieval systems would be installed at existing closed-loop in-reactor assembly/open test assembly positions in row 6 of the reactor core that are located under spool pieces in the reactor head. Figure 18 is a conceptual description of the cable-type system, which consists of three major components: a 40-ft long in-reactor thimble assembly, a replaceable string or chain of isotope target carriers, and a target carrier insertion and retrieval system.

The target carrier insertion and retrieval system(s) would be installed external to the reactor to shuttle a target carrier chain into and out of the core region. This system could use a form of mechanical cable insertion and retrieval mechanism. Ideally, the insertion and retrieval system would load irradiated target chains directly into the transportation cask for shipment to the hot cell laboratory facilities in the 300 Area for isotope separation and purification.

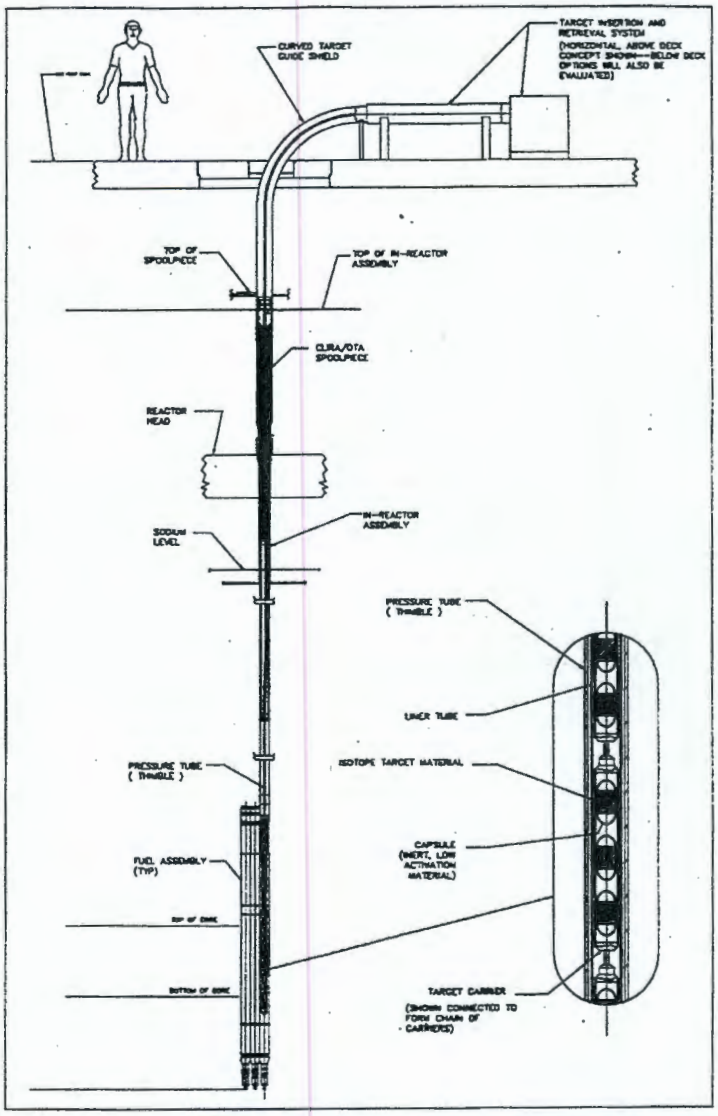


Figure 18. Conceptual Depiction of the Rapid Retrieval System

In addition to irradiating solid (and molten) targets in the rapid retrieval system carrier chains, gas targets also could be irradiated to produce short-lived isotopes. Two options would be evaluated for producing the gas-based isotopes. One option would involve one or more small diameter, thin-wall tubes routed down through the in-reactor thimble assembly into the active core region. These tubes would be connected to a shielded ex-reactor gaseous isotope recovery system. The practice of routing external gas lines into the active core region is not new at the FFTF and has been used in several irradiation test assembly

designs installed in the reactor (e.g., MOTA used externally supplied gas mixtures to control material sample temperatures, and FMOTA additionally had gas lines routed to a glovebox for tritium sampling and gas analysis).

A second gas target option would involve irradiating capsules filled with a high-pressure target gas. The gas filled capsules would be installed in a target carrier and become part of a typical target chain.

Long Term Irradiation Vehicle (LTIV). The LTIV used for production of long-lived isotopes would consist of a bundle of target pins installed inside a nozzle, duct, and handling socket assembly similar in appearance to an FFTF 12-foot-long fuel assembly (Figure 19). Depending on the isotopes to be produced, the pin bundle could contain moderator pins and neutron shield pins. A design that would allow reuse of the long-term irradiation assembly nozzle, duct, and handling socket hardware would be considered during the design process in an effort to reduce costs and waste generation. Figure 16 is a picture of the Cobalt 60 test vehicle prior to installation of the outer hexagonal duct This assembly was used in Operating Cycle 11B.

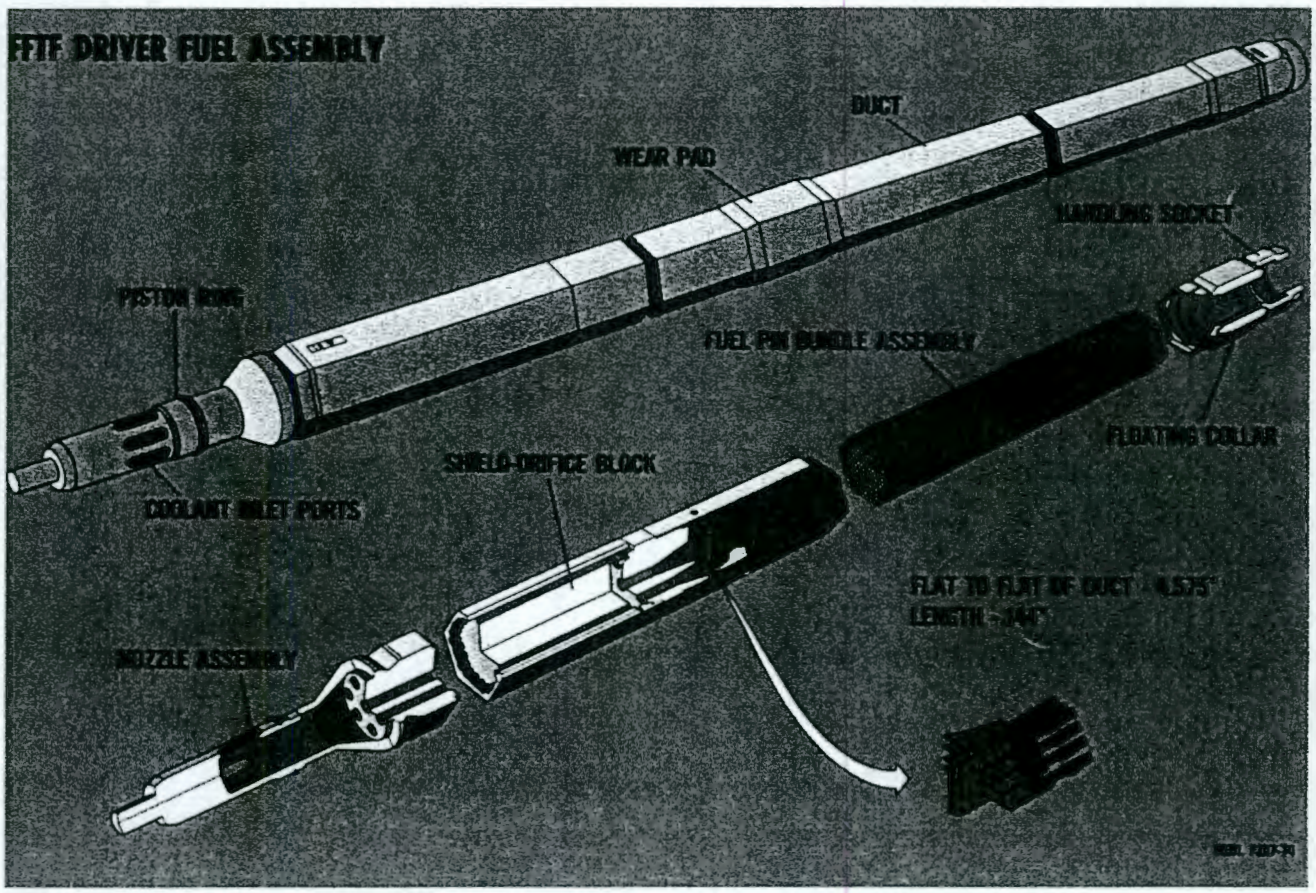


Figure 19. Standard 12-Foot Fuel Assembly

The LTIV would be installed in the reactor during normal refueling operations and would be handled using the standard FFTF and component handling equipment. After irradiation, the assembly would be transferred to the IEM Cell for disassembly prior to shipment of the pins to the 300 Area laboratories for isotope extraction and purification.

5.0 Plant Status and Restart Activities

The FFTF is currently defueled with 77 of the main plant systems still operational to support the storage of reactor fuel, operate the sodium systems, and supply general building utilities. Twenty-three of the systems (or portions thereof) that were no longer needed after fuel was removed from the reactor vessel have been secured in a recoverable configuration requiring minimal or no maintenance. Current standby plant activities have focused on maintaining the "health of the facility" to minimize degradation and facilitate a potential restart. This includes routine surveillance and preventive maintenance to ensure that system integrity and configuration control are maintained as well as selected upgrades to critical plant components.

The FFTF has an active program to identify systems or components that need to be updated or replaced in order to maintain the facility in pace with current technology. Most of these modifications consist of either mechanical upgrades to equipment or replacement of outdated control and computer systems. For example, the computer control systems for the In-Vessel Handling Machine, BLTC, Solid Waste Cask, and Interim Decay Storage were all upgraded before to commencing fuel wash activities. These systems now use contemporary controls that significantly extend the service life and reliability of these fuel-handling machines. Also, an ion exchange system was installed in the sodium removal system before initiating fuel offload activities. This new system allows wash water to be cleaned and reused after each wash cycle, thus significantly reducing the amount of radioactive waste produced. Another significant waste minimization/pollution prevention initiative that was recently completed was replacement of the ozone-depleting refrigerant in the plant chillers with ozone-free refrigerant.

Some plant modifications are currently in progress to improve safety, reliability, and efficiency of operations for either shutdown or restart activities. If the FFTF is directed to restart, several upgrades are planned in order to return systems to operation, improve reliability, conform to current standards, improve efficiency, or minimize waste. Following is a brief description of these ongoing or planned modifications:

- **Plant Protection System** – upgrade scram breakers, power supplies, and signal conditioners
- **Zero-Time-Outage Motor Sets** – upgrade zero-time-outage motor generator sets with solid-state electronic units
- **Plant Data System** – upgrade plant data system computers
- **Closed Loop Ex-Vessel Machine (CLEM)** – upgrade CLEM (refueling machine) control system
- **Cooling Towers** – upgrade the conductivity metering system on three cooling towers and replace the electronic sensors and controls
- **Electrical Distribution Transformers** – install two new transformers to replace PCB-filled units that were removed during standby
- **Chiller Controls** – upgrade chiller controls
- **Elastomer Seal Replacement** – a program would be established to assess and replace elastomer seals during the start-up period using advancements that have been made in seal technology

♦ **Solid Waste Cask Upgrade** – evaluate the hoist drive system and redesign of the mechanical overload protection system in the hoist

♦ **Simulator Upgrades** – a program to upgrade the existing simulator to reach commercial simulator standards was in progress but was discontinued when the FFTF was directed to be placed in standby in 1992.

As indicated in Figure 20 approximately 3½ years are required to achieve restart of the reactor following a Record of Decision that recommends restart. This schedule is dependent upon annual funding at levels indicated in Table 1. Restart activities would be managed and directed using a project approach for control and reporting to achieve the best schedule and cost effectiveness. Attachment 2 provides a more detailed listing of the activities associated with restart.

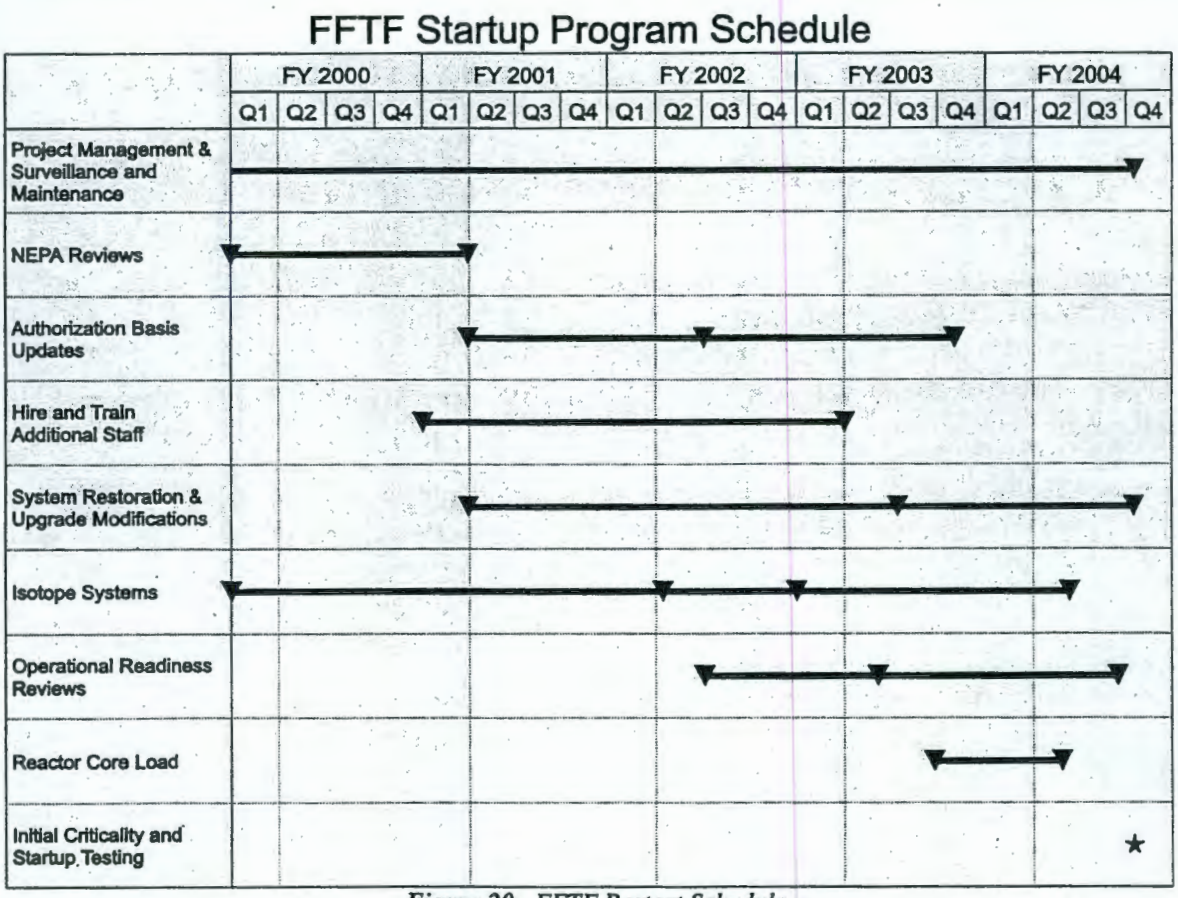


Figure 20. FFTF Restart Schedule

Table 1 Restart Funding Profile

	FY-2000	FY-2001	FY-2002	FY-2003	FY-2004
Project Management	3.6	5.2	5.4	5.9	4.6
Maintain Plant (Facility Operations)	31.9	33.5	38.2	40.6	31.5
Safety & Permitting	2.2	4.6	5.3	2.0	1.4
Plant Recovery & Upgrades	1.9	12.8	11.9	11.6	7.9
Isotope Systems	0.8	4.1	6.3	8.1	3.9
Total	**40.4**	**60.2**	**67.1**	**68.2**	**49.3**

6.0 Lifetime Projection

The primary life-limiting mechanism for the FFTF is radiation-induced material degradation to key internal reactor components. The results of a detailed analysis based on operation at 400 megawatts and a 75% capacity factor indicate that the facility has at least 22 years of operation remaining. Operation at only 100 megawatts would essentially eliminate this life-limiting aspect for the facility.

7.0 Conclusions

The FFTF has demonstrated its ability to support multiple research activities, provide irradiation services to researchers both nationally and internationally, and produce a wide variety of high-purity isotopes. The size, power output, and extensive instrumentation and characterization of the reactor and heat transport system make the facility an attractive choice for multiple research needs.

8.0 References

Hanford Engineering Development Laboratory (HEDL). 1980. *Summary Description of the Fast Flux Test Facility*. HEDL-400, Richland, Washington.

Pacific Northwest National Laboratory (PNNL). 1982 to 1998. *Annual Hanford Site Environmental Report*. Richland, Washington.

Pacific Northwest National Laboratory (PNNL). 1985. "Radiation and Environmental Protection Experience at the Fast Flux Test Facility (FFTF)." Proceedings of the International Topical Meeting on Fast Reactor Safety, Volume 1, April 21-25, 1985, <place>.

U.S. Department of Energy – Richland Operations Office (DOE-RL). 1990. *Radionuclide Air Emissions Report for the Hanford Site*. DOE-RL-91-10, Richland, Washington.

Attachment 1

FFTF Performance History: and Significant Events and Accomplishments

February 1980	**Initial nuclear startup; attained criticality**
November 1981	**Demonstrated use of natural circulation to cool the reactor core in the event of power failure to the coolant pumps**
April 1982	**Normal cycle operations commenced**
November 1982	**First operating cycle lasted 53 days; longest ever achieved for a sodium-cooled reactor**
April 1983	**Named one of the nation's top ten engineering achievements of 1982 by the National Society of Professional Engineers**
October 1983	**Concluded three 100-day operating cycles; another first for sodium-cooled reactors**
October 1983	**Achieved prototypic assembly fuel burn-up of more than 80,000 megawatt days per metric ton of fuel with flawless performance, setting another record**
April 1984	**Achieved prototypic assembly fuel burnup of 100,000 megawatt days per metric ton of fuel, setting another record and an industry first**
April 1984	**Completed 101 days of continuous operation, setting another record**
May 1984	**Acclaimed as "An Outstanding Engineering Achievement" by Nuclear News magazine**
June 1985	**Achieved prototypic assembly fuel burnup of 135,000 megawatt days per metric ton of fuel, setting a record not just for fuel but for the materials used in fuel assemblies**
November 1985	**Called "A Facility for the Future" by Nuclear Engineering International magazine**
December 1985	**Achieved prototypic fuel burnup of 152,000 megawatt days per ton of fuel; assembly was in core for three years**
March 1986	**Produced gadolinium-153, a rare isotope used in the early detection of osteoporosis**

June 1986	**Earned American Nuclear Society award for meritorious performance in reactor operations**
July 1986	**Demonstrated passive safety features, including "automatic nuclear shutdown" during which coolant pumps were stopped with no reactor scram**
September 1986	**Sixteen test assemblies were readied for a new core demonstration project using advanced fabrication techniques and materials; largest mixed-oxide fuel experiment conducted to date, demonstrating completely new technology for an advanced reactor concept**
February 1987	**Demonstrated, through fuel tests and alloys, the potential for future reactors to operate from 5 to 10 years without requiring refueling; fuels achieved more than 150% of their designed burnup**
June 1987	**Set another record with 105 days of continuous operation at full power**
December 1987	**Finished the year with 100% operational efficiency**
March 1988	**Completed space reactor technology tests, demonstrating ability to operate thermionic fuel elements up to 10 years in space**
October 1988	**Set another record for continuous operation at full power – 126 days**
January 1989	**Prepared first twin set of experiments for fusion research and liquid metal breeder reactor alloys**
April 1989	**Achieved reactor assembly fuel burnup of 190,000 megawatt days per metric ton of fuel; by this time, the same assemblies had been in the reactor for 7 years**
June 1989	**Demonstrated the ability to produce plutonium-238 and destroy or transform radioactive waste, with the result that three radioisotopes were produced and delivered to medical research programs in the United States**
November 1989	**Completed fourth integrated leak rate test, demonstrating continued structural integrity of the FFTF reactor containment building**
January 1990	**Began irradiation of the first multi-national experiment devoted exclusively to fusion energy research; experiment specimens were designed and fabricated by researchers from Japan and the United States**
January 1990	**Completed the equivalent of 3 years operation on the Core Demonstration Experiment, demonstrating the promise of a truly long-lived fuel design and material**
February 1990	**Celebrated tenth anniversary of initial reactor criticality**
December 1991	**Completed the year with 100% operational efficiency**

February 1992	**Received the NEA's Federal Design Achievement Award**
April 1992	**Ordered to stand-by due to lack of mission**
May 1992	**Recipient of the National Energy Resources Organization R&D Award for International Fusion Experiment**
December 1992	**FFTF plant achieved hot standby**

Table A-1. Testing Performed at FFTF

Test Description	Test ID	Number of Assemblies	Purpose of Test
Control Rod/Absorber Tests:			
FFTF Reference Absorber	CR	2	Evaluate performance of FFTF reference control and safety rods.
Vented Absorber Test	HA003	1	Demonstrate long-life pin performance (fixed shim, pins at 1/2 in position).
Advanced Absorber Test	ADVAB	3	Demonstration of long-life absorber assembly (vented pins, round ducts).
Instrumented Absorber Test	AOTA	1	Monitoring of temperatures and pressures during operation for FFTF reference control rod/absorber assembly.
High-Enrichment, High-Burnup Absorber Test	HEHB	1	High-enriched, high-burnup, advanced absorber assembly containing both sealed and vented pins to evaluate long-life performance.
Driver Fuel Assembly Tests:			
Driver Fuel Assembly Evaluation	DE	6	Examined at various intervals for irradiation performance of the standard FFTF DFA fuel and hardware components.
Core Characterizers:	HF	4	Used to characterize fuel behavior after rapid rise to power and 8-day power run. Four were tested to perform comparative evaluations of performance in reactor core rows 1, 4, 5, and 6.
Thermal Performance Fuel Test	DEA-2	1	Contained test pins and standard DFA pins to evaluate "power to melt" relationships with various pin specifications.
Tag Gas Burnin/Burnout	DE	2	Early evaluation of gas tag performance with varying plenum sizes, also examined flow-induced wear for a zone 1 DFA.

Table A-1. (contd)

Test Description	Test ID	Number of Assemblies	Purpose of Test
Material and Other Tests:			
Materials Open Test Assembly	MOTA	7	Perform irradiation testing of material specimens coupled with the capability to vary specimen temperatures during irradiation.
Fusion Materials Open Test Assembly	FMOTA	2	Evaluate tritium production with irradiation of LiO^2 blanket as well as irradiation testing of multiple material specimens.
Vibration Open Test Assembly	VOTA	1	Provide core vibration measurements to monitor response of reactor internals to flow induced vibration.
Materials Tests	HM	5	Monitoring properties of reactor component materials exposed to the reactor environment over time for component life-time studies.
Fracture Mechanics Tests	FMA	3	Part of the FFTF archive and surveillance program - test irradiates fracture mechanics specimens of several different alloys and weldments.
Fuel Assembly Duct Material Tests:			
Advanced Alloy Duct	AAD	7	D9 alloy duct to demonstrate increased driver lifetime.
D9 Duct, Improved Fuel	D9	4	D9 alloy duct, cladding and wire wrap to demonstrate increased lifetime.
Fuel Assembly Cladding Material Tests:			
Cladding Vendor Test	CV-1	1	Determine differences in performance of cladding from different vendors.
Fuel Assembly Spacer Tests:			
Grid Spaced Driver	GF, WF	5	Evaluate performance of various pin bundle concepts.
Advanced Wire Wrap	AW-1	1	Evaluate performance with distributed wireless pins.
Modified Wire Wrap	MW	6	Evaluate performance with differing clearance and pitch.

Table A-1. (contd)

Test Description	Test ID	Number of Assemblies	Purpose of Test
Fuel Performance and Design Life Tests:			
Beyond Design Burnup Tests	RTCB	8	FFTF design goal burnup is 80 MWd/kg; these tests were run to 100 MWd/kg. Run-to-cladding-breach (RTCB) tests.
Series 3 Fuel Test	C-1	1	Relaxed fuel specification test and multiple cladding types.
High-Power Test	DE-9	1	High pin power-lifetime test with fuel melting to show benign effects.
High-Temperature Test	DE-HTD	1	Evaluation of 316SS cladding at high temperatures.
Advanced Oxide Test	ACO, FO, PO	11	Two-year and three-year fuel tests with different cladding and duct material.
Metal Fuel Test	IFR, MFF	8	Multiple test for evaluation of component and reactor performance with metal fuel, sodium bonded assemblies in HT9 and D9 alloy hardware.
Fueled Open Test Assembly	FOTA	2	Instrumented fuel assemblies to provided on-line data for evaluation of fuel performance and thermo-hydraulic models - FOTA-1 was used for central core performance and FOTA-2 provided outer core performance data.
Carbide Fuel Tests	AC, CAN, FC	3	Demonstrate performance of carbide fuel and data supporting 3-year fuel.
MONJU Fuel Tests	MFA	2	Demonstrate MONJU (Japan) fuel assembly performance and lifetime capabilities.
MONJU Blanket Test	MBA	2	Demonstrate MONJU (Japan) blanket assembly performance and lifetime capabilities.
Enriched Uranium Oxide Fuel	UO-1	1	To provide confirmation of the performance of UO_2 fuel and fuel pins prototypic of the proposed series IV fuel assemblies with enriched uranium oxide fuel and D9 cladding material.

Table A-1. (contd)

Test Description	Test ID	Number of Assemblies	Purpose of Test
Space Power	FSP	2	Provide irradiation performance data on Nb-1Zr clad uranium nitride fuel with fuel centered in a lithium bonded capsule.
Gel Process Fuel	DIPRESS	1	Demonstration of using direct press spheroidized feed based on gel sphere conversion process.
Large Bundle Porosity	BUND-1	1	Evaluate the performance of a fuel subassembly with large pin bundle to duct clearances and reduced wire wrap pitch.
Radionuclide Trap	RNTT-1	1	Sodium chemistry test to evaluate transport of radioactive corrosion products from clad to heat transport system.
Advanced Blanket Assembly	ABA	6	Long lifetime inner blanket assembly with HT9 duct and cladding.
Axial Blanket Assembly	AB	3	Provide data on UO_2 and ThO_2 axial blanket performance.
High-Enriched Fuel Assembly	SRF	4	Standard and high enriched fuel surrounded by B_4C filter pins to allow subsequent high power safety tests.
Core Demonstration Experiment Tests	ACO	12	Long life (3-year) fuel assemblies with MOX fuel and HT9 hardware.
Clinch River Breeder Reactor Tests	CRBR	3	Testing of CRBR fuel design with varying clearances and materials.
Isotope Production Tests:			
Cobalt-60 Test	CO	1	Demonstrate that significant quantities of commercial and strategic radioactive isotopes can be produced in the FFTF. The test contained yttrium hydride moderator pins with target pins for the production of cobalt-60 and gadolinium-153.

Table A-1. (contd)

Test Description	Test ID	Number of Assemblies	Purpose of Test
Multiple Isotope Production	MIP	1	Provide physics data on plutonium-238 isotope production and also demonstrate the capability of the FFTF to produce more than 20 other radioisotopes important for medical, industrial, and defense needs (see Table F). This test used yttrium hydride pins as the moderating material surrounding the various capsules of differing target materials.
Total Test Assemblies		**137**	

Table A-2. MIP Target Materials and Quantities

Priority	Target	Maximum Total Mass	Number of Subcapsules	Primary Product	Potential Use
1	Np - 237	160 mg	18	Pu-238	Heat Source
2	Cm-244, Cm-246, Cm-248	200 ng, 20 ng		Cf-252	Neutron Source
	Cf-249, Cf-252	100 ng, 20 ng	3[a]	Es Isotopes	Research
	Pu-240, Pu-242	100 ng, 100 ng		Cf-252 Precursors	Cf Production
	Am-243	100 ng		Cf-252 Precursors	Cf Production
	Am/High Exposure Pu	20 mg	10		
	Tc-99	20 mg	2	Ru-99	Research
	I-129	20 mg	2	Xe-129	Research
	Pu-236	10 mg	4	Pu-237	Research
3	Li-6	1 mg	12[b]	H-3	Radioluminescent Lighting
	Nd-146	30 mg	2	Pm-147	Heat Source
	Nd-Natural	30 mg	2	Pm-147	Heat Source
	Cd-108	10 mg	2	Cd-109	Pediatric Imaging
	Ag-107	40 mg	2	Cd-109	Pediatric Imaging
	Se-74	10 mg	1	Se-75	Brain Imaging
	Nd-150	30 mg	2	Sm-151	Heat Source
	Sm-Natural	30 mg	2	Pm-145	Heat Source
	Ir-Natural	40 mg	2	Ir-192	Weld Checking
	Os-190	10 mg	2	Os-191	Cardiovascular Angiography
	Os-Natural	40 mg	2	Os-191	Cardiovascular Angiography
	Sc-Natural	20 mg	2	Sc-46	Medical
	Sr-84	5 mg	1	Sr-85	Medical
	Sr-88	20 mg	2	Sr-89	Bone Cancer Pain Relief
	Sr-Natural	40 mg	2	Sr-85	Medical
	Ni-58	40 mg	2	Co-57	Medical
	Ni-Natural	30 mg	2	Co-57	Medical
	Tm-Natural	30 mg	2	Tm-170	Leukemia Treatment
	Ta-Natural	10 mg	2	Ta-182	Cancer Treatment
	A1N-Natural	40 mg	2	C-14	Radiolabeling

Table A-2. (contd)

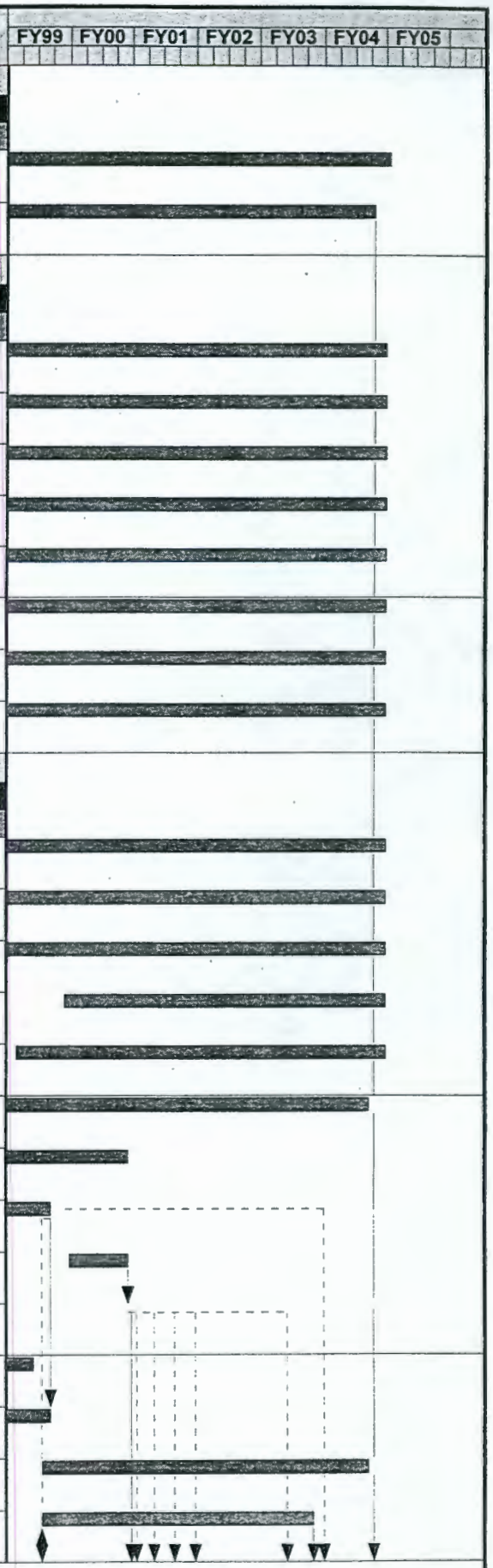
Priority	Target	Maximum Total Mass	Number of Subcapsules	Primary Product	Potential Use
	U-238	40 mg	2	Np-237	Pu-238 Production
	Re-185	20 mg	2	Re-186	Medical
	W-186	20 mg	2	W-188	Medical

(a) Supplied by Oak Ridge National Laboratory (ORNL).
(b) Supplied by Atomics International (AI).

Attachment 2
FFTF Restart Schedule

Consisting of 16 Pages

Activity ID	Activity Description	Orig Dur	Integrated Start	Integrated Finish
PROGRAM SUMMARY				
ARA025	FFTF Project	1,518	01OCT98	18OCT04
GA0010	FFTF RESTART PROGRAM	1,453*	01OCT98	16JUL04
PROJECT MANAGEMENT				
ARA050	Maintain Safe & Compliant Materials in FFTF	1,506	01OCT98	30SEP04
ARA100	Project Planning Integration	1,506	01OCT98	30SEP04
AR1B030	TPO Program Management	1,506	01OCT98	30SEP04
AR1B1033	FFTF Planning/Scheduling Mgt.	1,506	01OCT98	30SEP04
AR1B1035	FFTF Intergration Mgt.	1,506	01OCT98	30SEP04
AR1B1018	FFTF SRID Administration	1,506	01OCT98	30SEP04
AR1B1000	FFTF Executive Direction & Support	1,506	01OCT98	30SEP04
AR1B1022	FFTF RSM Engineering Support	1,506	01OCT98	30SEP04
EIS/REGULATORY REQUIREMENTS				
EIS/REGULATORY REQUIREMENTS				
AR1B1172	FFTF Sampling & Lab Support	1,506	01OCT98	30SEP04
AR1B1272	FFTF Waste Characterization	1,506	01OCT98	30SEP04
AR1B1372	FFTF Pollution Prevention	1,506	01OCT98	30SEP04
AR1B1472	FFTF LLW Disposal	1,276	01SEP99*	30SEP04
AR1B1572	FFTF Quarterly Waste Disposal	1,464	02DEC98	30SEP04*
ARV050	EIS/Regulatory Requirements (Restart)	1,432	01OCT98	15JUN04
ARV100	Environmental Program	486	01OCT98	07SEP00
GA0021	ENVIRONMENTAL PROGRAM	179*	01OCT98	17JUN99
GA0027	MISSION RESERVE	235	01OCT99*	07SEP00
GA0040	NEPA ROD	0		07SEP00
GA0060	CAA NOTIFICATION/NOC FOR FFTF RESTART FY99	105	01OCT98	04MAR99
GA0075	OBTAIN WATER PERMITS FY01	179	01OCT98	17JUN99
ARV150	SAR AND Regulatory Process	1,286	03MAY99	15JUN04
GA0080	SAR AND REGULATORY PROCESS	1,068*	03MAY99	04AUG03



Project Start 01OCT98
Project Finish 18OCT04
Data Date 01OCT98
Run Date 06JUL99

Early Bar
Progress Bar
Critical Activity

ST5C

ADVANCED REACTOR
START-UP
CASE 5

Sheet 1 of 16

Date	Revision	Checked	Approved

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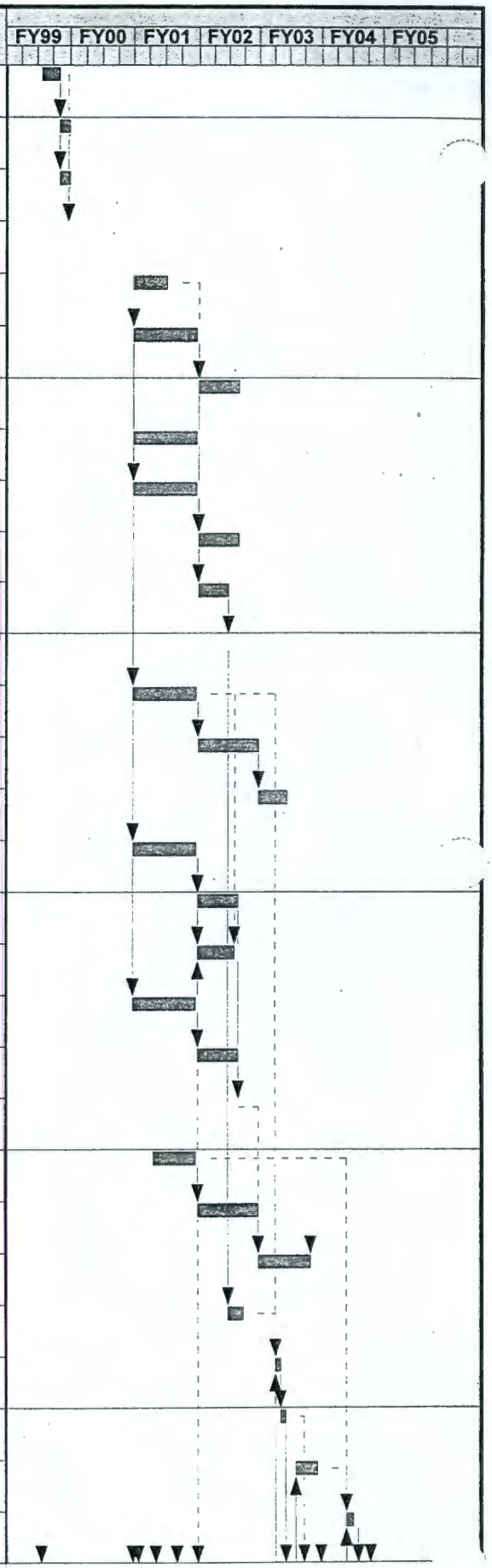
Activity ID	Activity Description	Orig Dur	Integrated Start	Integrated Finish
GA0100	DETERMINE REGULATING AGENCY	65	03MAY99*	04AUG99
GA0110	ESTABLISH SAR UPGRADE METHOD	40	05AUG99	30SEP99
GA0120	DEFINE ORR REQTS AND PROCESS	40	05AUG99	30SEP99
GA0130	AGREEM'T FROM SPO-RL/FDH	0		30SEP99
GA0160	HUMAN FACTORS ENG EVAL	127	02OCT00*	04APR01
GA0170	SEISMIC UPGRADE EVALUATION FY01	251	02OCT00	28SEP01
GA0171	SEISMIC UPGRADE EVALUATION FY02	165	01OCT01	29MAY02
GA0173	SODIUM FIRE RE-EVALUATION FY01	251	02OCT00*	28SEP01
GA0175	REVISE PRESENT SAR FOR FUEL LOAD FY01	251	02OCT00	28SEP01
GA0177	REVISE PRESENT SAR FOR FUEL LOAD FY02	165	01OCT01	29MAY02
GA0180	COMPLETE SAR REVISION FOR FUEL LOAD	127	01OCT01	04APR02
GA0220	SUBMIT SAR TO RL FOR APPROVAL OF FUEL LOAD	0		04APR02
GA0230	SAR REVIEW/APPROVAL PERIOD FOR FUEL LOAD FY01	251	02OCT00	28SEP01
GA0232	SAR REVIEW/APPROVAL PERIOD FOR FUEL LOAD FY02	250	01OCT01	30SEP02
GA0234	SAR REVIEW/APPROVAL PERIOD FOR FUEL LOAD FY03	115	01OCT02	18MAR03
GA0280	REVISE SAR FOR Rx OPERATION FY01	251	02OCT00	28SEP01
GA0282	REVISE SAR FOR Rx OPERATION FY02	165	01OCT01	29MAY02
GA0285	COMPLETE SAR FOR RX OPERATIONS	151	01OCT01	08MAY02
GA0290	COMPLETE LEVEL 1 PRA ANALYSIS FOR RX OPS FY01	251	02OCT00	28SEP01
GA0292	COMPLETE LEVEL 1 PRA ANALYSIS FOR RX OPS FY02	170	01OCT01	05JUN02
GA0310	SUBMIT SAR TO RL FOR APPROVAL OF REACTOR OPS	0		29MAY02
GA0320	SAR REVIEW/APPROVAL FOR REACTOR OPS FY01	168	01FEB01*	28SEP01
GA0322	SAR REVIEW/APPROVAL FOR REACTOR OPS FY02	250	01OCT01	30SEP02
GA0324	SAR REVIEW/APPROVAL FOR REACTOR OPS FY03	211	01OCT02	04AUG03
GA3605	MANAGEMENT SELF-ASSESSMENT FOR CORE LOAD	63	05APR02*	03JUL02
GA3610	FDH ORR FOR CORE LOAD	21	07JAN03	04FEB03
GA3620	DOE-ORR FOR CORE LOAD	22	05FEB03	07MAR03
GA3642	MANAGEMENT SELF-ASSESSMENT FOR REACTOR OPS	93	07MAY03*	18SEP03
GA3645	FDH ORR FOR Rx OPS	33	27FEB04	13APR04



Project Start	01OCT98	Early Bar
Project Finish	18OCT04	Progress Bar
Data Date	01OCT98	Critical Activity
Run Date	06JUL99	

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ST5C

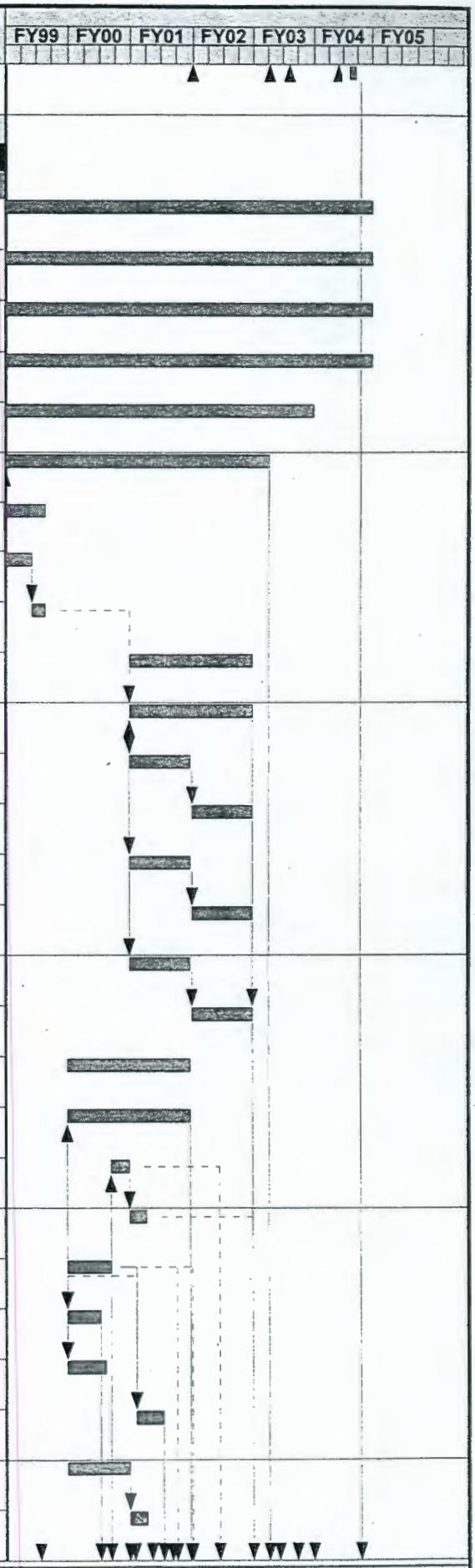
ADVANCED REACTOR

START-UP

CASE 5

Date	Revision	Checked	Approved

Activity ID	Activity Description	Orig Dur	Integrated Start	Integrated Finish
GA3650	DOE ORR FOR Rx OPS	23	13MAY04	15JUN04
TRAINING				
AR1B1073	FFTF Analysis and Support	1,506	01OCT98	30SEP04
AR1B1070	FFTF Training Mgt./Support	1,506	01OCT98	30SEP04
AR1B1074	FFTF Policies and Procedures	1,506	01OCT98	30SEP04
AR1B1072	FFTF Environmental/Waste Support	1,506	01OCT98	30SEP04
AR5000	Restart Training Activities	1,254	01OCT98	30SEP03
GA0350	RESTART TRAINING ACTIVITIES	1,068*	01OCT98	06JAN03
AR5100	Simulator Reqmts	167	01OCT98	01JUN99
GA0353	DEFINE SIMULATOR/TRAINING REQMTS	105	01OCT98	04MAR99
GA0355	DEFINE SIMULATOR/TRAINING REQMTS	62	05MAR99	01JUN99
AR5200	Simulator Upgrades	501	02OCT00	30SEP02
GA0359	SIMULATOR UPGRADES	501*	02OCT00	30SEP02
GA0362	INSTALL PDS EQUIVALENT FY01	251	02OCT00	28SEP01
GA0363	INSTALL PDS EQUIVALENT FY02	250	01OCT01	30SEP02
GA0365	ATTENDED AREA PANEL UPGRADE FY01	251	02OCT00	28SEP01
GA0366	ATTENDED AREA PANEL UPGRADE FY00	250	01OCT01	30SEP02
GA0368	COMPUTER & FULL FUNCTION MODELING UPGRADE FY01	251	02OCT00	28SEP01
GA0369	COMPUTER & FULL FUNCTION MODELING UPGRADE FY02	250	01OCT01	30SEP02
AR5300	Upgrade Training Programs	502	01OCT99	28SEP01
GA0392	UPGRADE TRAINING PROGRAMS	502*	01OCT99	28SEP01
GA0393	DEVELOP RT CLASS	78	09JUN00	29SEP00
GA0394	DEVELOP OE CLASS	64	02OCT00	04JAN01
GA0395	DEVELOP OT CLASS	173	01OCT99*	08JUN00
GA0396	DEVELOP TECH STAFF TRAINING	132	01OCT99	11APR00
GA0397	DEVELOP MAINTENANCE TRAINING	152	01OCT99	09MAY00
GA0398	PREPARE FOR Rx REFUELING RETRAINING	108	08NOV00	16APR01
GA0399	UPGRADE OPERATOR TRAINING PROGRAM FY00	251	01OCT99*	29SEP00
GA0400	UPGRADE OPERATOR TRAINING PROGRAM FY01	63	02OCT00	03JAN01



Project Start 01OCT98
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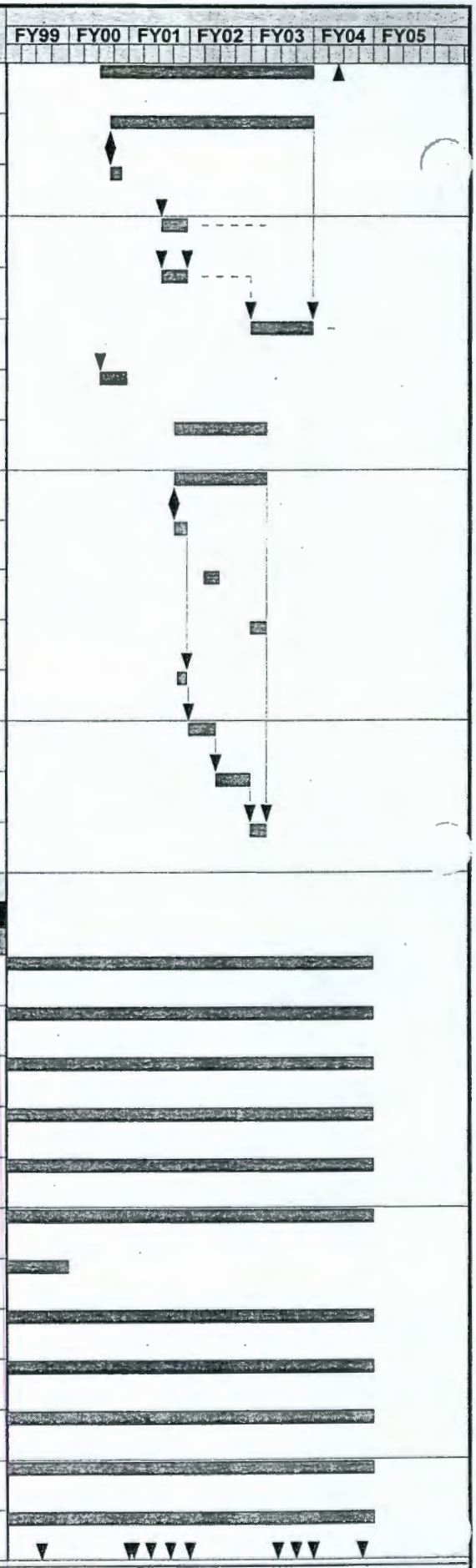
AR5400	Facility Personnel Retraining	871	12APR00	30SEP03
GA0401	FACILITY PERSONNEL RETRAINING	830*	09JUN00	30SEP03
GA0402	MAINTENANCE RETRAINING	53	09JUN00	24AUG00
GA0403	Rx REFUELING/SDW TRAINING	109	17APR01	19SEP01
GA0404	PREPARE FOR RO/OE RETRAINING	116	17APR01	28SEP01
GA0406	RO/OE REQUALIFICATION FY03	251	01OCT02	30SEP03
GA0407	TECH STAFF TRAINING	111	12APR00	19SEP00
AR5500	New Operator Training	378	02JUL01	06JAN03
GA0410	NEW OPERATOR TRAINING	378*	02JUL01	06JAN03
GA0413	HIRE 5 NEW OPERATORS FY01	63	02JUL01*	28SEP01
GA0414	HIRE 5 NEW OPERATORS FY02	63	02JAN02*	01APR02
GA0415	HIRE 4 NEW OPERATORS FY03	63	01OCT02*	02JAN03
GA0416	ORIENTATION	45	27JUL01	28SEP01
GA0419	CONDUCT OT CLASS	108	01OCT01	08MAR02
GA0421	CONDUCT RT CLASS	142	11MAR02	30SEP02
GA0425	CONDUCT OE CLASS	65	01OCT02	06JAN03
PLANT OPERATIONS				
ARA150	INVENTORY CONTROL	1,506	01OCT98	30SEP04
AR1B130K	FFTF Spare Part Inventory	1,506	01OCT98	30SEP04
AR1B130L	FFTF Parts Withdrawal/Return	1,506	01OCT98	30SEP04
ARB050	FFTF STANDBY OPERATIONS	1,506	01OCT98	30SEP04
AR1B1010	FFTF OPES Admin/Mgt.	1,506	01OCT98	30SEP04
AR1B1024	FFTF Aux System Electrical Support	1,506	01OCT98	30SEP04
AR1B1123	RSB Roof Recoating & Inspection	251	01OCT98	30SEP99
ARE050	FFTF MAINTENANCE	1,506	01OCT98	30SEP04
AR1B1060	FFTF Maintenance support	1,506	01OCT98	30SEP04
ARF050	FMEF	1,506	01OCT98	30SEP04
AR1B170A	FMEF S & M Support	1,506	01OCT98	30SEP04
ARK050	Remove Materials from FFTF	1,506	01OCT98	30SEP04



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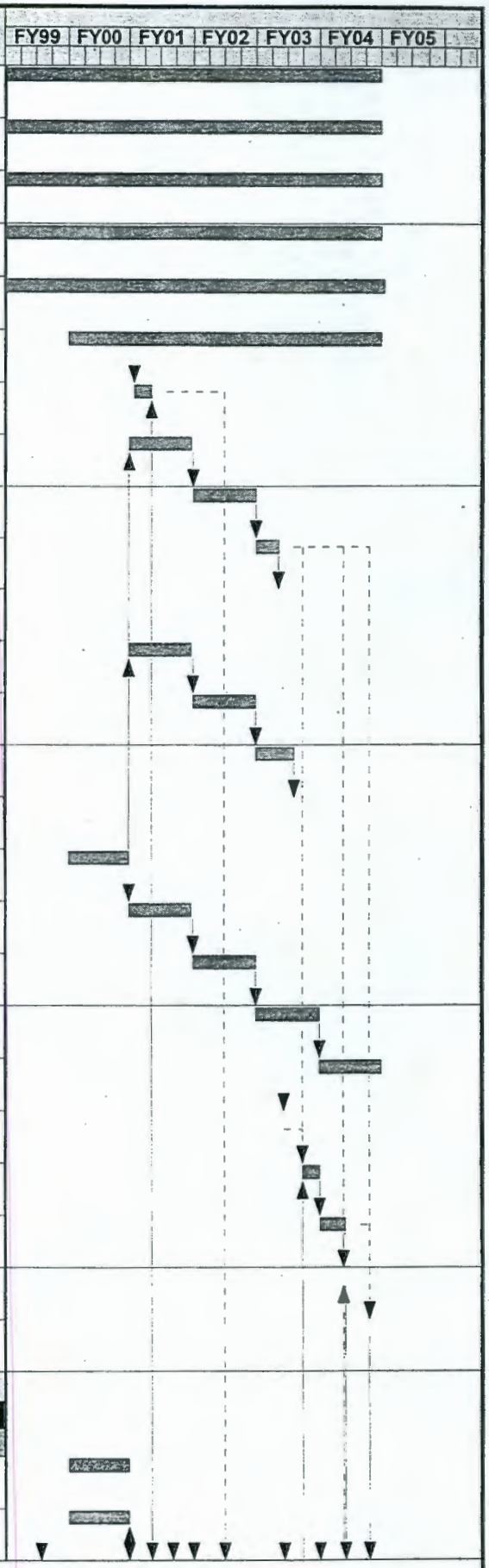
ARK100	Fuel Handling	1,506	01OCT98	30SEP04
AR1B1026	FFTF Fuel Handling I & C Support	1,506	01OCT98	30SEP04
ARP050	IRME Cell & Refueling Admin	1,506	01OCT98	30SEP04
AR1B1028	FFTF IRME & Refueling Engineering Support	1,506	01OCT98	30SEP04
AR4000	FFTF Restart	1,518	01OCT98	18OCT04
AR4100	FFTF Restart Operations	1,255	01OCT99	30SEP04
GA1355	LOAD IVSM	60	03NOV00	01FEB01
GA1380	SYSTEM TESTING PROGRAM FOR FUEL LOAD FY01	251	02OCT00	28SEP01
GA1382	SYSTEM TESTING PROGRAM FOR FUEL LOAD FY02	250	01OCT01	30SEP02
GA1384	SYSTEM TESTING PROGRAM FOR FUEL LOAD FY03	88	01OCT02	06FEB03
GA1385	SYSTEMS TESTED FOR FUEL LOAD	0		06FEB03
GA1386	SYSTEM TESTING PROGRAM FOR RX OPS FY01	251	02OCT00	28SEP01
GA1388	SYSTEM TESTING PROGRAM FOR RX OPS FY02	250	01OCT01	30SEP02
GA1389	SYSTEM TESTING PROGRAM FOR RX OPS FY03	150	01OCT02	06MAY03
GA1390	SYSTEMS TESTED FOR RX OPS	0		06MAY03
GA1360	DEFINE RESTART TEST REQTS	251	01OCT99*	29SEP00
GA1395	FFTF PROCEDURE UPGRADES & RESTORATION FY01	251	02OCT00	28SEP01
GA1400	FFTF PROCEDURE UPGRADES & RESTORATION FY02	250	01OCT01	30SEP02
GA1410	FFTF PROCEDURE UPGRADES & RESTORATION FY03	251	01OCT02	30SEP03
GA1420	FFTF PROCEDURE UPGRADES & RESTORATION FY04	252	01OCT03	30SEP04
GA3630	BEGIN CORE LOAD	0	10MAR03	
GA3640	REACTOR CORE LOADING	68	24JUN03	30SEP03
GA3641	REACTOR CORE LOADING	101	01OCT03	26FEB04
GA3655	CORE LOAD COMPLETE	0		26FEB04
GA3665	INITIAL REACTOR START-UP	0		16JUL04
IEMC RECOVERY				
AR6000	IEMC Recovery	251	01OCT99	29SEP00
GA1310	ENGR & MOVE TRNG FACILITY	251	01OCT99*	29SEP00



Project Start 01OCT98
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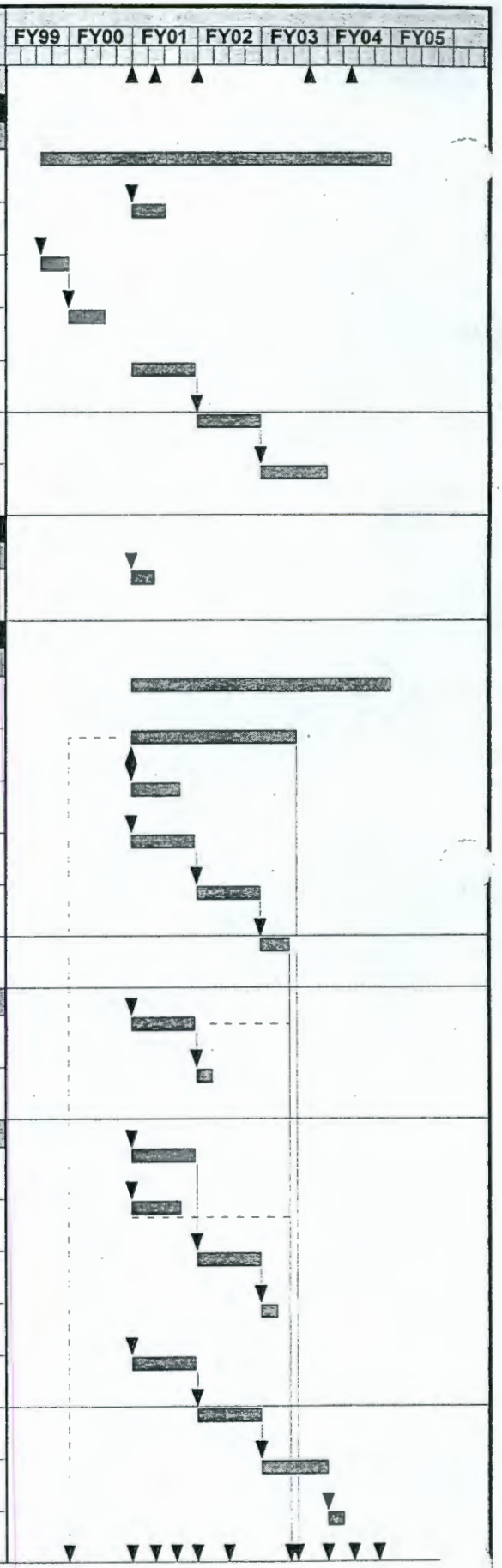
RESTORATION OF SYSTEMS				
GENERAL SYSTEM RESTORATION ACTIVITIES				
AR6200	Restoration of Systems	1,360	03MAY99	30SEP04
GA3249	UPGRADE DRAWING STATUS	126	02OCT00	03APR01
GA3259	REVIEW SPARE PARTS STATUS	105	03MAY99*	30SEP99
GA3260	REVIEW SPARE PARTS STATUS	146	01OCT99	01MAY00
GA3264	REPLENISH SPARE PARTS FY01	251	02OCT00*	28SEP01
GA3266	REPLENISH SPARE PARTS FY02	250	01OCT01	30SEP02
GA3268	REPLENISH SPARE PARTS FY03	251	01OCT02	30SEP03
RESTORE SYS REQD FOR INIT ASSY MOVES				
REACTOR REFUELING (SYS. 41)				
GA3369	RESTORE LLFM INSTRUMENTATION	84	02OCT00	01FEB01
RESTORE SYS REQD FOR CORE LOADING				
ELECTRICAL POWER (SYS. 12)				
AR6500	Restore Sys Req'd for Core Loading	1,004	02OCT00	30SEP04
GA3014	RESTORE SYS REQ'D FOR CORE LOADING	636*	02OCT00	15APR03
GA3040	RESTORE DIESEL GEN	190	02OCT00	03JUL01
GA3345	REPLACE ZTO POWER FY01	251	02OCT00	28SEP01
GA3350	REPLACE ZTO POWER FY02	250	01OCT01	30SEP02
GA3355	REPLACE ZTO POWER FY03	105	01OCT02	04MAR03
SUPPORT BUILDINGS (SYS. 21)				
GA3830	COMP CTRL RM BOUNDARY INTEGRITY ITEMS (DOORS) 01	251	02OCT00	28SEP01
GA3835	COMP CTRL RM BOUNDARY INTEGRITY ITEMS (DOORS) 02	61	01OCT01	31DEC01
CONTAINMENT SYSTEM (SYS. 27)				
GA3310	RE-ESTABLISH SISI PROGRAM (RESET CONTAINMENT) 01	251	02OCT00	28SEP01
GA3311	AIRLOCK REPAIRS/RESTORATION	190	02OCT00	03JUL01
GA3312	RE-ESTABLISH SISI PROGRAM (RESET CONTAINMENT) 02	250	01OCT01	30SEP02
GA3313	RE-ESTABLISH SISI PROGRAM (RESET CONTAINMENT) 03	62	01OCT02	31DEC02
GA3314	RE-ESTABLISH REMAINDER OF SISI PROGRAM FY01	251	02OCT00	28SEP01
GA3316	RE-ESTABLISH REMAINDER OF SISI PROGRAM FY02	250	01OCT01	30SEP02
GA3318	RE-ESTABLISH REMAINDER OF SISI PROGRAM FY03	251	01OCT02	30SEP03
GA3319	RE-ESTABLISH REMAINDER OF SISI PROGRAM FY04	63	01OCT03	02JAN04



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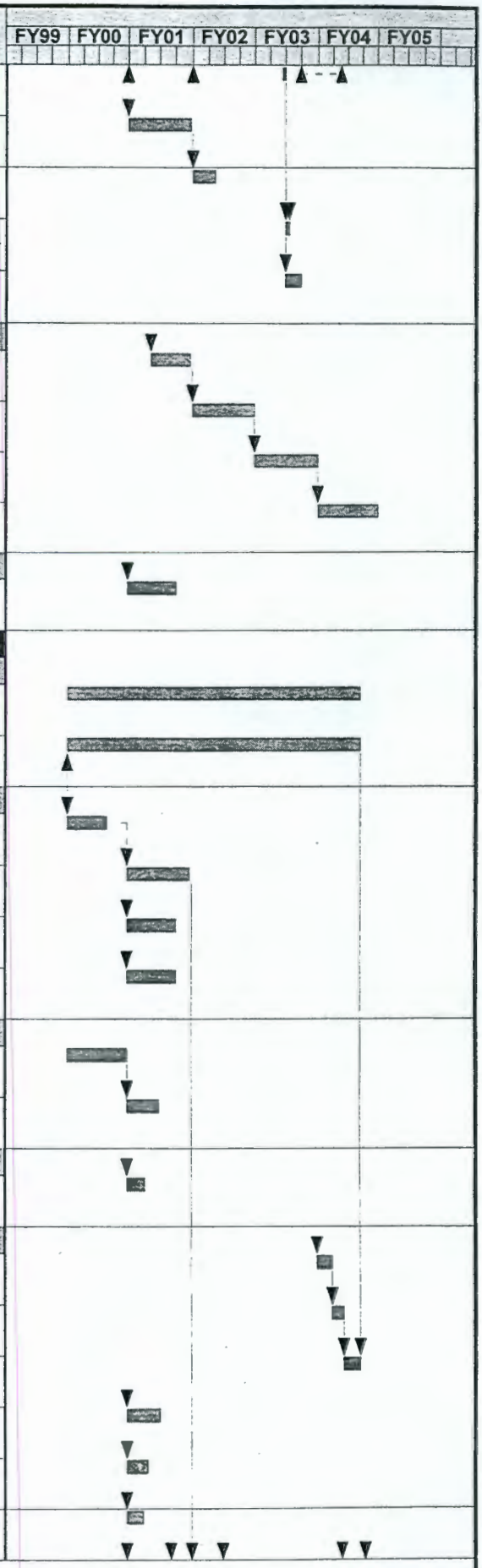
GA3320	CONDUCT ILRT	15	05MAR03	25MAR03
GA3325	ILRT PREPARATION FY01	251	02OCT00	28SEP01
GA3330	ILRT PREPARATION FY02	93	01OCT01	14FEB02
GA3340	PLANT RESTORATION FROM ILRT	15	26MAR03	15APR03
GA3600	RESTORE CIS TO OPERATION	63	26MAR03	23JUN03
REACTOR REFUELING (SYS. 41)				
GA3269	REPLACE INFLATABLE SEALS ON IVHM's FY01	167	02FEB01	28SEP01
GA3270	REPLACE INFLATABLE SEALS ON IVHM's FY02	250	01OCT01	30SEP02
GA3271	REPLACE INFLATABLE SEALS ON IVHM's FY03	251	01OCT02	30SEP03
GA3272	REPLACE INFLATABLE SEALS ON IVHM's FY04	252	01OCT03	30SEP04
INSTRUMENTATION & CONTROL (SYS. 93)				
GA3718	RESTORE & RELOCATE C-177 INSTRUMENTATION	190	02OCT00	03JUL01
RESTORE SYS REQD FOR RX OP				
SUMMARY				
AR6800	Restore Sys Req'd for RX Ops	1,188	01OCT99	24JUN04
GA3012	RESTORE SYS REQD FOR RX OPS	1,188*	01OCT99	24JUN04
ELECTRICAL POWER (SYS. 12)				
GA3015	DEFINE PCB XFORMER PROGRAM	169	01OCT99*	02JUN00
GA3020	REPLACE B-39 LOAD CENTER	251	02OCT00	28SEP01
GA3023	REPLACE X9 AND X29 TRANSFORMERS	190	02OCT00	03JUL01
GA3379	UPGRADE LOWER CONTAINMENT LIGHTING	190	02OCT00	03JUL01
COMMUNICATIONS (SYS. 15)				
GA3390	UPGRADE COMMUNICATIONS SYSTEM FY00	251	01OCT99*	29SEP00
GA3392	UPGRADE COMMUNICATIONS SYSTEM FY01	124	02OCT00*	30MAR01
SUPPORT BUILDINGS (SYS. 21)				
GA3820	EVALUATE/REPLACE SHIELDING OF CELL OPENINGS	63	02OCT00	03JAN01
SERVICE PIPING (SYS. 23)				
GA3399	EVALUATE COOLING TOWER HEAT/WATER LOADS	60	01OCT03*	29DEC03
GA3410	UPGRADE COOLING TOWER WATER SUPPLY PIPING	49	30DEC03*	09MAR04
GA3420	UPGRADE COOLING TOWER WATER REMOVAL PIPING	76	10MAR04*	24JUN04
GA3432	RESTORE COOLING TOWERS E-342, 343 & 344	129	02OCT00	06APR01
GA3439	REPLACE AND INSTALL NEW A4B-4 BREAKERS FOR E-21	83	02OCT00	31JAN01
GA3441	RECOVER E-21 CHILLER OUT OF LAYUP	59	02OCT00	27DEC00



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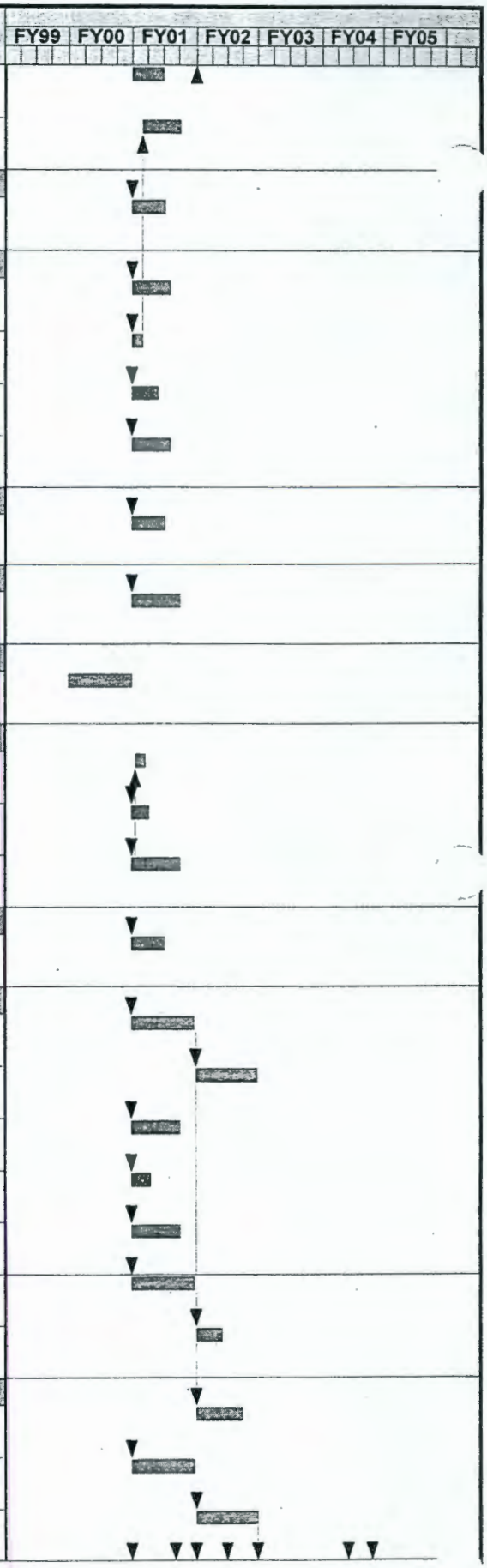
GA3443	RESTORE INSTRUMENT AIR BACKUP SYSTEM	120	02OCT00	26MAR01
GA3448	RESTORE MOBILTHERM SYSTEM	148	01DEC00	03JUL01
HEATING & VENTILATION (SYS. 25)				
GA3455	RESTORE H&V SYSTEMS (MECHANICAL/ELECTRICAL)	130	02OCT00*	09APR01
FIRE PROTECTION (SYS. 26)				
GA3470	RESTORE FIRE SMOKE DAMPERS (ETLs)	152	02OCT00	09MAY01
GA3472	RESTORE AFFF	42	02OCT00	30NOV00
GA3473	RESTORE FIRE TESTING PER NFPA 25	98	02OCT00	22FEB01
GA3474	ADDRESS FHA SPRINKLER ISSUE (FFTF-FHA-94-02)	152	02OCT00	09MAY01
CONTAINMENT SYSTEM (SYS. 27)				
GA3484	RE-INSTALL SHIELD PLUGS	125	02OCT00	02APR01
CONTAINMENT MARGINS (SYS. 27M)				
GA3480	RESTORE CONTAINMENT MARGINS SYSTEM	190	02OCT00	03JUL01
REACTOR (SYS. 31/32)				
GA3273	UPGRADE OUTER HEAD HEATER & CONTROLS	251	01OCT99*	29SEP00
REACTOR HEAT TRANSPORT (SYS. 51)				
GA3042	RESTORE PWR TO MAIN MOTORS	43	16OCT00	15DEC00
GA3117	REFURBISH DHX	63	02OCT00	03JAN01
GA3543	REMOVE BIRD WASTE & INSULATION FROM DHX's	190	02OCT00	03JUL01
AUX. LIQUID METAL SYSTEM (SYS. 81)				
GA3505	PRIMARY AND SECONDARY DRAINLINE RESTORATION	131	02OCT00	10APR01
INERT GAS RECEIVING & PROCESSING (SYS. 82)				
GA3520	INSTALL NEW NASA CONTROL SYSTEM FY01	251	02OCT00	28SEP01
GA3525	INSTALL NEW NASA CONTROL SYSTEM FY02	250	01OCT01	30SEP02
GA3536	RESTORE/UPGRADE CAPS HARDWARE	190	02OCT00	03JUL01
GA3537	REPLACE ARGON BOTTLE RACK	73	02OCT00	17JAN01
GA3538	RESTORE/UPGRADE RAPS HARDWARE	190	02OCT00	03JUL01
GA3559	REFURBISH/REPLACE PANEL POWER SUPPLIES FY01	251	02OCT00	28SEP01
GA3560	REFURBISH/REPLACE PANEL POWER SUPPLIES FY02	100	01OCT01	26FEB02
IMPURITY MONITORING & ANALYSIS (SYS. 85)				
GA3555	RESTORE HTS-S SODIUM SYSTEM	190	01OCT01	03JUL02
GA3556	ESTABLISH & VERIFY SODIUM ANALYSIS CAPABILITY 01	251	02OCT00	28SEP01
GA3557	ESTABLISH & VERIFY SODIUM ANALYSIS CAPABILITY 02	250	01OCT01	30SEP02



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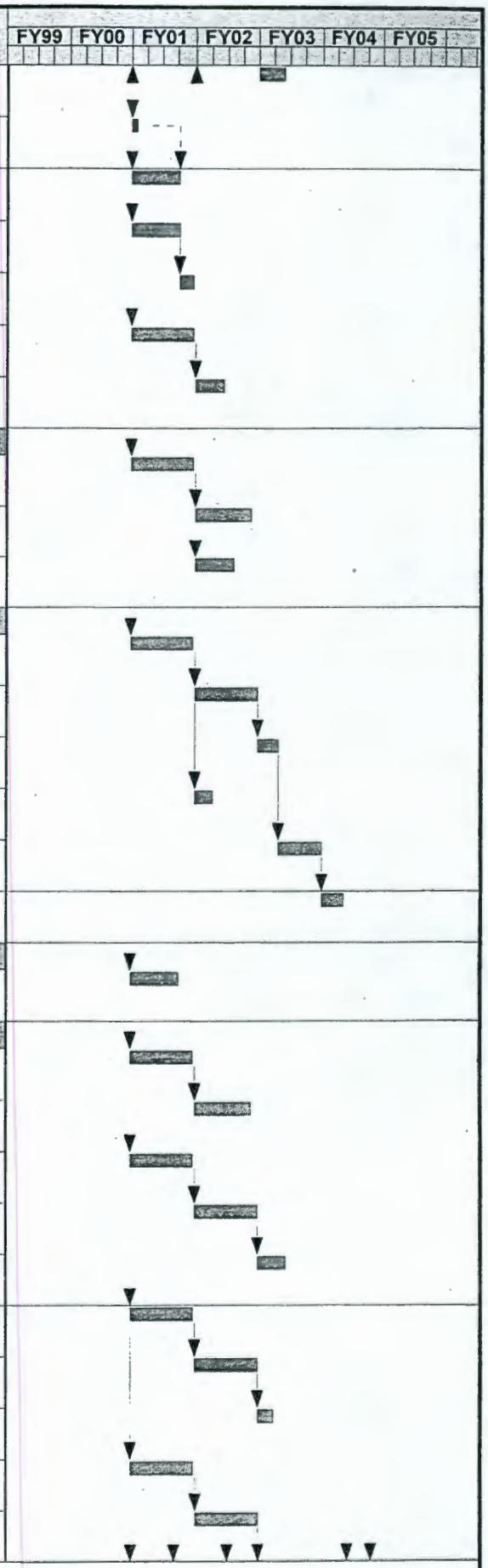
GA3558	ESTABLISH & VERIFY SODIUM ANALYSIS CAPABILITY 03	103	01OCT02	28FEB03
GA3567	RESTORE HTS-S GAS FLOW	21	02OCT00	30OCT00
GA3577	REPLACE HTS-S LN2 TANK	190	02OCT00	03JUL01
GA3587	RESTORE COVER GAS ANALYSIS CAPABILITY FY01	190	02OCT00	03JUL01
GA3589	RESTORE COVER GAS ANALYSIS CAPABILITY FY02	61	05JUL01	28SEP01
GA3597	RESTORE MULITI-PURPOSE SAMPLERS & UPGD CTRLS 01	251	02OCT00	28SEP01
GA3599	RESTORE MULITI-PURPOSE SAMPLERS & UPGD CTRLS 02	110	01OCT01	12MAR02
REACTOR PLANT CONTROL SYSTEM (SYS. 90)				
GA3570	PROCURE NEW SCRAM BREAKERS FY01	251	02OCT00	28SEP01
GA3575	PROCURE NEW SCRAM BREAKERS FY02	223	01OCT01	21AUG02
GA3720	RESTORE ROD CONTROL SYSTEM	150	01OCT01	07MAY02
DIGITAL DATA HANDLING & DISPLAY (SYS. 91)				
GA3085	DESIGN/INSTALL PLANT DATA SYS FY01	251	02OCT00	28SEP01
GA3087	DESIGN/INSTALL PLANT DATA SYS FY02	250	01OCT01	30SEP02
GA3089	DESIGN/INSTALL PLANT DATA SYS FY03	81	01OCT02	28JAN03
GA3090	RESTORE,FOR FUEL LOAD	67	01OCT01	09JAN02
GA3093	CALIBRATE AND TEST PDS FY03	170	29JAN03	30SEP03
GA3095	CALIBRATE AND TEST PDS FY04	90	01OCT03	10FEB04
RX & VESSEL INSTRUMENTATION (SYS. 92)				
GA3100	RESTORE/UPGRADE RX TEMPERATURE TO PDS INTERFACE	190	02OCT00	03JUL01
INSTRUMENTATION & CONTROL (SYS. 93)				
GA3660	CALIBRATE/REPLACE MHTS RTDS FY01	251	02OCT00	28SEP01
GA3662	CALIBRATE/REPLACE MHTS RTDS FY02	224	01OCT01	22AUG02
GA3670	REPLACE SEISMIC MONITORING SYSTEM FY01	251	02OCT00	28SEP01
GA3672	REPLACE SEISMIC MONITORING SYSTEM FY02	250	01OCT01	30SEP02
GA3674	REPLACE SEISMIC MONITORING SYSTEM FY03	104	01OCT02	03MAR03
GA3680	UPGRADE/RESTORE ALARM PANELS FY01	251	02OCT00	28SEP01
GA3682	UPGRADE/RESTORE ALARM PANELS FY02	250	01OCT01	30SEP02
GA3684	UPGRADE/RESTORE ALARM PANELS FY03	60	01OCT02	27DEC02
GA3686	UPGRADE/RESTORE RILEY PANEL ALARMS FY01	251	02OCT00	28SEP01
GA3688	UPGRADE/RESTORE RILEY PANEL ALARMS FY02	250	01OCT01	30SEP02



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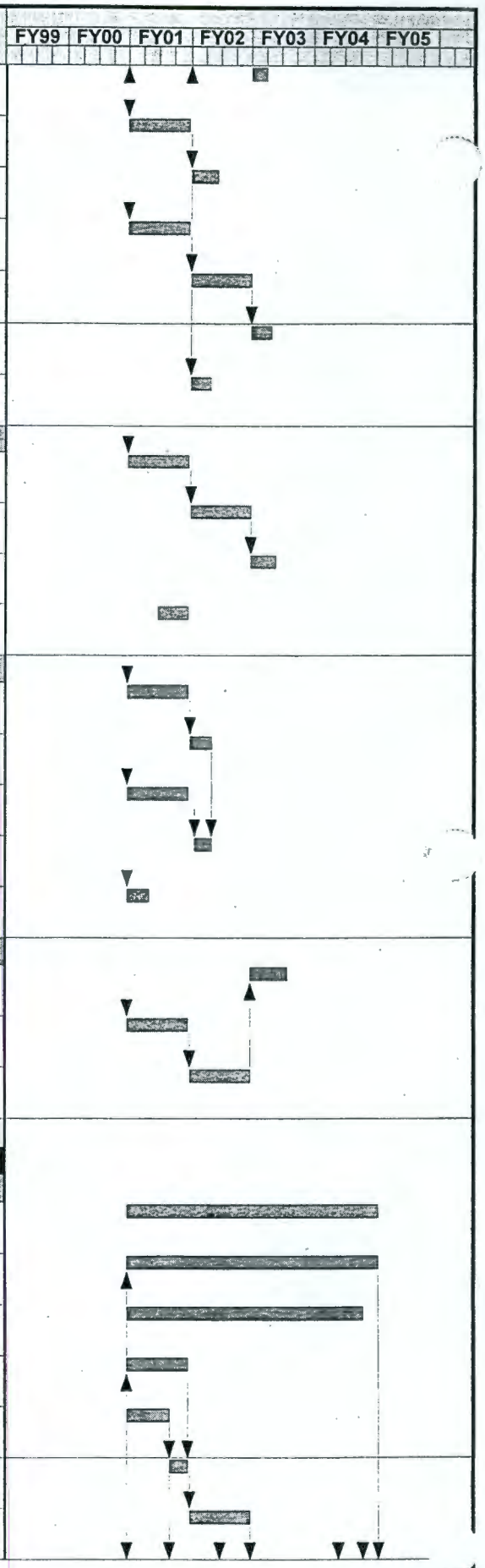
GA3690	UPGRADE/RESTORE RILEY PANEL ALARMS FY03	60	01OCT02	27DEC02
GA3692	PULSE NEUTRON CALIBRATION OF SEC VENTURI FM FY01	251	02OCT00	28SEP01
GA3694	PULSE NEUTRON CALIBRATION OF SEC VENTURI FM FY02	112	01OCT01	14MAR02
GA3727	REPLACE SODIUM IONIZATION DETECTORS (SIDs) FY01	251	02OCT00	28SEP01
GA3728	REPLACE SODIUM IONIZATION DETECTORS (SIDs) FY02	250	01OCT01	30SEP02
GA3729	REPLACE SODIUM IONIZATION DETECTORS (SIDs) FY03	80	01OCT02	27JAN03
GA3731	INSPECT & REPAIR PROCESS/SAMPLE LOOP H.T. INST.	84	01OCT01	01FEB02
FUEL FAILURE MONITORING SYSTEM (SYS. 94)				
GA3700	REPLACE FGMS COMPUTER FY01	251	02OCT00	28SEP01
GA3702	REPLACE FGMS COMPUTER FY02	250	01OCT01	30SEP02
GA3704	REPLACE FGMS COMPUTER FY03	102	01OCT02	27FEB03
GA3760	RESTORE DNM SYSTEM	127	02APR01*	28SEP01
RADIATION MONITORING (SYS. 96)				
GA3730	PROCURE AREA MONITOR PREAMP CARDS FY01	251	02OCT00	28SEP01
GA3732	PROCURE AREA MONITOR PREAMP CARDS FY02	93	01OCT01	14FEB02
GA3750	RESTORE RAMS FY01	251	02OCT00	28SEP01
GA3752	RESTORE RAMS FY02	70	01NOV01	14FEB02
GA3850	RESTORE PROCESS RADIATION MONITORS	84	02OCT00	01FEB01
PLANT PROTECTION SYSTEM (SYS. 99)				
GA3790	PERFORM PPS ACCEPTANCE TESTING	152	01OCT02	08MAY03
GA3800	REPLACE PPS POWER SUPPLIES FY01	251	02OCT00	28SEP01
GA3805	REPLACE PPS POWER SUPPLIES FY02	250	01OCT01	30SEP02
ISOTOPE PRODUCTION				
AR7000	FFTF Isotope Cost & Schedule	1,016	02OCT00	18OCT04
GA1430	FFTF ISOTOPE COST & SCHEDULE	1,016*	02OCT00	18OCT04
AR7100	In-reactor Hardware	951	02OCT00	16JUL04
GA1440	IN-REACTOR HARDWARE	251*	02OCT00	28SEP01
GA1450	CONCEPTUAL DESIGN FOR 1 DIFF 40 FT THIMBLES	169	02OCT00*	04JUN01
GA1475	DESIGN & FAB 1 DIFF 40 FT THIMBLES FY00	82	05JUN01*	28SEP01
GA1476	DESIGN & FAB 1 DIFF 40 FT THIMBLES FY01	251	01OCT01	01OCT02



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Project Finish	18OCT04	Progress Bar	
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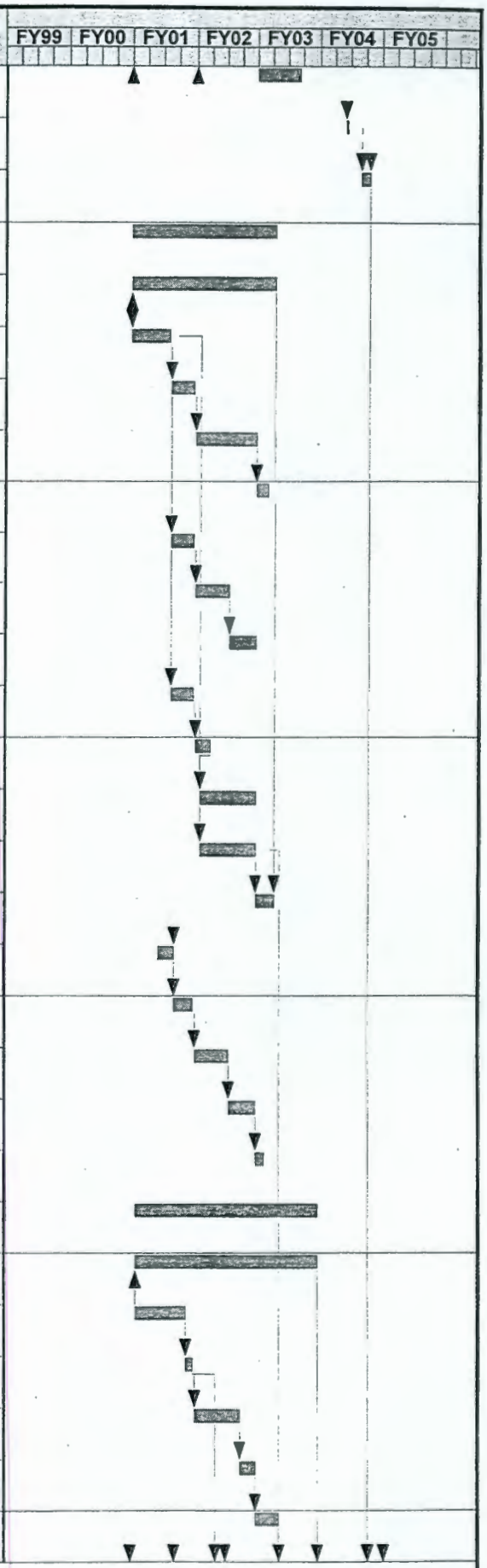
Activity ID	Activity Description	Orig Dur	Integrated Start	Integrated Finish
GA1477	DESIGN & FAB 1 DIFF 40 FT THIMBLES FY02	167	02OCT02	02JUN03
GA1480	CONDITION & INSTALL 1 40FT ASSEMBLIES IN REACTOR	11	27FEB04	12MAR04
GA1485	INSTALL & TEST MEDICAL ISOTOP SYSTEMS AT REACTOR	33	28MAY04	16JUL04
AR7300	Ex-Reactor Hardware	571	02OCT00	13JAN03
GA1550	EX-REACTOR HARDWARE	571*	02OCT00	13JAN03
GA1575	CONCEPTUAL DESIGN OF EX-REACTOR HARDWARE	154	02OCT00	11MAY01
GA1625	RAPID RETRIEVAL SYS R3 ADPTR HDW CTR ISLA FY00	97	14MAY01*	28SEP01
GA1630	RAPID RETRIEVAL SYS R3 ADAPTER HDW CTR ISLA FY01	250	01OCT01	30SEP02
GA1635	RAPID RETRIEVAL SYS R3 ADAPTER HDW CTR ISLA FY02	44	01OCT02	03DEC02
GA1650	HE CIRCULATION/SODIUM DETECTION SYS FOR R3 FY00	97	14MAY01*	28SEP01
GA1655	HE CIRCULATION/SODIUM DETECTION SYS FOR R3 FY01	142	01OCT01	25APR02
GA1660	PLANT MODIFICATIONS FOR MEDICAL ISOTOPE SYSTEMS	108	26APR02	30SEP02
GA1700	R3 TARGET CHAIN (NOT COST OF TARGET MTL) FY00	97	14MAY01*	28SEP01
GA1710	R3 TARGET CHAIN (NOT COST OF TARGET MTL) FY01	63	01OCT01	03JAN02
GA1725	R3 TARGET INSERTION/RETRIEVAL/SHIPPING	226	02NOV01	30SEP02
GA1750	INTEGRATED MOCKUP SYSTEM TESTING FY01	229	30OCT01	30SEP02
GA1752	INTEGRATED MOCKUP SYSTEM TESTING FY02	70	01OCT02	13JAN03
GA1755	CONCEPTUAL DESIGN FOR LTIV	65	05MAR01*	04JUN01
GA1760	DESIGN&FAB LTIV (NOT COST OF TARGET MTL) FY00	82	05JUN01*	28SEP01
GA1762	DESIGN&FAB LTIV (NOT COST OF TARGET MTL) FY01	136	01OCT01	17APR02
GA1765	HARDWARE & PROCED DISASSEMBLY OF LTIV FY01	114	18APR02	30SEP02
GA1770	HARDWARE & PROCED DISASSEMBLY OF LTIV FY02	37	01OCT02	20NOV02
AR7400	Isotope Casks	727	03NOV00	29SEP03
GA1775	ISOTOPE CASKS	727*	03NOV00	29SEP03
GA1800	CONCEPTUAL DESIGN	195	03NOV00*	14AUG01
GA1825	DESIGN FY00	32	15AUG01	28SEP01
GA1830	DESIGN FY01	186	01OCT01	27JUN02
GA1850	FABRICATION & ASSEMBLY FY01	64	28JUN02	30SEP02
GA1860	FABRICATION & ASSEMBLY FY02	94	01OCT02	14FEB03



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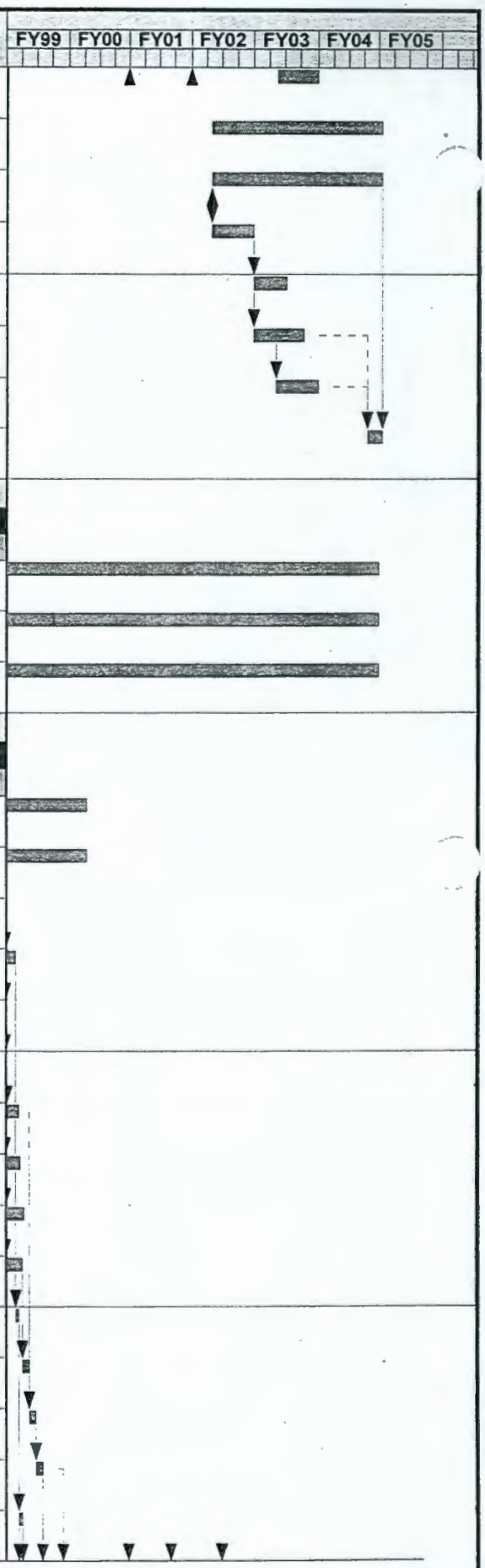
GA1875	CASK QUALIFICATION	156	18FEB03	29SEP03
AR7800	Project Administration	685	29JAN02	18OCT04
GA1900	PROJECT ADMINISTRATION	685*	29JAN02	18OCT04
GA1950	SAFETY/EVALUATION/SAR INPUT CHANGES FY01	170	29JAN02	30SEP02
GA1955	SAFETY/EVALUATION/SAR INPUT CHANGES FY02	133	01OCT02	11APR03
GA1975	DEVELOP PROCEDURES	195	03OCT02	15JUL03
GA2000	DEVELOP & IMPLEMENT TRAINING	167	03FEB03	30SEP03
GA2025	ACCEPTANCE TESTING/RA	65	19JUL04	18OCT04
SAFEGUARDS & SECURITY				
ARA125	Material & Property Security (SAS)	1,506	01OCT98	30SEP04
GA0640	SAFEGUARDS AND SECURITY	1,506*	01OCT98	30SEP04
AR1B1015	FFTF Safeguard & Security	1,506	01OCT98	30SEP04
PLANT MODS/UPGRADES - CLEM				
ARN050	Clem Upgrade	331	01OCT98	27JAN00
AR1B1027	FFTF Clem Upgrade Support	331	01OCT98	27JAN00
DE1600	CLEM - FY99 START MILESTONE	0	01OCT98	
DE1602	CLEM - WIRING DIAGRAMS	41	01OCT98	30NOV98
DE1605	CLEM - HARDWARE LAYOUT DRAWING	10	01OCT98	14OCT98
DE1610	CLEM - GRAPHIC INTERFACE SCREENS	7	01OCT98	09OCT98
DE1620	CLEM - OPERATOR SCREEN FUNCTIONS	45	12OCT98	15DEC98
DE1630	CLEM - INTERLOCKS	62	01OCT98	31DEC98
DE1640	CLEM - LADDER LOGIC DIAGRAMS	70	01OCT98	13JAN99
DE1650	CLEM - REPORT FORMAT	64	01OCT98	05JAN99
DE1700	CLEM - DESIGN REVIEW	14	01DEC98	18DEC98
DE1710	CLEM - DATA STORAGE FORMAT	29	06JAN99	16FEB99
DE1720	CLEM - BENCH TEST AND DEBUG	30	17FEB99	30MAR99
DE1730	CLEM - SOFTWARE DESIGN REVIEW	30	31MAR99	11MAY99
DE1860	CLEM - MATERIAL TAKEOFF	11	21DEC98	07JAN99



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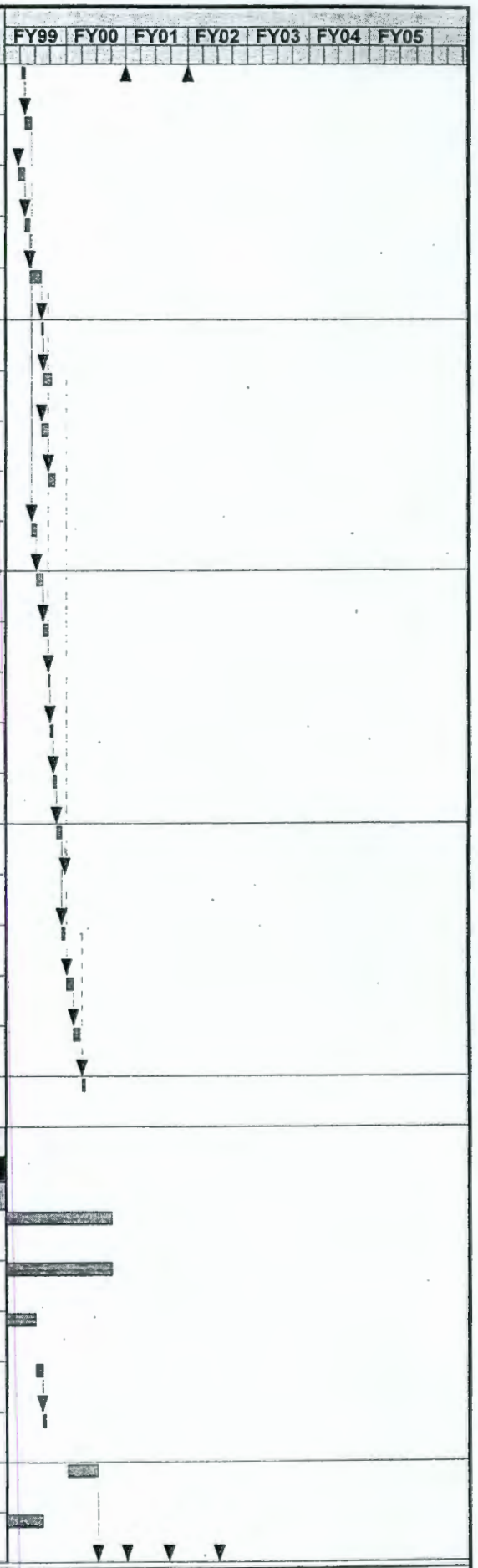
DE1870	CLEM - PLACE PURCHASE REQUISITIONS	15	08JAN99	28JAN99
DE1880	CLEM - DELIVERY PERIOD	29	29JAN99	11MAR99
DE1890	CLEM - SHOP WORK INSTRUCTIONS	24	21DEC98	26JAN99
DE1900	CLEM - SHOPTEST INSTRUCTIONS	19	27JAN99	23FEB99
DE1910	CLEM - FIELD WORK INSTRUCTIONS	50	24FEB99	04MAY99
DE1920	CLEM - CG&A INSTRUCTIONS	11	05MAY99	19MAY99
DE1930	CLEM - ACCEPTANCE TEST PROCEDURES	31	20MAY99	02JUL99
DE1940	CLEM - REVISE OPERATING PROCEDURES	24	12MAY99	15JUN99
DE1945	CLEM - OPERATOR TRAINING	25	16JUN99	22JUL99
DE1950	CLEM - PANEL FABRICATION	21	12MAR99	09APR99
DE1960	CLEM - PANEL WIRING	24	12APR99	13MAY99
DE1970	CLEM - SHOP TESTING	25	14MAY99	18JUN99
DE1980	CLEM - MOBILIZE	5	21JUN99	25JUN99
DE1990	CLEM - DISCONNECT AND REMOVE OLD EQUIPMENT	10	28JUN99	13JUL99
DE2000	CLEM - INSTALL NEW HARDWARE	20	14JUL99	10AUG99
DE2010	CLEM - INSTALL NEW WIRING	19	11AUG99	07SEP99
DE2015	B19-99-403 CLOSED LOOP EX-VESSEL MACHINE CONTROL	0		30SEP99*
DE2020	CLEM - TESTING AND DEBUGGING	15	08SEP99	28SEP99
DE2030	CLEM - ATP PHASE I	28	01OCT99*	09NOV99
DE2040	CLEM - ATP PHASE II	30	10NOV99	23DEC99
DE2060	CLEM - AS-BUILTS	20	30DEC99*	27JAN00
PLANT MODS/UPGRADES - SRS				
RX & VESSEL INSTRUMENTATION (SYS. 92)				
ARR050	SRS C1167	441	01OCT98	05JUL00
AR1B102B	FFTF SRS C1167 Support	441	01OCT98	05JUL00
DE2190	SRS C1167 - PREPARE DRAWINGS	124	01OCT98	31MAR99
DE2200	SRS C1167 - PROCURE HARDWARE	27	01APR99*	07MAY99
DE2205	SRS C1167 - UPGRADE M/M INTERFACE SOFTWARE	15	10MAY99	28MAY99
DE2210	SRS C1167 REPLACE FIELD HARDWARE	127	01OCT99*	04APR00
DE2220	SRS C1167 - PROGRAM PLC	151	01OCT98	07MAY99



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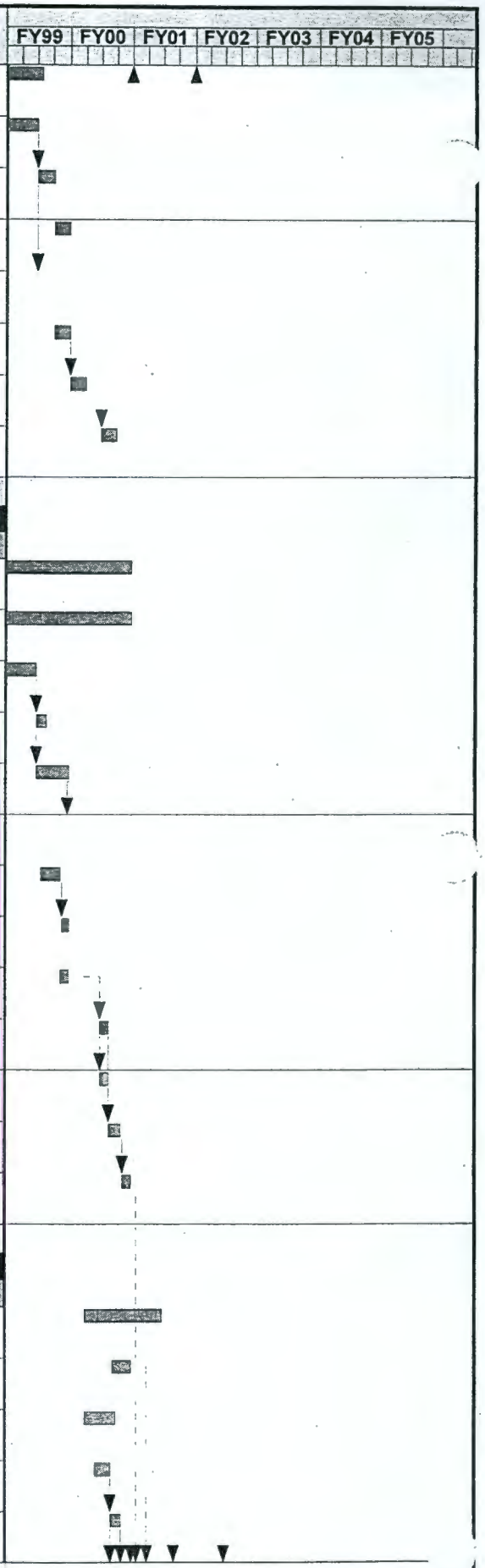
DE2230	SRS C1167 - PREP LOOP DIAGRAMS	144	01OCT98	28APR99
DE2240	SRS C1167 - FINALIZE SCREENS	125	01OCT98	01APR99
DE2242	SRS C1167 - SW CONVERSION	65	02APR99	02JUL99
DE2244	SRS C1167 - SW TESTS	61	07JUL99*	30SEP99
DE2245	B19-99-400 DESIGN REVIEW FOR THE SRS UPGRADE	0		01APR99
DE2250	SRS C1167 - PREP PROCEDURES (DRAFT OP)	61	07JUL99*	30SEP99
DE2255	SRS C1167 - PREP PROCEDURES (FINAL OP)	61	01OCT99*	30DEC99
DE2260	SRS C1167 - TESTING	63	05APR00*	05JUL00
PLANT MODS/UPGRADES - SWC				
ARL50	SWC	501	01OCT98	28SEP00
AR1B1032	FFTF SWC Engineering Support	501	01OCT98	28SEP00
SH130	SWC - HOIST DESIGN	124	01OCT98	31MAR99
SH140	SWC - DESIGN REVIEW/APPROVAL	42	01APR99	28MAY99
SH150	SWC - HOIST PROCURE/FAB	127	01APR99	30SEP99
SH160	B19-99-404 SWC - PEP MILESTONE	0		30SEP99
SH170	SWC - GRAPPLE DESIGN	77	03MAY99*	20AUG99
SH182	SWC - GRAPPLE PROCURE/FAB	28	23AUG99	30SEP99
SH190	SWC - FIELD INSTALL	33	16AUG99*	30SEP99
SH200	SWC - CG&A	34	31MAR00*	17MAY00
SH205	OPERATOR TRAINING	40	31MAR00	25MAY00
SH210	SWC - ATP	54	18MAY00	04AUG00
SH220	SWC - TRRT/ISSUE PROC'S	38	07AUG00	28SEP00
PLANT MODS/UPGRADES - OTA SHEAR				
ARM050	Shear ATP	310	05JAN00*	28MAR01
SH230	OTA SHEAR - DSWC PREPS	79	08JUN00*	29SEP00
SH240	OTA SHEAR - FAB SUPPORT FIXTURE	127	05JAN00*	05JUL00
SH250	OTA SHEAR - OPS AT IEMCTF (OP CERT)	63	06MAR00*	01JUN00
SH260	OTA SHEAR - MOVE EQUIPMENT	43	02JUN00	03AUG00



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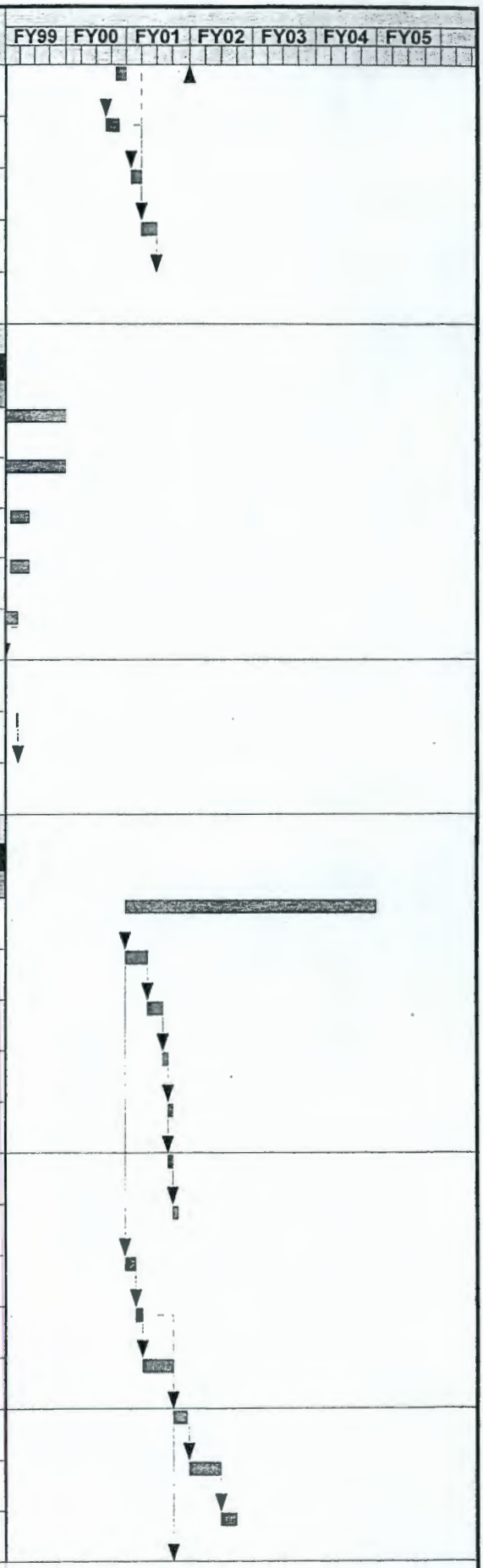
SH270	OTA SHEAR - IEMC ELEC MOD	40	04AUG00	29SEP00
SH280	OTA SHEAR - PREPARE ATP	57	02JUN00	23AUG00
SH290	OTA SHEAR - REMOVE WASTE CONT.	42	27OCT00*	29DEC00
SH300	OTA SHEAR - ATP	61	02JAN01	28MAR01
SH305	B10-98-103 OBTAIN RRB RELEASE FOR OTA SHEAR OPER	0		28MAR01
PLANT MODS - MISC				
AR1B1223	FFTF T-196 Air Dryer Hard Piping	251	01OCT98	30SEP99
SD0200	FY99 T196 AIR DRYER HARD PIPING	251	01OCT98	30SEP99
AR1B102A	FFTF G-3 Generator Repairs/Purchase	80	02NOV98*	01MAR99
SE0080	FY99 G-3 GENERATOR REPAIR MATERIAL PURCHASE	80	02NOV98*	01MAR99
AR1B1025	G-3 Fuel Oil Tank Leak Detection	57	01OCT98*	22DEC98
ARSE078	B10-99-002 G-3 Fuel Oil Tank Leak Detector	0		30SEP98
SE0075	G-3 FUEL OIL TANK LEAK DETECTOR	12	07DEC98*	22DEC98
SE0078	B10-99-002 G-3 FUEL OIL TANK LEAK DETECTOR	0		22DEC98
CORE ENGINEERING FOR REACTOR RE-START				
AR8000	Engineering for Restart	1,004	02OCT00	30SEP04
GA0800	ESTABLISH COMPUTER CODES & VERIFY OPERATION	84	02OCT00	01FEB01
GA0810	PREPARE REFERENCE CORE DESIGN FOR EIS/SAR	63	02FEB01	02MAY01
GA0820	CALCULATE SAR SAFETY COEFFICIENTS	21	03MAY01	01JUN01
GA0830	CALCULATE BOUNDING ACCIDENTS FOR SAR	21	04JUN01	02JUL01
GA0840	CORE SAFETY COEFICIENTS & ACCIDENTS FOR SAR	21	04JUN01	02JUL01
GA0850	DRAFT SAR CHAPTERS	21	03JUL01	01AUG01
GA0860	CONFIRM NUCLEAR ANALYSIS DATABASE FOR MOX	42	02OCT00	30NOV00
GA0870	DEFINE CORE LOADING SEQUENCE	21	01DEC00	03JAN01
GA0875	DOCUMENT INITIAL RELOAD OF CORE P14A TEST	127	04JAN01	03JUL01
GA0880	CALCULATE REFUELING CONSTANTS	61	05JUL01	28SEP01
GA0885	RESTORE OPERATIONS SURVEILLANCE CODES	125	01OCT01	02APR02
GA0890	RESTORE NUCLEAR INSTRUMENTATION CALIBRATION	63	03APR02	01JUL02



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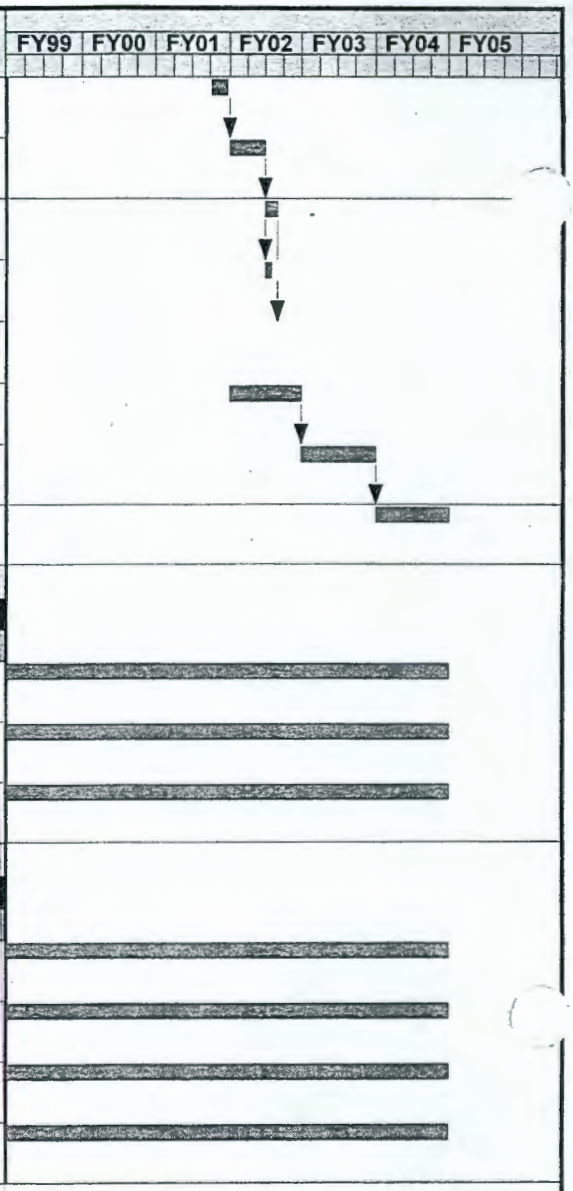
GA0900	DEFINE REFUELING TO GO TO P14B CORE	61	05JUL01	28SEP01
GA0910	PREPARE RELOAD DESIGN REPORT FOR P14B	125	01OCT01	02APR02
GA0920	SAFETY REVIEW/CONCURRENCE FOR RDR P14B	42	03APR02	31MAY02
GA0930	PREPARE OPERATING PHYSICS TABLES FOR P14B	21	03APR02	01MAY02
GA0940	CORE LOADING APPROVED FOR P14B OPERATIONS	0		31MAY02
GA0980	CORE LOADING FY02 PHYSICS SUPPORT	250	01OCT01*	30SEP02
GA0990	CORE LOADING FY03 PHYSICS SUPPORT	251	01OCT02	30SEP03
GA1000	CORE LOADING FY04 PHYSICS SUPPORT	252	01OCT03	30SEP04
ENGINEERING				
ARD050	MAINTAIN FFTF SYST DESIGN	1,506	01OCT98	30SEP04
AR1B130A	FFTF Engineering Management	1,506	01OCT98	30SEP04
AR1B1023	FFTF Mechanical Engineering Support	1,506	01OCT98	30SEP04
GENERAL SUPPORT				
ARC050	SELF ASSESSMENTS & SUPPORT	1,506	01OCT98	30SEP04
AR1B1045	FFTF Radiological Control Support	1,506	01OCT98	30SEP04
AR1B1080	FFTF Safety Support	1,506	01OCT98	30SEP04
AR1B1040	FFTF Quality Assurance	1,506	01OCT98	30SEP04



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PNNL-12228

Pacific Northwest National Laboratory
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Isotope Production at the Hanford Site in Richland, Washington

June 1999

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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PNNL-12228

Isotope Production at the Hanford Site in Richland, Washington

June 1999

Information provided to the Nuclear Energy Research Advisory Committee's subcommittee on the development of a "Long-Term Isotope Research and Production Plan"

Prepared by the Hanford Radioisotopes Program staff at the
Pacific Northwest National Laboratory
Richland, Washington 99352

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1.0 Introduction

This report was prepared in response to a request from the Nuclear Energy Research Advisory Committee (NERAC) subcommittee on "Long-Term Isotope Research and Production Plans." The NERAC subcommittee has asked for a reply to a number of questions regarding (1) "How well does the Department of Energy (DOE) infrastructure serve the need for commercial and medical isotopes?" and (2) "What should be the long-term role of the federal government in providing commercial and medical isotopes?"

Our report addresses the questions raised by the NERAC subcommittee, and especially the 10 issues that were raised under the first of the above questions (see Appendix). These issues are related to the isotope products offered by the DOE Isotope Production Sites, the capabilities and condition of the facilities used to produce these products, the management of the isotope production programs at DOE laboratories, and the customer service record of the DOE Isotope Production Sites.

An important component of our report is a description of the Fast Flux Test Facility (FFTF) reactor at the Hanford Site and the future plans for its utilization as a source of radioisotopes needed by nuclear medicine physicians, by researchers, and by customers in the commercial sector.

In response to the second question raised by the NERAC subcommittee, it is our firm belief that the supply of isotopes provided by DOE for medical, industrial, and research applications must be strengthened in the near future. Many of the radioisotopes currently used for medical diagnosis and therapy of cancer and other diseases are imported from Canada, Europe, and Asia. This situation places the control of isotope availability, quality, and pricing in the hands of non-U.S. suppliers. It is our opinion that the needs of the U.S. customers for isotopes and isotope products are not being adequately served, and that the DOE infrastructure and facilities devoted to the supply of these products must be improved. This perception forms one of the fundamental bases for our proposal that the FFTF, which is currently in a standby condition, be reactivated to supply nuclear services and products such as radioisotopes needed by the U.S. medical, industrial, and research communities.

2.0 Radioisotope Production at the Hanford Site

2.1 History of Isotope Production Activities at the Hanford Site

The Hanford Site, under management of the Westinghouse Hanford Company (WHC), began isotope production at the FFTF in the 1980s. More than 40 radioisotopes of interest to medical and commercial clients were produced. In many cases, only trace quantities of isotopes, suitable for research applications, were produced. However, several isotopes, such as gadolinium-153 and cadmium-109, were produced in larger quantities and sold for medical applications. All of the radiochemical processing of isotope targets irradiated at FFTF was performed in the radiochemistry laboratories of the Pacific Northwest National Laboratory (PNNL). In 1991, at the request of DOE, the Hanford Site began weekly production of

yttrium-90, which was in the early stages of clinical testing for the treatment of Hodgkin's lymphoma using a radiolabeled antibody method. PNNL scientists developed a process that was patented in 1996 for the production of ultrapure yttrium-90 from strontium-90 that was retrieved from nuclear waste stockpiles at Hanford (U.S. patent no. 5,512,256, awarded April 30, 1996).

In 1996 WHC transferred the management of the DOE-supported radioisotopes program to PNNL. Under PNNL the program was expanded to include research on the production and applications for cancer therapy of alpha-emitting isotopes such as radium-223 and actinium-225 and the bismuth-213 isotope obtained by decay of actinium-225. In addition, through active marketing conducted in collaboration with DOE-HQ staff, the medical use of yttrium-90 and worldwide sales of this isotope have rapidly increased during the past three years. In part because of its successful management of the medical isotopes program at the Hanford Site, PNNL was requested by the Secretary of Energy in May 1999 to lead the development of a scoping plan for the future missions of the FFTF, an important component of which is the production of radioisotopes to fill the needs of medical and commercial users.

2.2 Current Program Activities Sponsored by the Department of Energy

2.2.1 Isotope Production Activities

The primary medical isotope produced and sold by PNNL under the sponsorship of the DOE Office of Nuclear Energy, Science and Technology's Isotope Programs Office (DOE/NE-70) has been yttrium-90. Largely because of successful clinical trials in the U.S. and Europe and the consistent weekly supply of high-purity yttrium-90 supplied by PNNL, the sales of this isotope increased rapidly from FY 1996 to FY 1998. The 14-fold increase in sales of this isotope over a two-year period is illustrated in Figure 1.

The rapid increase in yttrium-90 sales led to a successful effort to commercialize the production, marketing, sales, and distribution of this isotope product during the past year (described in Section 2.2.2).

A second area in which research and development activities have been focused during the past three years is the development of efficient separation chemistries for alpha emitters of interest in cancer therapy. The following specific noteworthy accomplishments in alpha-emitter research have been supported primarily by DOE/NE-70:

1. new processes for separating and purifying thorium-229, actinium-225, and radium-223 from a mixture of radionuclides were developed, and a U.S. patent was awarded in September 1998 (No. 5,809,394)

2. a new and highly efficient anion exchange procedure was developed to isolate bismuth-213 from its actinium-225 parent, and a U.S. patent was awarded in May 1998 (No. 5,749,042)

3. an automated, computer-controlled generator technique was developed at PNNL, and subsequently demonstrated to achieve an efficient separation of bismuth-213 while allowing complete recovery of the actinium-225 parent species; a U.S. patent application for this technology was filed in 1998

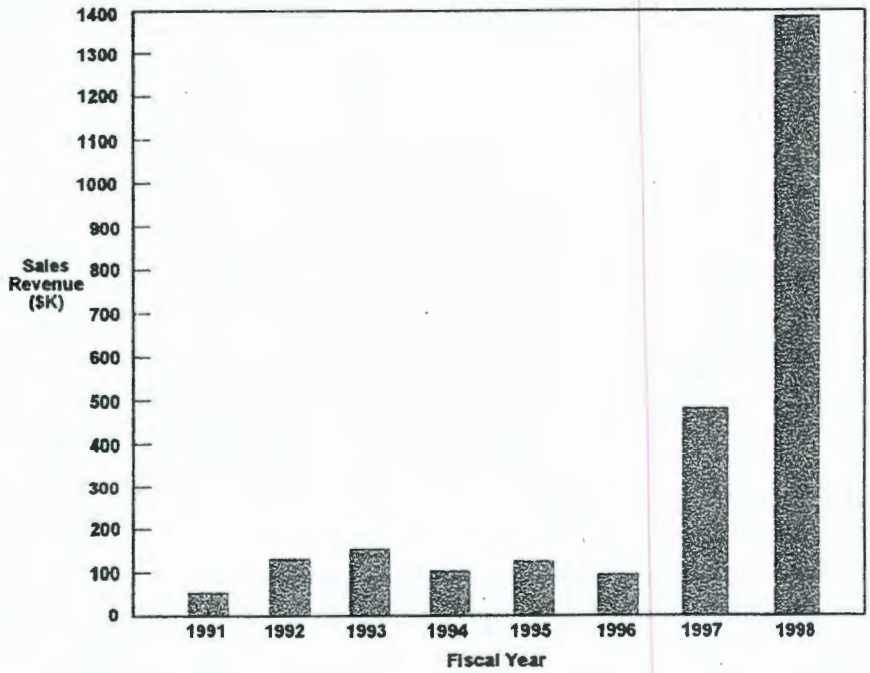


Figure 1. Annual Sales of Yttrium-90 Produced at the Hanford Site Since FY 1991

4. advances were made in developing chelation and linker chemistry for actinium-225 and radium-223 in collaborative work with scientists from the University of Idaho and the University of Washington; two U.S. patent applications were filed in 1998 for new chelating agents of the calixarene and crown ether families that selectively bind actinium-225 and radium-223. [This work was initiated with support from Laboratory-Directed Research and Development (LDRD) funds, and subsequently funded by DOE/NE-70.]

Other research activities with radioisotope products have focused on developing methods for delivering isotopes and radiopharmaceutical products to disease sites. An example of ongoing research supported by the DOE Office of Biological and Environmental Research involves the use of a radioactive polymer composite for administering high-dose brachytherapy to tumors of the prostate gland and other tissues. In this procedure, a direct injection into the tumor mass is made of an isotope solution contained in a polymer material that is a fluid at room temperature, but quickly gels at body temperature and retains the isotope within the tumor region. A U.S. patent application on this procedure was filed in 1998.

With the completion of commercialization of the yttrium-90 production program, PNNL will not continue to serve as a DOE/NE-70 isotope production site in FY 2000. However, special projects related to retrieval of medical isotopes such as thorium-228 from stored nuclear stockpiles will be carried out on request.

2.2.2 Commercialization and Leasing/Licensing of Isotope Products

During FY 1998, a Request for Proposal (RFP) was issued by DOE to commercialize the production, marketing, sales, and distribution of yttrium-90. The proposals submitted were evaluated by a joint

DOE/PNNL team to select a short list of companies whose proposals were considered acceptable. Negotiations began in mid-1998, and on October 22, 1998, an agreement to lease 40 curies of highly purified strontium-90 for a period of five years was signed by DOE and NEN Life Science Products, Inc. A separate license agreement to use PNNL's patented process for extracting yttrium-90 from its strontium-90 parent was signed by NEN on October 12, 1998.

Under the lease agreement, DOE receives an immediate fee of $25K and subsequent lease payments based on a percentage of the net sales value of yttrium-90 sold by NEN. The estimated value of this lease agreement for DOE is approximately $1M over a five-year period based on the current yttrium-90 annual sales. Under the license agreement, the management contractor organization for PNNL – the Battelle Memorial Institute – receives an initial fee of $75K and subsequent royalties based on a percentage of the net sales value of Y-90 sold by NEN. The estimated value of this agreement for Battelle is approximately $500K over a five-year license period.

The lease agreement between DOE and NEN allowed a period of six months for transitioning the yttrium-90 production operations from PNNL to NEN laboratories in Billerica, MA. At the beginning of May, 1999, NEN began producing and selling yttrium-90 to commercial customers. PNNL continued to produce yttrium-90 for medical customers involved in Phase 3 clinical trials until early June 1999, in order to allow adequate time for the Food & Drug Administration to review and approve NEN's Drug Master File and to certify NEN's yttrium-90 product as being of suitable quality for use in advanced Phase 3 clinical trials.

Based on the success of the yttrium-90 commercialization activity, PNNL is currently involved in efforts to commercialize other technology that has been developed for the medical application of radioisotopes. For example, negotiations are underway with a private company for use of PNNL's radioactive composite polymer delivery system for treating prostate tumors and other forms of cancer.

2.3 Future Plans for Isotope Production at the Hanford Fast Flux Test Facility

2.3.1 Background information on the FFTF

The FFTF's original mission was to support liquid metal reactor technology development and reactor safety by providing fuels and materials irradiation services. Although the U.S. liquid metal reactor program ended at about the same time that the FFTF commenced operation in 1982, the reactor continued operation for 10 years as a national research facility to test advanced nuclear fuels and materials, nuclear power plant operating procedures, and active and passive reactor safety technologies. The facility was also used to produce more than 40 different radioisotopes for use in research, medicine, and industry. In addition, FFTF generated tritium for the U.S. fusion research program and supported cooperative, international nuclear research activities. The reactor was shut down in December 1993, and since that time has been in a standby operational condition, pending a decision by DOE on its future use. In May 1999, the Secretary of Energy announced that a special 90-day study led by the Director of the Pacific Northwest National Laboratory, Dr. William Madia, would be conducted to establish whether the FFTF should be considered for future missions related to national and international nuclear technology needs.

This scoping plan for future FFTF missions will be reviewed by NERAC before submission to the Secretary of Energy on August 2, 1999.

2.3.2 Proposed Future Missions of the FFTF

Because the FFTF has a large target volume and can provide a high flux of neutrons at energies ranging from thermal to > 1 MeV, the facility is suitable for a wide variety of nuclear science and irradiation services missions. As part of the ongoing development of an FFTF scoping plan, these potential missions are being closely evaluated at the time this report is being prepared. The nuclear science and irradiation services provided by FFTF will focus on a core federal role of meeting multiple 21st Century needs, including:

- providing a large and reliable supply of radioisotopes for research, medical, and industrial applications
- promoting safer nuclear technology through reactor safety testing and the development of proliferation-resistant nuclear fuels
- producing power sources for deep-space exploration through the production of plutonium-238 for radioisotope thermoelectric generators (RTGs) and research on compact space reactor technology
- sustaining the nuclear option for power production through testing of fuels, components, and reactor instrumentation
- conducting advanced research and providing services related to the testing of materials for fusion reactors, hardening and testing of materials such as semiconductors, and research on transmutation of nuclear waste materials.

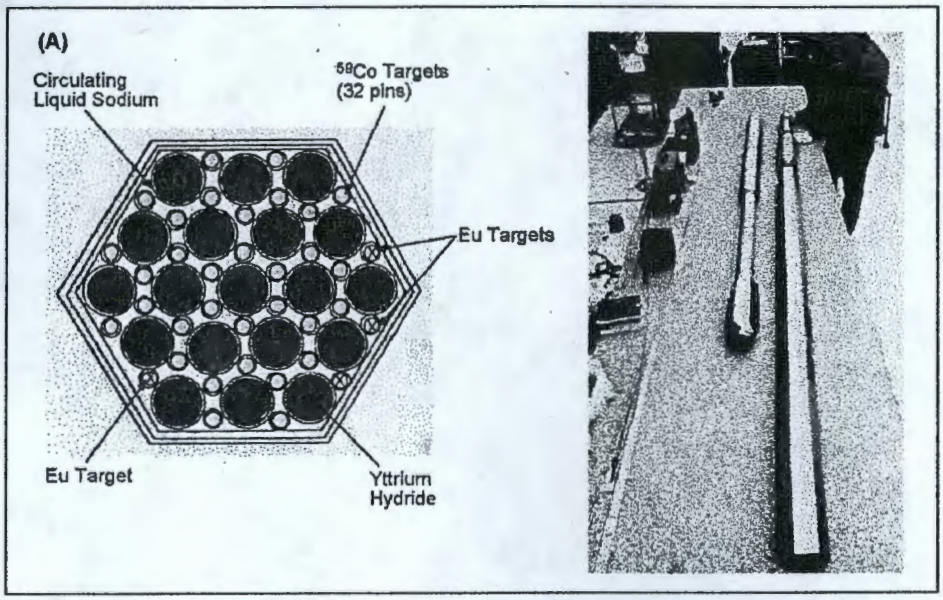
With the establishment of a long-term, stable core federal mission, FFTF would also offer valuable options for private sector users. A significant involvement of commercial, academic, and international users in the future plans for FFTF is realistic, since the reactor previously demonstrated its ability to support multiple users and still achieve a high capacity factor during its ten years of successful operation.

2.3.3 Capability of the FFTF for Isotope Production

The FFTF offers several special production advantages relative to other DOE or commercial reactors that are currently in operation in the United States:

1. **Neutron Energy Moderation**. The FFTF neutron energy spectrum peaks at ~300 keV, which provides a significant advantage for the production of several medical isotopes that require a high flux of fast and high-energy neutrons. An example is the production of copper-67 by an (n,p) reaction with a zinc-67 target. Through the introduction of energy moderators such as hydrides, the neutron energy spectrum within each target assembly can be moderated over a broad range of energies to provide a high flux of fast or epithermal neutrons. In this manner, the neutron energy at each target location can be tailored to achieve a maximum reaction rate for producing a specific isotope product.

This flux tailoring capability was demonstrated in tests at the FFTF during the 1980s. Figure 2A shows the composition of a hydrided assembly that was used in a test to simultaneously produce cobalt-60 and gadolinium-153 during the same irradiation cycle. Figure 2B shows the resulting neutron energy spectrum in the hydrided assembly as compared to the unmodified FFTF neutron spectrum. Because several hundred targets can be irradiated simultaneously within the FFTF core region, a wide range of isotope products can be produced during each FFTF operating cycle.



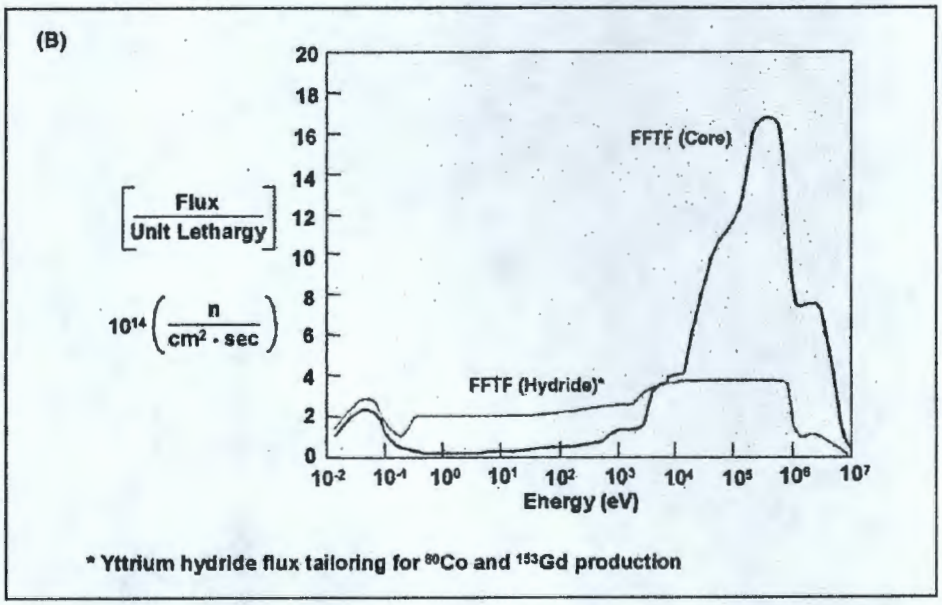


Figure 2. (A) Hydrided Test Assembly Used in a 1987 FFTF Experiment to Produce Gadolinium-153 and Cobalt-60. (B) Neutron flux profile for hydrided assembly shown in panel (A).

2. **High Neutron Flux**. The peak flux within the FFTF core region is ~7 x 10^{15} neutrons/cm^2/sec when the reactor is operated at full power, which is higher than that achieved by any other reactor used for isotope production in the United States. As a result, isotopes with high specific activities can be produced in large quantities during irradiation cycles that range from 10 days (for short-lived medical isotopes) to one year. Figure 3 illustrates the high neutron flux capabilities of FFTF relative to other U.S. reactors.

3. **Large Target Volume**. The core volume within the FFTF reactor vessel is ~1,000 liters, which is twice as large as the core volumes of the other existing DOE reactors combined. This feature provides a production advantage for isotopes that are needed in bulk quantities, or for which a small production cross-section must be offset by the irradiation of large target masses.

During the FFTF's ten years of operation, more than 40 different medical, industrial, and research isotopes were produced. The reactor also demonstrated the capability to produce multiple isotope species during the same irradiation cycle. As the demand for medical isotopes increases, the FFTF could meet multiple isotope production needs while supporting other nuclear science and irradiation services missions.

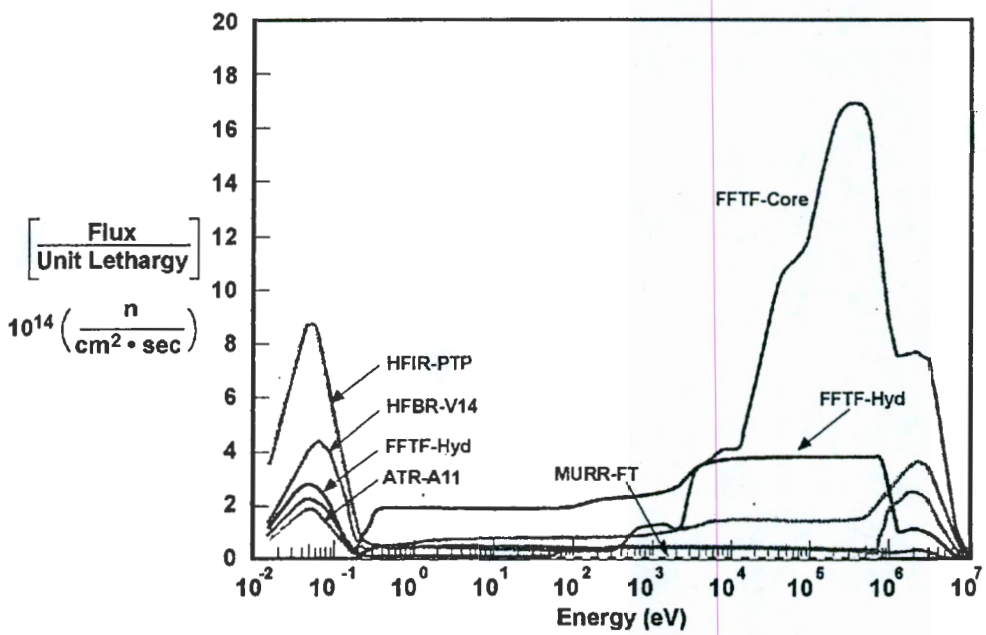


Figure 3. Comparison of FFTF Neutron Spectra With and Without Yttrium Hydride (Hyd) Moderator Pins; Also Shown are Neutron Spectra From the Core Regions of the High Flux Isotope Reactor (HFIR, Oak Ridge National Laboratory), the High Flux Beam Reactor (HFBR, Brookhaven National Laboratory), the Advanced Test Reactor (ATR, Idaho National Environmental and Engineering Laboratory), and the Missouri University Research Reactor (MURR).

2.3.4 Candidate Medical Isotopes to be Produced at FFTF and Comparison with Market Demand and Other DOE Reactor Capabilities

In planning for a future isotope production mission at FFTF, consideration has been given to the projected future demand for a broad range of radioisotopes required for medical and commercial applications. The present and future availability of these isotopes from domestic sources has been analyzed, as well as the FFTF's capability to supplement the supply of these isotopes to meet the projected future demand. From these analyses, together with recent forecasts of the medical isotopes market such as those conducted by Frost and Sullivan[1] and the Medical University of South Carolina,[2] it is apparent that the greatest challenge in meeting the market requirements over the coming two decades will be in the area of therapeutic medical isotopes. A focus of the planning activities for the future FFTF radioisotope production mission has therefore been placed on these isotopes, several of which are currently unavailable, or available only in limited quantities, from sources in the U.S. and worldwide.

For initial planning purposes, a set of 30 medical isotopes was selected on the basis of information obtained from several sources, including (1) the above-mentioned medical market forecasts, (2) reviews of the medical literature and the ~120 ongoing clinical trials that utilize radioisotopes for the treatment of cancer and other diseases, and (3) the report of an expert panel that was formed by DOE in 1998 to assess the future demand for medical isotopes.[3] These 30 isotopes are listed in Table 1, along with a description of their medical applications. These applications primarily involve the diagnosis and treatment of three major classes of disease — cancer, vascular disease (arterial restenosis), and arthritis. Some of these isotopes have both diagnostic and therapeutic applications (e.g., iodine-131). It should also be noted that several of the isotopes serve as "generators" for other therapeutic medical isotopes that are obtained as decay products [e.g., tungsten-188 for rhenium-188, thorium-229 for actinium-225 (and bismuth-213), thorium-228 for bismuth-212, and actinium-227 for radium-223]. Table 1 also presents the reaction process used to transmute the target isotope through neutron irradiation to make the desired medical isotope product. Three types of reaction processes are considered, namely, the capture of a neutron with ejection of either a gamma ray or a proton, and inelastic excitation which transforms the target isotope nucleus to an excited isomeric state.

From an analysis of the production requirements for these 30 reactor-generated isotopes, it becomes quickly evident that several of them have small (<5 barn) production cross-sections and require target irradiation with fast or high-energy neutrons. The cross-sections and neutron energy requirements for the 30 isotopes listed in Table 1 are depicted schematically in Figure 4. It is apparent from this representation of the isotope production requirements that the FFTF, because of its high flux of fast neutrons and the ability to perform flux tailoring using hydride energy moderation, is ideally suited for the efficient production of a majority of the medical isotopes listed in Table 1.

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[1] "FFTF Medical Isotopes Market Study (2001-2020)," Frost and Sullivan, Inc., Mountain View, California; Pacific Northwest National Laboratory report PNNL-11774, Richland, Washington (1997).

[2] "Evaluation of Medical Radionuclide Production with the Accelerator Production of Tritium (APT) Facility," Medical University of South Carolina report (July 15, 1997).

[3] Expert Panel Report: "Forecast Future Demand for Medical Isotopes," DOE Cooperative Program Project #130, final report (April 1998).

Table 1. Thirty Candidate Medical Isotopes for Production at FFTF

Medical Isotope	Medical Applications	Reactions
Actinium-227 (Ac-227)	Parent of Ra-223 [monoclonal antibody attachment used for cancer treatment by radioimmunotherapy (RIT)]	Ra226(n,γ)Ra227/Ac227
Gold-198 (Au-198)	Mini-gun, treating ovarian cancer, prostate cancer, brain cancer, intracavity therapy	Au197(n,γ)Au198
Cadmium-109 (Cd-109)	Cancer detection, pediatric imaging	Cd108(n,γ)Cd109 Or Ag107(n,γ)Cd108 Cd 108(n,γ)Cd109
Copper-64 (Cu-64)	SPECT imaging, dosimetry studies, cerebral and myocardial blood flow, colorectal cancer therapy	Zn64(n,p)Cu64
Copper-67 (Cu-67)	Cancer treatment/diagnostics, radioimmunotherapy (RIT), planar imaging, SPECT imaging	Zn67(n,p)Cu67
Gadolinium-153 (Gd-153)	Dual photon source, osteoporosis detection, SPECT imaging	Eu (n,γ)Eu152/Gd152 Gd152 (n,γ)Gd153
Holmium-166 (Ho-166)	Treatment of rheumatoid arthritis, radiolabeling and monoclonal antibody techniques	Ho165(n,γ)Ho166
Iodine-125 (I-125)	Osteoporosis detection, diagnostic imaging, tracer drugs, monoclonal antibodies, brain cancer treatment (I-131 replacement), radiolabeling, tumor imaging, mapping of receptors in the brain, interstitial radiation therapy, brachytherapy for treatment of prostate cancer, determination of glomerular filtration rate (GFR), determination of plasma volume, detection of deep vein thrombosis of the legs	Xe124(n,γ)Xe125/I125
Iodine-131 (I-131)	Lymphoid tissue tumor/hyperthyroidism treatment, antibody labeling, brain biochemistry in mental illness, diagnosis of thyroid disorders by gamma camera imaging or counting, radio-immunotherapy, imaging, cellular dosimetry, adrenal medulla scintigraphy, treatment of Grave's disease, treatment of goiters, treatment of prostate cancer, treatment of hepatocellular carcinoma, treatment of melanoma, locate metastatic lesions, treatment of neuroblastoma and malignant pheochromocytoma, internal (systemic) radiation therapy, treatment of thyroid carcinoma, study of kidney functions, construction of renogram, adrenal cortex imaging, investigations of hepatobillary function, determination of plasma volume	Te130(n,γ)I131
Iridium-192 (Ir-192)	Brachytherapy, brain and spinal cord tumor treatment, restenosis stents, seed implants for breast and prostate tumors	Ir191(n,γ)Ir192
Lutetium-177 (Lu-177)	Heart disease treatment (restenosis therapy), cancer therapy (RIT)	Lu176(n,γ)Lu177
Molybdenum-99 (Mo-99)	Parent for Tc-99m generator used for brain, liver, lungs, heart imaging	Mo98(n,γ)Mo99
Osmium-194 (Os-194)	Monoclonal antibody attachment used for cancer treatment (RIT)	Os192(n,γ)Os193 Os193(n,γ)Os194
Phosphorus-32 (P-32)	Polycythemia rubra vera (blood cell disease) and leukemia treatment, bone disease diagnosis/treatment, SPECT imaging of tumors, pancreatic and liver cancer treatment, radiolabeling, labeling nucleic acids for in vitro research, diagnosis of superficial tumors, cardiovascular disease treatment (restenosis), intracavity therapy	S32(n,p)P32 Or P32(n,γ)P33

Table 1. (Contd)

Medical Isotope	Medical Applications	Reactions
Phosphorus-33 (P-33)	Leukemia treatment, bone disease diagnosis/treatment, SPECT imaging of tumors, radiolabeling, restenosis treatment	S33(n,p)P33
Palladium-103 (Pd-103)	Prostate cancer treatment	Pd102 (n,γ)Pd103
Platinum-195m (Pt-195m)	Noninvasive monitoring of drug biodistribution and metabolism, studies with intra-arterial Pt-195m-cisplatin	Pt195(n,n')Pt195m Or Pt194(n,γ)Pt195m
Rhenium-186 (Re-186)	Cancer treatment/diagnostics, monoclonal antibodies, bone cancer pain relief, treatment of rheumatoid arthritis, treatment of prostate cancer, bone cancer pain relief	Re185(n,γ)Re186
Scandium-47 (Sc-47)	Bone cancer pain relief, radioimmunotherapy (RIT)	Ti47(n,p)Sc47
Selenium-75 (Se-75)	Radiotracer used in brain studies, imaging of adrenal cortex by gamma-scintigraphy, lateral locations of steroid secreting tumors, pancreatic scanning, detection of hyperactive parathyroid glands, measure rate of bile acid loss from the endogenous pool	Se74(n,γ)Se75
Samarium-145 (Sm-145)	Treatment of ocular cancer	Sm144(n,γ)Sm145
Samarium-153 (Sm-153)	Cancer treatment/diagnostics, bone cancer pain relief, treatment of leukemia	Sm152(n,γ)Sm153
Strontium-85 (Sr-85)	Detection of bone lesions, brain scans	Sr84(n,γ)Sr85
Strontium-89 (Sr-89)	Bone cancer pain relief, treatment of prostate cancer, treatment of multiple myeloma, osteoblastic therapy, potential agent for treatment of bone metastases from prostate and breast cancer	Sr88(n,γ)Sr89 Or Y89(n,p)Sr89
Thorium-228 (Th-228)	Cancer treatment (RIT), monoclonal antibodies, parent of Bi-212	Ra226(n,γ)Ra227/Ac227 Ac227(n,γ)Ac228/Th228
Thorium-229 (Th-229)	Grandparent of Bi-213 (alpha emitter used in cancer treatment (RIT)), parent of Ac-225	Ra226(n,γ)Ra227/Ac227 Ac227(n,γ)Ac228/Th228 Th228(n,γ)Th229
Tin-117m (Sn-117m)	Bone cancer pain relief	Sn117(n,n')Sn117m Or Sn116(n,γ)Sn117m
Tungsten-188 (W-188)	Cancer treatment (RIT), parent for Re-188 generator	W186(n,γ)W187 W187(n,γ)W188
Xenon-127 (Xe-127)	Neuroimaging for brain disorders, research on variety of neuropsychiatric disorders (especially schizophrenia and dementia), higher resolution SPECT studies with lower patient dose, lung imaging evaluation of pulmonary ventilation, indicator for measurement of local cerebral blood flow	Xe126(n,γ)Xe127
Yttrium-91 (Y-91)	Cancer treatment (RIT), cellular dosimetry	Zr91(n,p)Y91

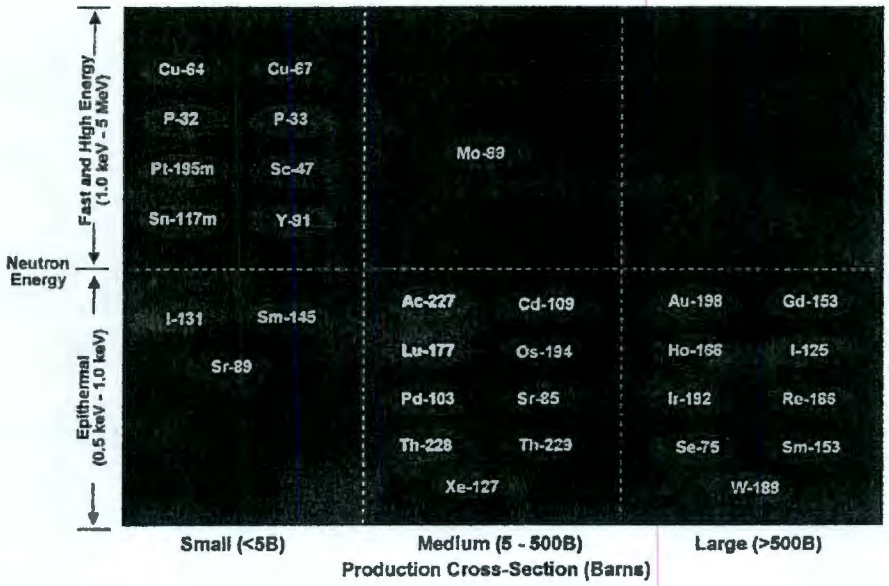

Figure 4. Neutron Energy Requirements for Optimum Production of Reactor-Generated Medical Isotopes

Further evidence for the advantages of using a reactor such as FFTF to produce these 30 medical isotopes is provided by a calculation of the ratio of the resonance integral to the thermal cross-section for isotope production. These calculations are presented in Table 2, from which it is apparent that the majority of isotopes listed in Table 1 have a ratio of the resonance integral to the thermal cross-section that is significantly greater than one. Under this condition, the high fluxes of fast and epithermal neutrons provided by FFTF offer distinct production advantages.

For the 30 isotopes listed in Table 1, extensive calculations have been made of the rate of production that can be achieved in FFTF operating at power levels up to 400 MW. These calculations have been made using neutron flux data obtained by an MCNP computer code.[4] The calculations involve combining neutron flux data with cross-section data obtained primarily from the BNL-325 data source[5] and the ENDF/B cross-section data files.[6]

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[4] Briesmeister, J.F., "Monte Carlo Neutron Particle Code (MCNP): A General Monte Carlo N-Particle Transport Code, Version 4A," Los Alamos National Laboratory report (November 1993).

[5] Mughabghab, S.F., "Neutron Cross Sections Volume 1: Neutron Resonance Parameters and Thermal Cross Sections," Academic Press, New York (1984).

[6] McLane, V. et al., "ENDF-201 ENDF/B-VI Summary Documentation Supplement I; ENDF/HE-VI Summary Documentation," Brookhaven National Laboratory Rep. No. BNL-NCS-177541 (1996).

Table 2. FFTF Production Advantages for Medical Isotopes

Isotope	Target Material	(I_γ / σ_t)[a]	Cross-Section[b]	Optimum Neutron Energy[c]
Ac-227	Ra-226	21.5	M	E
Au-198	Au-197	15.7	L	E
Cd-109	Cd-108	15.0	M	E
Cu-64	Zn-64	N/A	S	H
Cu-67	Zn-67	N/A	S	H
Gd-153	Natural Eu	0.9	L	E
Ho-166	Ho-165	11.1	L	E
I-125	Xe-124	2.5	L	E
I-131	Te-130	2.5	S	E
Ir-192	Ir-191	5.5	L	E
Lu-177	Lu-175	34.0	M	E
Mo-99	Mo-98	50.0	M	F
Os-194	Os-192	2.5	M	E
P-32	S-32	N/A	S	H
P-33	S-33	N/A	S	H
Pd-103	Pd-102	3.3	M	E
Pt-195m	Pt-195	N/A	S	F
Re-186	Re-185	15.2	L	E
Sc-47	Ti-47	N/A	S	H
Se-75	Se-74	12.5	L	E
Sm-145	Sm-144	1.5	S	E
Sm-153	Sm-152	14.4	L	E
Sn-117m	Sn-117	N/A	S	F
Sr-85	Sr-84	13.8	M	E
Sr-89	Sr-88	10.3	S	E
Th-228	Ra-226	21.5	M	E
Th-229	Ra-226	21.5	M	E
W-188	W-186	12.9	L	E
Xe-127	Xe-126	17.1	M	E
Y-91	Zr-91	N/A	S	H

(a) Ratio of resonance integral (I_γ) to thermal cross-section (σ_t). A ratio >1 indicates production advantages at neutron energies above thermal. Ratios marked N/A are associated with reactions involving fast/high energy neutrons that do not occur with thermal neutrons.

(b) Cross-sections (resonance integrals) characterized as S (small, <5 barns), M (medium, 5 – 500 barns), and L (large, >500 barns).

(c) Neutron energies represented as T (thermal, <0.5 eV), E (epithermal, 0.5 eV – 1 keV), F (fast, 1 keV – 1 MeV), and H (high-energy, >1 MeV).

For purposes of calculating the FFTF production rates of the 30 isotopes listed in Table 1, a representative core map for FFTF operations in a future multiprogram mission has been developed. The important features of this core configuration for medical isotope production are:

- One assembly located in Row 4 and two assemblies in Row 6 are available for production of short-lived isotopes ($t_{1/2} \leq 2$ weeks) that require the removal of targets using a rapid radioisotope retrieval (R3) system while the reactor is at full power.

- A continuous-flow gas line is available in Row 2 for the production of products such as iodine-125 (from a xenon-124 gas target).

- A total of 3 to 12 positions for the production of longer-lived isotope products are available in Row 6 of the core region; these products would be produced using a long-term irradiation vehicle (LIV) for the targets, which would be removed only at the end of an operating cycle when the reactor power is reduced for scheduled maintenance procedures. A preliminary analysis indicated that at least 9, and possibly 12, LIVs in Row 6 could be used for medical isotope production without significantly impacting other FFTF irradiation services.

In the current model of the FFTF core configuration, 48 LIV assemblies in Row 9 (the outermost row of the reflector region) can be dedicated to the production of cobalt-60 for sale to companies that manufacture sterilization equipment and medical teletherapy units. Based on the calculated cobalt-60 production yield for three 100-day FFTF operating cycles, ~ 4 million curies of this isotope can be produced annually.

Although the FFTF has a rated power of 400 MW, initial operations in the proposed future multiprogram mission will be conducted at a power level of 100 MW. This choice of power level will permit the use of existing reactor fuel supplies for at least five years, and will extend the reactor's lifetime well beyond the current estimate of 22 years for operation at a 400-MW power level. Accordingly, estimates of medical isotope production rates presented in this report are for FFTF operations at 100 MW.

Table 3 presents a summary of the calculated rates of production in FFTF of the 30 medical isotopes listed in Table 1. These calculations were made for irradiation cycles ranging from 10 days for the shortest lived isotope species to 100 days for the longer-lived isotopes. It is assumed that the typical FFTF operating cycle between scheduled maintenance procedures will be approximately 100 days. The target masses shown in Table 3 were selected on the basis of available volume in the R3 irradiation vehicles used for short-lived isotope products, and also on the basis of the availability and cost of enriched target materials. In nearly all of the target materials the burnout rate calculated for typical irradiation cycles is small, thereby permitting reuse of the residual target materials following radiochemical separation of the product isotopes. The calculations presented in Table 3 also take into account the use of hydrided assemblies to provide neutron energy moderation for optimizing the production of isotopes that have large cross-sections in the epithermal range. In addition, target self-shielding effects were calculated and have been taken into account in the isotope production rates presented in Table 3.

Table 3. Production Rates at 100 MW of 30 FFTF Medical Isotopes

	Product Isotope	Half Life	Primary Target Isotope	Target Vehicle[a]	Irradiation Time (days)	Primary Target Isotope Mass (g)	Product Isotope Specific Activity (Ci/g)	Product Isotope Activity Produced (Ci)[b]
1	Ac-227	21.8 years	Ra-226	LIV-H	100	3.3E+01	7.2E+01	3.4E+01
2	Au-198	2.69 days	Au-197	R3-H	10	1.4E-01	1.3E+03	7.9E+01
3	Cd-109	462.0 days	Cd-108	LIV-H	100	1.0E+03	2.1E+00	6.5E+02
4	Cu-64	12.7 hours	Zn-64	R3	10	1.1E+01	3.8E+06	9.6E+01
5	Cu-67	2.58 days	Zn-67	R3	10	9.3E+01	7.5E+05	3.7E+00
6	Gd-153	242 days	Natural Eu	LIV-H	100	1.7E+03	3.4E+01	1.1E+03
7	Ho-166	1.12 days	Ho-165	R3-H	10	1.3E-01	3.1E+02	1.7E+01
8	I-125	60.1 days	Xe-124	Gas Line	100	4.3E+00	1.7E+04	2.4E+03
9	I-131	8.04 days	Te-130	R3-H	25	1.4E+02	5.5E+04	2.6E+02
10	Ir-192	73.8 days	Ir-191	LIV	100	1.5E+04	1.4E+02	3.5E+03
11	Lu-177	6.68 days	Lu-175	R3-H	25	2.7E-03	2.8E+03	4.0E-01
12	Mo-99	2.75 days	Mo-98	R3-H	10	2.1E+01	5.5E+01	1.0E+03
13	Os-194	6.0 years	Os-192	LIV	100	2.3E+05	5.6E-05	2.2E+00
14	P-32	14.3 days	S-32	R3	25	2.0E+01	2.8E+05	3.5E+01
15	P-33	25.3 days	S-33	LIV	100	7.1E+00	1.5E+05	6.5E+01
16	Pd-103	17.0 days	Pd-102	R3-H	25	5.4E+01	1.5E+03	1.2E+03
17	Pt-195m	4.02 days	Pt-195	R3-H	25	5.0E+01	5.6E+01	1.2E+02
18	Re-186	3.78 days	Re-185	R3-H	25	1.5E+01	4.5E+01	3.0E+03
19	Sc-47	3.35 days	Ti-47	R3	10	7.2E+01	8.2E+05	1.8E+01
20	Se-75	120.0 days	Se-74	LIV-H	100	3.0E-01	5.9E+02	1.7E+01
21	Sm-145	340 days	Sm-144	LIV-H	100	1.1E+01	9.4E+00	1.1E+01
22	Sm-153	1.93 days	Sm-152	R3-H	10	8.3E-03	4.6E+02	3.5E+01
23	Sn-117m	13.6 days	Sn-116	R3-H	25	2.7E+00	3.6E+01	4.4E+01
24	Sr-85	64.8 days	Sr-84	LIV-H	100	3.4E+03	1.2E+02	2.0E+03
25	Sr-89	50.5 days	Sr-88	LIV-H	100	2.5E+02	7.2E-01	1.4E+02
26	Th-228	1.91 years	Ra-226	LIV-H	100	3.3E+01	6.4E+02	1.4E+02
27	Th-229	7300 years	Ra-226	LIV-H	100	3.3E+01	4.8E-02	2.7E-02
28	W-188	69.4 days	W-186	LIV-H	100	3.0E+04	1.1E+00	5.5E+03
29	Xe-127	36.4 days	Xe-126	LIV	100	1.2E+00	3.4E+02	6.5E+01
30	Y-91	58.5 days	Zr-91	LIV	100	9.5E+03	2.5E+04	1.7E+01

(a) Abbreviations are LIV: Long Irradiation Vehicle (10,000 cc total target volume per assembly); LIV-H: Hydrided LIV; R3: Rapid Radioisotope Retrieval System (24 cc target volume); R3-H: Hydrided R3; Gas Line: Target volume is 5000 cc.

(b) Product yields are given per assembly per operating cycle. Target masses per assembly are based on available target volume, allowing for volume fraction occupied by yttrium hydride pins, and on expected availability of target isotopes at high enrichment.

Using the data from Table 3, an estimate has also been made of the extent to which FFTF could meet the projected market demand in year 2005 for several therapeutic medical isotopes. For this purpose, a patient population database provided by the Frost and Sullivan market analysis company (Mountain View, CA) was used. This database provides information on the number of patients in the U.S. that will be treated for 26 classes of disease over the coming two decades, and makes conservative estimates of the fraction of patients that would receive radioisotope therapy. Using information from ongoing clinical trials and consultation with nuclear medicine specialists, estimates were made of the number of curies quantities of 17 medical isotopes that would be required to treat the patient population that is expected to receive radioisotope therapy.

Table 4 summarizes the projected U.S. demand in year 2005 for 17 therapeutic isotopes, and the FFTF's annual production capability for these isotopes when operating at a power level of 100 MW. The year 2005 was selected for this comparison because it represents the first full year that FFTF would return to full-scale operations under the current planning schedule. The estimate of the medical isotopes market in year 2005 is also expected to be more reliable than a longer-range projection.

Table 4. FFTF Medical Isotope Production versus U.S. Demand

Isotope	Half-Life	Target Vehicle[a]	Irradiation Time (days)	Cycles per Year	Projected U.S. Demand in 2005[b] (Ci)	FFTF Yearly Production Per Assembly (Ci)[c]	No. Assemblies to Meet Total U.S. Demand[d]
Ac-227[e]	21.8 years	LIV-H	100	3	2.9E+01	1.0E+02	0.3
Cu-64	12.7 hours	R3	10	25	4.0E+00	2.4E+02	0.02
Cu-67	2.58 days	R3	10	25	2.6E+02	9.3E+01	2.8
Ho-166	1.12 days	R3-H	10	25	5.6E+02	4.3E+02	1.3
I-125	60.1 days	Gas Line	100	3	6.5E+02	7.2E+03	0.09
I-131	8.04 days	R3-H	25	10	1.4E+04	2.6E+03	5.4
Ir-192	73.8 days	LIV	100	3	2.5E+03	1.0E+04	0.25
Lu-177	6.68 days	R3-H	25	10	5.0E+00	4.0E+00	1.2
P-32	14.3 days	R3	25	10	3.8E+01	3.5E+02	0.09
Pd-103	17.0 days	R3-H	25	10	2.5E+03	1.2E+04	0.2
Re-186	3.78 days	R3-H	25	10	7.3E+02	3.0E+04	0.02
Sc-47	3.35 days	R3	10	25	4.7E+02	4.5E+02	1.0
Sm-153	1.93 days	R3-H	10	25	1.3E+03	8.8E+02	1.5
Sn-117m	13.6 days	R3-H	25	10	4.7E+01	4.4E+02	0.1
Sr-89	50.5 days	LIV-H	100	3	6.3E+01	4.2E+02	0.15
Th-229[e]	7300 years	LIV-H	100	3	8.4E-01	8.1E-02	10.4
W-188[e]	69.4 days	LIV-H	100	3	1.5E+02	1.6E+04	0.01

(a) Abbreviations are LIV: Long Irradiation Vehicle (10,000 cc total target volume per assembly); LIV-H: Hydrided LIV; R3: Rapid Radioisotope Retrieval System (24 cc target volume); R3-H: Hydrided R3; Gas Line: Target volume is 5000 cc.

(b) Based on projected patient populations treated with isotopes for 26 classes of disease (Frost and Sullivan medical isotope market survey, 1997).

(c) Based on isotope production rates shown in Table 3 and the number of operating cycles per year shown in this table.

(d) FFTF will have up to 3 core positions for the production of short-lived isotopes in R3 assemblies and up to 12 core positions for producing longer-lived isotopes in LIV assemblies; there will be one gas line.

(e) Ac-227, Th-229, and W-188 are the generators for the short-lived medical isotopes Ra-223, Ac-225/Bi-213, and Re-188, respectively.

From the information presented in Table 4, it is clear that FFTF can supply all, or a large fraction of, the projected U.S. requirement for these 17 therapeutic isotopes in the year 2005. This conclusion is based on the favorable comparison shown in Table 4 between the projected market demand and the production capacity of FFTF. Even for those isotope products that will require more than one core assembly to meet the production demand, a sufficient number of R3 and LIV target assemblies can be deployed to increase the FFTF's production capacity up to a level that meets the projected demand.

A comparison has also been made of the isotope production capacity of FFTF relative to the High Flux Isotope Reactor (HFIR) at the Oak Ridge National Laboratory, which is currently a major source of medical isotopes produced under the DOE/NE-70 program. This comparison was made on the basis of two key factors: (1) the curies of a product isotope that can be produced per gram of target material in a typical irradiation cycle, and (2) the target volume available in the reactor's core region. These factors

Table 5. Comparison of Medical Isotope Production by FFTF and HFIR[a]

Isotope	Target Material	Ci Product/g Target[b]		Production Ratio	Target Volume[c] (cm^3)		Volume Ratio	FFTF Advantage
		FFTF	HFIR	(FFTF/HFIR)	FFTF	HFIR	(FFTF/HFIR)	(Prod. Ratio x Vol. Ratio)
Ac-227	Ra-226	2.53E+00	1.52E+00	1.7	38500	464	83.0	140
Cd-109	Cd-108	6.19E+00	5.34E+00	1.2	77100	464	166.2	190
Cu-64	Zn-64	1.56E+00	1.18E+00	1.3	72	12.9	5.6	9.5
Cu-67	Zn-67	6.79E-02	4.90E-02	1.4	72	12.9	5.6	7.8
Ho-166	Ho-165	1.59E+03	1.25E+03	1.3	72	12.9	5.6	7.3
I-131	Te-130	6.61E+00	3.59E+01	0.2	72	12.9	5.6	1.1
Ir-192	Ir-191	1.26E+02	5.23E+01	2.4	77100	464	166.2	400
Mo-99	Mo-98	7.88E+01	2.74E+01	2.9	72	12.9	5.6	16.2
Os-194	Os-192	6.80E+00	8.00E+00	0.9	77100	464	166.2	140
P-32	S-32	5.90E+00	4.28E+00	1.4	72	12.9	5.6	7.8
P-33	S-33	1.84E+01	4.93E+01	0.4	77100	464	166.2	62
Pd-103	Pd-102	1.12E+02	2.95E+02	0.4	72	12.9	5.6	2.2
Pt-195m	Pt-195	5.77E+00	4.08E+00	1.4	72	12.9	5.6	7.8
Re-186	Re-185	3.51E+03	7.83E+03	0.4	72	12.9	5.6	2.2
Sc-47	Ti-47	1.66E+00	1.09E+00	1.5	72	12.9	5.6	8.4
Se-75	Se-74	1.43E+03	6.08E+03	0.2	38500	464	83.0	20
Sm-145	Sm-144	2.00E+01	1.00E+01	2.0	38500	464	83.0	170
Sm-153	Sm-152	7.33E+03	1.91E+03	3.8	72	12.9	5.6	21
Sr-89	Sr-88	6.34E-01	1.76E+00	0.4	38500	464	83.0	30
Th-228	Ra-226	1.30E+02	9.11E+01	1.4	38500	464	83.0	120
Th-229	Ra-226	3.70E-02	2.00E-02	1.9	38500	464	83.0	150
W-188	W-186	5.95E+00	4.99E+01	0.1	38500	464	83.0	9.9
Xe-127	Xe-126	2.95E+02	6.88E+02	0.4	77100	464	166.2	71

(a) HFIR is the High Flux Isotope Reactor located at the Oak Ridge National Laboratory in Oak Ridge, Tennessee.
(b) For consistency with data available for HFIR, the isotope production calculations shown in this table are based on peak fluxes rather than volume-average fluxes, and do not include self-shielding corrections. In contrast, the information contained in Tables 3 and 4 is based on calculations that used volume-averaged fluxes in the target assemblies and included self-shielding corrections.
(c) Target volumes for the FFTF are based on the use of 3 R3 and 9 LIV assemblies for medical isotope production.

were calculated for isotope targets placed in the high-flux region of the HFIR reactor (the "flux trap"), and for isotope production assemblies placed in Rows 4 and 6 of the FFTF's core region. As shown by the calculations presented in Table 5 for 23 medical isotopes, the rate of production per gram of target material is similar in HFIR and FFTF for many of the product isotopes. However, the large core volume of the FFTF compared to the HFIR flux trap provides a distinct overall production advantage for FFTF over HFIR for all of the 23 isotopes that were analyzed.

2.4 Organizational Structure of the Radioisotopes Production Program

2.4.1 Pacific Northwest National Laboratory's Radiochemical Processing Group

Radiochemical research and development at PNNL are conducted by members of the Radiochemical Processing Group (RPG), which consists of 75 technical and administrative staff located in a 144,000 ft^2 Category II nuclear facility — the Radiochemical Processing Laboratory (described in Section 2.5.1 of this report). The RPG, headed by Dr. John LaFemina, is administratively located within the Environmental Technology Division (ETD), one of the four major research divisions at PNNL. The organizational structure of the ETD and the RPG are illustrated in Figure 5.

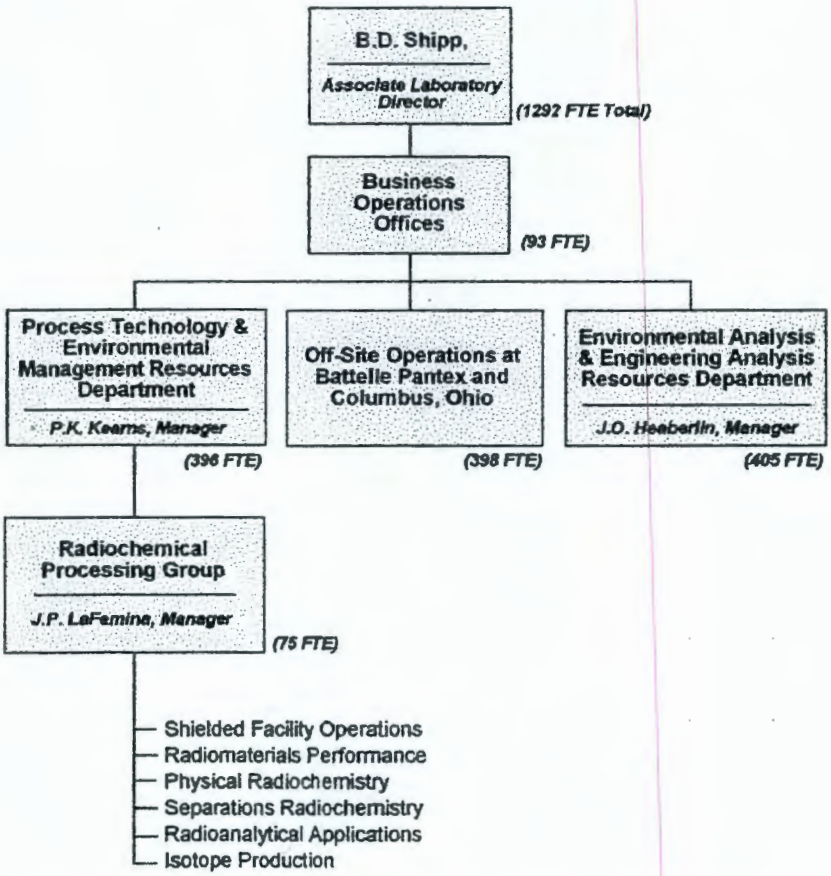

Figure 5. Organizational Chart for the PNNL Environmental Technology Division

The primary missions of the RPG are to create and implement innovative processes for environmental cleanup and the beneficial use of radioactive materials. Primary areas of research include (1) the development of technologies for the cleanup of hazardous radiological wastes, (2) the processing and disposal of nuclear fuels, and (3) the production of medical isotopes. The total business volume of the RPG in FY 1999 is projected to be $38M, the majority of which is based on DOE funding from the Office of Environmental Management, Defense Programs, the Office of Civilian Radioactive Waste Management, and the Office of Nuclear Energy, Science and Technology.

The RPG's staff is divided into six teams that represent the main technical capabilities of this organizational unit: (1) shielded facility operations for work with high levels of radioactive materials, (2) radiomaterials performance, (3) physical radiochemistry, (4) separations radiochemistry, (5) radioanalytical applications, and (6) isotope production.

2.4.2 Fast Flux Test Facility

The current organizational structure of the FFTF is shown in Figure 6. As discussed in Section 2.1 of this report, the reactor is currently in a standby mode of operation. Approximately 250 technical and administrative staff are involved in maintaining all of the essential operating systems and support services in a functional condition, including the reactor's liquid sodium heat transport system. The operating budget for the FFTF in FY 1999 is $40M.

Plans are being developed for the FFTF's operational and organizational structures if DOE makes a decision to restart the reactor for a future nuclear science and irradiation services mission. For operations at a 100-MW power level, a total support staff of 410 FTE is expected to be required. The annual baseline operating budget under this condition will be $55M during the first year of full-scale reactor operations in FY 2005.

As part of the 90-day FFTF scoping study that is currently in progress, a business model is being developed that will incorporate the organizational and fiscal requirements for support of the wide range of products and services to be offered by the reactor. An emphasis is being placed on the development of productive partnerships between the federal government and private sector organizations that will benefit from the reactor's capabilities.

2.4.3 Isotope Program Management

As described in Section 2.4.1, the isotopes program at PNNL is located organizationally within the RPG. The Manager of the DOE-sponsored Hanford Radioisotopes Program, Dr. Thomas Tenforde, also functions as the lead scientist for the RPG's 12-member Isotope Production Team. In that capacity he has line management responsibilities for the staff and facilities involved in the radiochemical processing of isotopes for commercial and medical applications. These staff, together with a matrixed team of nuclear physicists, engineers, radiochemists, and nuclear safety specialists from PNNL and other Hanford

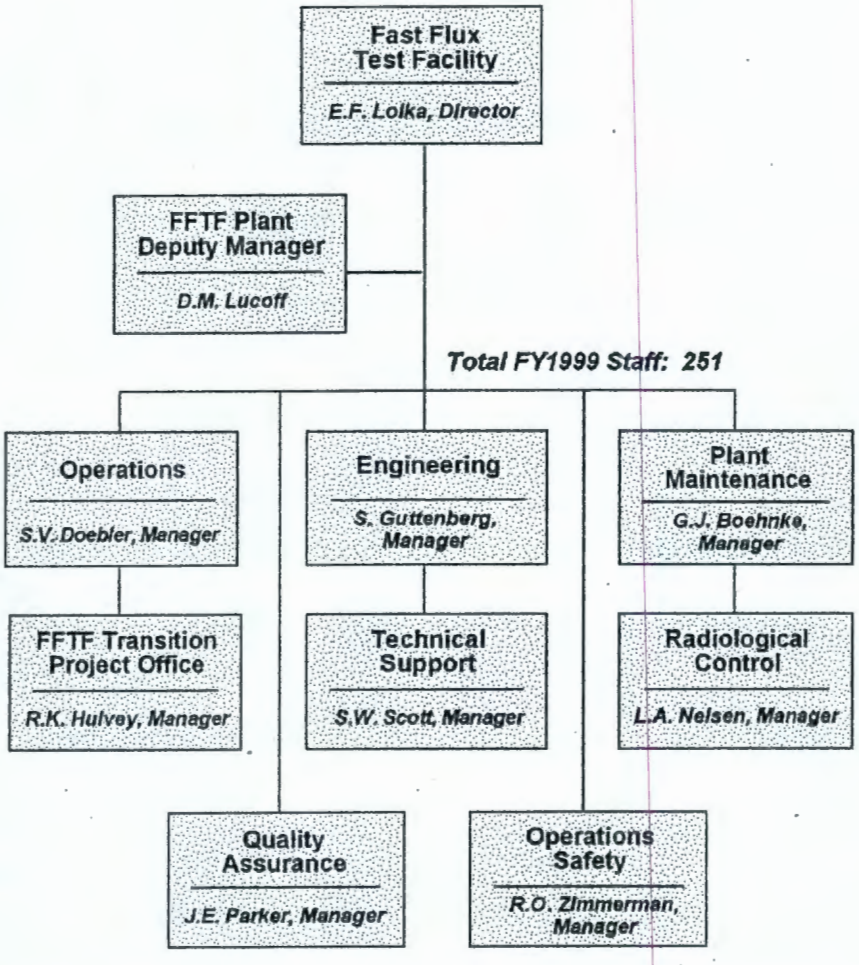

Figure 6. Organizational Chart for the Fast Flux Test Facility

contractor organizations, have functioned since 1997 as a support group for planning the proposed future FFTF isotope production mission. In all of these activities, excellent communication channels have been maintained between members of the isotopes program and key staff in the DOE Richland Operations Office.

2.5 Isotope Production Facilities

2.5.1 Radiochemical Processing Laboratory

The Radiochemical Processing Laboratory (RPL), which houses the research and development activities of the RPG (discussed in Section 2.3.1), is located in the 300 Area of the Hanford Site and is designated as Building 325. The RPL contains laboratories and specialized facilities designed for work with nonradioactive materials, microgram-to-kilogram quantities of fissionable materials, and up to megacurie quantities of other radionuclides. The RPL was built in 1953 and consists of a central area that

contains general purpose laboratories designed for low-level radioactive work, a front wing that contains office space and shops, and two annexes that provide shielded enclosures with remote manipulators for high-level radiochemical work.

The total space within the RPL is 143,700 ft^2, of which 44,500 ft^2 is occupied by general chemistry laboratories. Figures 7 and 8 show the floor plans for the first floor and the basement of the RPL. These figures have been color-coded to show the results of a recent survey of space utilization in the RPL, which indicated that 6,950 ft^2 (15.6%) is presently unoccupied. All of the occupied, and nearly all of the unoccupied, laboratories are functional and fully equipped with standard utilities. Several of the laboratories, especially those used for radioanalytical work, have been renovated during the past few years. The upgrading and modernization of equipment within the chemistry laboratories has been given a high priority during the past two years.

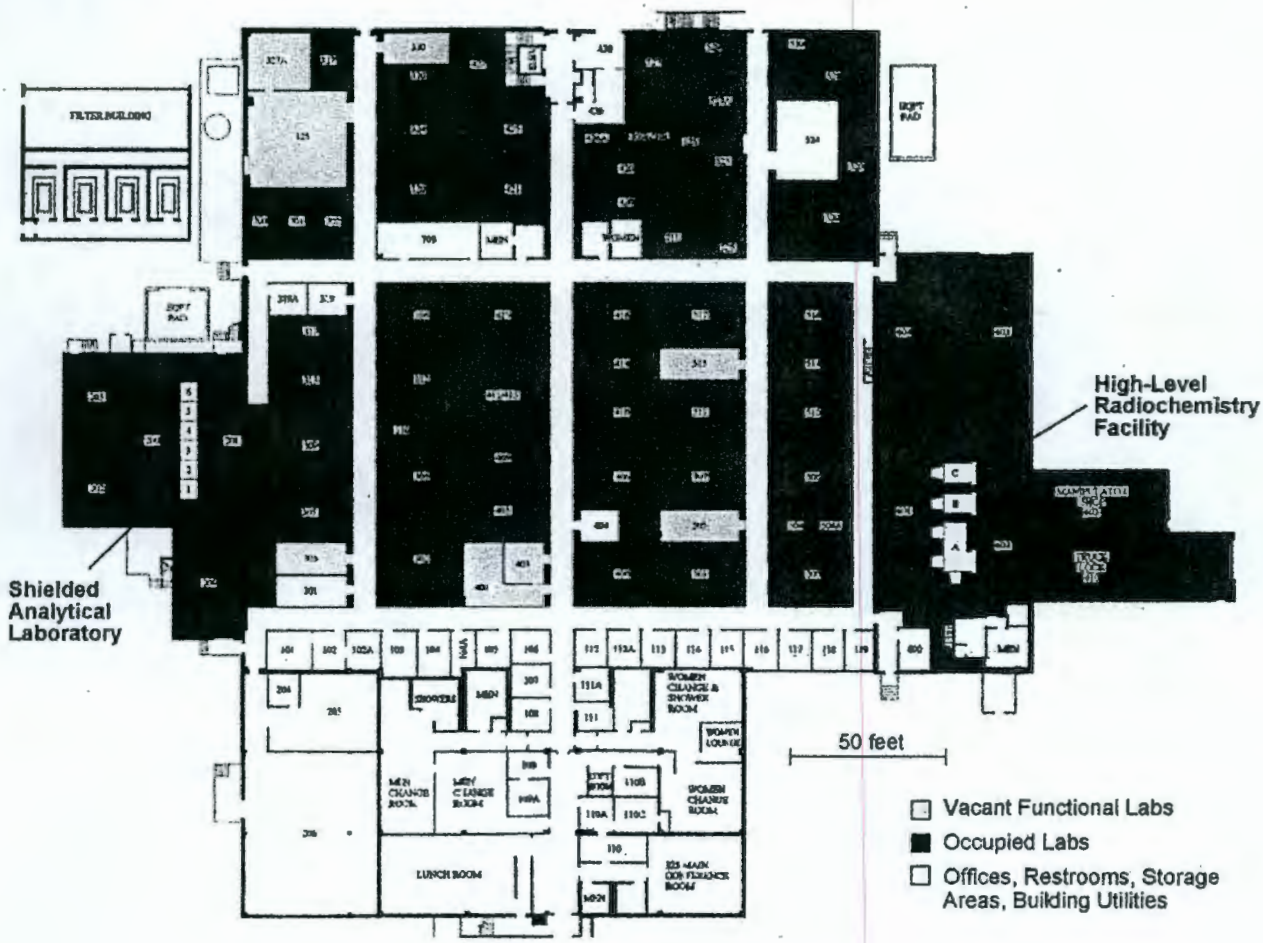

Figure 7. Map of the First Floor of the Radiochemical Processing Laboratory, Showing Occupied and Vacant Chemistry Laboratories

During the space utilization survey at the RPL, an assessment was made of the number of fume hoods and shielded glove boxes (including several small hot cells) that are available in the chemistry laboratories for additional programmatic work. Of the 79 functional fume hoods and 23 shielded glove boxes, 50 and 15, respectively, are available for additional work.

A special feature of the RPL is the existence of two heavily shielded facilities located in annexes on the East and West sides of the building (see Figure 7). These shielded facilities are the High-Level Radiochemistry Facility (HLRF) and the Shielded Analytical Laboratory (SAL). These two hot cell complexes, which are heavily utilized at the present time, provide capabilities for conducting bench-scale to pilot-scale work with a wide variety of highly radioactive materials. Capabilities include those required to conduct radiochemical separation and purification procedures, irradiated fuel or target

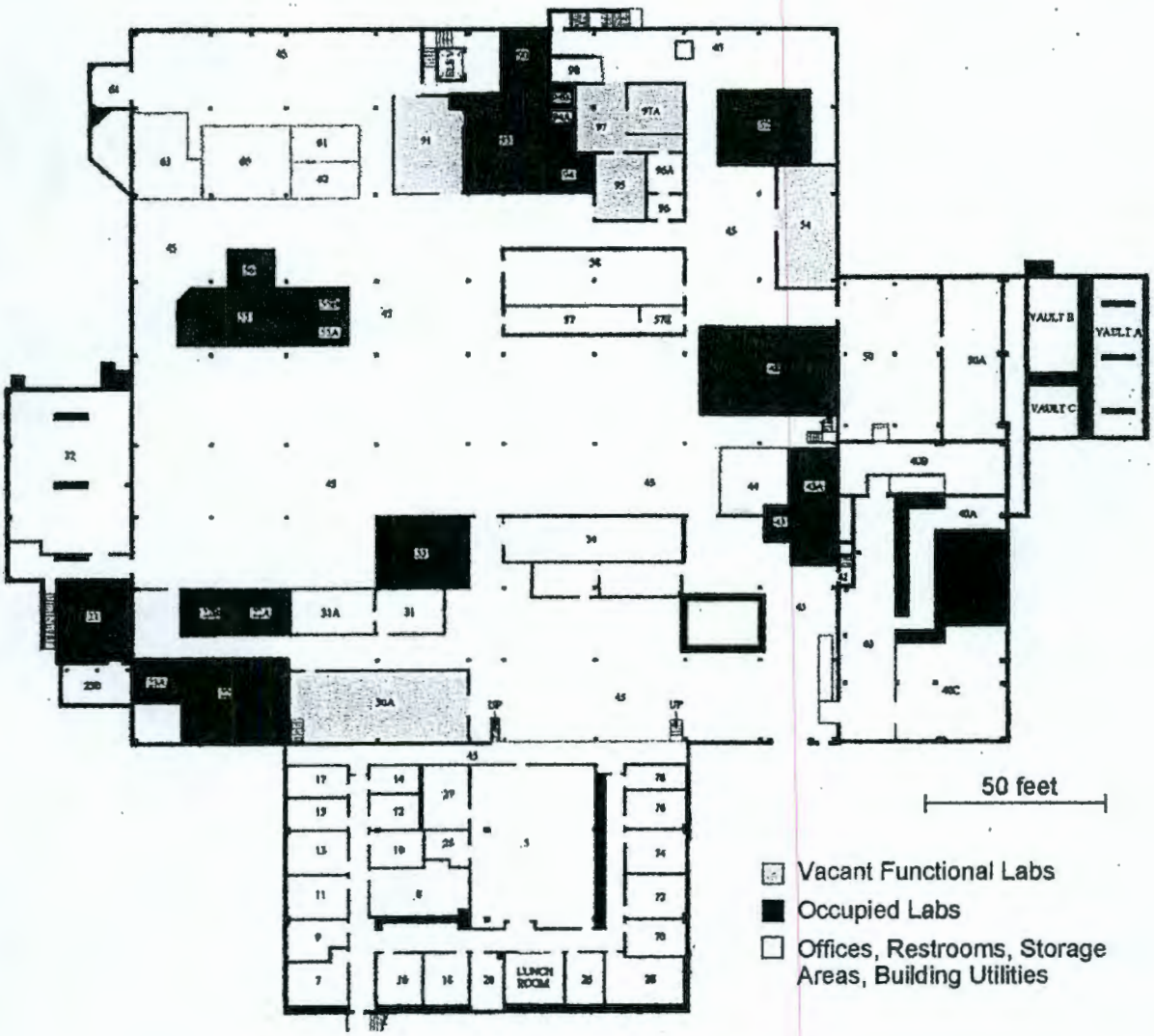

Figure 8. Map of the Basement of the Radiochemical Processing Laboratory, Showing Occupied and Vacant Chemistry Laboratories

sectioning and processing, metallography, physical properties testing of activated metals, thermal processing (including waste vitrification), and radioanalytical and preparatory chemistry operations.

The HLRF contains three large, interconnected hot cells designated as A-Cell, B-Cell, and C-Cell. The three cells are each 15 ft high and 7 ft deep; the A-Cell is 15 ft wide and the B-Cell and C-Cell are each 6 ft wide. In-cell operations are performed using medium-duty electromechanical manipulators, with viewing of the work through leaded-glass, oil-filled windows. Closed-circuit television cameras and VCRs have been installed for detailed inspection work within the hot cells. The A-Cell and C-Cell also have overhead bridges that contain hoists with a 2200-kg capacity. The hot cells are fully equipped with utilities, and have shielded service penetrations at the front wall for insertion of special instrumentation. Each hot cell contains several process vessels, which are located below the work deck and range in capacity from 4 to 320 liters. Access to each hot cell in the HLRF is provided by a large shielded door and a shielded double-door transfer port located in the rear wall of the cell. Cask payloads weighing up to 2200 kg can be transferred into and out of the hot cells using a bridge crane located in the canyon behind the cells.

The SAL contains six interconnecting hot cells, each of which is 5.5 ft wide, 5.5 ft deep, and 9.5 ft high. Each hot cell is equipped with a pair of medium-duty manipulators. Turntables built into the rear walls of the hot cells provide rapid transfers of radioactive samples into and out of the cells. The SAL hot cells are equipped to perform a wide variety of analytical chemistry operations with highly radioactive samples.

As part of the planning activities for a future radioisotope production mission at FFTF, an engineering assessment was made of the capabilities of the RPL to support the radiochemical processing requirements for a wide variety of irradiated target materials. Figures 9 and 10 illustrate a preliminary design of the RPL facilities modifications that could be made to accommodate the preparation and processing of targets and isotope products following irradiation at FFTF and transport in shielded casks to the RPL. Transport would take place over a distance of ~10 miles on a four-lane highway within the Hanford Site.

The general features and functions of the RPL laboratories that would be used for processing targets irradiated at FFTF have been described in a PNNL report.[7] In brief, some of the primary features of the these laboratories would be as follows:

1. A cluster of 10 laboratories would be available on the first floor of the RPL; each laboratory would contain a small hot cell, a shielded glove box, and a fume hood with interconnecting transfer ports.

2. A transfer port for receipt of casks containing irradiated targets into the A-Cell of the HLRF would be installed, and provision would be made in the C-cell for initial processing of highly radioactive targets (e.g., irradiated europium targets containing gadolinium-153 product).

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[7] "Medical Isotope Production at the Fast Flux Test Facility: A Technical and Economic Assessment." Pacific Northwest National Laboratory Rep. No. PNNL-SA-29592, Richland, Washington (1997).

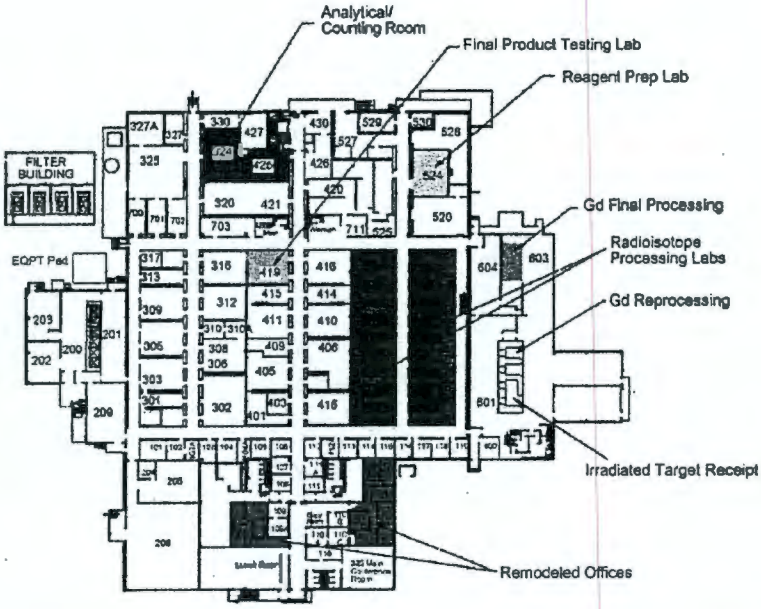

Figure 9. Proposed Locations on the First Floor of the Radiochemical Processing Laboratory for Hot Cell Operations and Radiochemical and Radioanalytical Laboratories to Be Used for FFTF Target Processing

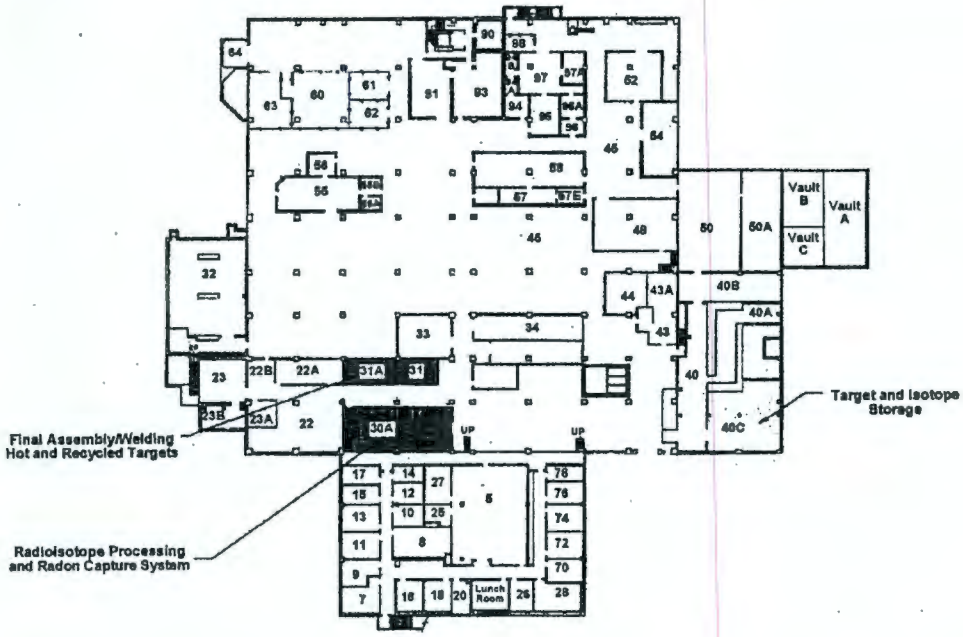

Figure 10. Proposed Locations in the Basement of the Radiochemical Processing Laboratory for Assembly, Processing, and Storage of FFTF Targets; Also Shown is the Laboratory with a Radon Gas Capture System That Will Be Used for Processing Radium-226 Targets

3. Target preparation and storage areas would be provided in the basement of the RPL, in close proximity to facilities for the assembly and welding of radioactive and recycled targets.

4. A 1500-ft^2 laboratory equipped with a radon gas capture system would be available in the RPL basement for the processing of radium-226 targets and the product isotopes generated by irradiation of these targets at FFTF (all of which generate radon gas as intermediate products in their decay chains).

2.5.2 FFTF

The FFTF consists of the reactor and several support buildings and equipment arranged around the central reactor containment building, as shown in Figures 11 and 12. The reactor is located in a shielded cell at the center of the containment building. Heat is removed from the reactor by liquid sodium that is circulated through three primary loops, which include the pumps, piping, and intermediate heat exchangers. As illustrated in Figure 13, the primary loops are connected to secondary loops consisting of pumps, piping, flow meters, and heat exchangers. At full-power operation, the reactor inlet temperature of the sodium is 360 ^{0}C and the outlet temperature is 527 ^{0}C. During a total loss of power, the FFTF is designed to shut down automatically and the reactor will continue to be cooled by natural circulation of the sodium. An emergency power source consisting of batteries will provide essential plant monitoring capabilities in the event of a shut down. The reactor also has safety features that can maintain cooling if a leak occurs in the liquid sodium heat transport system. These safety features involve the use of elevated piping and guard vessels around all of the major components of the reactor core.

Figure 14 is a cutaway view of the reactor containment building, showing the locations of the primary pumps and intermediate heat exchangers. Secondary sodium loops transport the reactor heat from the intermediate heat exchangers to the air-cooled tubes of the dump heat exchangers located outside of the reactor containment building.

Another major system located in the reactor containment building is the Closed Loop Ex-Vessel Handling Machine (CLEM) that is used to install fuel and target assemblies in the reactor and to remove them at the end of the irradiation cycle. Figure 15 is a photograph of the CLEM system.

After completion of an irradiation cycle, an irradiated assembly is transferred by CLEM from the reactor to the Interim Examination and Maintenance (IEM) Cell. In the IEM Cell, which is shown in Figure 16, the irradiated assembly is washed and dried to remove residual sodium prior to disassembly. Following this procedure, irradiated target pins are removed from the assembly using the IEM Cell's manipulators, and are then loaded into pin containers for removal from the IEM Cell. The pin container is then transferred to an intermediate holding cell using CLEM. A bottom-loading transfer cask, shown in Figure 14, is then used to transfer the pin container from the reactor containment building to the cask loading station in the Reactor Service Building. At the cask loading station the pin container is loaded into an appropriate transportation cask such as the T3 for transfer to radiochemical processing facilities at the RPL or other locations.

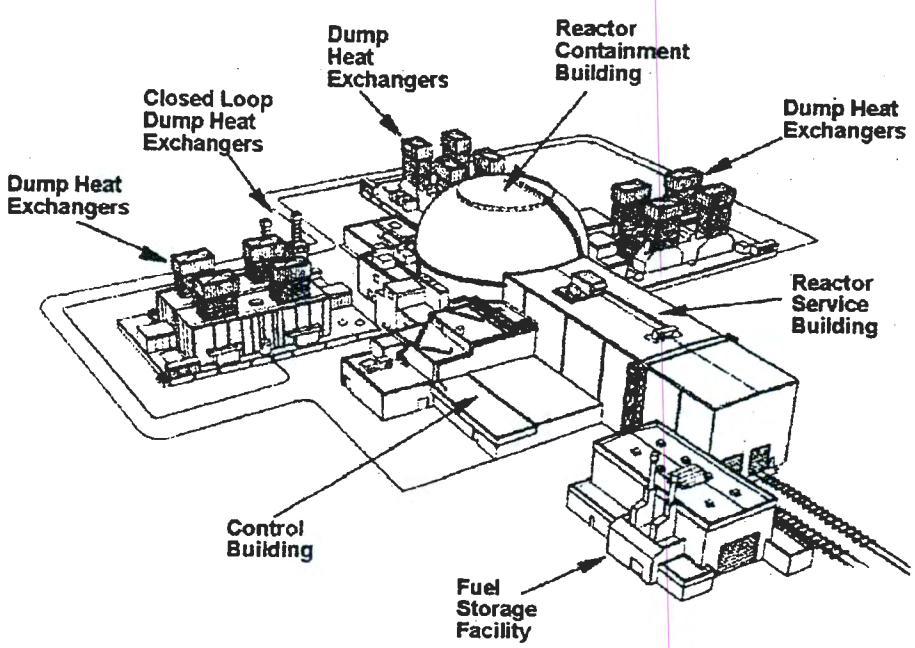

Figure 11. Fast Flux Test Facility Reactor Containment Building and External Support Facilities

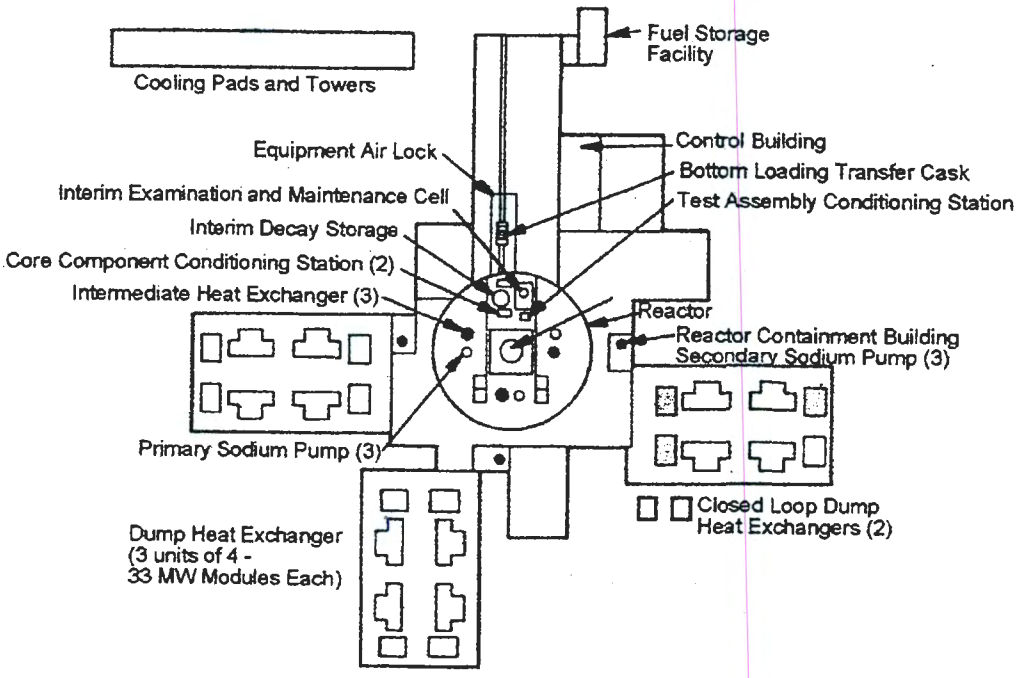

Figure 12. FFTF Plant Arrangement

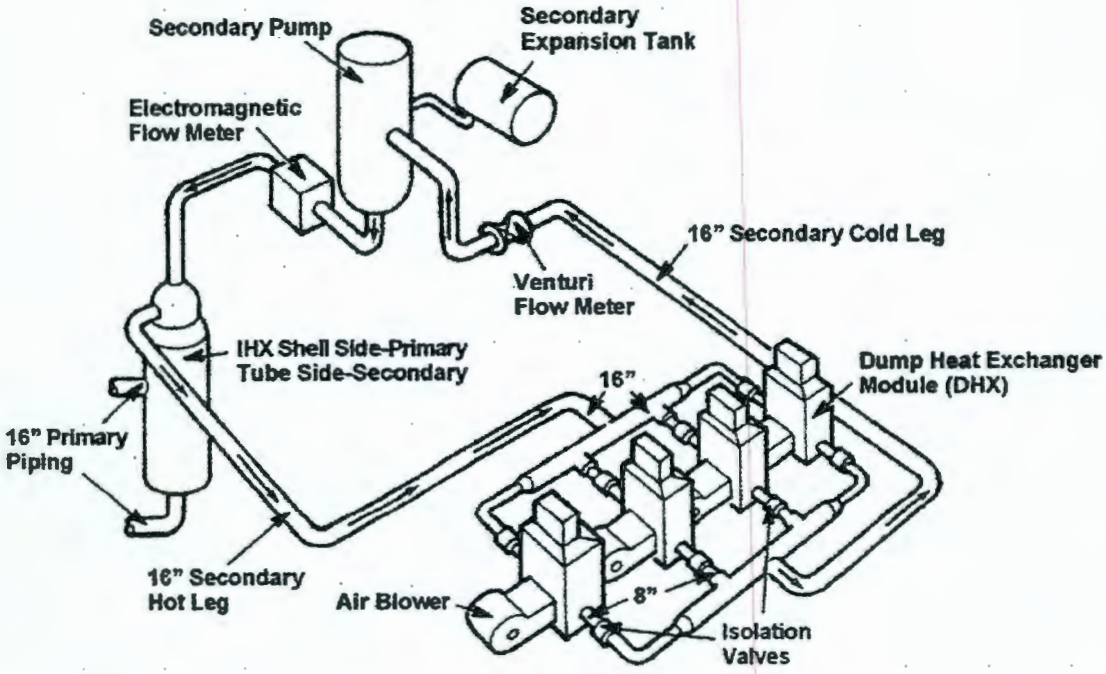

Figure 13. Schematic of FFTF Main Heat Transport System (MHTS)

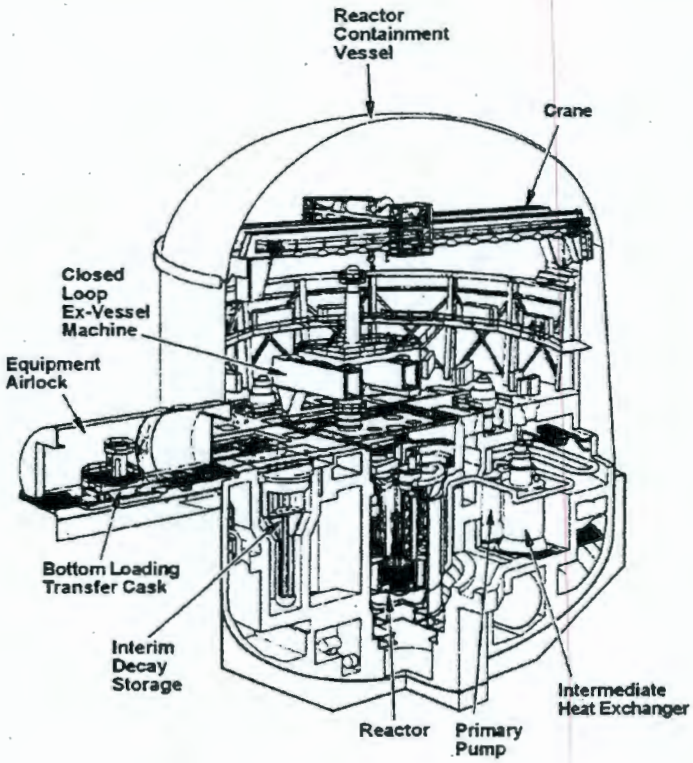

Figure 14. Cutaway View of the FFTF Reactor Containment Building

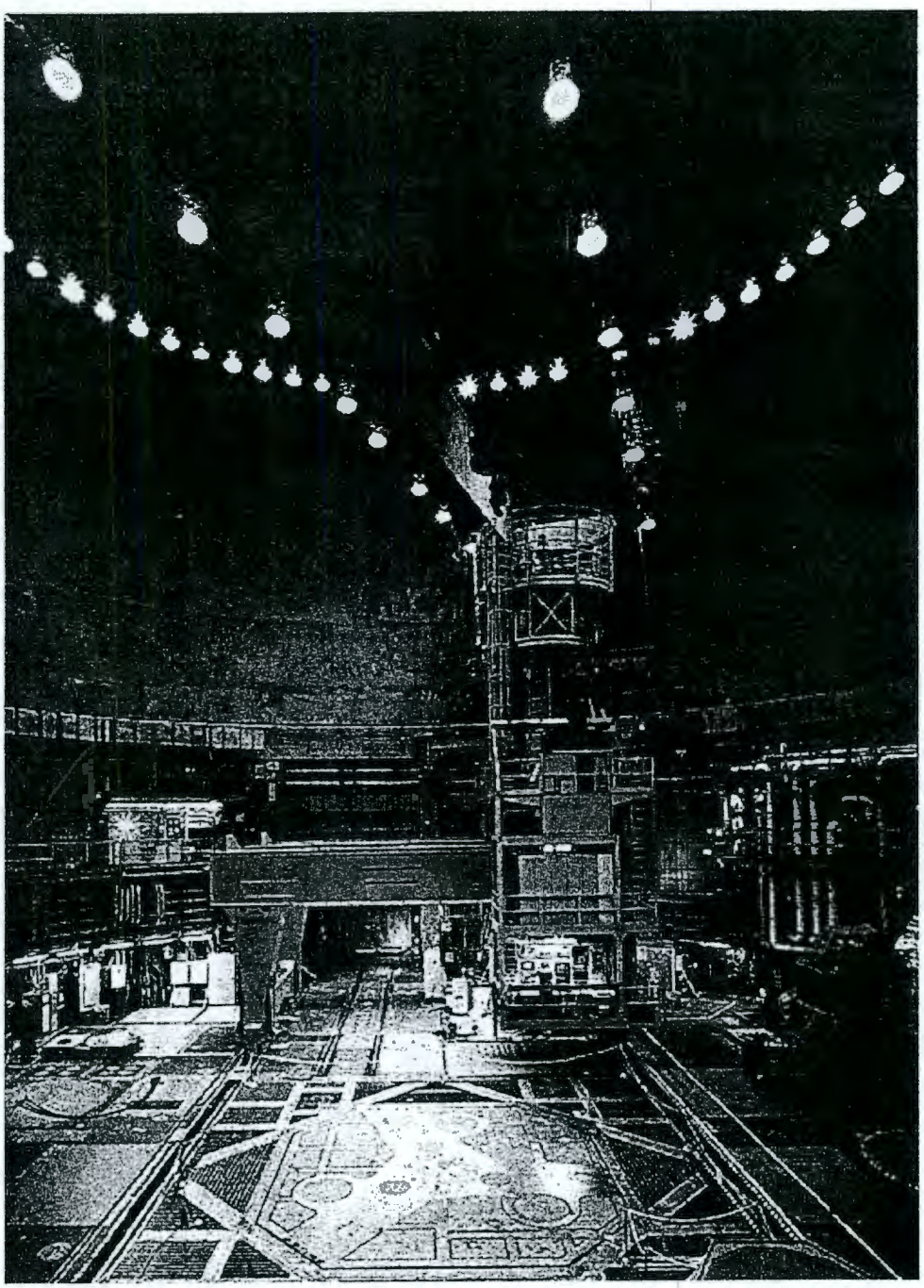

Figure 15. Closed Loop Ex-Vessel Machine (CLEM) for Installing Target Assemblies at FFTF

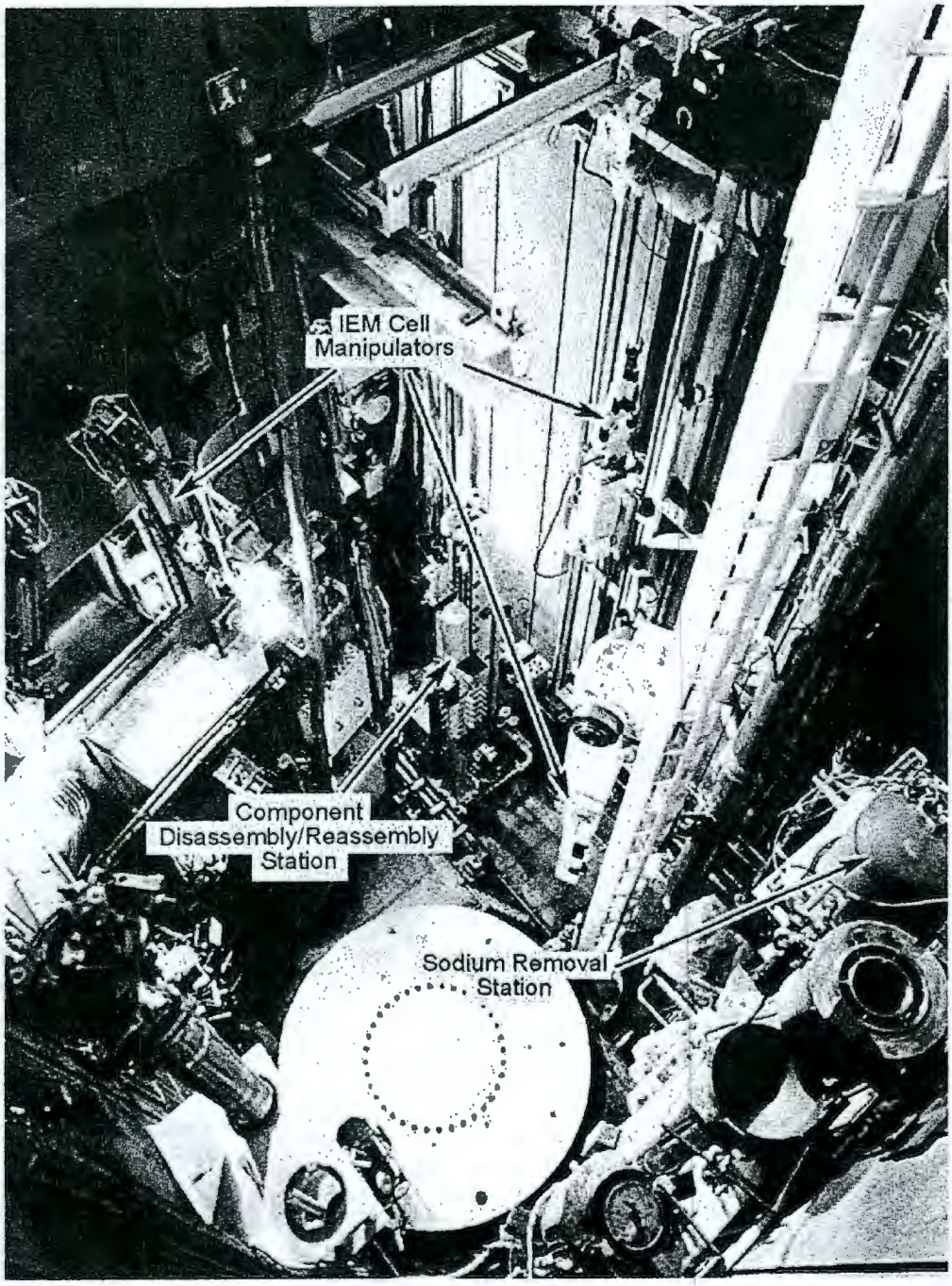

Figure 16. Interim Examination and Maintenance (IEM) Cell Used to Remove Residual Sodium from Target Assemblies and for Removal and Inspection of Target Pins

2.5.3 Other Facilities Relevant to the Proposed Future FFTF Isotope Production Mission

In planning for a proposed future FFTF isotope production mission, several facilities at the Hanford Site in addition to the RPL have been examined as possible locations for the preparation of targets and the processing of isotope products. In all cases, these facilities are in good condition and have some desirable physical features and equipment that could make them advantageous as locations for the preparation and/or processing of FFTF targets. Three of these facilities are briefly described below.

Building 306E. This facility is located in the 300 Area of the Hanford Site, and has been used to fabricate a variety of reactor components, fuel assemblies, and radioisotope target assemblies in the past. Some of the equipment and Non-Destructive Examination (NDE) equipment still exist in the building. Based on a preliminary engineering evaluation, a conceptual design plan has been developed for the utilization of Building 306E for the fabrication of isotope targets and gas tag capsules. Figure 17 shows the first floor plan of the building and the areas that would be used to fabricate and test the target pins for LIV assemblies and the encapsulated targets for R3 assemblies. The targets would be subjected to NDE and placed in secure storage areas within Building 306E before shipment to FFTF.

Postirradiation Testing Laboratory (PTL). The PTL is located in the 300 Area at the Hanford Site and is designated as Building 327. This facility contains 13 hot cells and support laboratories for the physical and metallurgical examination of irradiated fuels, fission products, and irradiated structural materials. A floor plan of the PTL is shown in Figure 18. The central region of the building contains a 215 ft. by 32 ft. canyon area, with two overhead bridge cranes that can transport shielded containers or heavy equipment weighing up to 20 tons. This central canyon area contains 10 large hot cells and transfer storage areas. All of the hot cells are heavily shielded and fully equipped with viewing windows, manipulators, and utilities. One of the hot cells is the Special Environmental Radiometallurgy Facility (SERF), which has an inert nitrogen gas atmosphere. The basement of the PTL contains equipment storage facilities, hot cell exhaust systems, high-level liquid waste piping, and the building's power and utility services.

Decontamination of the hot cell facilities at the PTL has been underway for two years, and is expected to be completed within the next two years. Only a small amount of programmatic work is currently being conducted at the PTL, and a study on the long-range utilization of this facility is underway. One option that is being explored is the use of part or all of the PTL's facilities by commercial companies under lease agreements. This alternative may be attractive for establishing long-term business relationships with companies interested in the preparation and processing of targets irradiated at FFTF.

Maintenance and Storage Facility (MASF). The MASF is a multi-purpose service center which supports the specialized maintenance and storage requirements of the FFTF. The building is located ~500 ft. north of FFTF, and is within the security perimeter of the 400 Area on the Hanford Site. The MASF provides the capability for sodium film removal, decontamination, repair, and storage of non-fuel components and hardware for the FFTF. A floor plan for the main building is shown in Figure 19. The MASF complex consists of the main building and a two-story service wing.

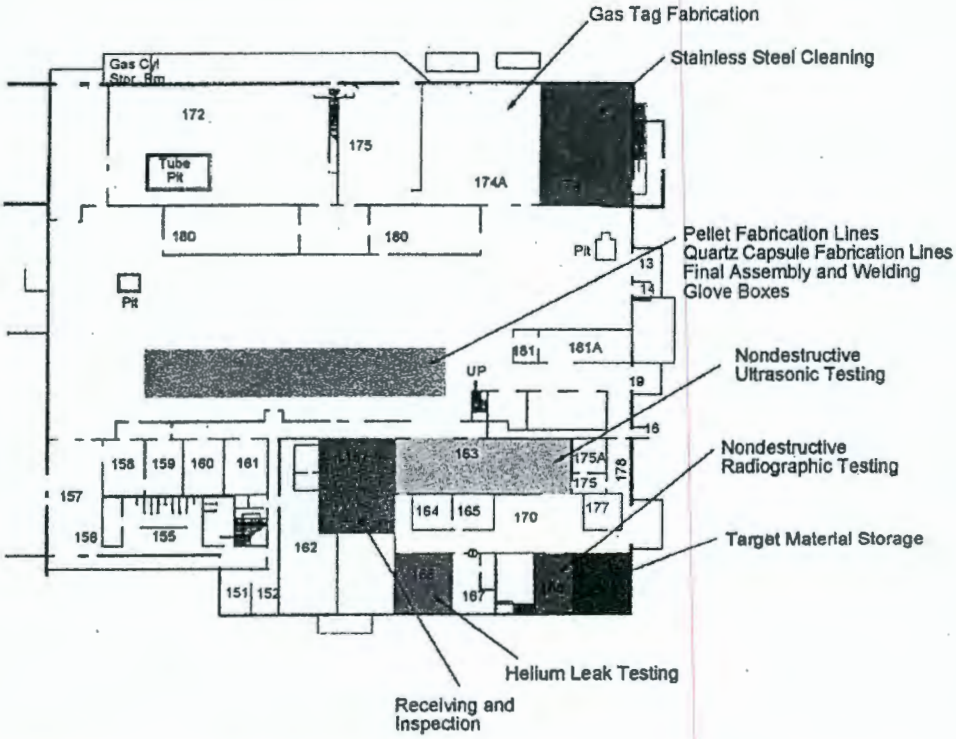

Figure 17. First Floor Plan for Building 306E, Showing Locations for FFTF Target Preparation and Nondestructive Testing

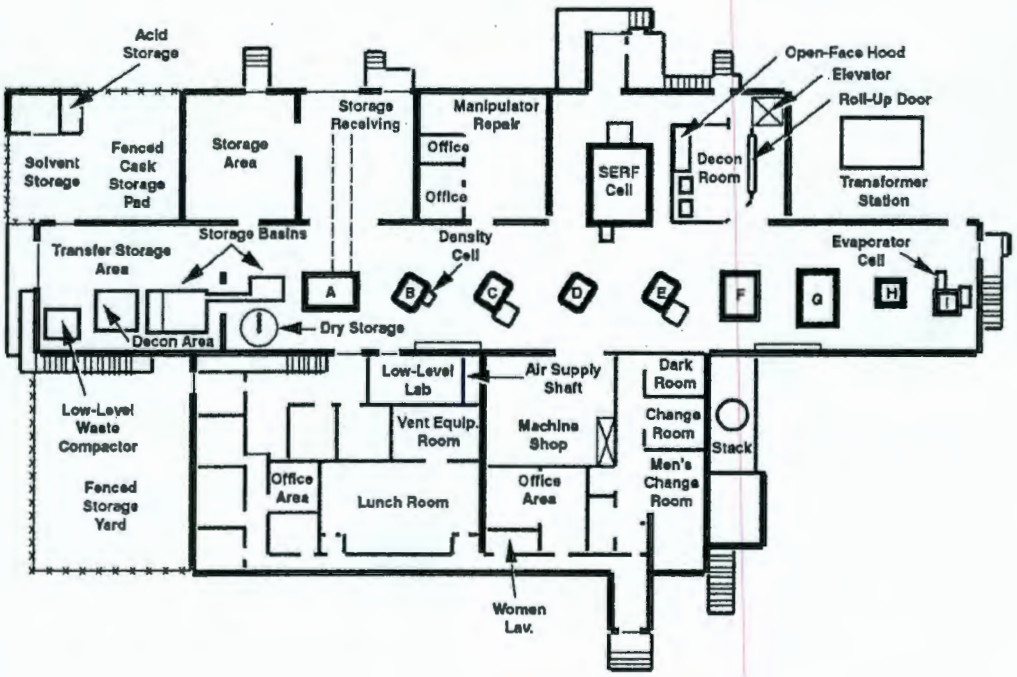

Figure 18. Floor Plan of the Postirradiation Testing Laboratory (PTL)

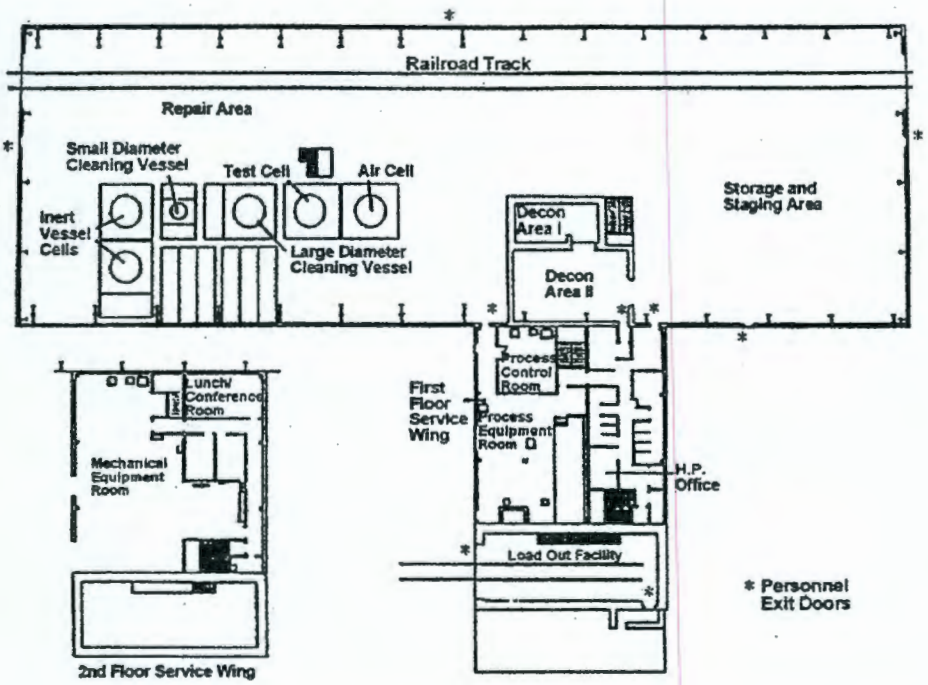

Figure 19. Floor Plan of the FFTF Maintenance and Storage Facility (MASF)

The main building of the MASF facility contains a 28,000 ft^2 area that is serviced by a 60-ton overhead bridge crane and a 10-ton auxiliary hoist. One half of this area is a high-bay section that is also serviced by a 200-ton overhead crane and a 25-ton auxiliary hoist. This section of the building has a height of 105 ft. and contains floor space for repairs and maintenance of large equipment. It also has below-grade shielded hot cells for sodium cleaning and equipment maintenance activities. The other half of the MASF's main building is a low-bay area with a height of 49 ft. and a 10-ton overhead hoist that is used to handle equipment during transport to and from the decontamination areas in MASF.

A special feature of the MASF is a large shielded enclosure that contains two shielded decontamination rooms (denoted as Decon I and II). These areas can be used for both remote and hands-on cleaning of small equipment items and tools that are contaminated with radioactive material. The Decon I area contains viewing windows and manipulators for remote operations and has a 5-ton overhead hoist.

2.5.4 Capital Investment Requirements

As part of the planning activities for a future FFTF nuclear science and irradiation services mission, an estimate has been prepared of the costs associated with restarting the reactor for steady-state operations at a 100 MW power level. This estimate, expressed in FY 1999 dollars, is $229M. The capital expenditures are distributed over a four-year period from FY 2001 – FY 2004, and include funds for (1) recovering systems that were shut down prior to the standby decision in late 1993, (2) equipment and instrumentation upgrades, (3) fabrication of R3 vehicles for retrieval of short-lived isotopes,

(4) modification of hot cells and support laboratories for target processing operations, and (5) staff increases and training. Once restarted, the estimated annual cost of FFTF operations is $55M. A more detailed description of the schedule and costs for FFTF restart are contained in a document submitted to DOE in March, 1999.[8]

2.6 Isotope Production Costs, Pricing, and Sales Record

2.6.1 Activity-Based Costing and Isotope Pricing

Approximately four to five months prior to the beginning of a new fiscal year, the PNNL isotopes program office prepares a budgeted operations statement with supporting schedules and cost/price analyses for each isotope product and related services. This statement contains detailed estimates of labor and supply costs for each element of work involved in the production, packaging, sales and distribution of isotope products. Estimates of labor and supply costs associated with process development projects are also included in the budgeted operations statement. An activity-based costing process is used, with the elements of work defined in a four-level work breakdown structure (WBS). As an example of this process, Table 6 shows the elements of the first three WBS levels for activities described in the FY 1999 budgeted operations statement prepared by PNNL.

Following a review of the annual operations statement by staff at DOE/NE-70 and final decisions on the fiscal year budget for the isotopes program, discussions are held between DOE and the PNNL manager of the Hanford Radioisotopes Program. Based on these discussions, any necessary modifications are made in the planned activities and associated costs. Upon receipt of formal guidance from DOE on funded activities during the coming fiscal year, the PNNL manager of the Hanford Radioisotopes Program prepares a detailed Project Management Plan (PMP) for approval by the DOE Richland Operations Office. Significant deviations from schedule or cost in any element of work described in the PMP are addressed by a formal change control process involving DOE review and, if necessary, budget adjustments that are subject to approval by DOE/NE-70. Revenues from isotope sales and expenses associated with all program activities are summarized in monthly, quarterly, and annual reports submitted to DOE.

The use of activity-based costing has been very beneficial in tracking expenses associated with the production, packaging, distribution and sales of medical isotopes produced by PNNL. During the period from 1996 to 1998 in which the revenue from sales of PNNL's yttrium-90 product increased 14-fold, increases also occurred in the costs of production, packaging and distribution of this product which could be closely monitored by using the activity-based costing method. An example of the type of activity flowchart developed by PNNL is shown in Figure 20 for work related to the packaging and shipping of yttrium-90 to medical customers. Using the four-level WBS approach, costs were closely estimated for each element of work shown in the flowchart. These costs are summarized in Table 7. A flowchart and

[8] "Capabilities and Economic Assessment of the Use of the Fast Flux Test Facility for Isotope Production and Research." Predecisional draft report for the DOE Office of Nuclear Energy, Science, and Technology (March 18, 1999).

activity-based cost analysis were also prepared for the radiochemical tasks associated with extraction of yttrium-90 from strontium-90 generators and the subsequent dispensing of the yttrium-90 product into customer vials. By using this activity-based approach, it was possible to anticipate increases in the expense associated with providing yttrium-90 to medical customers as a function of the number of vials prepared and the number of packages shipped to customers on a weekly basis. Accurate projections can also be made by this method of the monthly revenue *versus* expense profile, as well as the "economy of scale" achieved by serving a rapidly expanding market.

Table 6. Level 3 Work Breakdown Structure Outline

I	II	III	IV	Definition	B&R[a]
1				Radioisotopes	ST01
	4			Chemical Processing	ST01
		1		Yttrium-90	ST01
	5			Waste Mgmt	ST01
		1		Yttrium-90	ST01
	6			Quality Assurance	ST01
		1		Yttrium-90	ST01
	7			ES&H Safety, Regulatory Compliance	ST01
		1		Yttrium-90	ST01
	8			Packaging	ST01
		1		Yttrium-90	ST01
	9			Program Management	ST01
		1		Yttrium-90	ST01
3				Storage & Distribution	ST03
	1			Storage	ST03
		1		Sr-90	ST03
4				Research & Development	ST04
	1			Process Development	ST04
		2		Purify Ac-227 & Th-228	ST04
	2			Research	ST04
		2		Ra-223 Immunoconjugates	ST04
7				HQ Requests	ST07
	1			Y-90 Privatization	ST07
		1		Sr-90 Verification measurements	ST07
		2		Transition to NEN	ST07
8				Customer Sales & Services	ST08
	1			Order Processing	ST08
	2			Program Information & Cost/Price Studies	ST08
9				Travel	ST09
	1			Marketing	ST09
	2			Research & Development	ST09
	3			Program Travel	ST09
10				Equipment	ST10

(a) B&R is the DOE Budget and Reporting code.

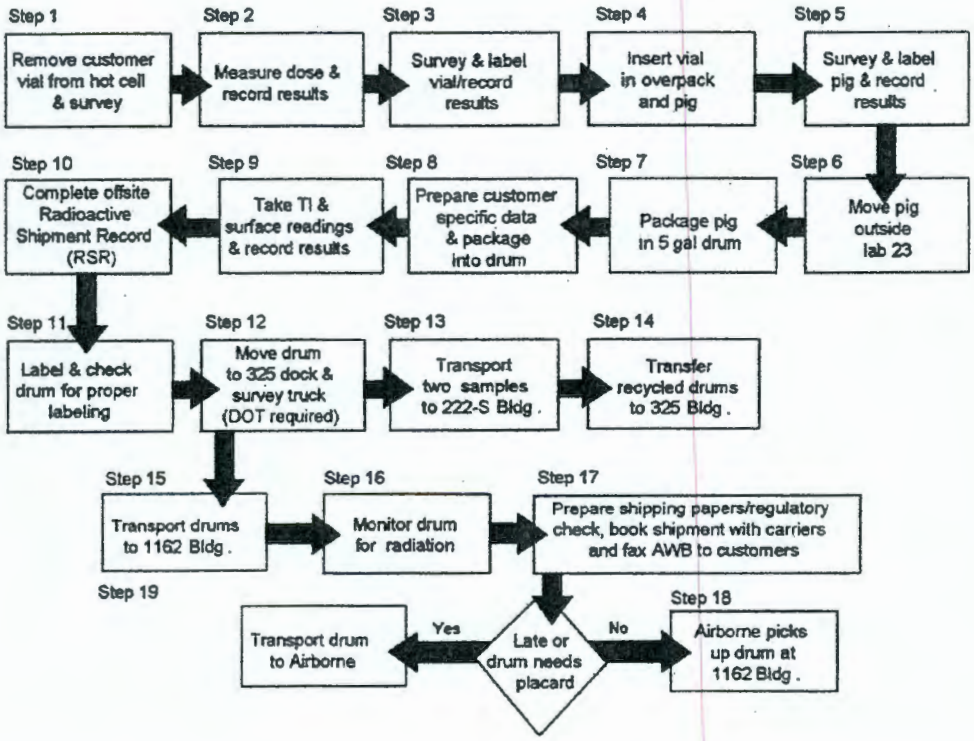

Figure 20. Flowchart Representing Procedures in the Packaging and Shipping of Vials of Yttrium-90 from PNNL to Medical Customers

Table 7. Yttrium-90 Packaging and Shipping Cost Analysis

		Activity Costs			
Steps	Description	PNNL	Waste Mgmt. Federal Services	DynCorp	Total
1	Remove customer vial from hot cell & survey	$ 76			$76
2	Measure dose & record results	27			27
3	Survey & label vial/record results	27			27
4	Insert vial in overpack and pig	12			12
5	Survey & label pig/record results	27			27
6	Move pig outside lab 23	8			8
7	Package pig in 5 gal drum	18			18
8	Prepare customer specific data & package into drum	36			36
9	Take TI & surface readings/record results	27			27
10	Complete offsite Radioactive Shipment Record (RSR)	44			44
11	Label & check drum for proper labeling	17			17
12	Move drum to 325 dock/survey truck (DOT required)	27			27
13	Transport 2 samples to 222-S Bldg. (production cost)	33		$175[a]	0
14	Transport recycled drums to 325 Bldg. (production cost)			0	
15	Transport drums to 1162 Bldg.	3		20	23
16	Monitor drum for radiation				0
17	Prepare shipping papers/regulatory check, book shipment with carriers/fax AWB to customers	35	$145		180
18	Airborne picks up drum at 1162 Bldg.				0
19	Transport drum to Airborne	3		20	23
	Materials	100			100
TOTAL COST					$672

(a) Not included as shipping cost, since the transport of samples to the 222-S Bldg. is for chemical analysis.

Pricing policies for all DOE isotope products are established by staff at DOE/NE-70, working in collaboration with program managers at the DOE Isotope Production Sites. An effort is made to achieve full-cost recovery for isotope products such as yttrium-90 that have a strong market position. However, for isotope products that are sold only in relatively small quantities for research applications, it is recognized that full-cost recovery is not possible and that the production of those isotopes must be subsidized by DOE. This is an appropriate role for the federal government to play, since it assures that a supply of isotopes is available for research and early-phase clinical trials at a stage when it is not economically feasible for commercial companies to provide these products.

2.6.2 Isotope Sales and Customer Service Record

A primary goal of staff in the Hanford Radioisotopes Program is rapid customer response and complete customer satisfaction. Although the program is relatively small, it has enhanced DOE's reputation as a reliable supplier of high-quality medical isotopes by professionally and enthusiastically serving its customers from the first phone call through the contracting, isotope production, delivery, and payment collection phases of each business transaction. Responses are also made to customer inquiries regarding isotopes that are not produced at the Hanford Site. These inquiries are answered by referring the customers to other DOE Isotope Production Sites or commercial suppliers. Our dedication to customer satisfaction is illustrated in Table 8, which shows that a 100% on-time record has been achieved for more than 1200 shipments of yttrium-90 sent by PNNL to medical customers over the past 2.5 years.

Table 8. Yttrium-90 Customer Service Record

	FY 1997	**FY 1998**	**FY 1999[a] (Oct. '98 - Apr. '99)**
Number of customers	26	44	40
Total number of shipments (cumulative)	233	808	1,203
Number of shipments sent on time	233 (100%)	575 (100%)	395 (100%)
Number of shipments received on time[b]	220 (94%)	566 (98%)	390 (99%)

(a) NEN™ Life Science Products, Inc., began supplying PNNL's customers with yttrium-90 in May, 1999, as the final stage in commercialization of this program.
(b) Late arrivals were the result of poor weather conditions or other problems encountered by the express mail carriers.

This dedication to customer service and satisfaction has been illustrated by comments received from many customers during the past two years. A few examples are the following:

" . . . consistently reliable yttrium" . . . (Immunomedics)
" . . . very high-purity, reliable product" . . . (University of California at Davis)
" . . . excellent turnaround time and ease of doing business" . . . (Stanford University)
" . . . superb customer service" . . . (Institut für Nuclearmedizin, Basel, Switzerland)

" . . . excellent, pure product compared to competitors" . . . (University of Gottingen)
" . . . unfailing, consistent labeling quality" . . . (City of Hope Medical Center)

One comment received from Du Pont Pharmaceuticals provides perhaps the best tribute to our philosophy of 100% customer satisfaction: "Thank you for setting the standard so high!"

Appendix

Questions Raised by NERAC Subcommittee

Appendix

Questions Raised by NERAC Subcommittee

NERAC Question	Addressed in Section(s) of This Report
How well does the Department's existing five-site production infrastructure serve the need for commercial and research isotopes?	
1. What is the physical condition of the isotope processing facilities and equipment?	2.5.1, 2.5.2, 2.5.3
2. What capital investments are needed to assure the near term operability of the facilities? If additional resources are needed, are they practical, e.g., technically rational, easily integrated into existing infrastructure, quickly implemented and supportable? Will any portion be sustainable over time by local financial and personnel resources?	2.5.4
3. What is the availability of the primary nuclear facility (accelerator or reactor) over the next five years (e.g., HFIR outage, LANSCE program changes)?	2.5.1, 2.5.2, 2.5.3
4. What understanding exists at each site about the priority of isotope production to serve isotope customers?	2.6.2
5. How much influence does each site manager have in planning the use of multi-purpose facilities?	2.4.3
6. What cost-containment measures are being pursued?	2.6.1
7. What "licensing" issues need to be addressed?	2.2.2
8. What unused or underused capacity, e.g., personnel, facilities, could be mobilized to support a growth in isotope demand?	2.5.1, 2.5.3
9. Summarize customer inquiries received during the past two years. What percent was filled, referred to other facilities, rejected? Explain unfilled requests.	2.6.2
10. How does each site manager rate customer satisfaction for his site? For the overall program?	2.6.2
What should be the long-term role of Government in providing commercial and research isotopes?	1, 2.6.1

PNNL-12249

Report to the Nuclear Energy Research Advisory Committee (NERAC) Subcommittee on "Long-Term Isotope Research and Production Plan" — Responses to Questions

July 1999

Information provided to the Nuclear Energy Research Advisory Committee's subcommittee on the development of a "Long-Term Isotope Research and Production Plan"

Prepared by the Hanford Radioisotopes Program staff at the
Pacific Northwest National Laboratory
Richland, Washington 99352

Introduction

This report presents responses to two series of questions that were raised by a subcommittee of the Nuclear Energy Research Advisory Committee (NERAC) that has been charged with producing a "Long-Term Isotope Research and Production Plan." The NERAC subcommittee is chaired by Dr. Richard Reba, and the Hanford Site Visit team, which comprises a subset of the subcommittee members, is chaired by Dr. Thomas Ruth.

The first set of questions raised by the subcommittee on isotope production at the Hanford Site was received from Dr. Ruth on May 10, 1999, and the second set was received from him on July 5, 1999. Responses to the first set of questions were prepared as part of a June 1999 report entitled "Isotope Production at the Hanford Site in Richland, Washington" (PNNL 1999a). The responses to these questions are summarized in this document, with frequent references to the June 1999 report for additional details. Responses to the second set of questions from the NERAC subcommittee are presented in this document for the first time.

1 Responses to the First Set of Questions

The set of questions received on May 10, 1999, consisted of two broad questions, the first of which contained 10 individual questions to which responses are given below.

1.0 How well does the Department's existing five-site production infrastructure serve the need for commercial and research isotopes?

1.1 What is the physical condition of the isotope processing facilities and equipment?

Response:

The primary isotope production facilities at the Hanford Site are the Radiochemical Processing Laboratory (RPL) (Building 325 in the 300 Area of the Hanford Site) and the Fast Flux Test Facility (FFTF) reactor (in the 400 Area of the Hanford Site). In addition, there are several other laboratory facilities that are suitable for various aspects of target preparation and radiochemical processing of isotopes. These facilities are discussed briefly in this document, with reference to PNNL (1999a) for additional details.

(a) **RPL.** The RPL is a 143,700 ft^2 building that contains laboratories and specialized facilities designed for work with nonradioactive materials, microgram-to-kilogram quantities of fissionable materials, and up to megacurie quantities of other radionuclides. The total space occupied by general chemistry laboratories is 44,300 ft^2, of which 6,950 ft^2 (15.6%) is presently unoccupied. All of the occupied, and nearly all of the unoccupied laboratories are functional and fully equipped with standard utilities. Several of the laboratories, especially those used for radioanalytical work, have been renovated during the past few years. The upgrading and modernization of equipment within the chemistry laboratories has been given a high priority during the past two years.

During a recent space utilization survey of the RPL, an assessment was made of the number of fume hoods and shielded glove boxes (including small hot cells) that are available for additional programmatic work. Of the 79 functional fume hoods and 23 shielded glove boxes, 50 and 15, respectively, are available for additional work.

A special feature of the RPL is the existence of two heavily shielded facilities located in annexes on the East and West sides of the building. These shielded facilities are the High-Level Radiochemistry Facility (HLRF) and the Shielded Analytical Laboratory (SAL). These two hot cell complexes, which are heavily utilized at the present time, provide capabilities for conducting bench-scale to pilot-scale work with a wide variety of highly radioactive materials. Capabilities include those required to conduct radiochemical separation and purification procedures, irradiated fuel or target sectioning and processing, metallography, physical properties testing of activated metals, thermal processing (including waste vitrification), and radioanalytical and preparatory chemistry operations.

The HLRF contains three large, interconnected hot cells designated as A-Cell, B-Cell, and C-Cell. The three cells are each 15 ft high and 7 ft deep; the A-Cell is 15 ft wide and the B-Cell and C-Cell are each 6 ft wide. In-cell operations are performed using medium-duty electromechanical manipulators, and the work is viewed through leaded-glass, oil-filled windows. The hot cells are equipped with television cameras, VCRs, overhead bridges, hoists, and standard utilities. They have shielded service penetrations at the front wall for insertion of special instrumentation.

The SAL contains six interconnecting hot cells, each of which is 5.5 ft wide, 5.5 ft deep, and 9.5 ft high. Each hot cell is equipped with a pair of medium-duty manipulators. Turntables built into the rear walls of the hot cells provide rapid transfers of radioactive samples into and out of the cells. The SAL hot cells are equipped to perform a wide variety of analytical chemistry operations with highly radioactive samples.

Additional information on the RPL, and its laboratory facilities that could be devoted to new isotope production missions in the future, is contained in PNNL (1999a) (Section 2.5.1).

(b) **FFTF.** The FFTF's original mission was to support liquid-metal reactor technology development and reactor safety by providing fuels and materials irradiation services. Although the U.S. liquid-metal reactor program ended at about the same time that the FFTF commenced operation in 1982, the reactor continued operation for 10 years as a national research facility to test advanced nuclear fuels and materials, nuclear power plant operating procedures, and active and passive reactor safety technologies. The facility was also used to produce more than 40 different radioisotopes for use in research, medicine, and industry. In addition, FFTF generated tritium for the U.S. fusion research program and supported cooperative, international nuclear research activities. The reactor was shut down in December 1993, and since that time has been in a standby operational condition, pending a decision by DOE on its future use. In May 1999, the Secretary of Energy announced that a special 90-day study led by the Director of the Pacific Northwest National Laboratory, Dr. William Madia, would be conducted to establish whether the FFTF should be considered for future missions related to national and international nuclear technology needs. The nuclear science and irradiation services provided by FFTF will focus on a core federal role of meeting multiple 21st Century needs, including:

1. providing a large and reliable supply of radioisotopes for research, medical, and industrial applications

2. promoting safer nuclear technology through reactor safety testing and the development of proliferation-resistant nuclear fuels

3. producing power sources for deep-space exploration through the production of plutonium-238 for radioisotope thermoelectric generators, and for research on compact space reactor technology

4. sustaining the nuclear option for power production through testing of fuels, components, and reactor instrumentation

5. conducting advanced research and providing services related to the testing of materials for fusion reactors, hardening and testing of materials such as semiconductors, and research on transmutation of nuclear waste materials.

These future missions, and the business plan for FFTF's proposed future operations, are described in a document that will be submitted to NERAC on July 20, 1999 for review before submission to the Secretary of Energy on August 2, 1999. This document is entitled "Program Scoping Plan for the Fast Flux Test Facility: A Nuclear Science and Irradiation Services User Facility"(PNNL 1999b).[a]

The FFTF consists of the reactor, which is capable of steady-state operation at a rated power level of 400 MW, and several support buildings and equipment arranged around the central reactor containment building. Heat is removed from the reactor by liquid sodium that is circulated through three primary loops, which include the pumps, piping, and intermediate heat exchangers. During a total loss of power, the FFTF is designed to shut down automatically and the reactor will continue to be cooled by natural circulation of the sodium. An emergency power source consisting of batteries will provide essential plant monitoring capabilities in the event of a shutdown. The reactor also has safety features that can maintain cooling if a leak occurs in the liquid sodium heat transport system.

Other major systems located in the FFTF reactor containment building are:

- the Closed Loop Ex-Vessel Handling Machine that is used to install fuel and target assemblies in the reactor and to remove them at the end of the irradiation cycle

- the Interim Examination and Maintenance (IEM) Cell, in which an irradiated assembly is washed and dried to remove residual sodium before disassembly; the target pins are then removed from irradiated assemblies with manipulators and placed in containers for removal from the IEM cell

- a Bottom-Loading Transfer Cask, which is used to transfer the pin container from the reactor containment building to a cask loading station in the Reactor Service Building.

Detailed descriptions and photographs of the FFTF containment building and the special facilities described above are contained in PNNL (1999a) (Section 2.5.2).

(c) **Other Available Facilities.** In planning for a proposed future FFTF isotope production mission, several facilities at the Hanford Site have been examined as possible locations for target preparation and the processing of isotope products. In all cases, these facilities have desirable physical features and equipment that could make them useful if an expansion of facilities is required later to meet a growth in the demand for FFTF isotope products. Three candidate facilities are:

(a) This document is referred to hereafter in this report as the "FFTF Scoping Plan."

1. *Building 306E.* Located in the 300 Area of the Hanford Site, this facility has been used in the past to fabricate a variety of reactor components, fuel assemblies, and radioisotope target assemblies. Some of the target fabrication equipment and non-destructive examination equipment still exist in the building and are available for use.

2. *Postirradiation Testing Laboratory.* Located in the 300 Area at the Hanford Site, this facility contains 13 hot cells and support laboratories for the physical and metallurgical examination of irradiated fuels, fission products, and irradiated structural materials. Decontamination of the hot cell facilities has been underway for two years, and is expected to be completed within the next two years. Only a small amount of programmatic work is currently being conducted, and a study on the long-range utilization of this facility is underway, including use by commercial companies under lease agreements. This alternative may be attractive for establishing long-term business relationships with companies interested in the preparation and processing of targets irradiated at FFTF.

3. *Maintenance and Storage Facility.* Located in the 400 Area of the Hanford Site about 500 ft north of FFTF, this facility is a multi-purpose service center that supports the specialized maintenance and storage requirements of the FFTF. A special feature of this facility is a large shielded enclosure that contains two shielded decontamination rooms that can be used for both remote and hands-on cleaning of equipment and tools. This facility, including the shielded enclosures, was not fully utilized during the ten years of full-scale FFTF operation, and consideration has been given to its possible use for the fabrication and disassembly of FFTF targets.

Additional details on each of these facilities are contained in PNNL (1999a) (Section 2.5.3).

1.2 What capital investments are needed to ensure the near-term operability of the facilities? If additional resources are needed, are they practical (e.g., technically rational, easily integrated into existing infrastructure, quickly implemented and supportable)? Will any portion be sustainable over time by local financial and personnel resources?

Response:

As part of the planning activities for a future FFTF nuclear science and irradiation services mission, an estimate has been prepared of the costs associated with restarting the reactor for steady-state operations at a 100-MW power level. This estimate, expressed in FY 1999 dollars, is $229M. The capital expenditures are distributed over a four-year period from 2001 – 2004, and include funds for (1) recovering systems that were shut down before the standby decision in late 1993, (2) equipment and instrumentation upgrades, (3) fabrication of rapid radioisotope retrieval (R3) vehicles for removal of short-lived isotope targets while the reactor is at power, (4) modification of hot cells and support

laboratories for target processing operations, and (5) staff increases and training. Once restarted, the estimated annual cost of FFTF operations is $55M. A more detailed description of the schedule and costs for FFTF restart is provided in the FFTF Scoping Plan (PNNL 1999b).

A business model has been developed as part of the FFTF Scoping Plan (PNNL 1999b) that incorporates plans for recovering approximately $100M of the restart costs over the projected 35-year operating life of the reactor. This business model was developed using the guidelines provided in DOE Order 2110.1A, "Pricing of Department Materials and Services and DOE Implementing Guidance on Federal Administrative Charges." The model is comparable to those currently in use at other DOE reactor facilities, and has been reviewed and accepted by the DOE Chief Financial Officer in meetings held during June 1999. The FFTF business model provides adequate resources to ensure both the near-term and sustained future operability of the reactor.

In this business model, the funding in FY 1999 dollars required during the reactor restart phase includes both the $229M discussed above and $55M in operating funds to maintain the FFTF's standby mode of operation during the period 2000-2001. During the projected 35-year operating lifetime of the reactor (2004-2038), a "value recovery charge" of ~4% will be applied to all private-sector irradiation services. The funds recovered through this charge will be placed in an investment fund that is expected to grow at an annual rate estimated to be ~5% above inflation, and thereby generate ~$100M to offset a portion of the restart costs.

The staffing infrastructure to support both the reactor operations and radiochemical processing of irradiated targets are in place and adaptable to rapid growth of the nuclear science and irradiation services components of the FFTF mission. As described in detail in the FFTF Scoping Plan and PNNL (1999a), the operations staff at the FFTF will increase from the current level of 260 full-time equivalent (FTE) to 410 FTE at the time of restart. This increase will accommodate the full set of operational services required for target insertion, irradiation, and retrieval in the isotope production program. Target preparation is expected to be carried out by a subcontractor working in facilities at the Hanford Site.

Radiochemical processing of the isotope targets will be carried out by members of the PNNL Radiochemical Processing Group (RPG), which consists of 75 technical and administrative staff that occupy the RPL (described in PNNL (1999a), Section 2.4.1). The isotope production team within the RPG currently has 12 staff members, of which 5 perform radiochemical processing operations. It is expected that the number of scientists and technicians performing radiochemical operations will increase to 21 FTE at the time FFTF commences full operation. This expansion will be achieved by reassignment of radiochemists and technical support staff within the RPG, and by new hires. In addition to the staff involved in radiochemical processing operations, it is expected that the number of staff involved in packaging and shipping will increase from 0.5 FTE to 7.5 FTE, and that the marketing, sales and administrative staff will increase from 1.5 FTE to 5.5 FTE.

Although the FFTF Scoping Plan (PNNL 1999b) does not explicitly include privatization of the reactor operations or the isotope production mission, discussions have been initiated with private-sector companies that may have an interest in commercializing various components of these operations (e.g., the marketing, sales, and distribution of isotope products). These discussions are expected to continue over

the coming five-year period (i.e., during the preparation of the FFTF Environmental Impact Statement and the reactor restart activities), with a reasonable probability of success in establishing partnership agreements between DOE and commercial organizations.

1.3 What is the availability of the primary nuclear facility (accelerator or reactor) over the next five years (e.g., HFIR outage, LANSCE program changes)?

Response:

If the current plans to initiate preparation of an Environmental Impact Statement in October, 1999 are met, then it is expected that FFTF will be restarted by July 2004. Details of the restart schedule are given in the FFTF Scoping Plan (PNNL 1999b). In addition, all of the target preparation and processing facilities such as the RPL are expected to remain available for work in support of the FFTF isotope production mission.

1.4 What understanding exists at each site about the priority of isotope production to serve isotope customers?

Response:

Because many of the isotopes produced at the Hanford Site are shipped to customers at medical centers for the treatment of critically ill cancer patients, the isotope production program receives a very high priority. For example, the staff performing the radioanalytical work and on-site transportation services in support of the isotopes program give this work the highest priority among their multiple tasks. A complete radionuclide analysis and Inductively Coupled Plasma (ICP) analysis of the chemical purity of the isotopes sent to customers are performed within 24 hours of the completion of isotope production. These data are then sent immediately to the customer for review before use of the isotope.

Another example of the high priority given to the medical isotopes program occurred five years ago when the RPL was shut down temporarily for safety upgrades. By direct order of the Manager of the DOE Richland Operations Office, Mr. John Wagoner, the production of yttrium-90 for medical customers was allowed to continue uninterrupted during the entire shutdown period, which lasted about one year.

1.5 How much influence does each site manager have in planning the use of multi-purpose facilities?

Response:

The Manager of the Hanford Radioisotopes Program, Dr. Thomas Tenforde, also serves as the lead scientist for the isotope production team within the RPG. The organizational structure and primary areas of research are described in PNNL (1999a) (Section 2.4.1). In his capacity as head of the isotope production team within the RPG, the manager of the Hanford Radioisotopes Program has line management responsibilities for the staff and facilities involved in the radiochemical processing of isotopes for commercial, medical, and research applications. These staff, together with a matrixed team

of nuclear physicists, engineers, radiochemists, and nuclear safety specialists from PNNL and other Hanford contractor organizations, have functioned since 1997 as a support group for planning the proposed future FFTF isotope production mission. An important part of this planning has been the identification of laboratory facilities that will be given a high priority for future use in support of the FFTF isotope production mission.

1.6 What cost-containment measures are being pursued?

Response:

Cost-containment efforts in the isotopes program are centered around the use of activity-based costing procedures for all isotope products. Following the costing procedures adopted by the DOE Office of Isotope Programs (NE-70), an annual cost/price analysis is performed on each isotope product using a four-level Work Breakdown Structure. Examples of this type of cost analysis are given in PNNL (1999a) (Section 2.6.1) and in the response given below to the first of the new set of questions received from the NERAC subcommittee on July 5, 1999.

In all aspects of isotope production, efforts are made to streamline the radiochemical laboratory procedures and to use the most economical services available from various contractor organizations at the Hanford Site. For example, ICP analyses of the chemical purity of isotope products are performed at the 222S Building under a subcontract with the Fluor Daniel Hanford Company, which is a less expensive option (by nearly a factor of 2) than performing these analyses in the RPL operated by PNNL.

1.7 What licensing issues need to be addressed?

Response:

If a decision is made to restart the FFTF, it will be subject to all DOE requirements for the operation of a nuclear facility, as described under DOE Order 425.1A ("Startup and Restart of Nuclear Facilities," 1995). Licensing of the FFTF under the regulations for commercial reactors will not be a regulatory requirement. However, it is expected that DOE will request the Nuclear Regulatory Commission to conduct a detailed technical review of the safety aspects of operating the facility, similar to the procedure that was followed prior to initial startup of the reactor in the early 1980s. In addition, the International Atomic Energy Agency (IAEA) may be requested to verify the inventory and characteristics of nuclear materials at the FFTF. The IAEA has declared its willingness to help facilitate FFTF's use by the international nuclear science community.

It is the goal of the Hanford Radioisotopes Program to transfer technology for the production and applications of medical isotopes to the private sector through appropriate licensing agreements. A recent example is the licensing agreement signed by NEN Life Science Products, Inc., on October 12, 1998, to use PNNL's patented process for extracting yttrium-90 from a strontium-90 generator in a highly purified form. Under this license agreement, the management contractor organization for PNNL — the Battelle Memorial Institute — receives an initial fee of $75K and subsequent royalties based on a percentage of the net sales value of yttrium-90 sold by NEN. The estimated value of this agreement for Battelle is

approximately $500K over a five-year license period. This licensing agreement was part of a broader commercialization effort in which NEN took over from PNNL all aspects of the production, marketing, sales, and distribution of yttrium-90 (described in more detail in PNNL (1999a), Section 2.2.2).

Based on the success of the yttrium-90 privatization activity, PNNL is currently involved in efforts to commercialize other technology that has been developed for the medical application of radioisotopes. For example, negotiations are underway with a private company for use of PNNL's radioactive composite polymer delivery system for treating prostate tumors and other forms of cancer.

In addition to technology licensing agreements, consideration has been given to establishing facility lease agreements under which commercial companies could perform work in DOE facilities at the Hanford Site. For example, a study is underway on the feasibility and opportunities for privatizing part or all of the Postirradiation Testing Laboratory described above in the response to Question 1.1. This facility, as well as other laboratories in the 300 Area of the Hanford Site, will be considered for use by private-sector companies in future work related to the preparation and processing of targets for FFTF isotope production.

1.8 What unused or underused capacity (e.g., personnel, facilities) could be mobilized to support a growth in isotope demand?

Response:

As discussed above in the response to Question 1.1, a recent survey of space utilization in the RPL indicated that ~7000 ft^2 of functional laboratory space is currently available for radiochemical work in new projects. It is anticipated that reassignment of laboratory space within the RPL will be made in the future to accommodate the full set of requirements for the radiochemical processing of multiple FFTF isotope targets. In addition, as also discussed above in the response to Question 1.2, there are extensive support facilities available for isotope target preparation and processing in Building 306E and in the Postirradiation Testing Laboratory at the Hanford Site.

With regard to the availability of trained staff who could be mobilized in support of a growth in isotope demand, there are currently about five scientists and technicians within the 75-member RPG that could be utilized in that capacity (in addition to the staff that are members of the isotope production team). The overall workload and availability for new assignments of radiochemistry staff in the RPG is driven primarily by funding for work in support of the Hanford nuclear waste cleanup mission and the processing and disposal of nuclear fuels. As the time approaches for restart of the FFTF reactor in mid-2004, an assessment will be made of staff assignments to support the isotope production mission. It appears likely at this time that recruitment and hiring of new staff will be required during the year preceding restart of the FFTF. However, as indicated above in the response to Question 1.2, ongoing discussions with private-sector companies could lead to privatization of various components of the FFTF isotope production program. The commercialization of various elements of work involved in the preparation, irradiation, and processing of isotope targets, as well as the marketing, sales, and distribution of the final isotope products, could have a significant impact on the staffing requirements that must be

met by PNNL and other contractor organizations at the Hanford Site involved in the FFTF isotope production mission.

1.9 Summarize customer inquiries received during the past two years. What percent was filled, referred to other facilities, or rejected? Explain unfilled requests.

Response:

During the past two years the primary isotope product supplied by the Hanford Site has been yttrium-90. Weekly shipments of this medical isotope have been supplied to more than 40 customers who are using yttrium-90 primarily for cancer radioimmunotherapy. As described in PNNL (1999a) (Section 2.6.2), PNNL provided more than 1200 consecutive on-time shipments of yttrium-90 to DOE customers during the two-year period preceding the commercialization of this program. No orders were rejected and there were no unfilled requests for yttrium-90 over the past two years.

Responses are also made to customer inquiries regarding isotopes that are not produced at the Hanford Site. These inquiries are answered within one work day by referring the customers to other DOE Isotope Production Sites or commercial suppliers.

1.10 How does each site manager rate customer satisfaction for his site? For the overall program?

Response:

The level of satisfaction expressed by customers for isotope products supplied by the Hanford Radioisotopes Program has consistently been very high. Our dedication to customer service, as exemplified by the 100% on-time record for more than 1200 shipments of yttrium-90 over the past two years, has earned a number of compliments in letters sent by satisfied customers (summarized in PNNL (1999a), Section 2.6.2). In addition to the timeliness of isotope shipments, the staff involved in isotope production have received a number of compliments for the consistently high quality of isotope products produced at the Hanford Site.

With regard to the overall DOE isotope program, it is our perception that customers are satisfied with the quality of the isotope products that are provided for medical, industrial, and research applications. However, improvements could be made in the availability and timely supply of isotopes that are in demand for therapeutic medical applications and research (e.g., copper-67 and bismuth-212 for early-stage cancer therapy trials and laboratory animal research).

2.0 What should be the long-term role of Government in providing commercial and research isotopes?

Response:

It is our firm belief that the supply of isotopes provided by DOE for medical, industrial, and research applications must be strengthened in the near future. This opinion is reinforced by the conclusions of a recent DOE Expert Panel Report on the future need for medical isotopes (Expert Panel 1999). Many of the radioisotopes currently used for medical diagnosis and therapy of cancer and other diseases are imported from Canada, Europe, and Asia. This situation places the control of isotope availability, quality, and pricing in the hands of non-U.S. suppliers. It is our opinion that the needs of the U.S. customers for isotopes and isotope products are not being adequately served, and that the DOE infrastructure and facilities devoted to the supply of these products must be improved. The need for greater U.S. capabilities to supply isotopes for medicine and research is one of the fundamental bases for our proposal to restart the FFTF as a national DOE resource.

Responses to the Second Set of Questions

The second set of questions received on July 5, 1999, consisted of four questions to which responses are provided below.

1.0 Detail how you set the price of a mCi of a radioisotope. The detail should show if the cost is fully loaded or incremental, and should include labor, materials and parts, facility rental and amortization costs, listing of all actual overhead charges, waste disposal, and all other costs that are tagged to the cost of producing, marketing, selling, and distributing of the product (e.g., customer service, distribution, and ordering). Illustrate the above question with examples for the following radioisotopes: I-131, I-125, Pd-103, P-32, and several research radioisotopes.

Response:

[N.B.: The pages on which the response to the above question is presented are labeled as BUSINESS SENSITIVE to indicate the proprietary nature of the data that are displayed.]

Prices are set by the Department of Energy's Isotope Programs Office (NE-70) using information provided by the Isotope Production Sites in the form of cost/price analyses for all isotope products. The Isotope Production Sites themselves do not set prices for the isotope products produced under the DOE contract. The pricing guidelines used by DOE are described in the annual financial statement, which is audited on a yearly basis by KPMG Peat Marwick. These guidelines state, in brief, that the prices are set on the basis of (1) actual production costs, (2) market value of the product, (3) needs of the research community for the product, and (4) other factors.

In response to the NERAC subcommittee's question, cost/price analyses have been prepared for I-131, I-125, P-32 and Pd-103, as well as several isotopes that are currently in demand for research and early-stage clinical trials. The cost/price analyses were prepared in a format consistent with that used by DOE Isotope Production Sites, and the labor costs are fully burdened. The following are the overhead rates in FY 1999 applied to labor costs by PNNL and the Babcock & Wilcox Hanford Company (BWHC):

- PNNL: G&A + Nuclear Assessment — 44.8%
  Program Development and Marketing — 6.0%
  Service Assessment — 1.0%

- BWHC: Project Management Account — 16.0%
  G&A + Service Assessment — 15.7%

In the cost/price analyses, the labor rates that are used assume that the target preparation, target insertion and retrieval, and irradiation services are performed by BWHC as a subcontractor organization, and the target processing and packaging are performed by PNNL. It is also assumed that PNNL manages the isotopes program office and handles customer sales and service functions.

The following analysis of cost for producing isotopes of interest for research and medical applications is based on several assumptions: (1) the reactor is assumed to be in a steady-state mode of operation, with all equipment and operating procedures in place; (2) the target loading is designed to produce quantities of isotopes per operating cycle that could fill, on the average, about 10 to 20% of the projected U.S. market demand during the period 2005-2010; (3) the irradiation fee for each isotope product is based on the volume of space occupied by the target material in one or more assemblies; (4) all labor costs are fully burdened in accordance with the overhead rates presented above; (5) shipping of the isotope products is FOB Hanford; (6) a 12% added cost multiplier plus a 4% value recovery factor, or 16% total, is applied to the work done by the subcontractor on target fabrication, target testing and qualification, target irradiation, and target insertion and retrieval operations (to recover ~$100M in costs associated with the reactor restart over a 35-year operating period as discussed under the response given above to Question 1.2 in the first set of questions). The cost analyses are performed per target assembly per operating cycle, which ranges from 10 days to 100 days, depending upon the half-life of the isotope product.

1.1 Four Isotope Products Requested by the NERAC Subcommittee

Iodine-131

Iodine-131 ($t_{1/2}$ = 8.0 days) is produced by irradiation of tellurium-130 targets in a hydrided rapid radioisotope retrieval (R3) assembly for 25 days. The iodine-131 product is separated from the tellurium target material by a dry distillation procedure (~400-500 °C in a tubular apparatus evacuated to ~10^{-5} mm) with cryogenic trapping of the iodine gas. The product is analyzed by inductively coupled plasma atomic emission spectroscopy (ICP-AES) for chemical purity, and by gamma energy analysis (GEA) for nuclide content.

Table 1 summarizes the production cost per cycle for production of iodine-131. The product yield at the end of the 25-day cycle is 260 curies, with a production cost of $1.02 per millicurie. This cost compares favorably with the current market prices for radiochemically pure iodine-131, which range from $1.50 to $15.00 per millicurie (depending upon the supplier).

As an example of the activity-based cost analysis that is the basis for the cumulative costs shown in Table 1, the cost estimates for target fabrication, testing and qualification, and insertion and retrieval at FFTF are shown in Table 2. The irradiation charge shown in Table 1 is based on the FFTF business model that is described in detail in the FFTF Scoping Plan (PNNL 1999b).

Table 3 provides details for iodine-131 on the activity-based costing of the target processing, product packaging, and transport to the express mail carrier at a local airport.

Table 1. Summary of Costs for Production at FFTF of Iodine-131

Estimated Budget		I-131		
Activity[a]	Estimate 10 Cycles Per Year	FY99 Estimate Per Cycle	Units Produced (mCi Per Cycle)	Production Cost Per Unit ($/mCi)[b]
Fabrication of Targets (ST0101010)	$758,000	$75,800	260,000	$0.29
Irradiation of Targets (ST0101020)	$1,557,000	$155,700	260,000	$0.60
Chemical Processing (ST0101040)	$60,000	$6,000	260,000	$0.02
Waste Management (ST0101050)	$38,000	$3,800	260,000	$0.01
Quality Assurance (ST0101060)	$77,000	$7,700	260,000	$0.03
ES&H, Regulatory Compliance & Safety (ST0101070)	$13,500	$1,350	260,000	$0.01
Product Packaging (ST0101080)	$22,000	$2,200	260,000	$0.01
Program Management (ST0101090)	$120,500	$12,050	260,000	$0.05
Production Total (ST01)	**$2,646,000**	**$264,600**	**260,000**	**$1.02**
Customer Sales & Service @ 8% of Processing Cost	$15,000	$1,500		
I-131 GRAND TOTAL		**$266,100**		

(a) Shipments are sent FOB Hanford
(b) Based on number of curies at production.

Table 2. Target Fabrication and Testing Costs for Iodine-131

	Target Fabrication at FFTF		Target Testing		Target Insert and Retrieval		Ship to RPL	
	Hrs	Cost	Hrs	Cost	Hrs	Cost	Hrs	Cost
Project Manager	73	$7,260	37	$3,740	2	$200		
Scientist	143	$12,870	77	$6,930	4	$360		
Technician	270	$18,900	133	$9,310	56	$3,920		
On-Site Transport							4	$1,060
Sub-Total Burdened Labor	**486**	**$39,030**	**247**	**$19,980**	**62**	**$4,480**	**4**	**$1,060**
Material 1 Supplies		$5,900						
Material 2 Equipment		$2,950						
Sub-Total		$8,850						
Sub-Total Burdened Material		**$8,850**		**$0**		**$0**		**$0**
Subcontract: On-Site Transportation							2	$530
% Burden Factor								
Sub-Total Burdened Subcontracts		**$0**		**$0**		**$0**	**2**	**$530**
Other: Rad Waste Disposal		$3,000						
Sub-Total Other		**$3,000**		**$0**		**$0**		**$0**
Task Total	**486**	**$50,880**	**247**	**$19,980**	**62**	**$4,480**	**4**	**$1,590**

ST01 FTE Hours	799	
ST01 Burdened FTE Cost		**$64,550**
ST01 Burdened Material		**$8,850**
ST01 Subcontract Cost		**$530**
ST01 Other Cost		**$3,000**
ST01 I-131 Targetry Cost		**$76,930**
Value Recovery & Added Cost Multipliers	16%	**$12,300**
GRAND TOTAL		**$89,230**

Table 3. Radiochemical Processing, Packaging, and Shipping Costs for Iodine-131

	Preparation and Receiving		Process Target		Analytical and QA/QC		Package and Ship Product	
	Hrs	Cost	Hrs	Cost	Hrs	Cost	Hrs	Cost
Technical Specialist A	4	$350						
Manager A	3	$530						
Manager B	2	$300						
Scientist	2	$250	7	$875			1	$125
Technician A	6	$630	24	$2,520			1	$105
Technician B	4	$420			6	$630	3	$315
Technical Specialist B							1	$95
On-site Transport							2	$530
Radiation Specialist	4	$420	8	$840			1	$105
Analytical					4	$6,965		
QA Specialist					1	$105		
Sub-Total Burdened Labor	**25**	**$2,900**	**39**	**$4,235**	**11**	**$7,700**	**9**	**$1,275**
Material 1 Packaging Material								$200
Material 2 Supplies & Chemicals				$700				
Sub-Total Unburdened Material				$700				$200
% Burden Factor 19.4%				$135				$40
Sub-Total Burdened Material		**$0**		**$835**		**$0**		**$240**
Subcontract: On-Site Transportation				$265				$550
% Burden Factor 19.4%				$50				$105
Sub-Total Burdened Subcontracts		**$0**		**$315**		**$0**		**$655**
Other: Rad Waste Disposal			3	$800				
Sub-Total Other		**$0**	**3**	**$800**		**$0**		**$0**
Task Total	**25**	**$2,900**	**42**	**$6,185**	**11**	**$7,700**	**9**	**$2,170**

ST01 FTE Hours	87	
ST01 Burdened FTE Cost		**$16,110**
ST01 Burdened Material		**$1,075**
ST01 Subcontract Cost		**$970**
ST01 Other Cost		**$800**
ST01 I-131 Processing Cost		**$18,955**
Customer Sales & Service @ 8%		**$1,500**
GRAND TOTAL		**$20,455**

Iodine-125

Iodine-125 ($t_{1/2}$ = 60.1 days) will be produced by irradiation of xenon-124 gas in a gas loop assembly for 100 days. The target gas is transmuted to xenon-125 ($t_{1/2}$ = 17.1 hr), which then decays to the iodine-125 product that is cryogenically trapped. The inert xenon target gas and the krypton gas used to push xenon through the gas line are distilled off, and the iodine-125 product is removed chemically from the wall of the cryotrap. The product is then analyzed for chemical purity and radionuclide content. The production costs for 43.3 curies of iodine-125 are shown in Table 4. The unit production cost is $14.63 per millicurie, which is within the range of market prices of $8 to $20 per millicurie for iodine-125.

Palladium-103

Palladium-103 ($t_{1/2}$ = 17.0 days) will be produced by irradiation of palladium-102 in a hydrided R3 assembly for 25 days. Following irradiation, the target material will be dissolved in nitric acid or aqua regia, evaporated to dryness, brought back into solution with the acid selected by the customer, and analyzed for chemical purity and radionuclide content. No separation will be made of the palladium-102 target material and the palladium-103 product. The production costs for 48 curies of palladium-103 are shown in Table 6. The unit production cost is $7.46 per millicurie, which is slightly below the market price of $9 to $12 per millicurie.

Table 4. Summary of Costs for Production at FFTF of Iodine-125

Estimated Budget		I-125		
Activity[a]	Estimate 3 Cycles Per Year	FY99 Estimate Per Cycle	Units Produced (mCi Per Cycle)	Production Cost Per Unit ($/mCi)[b]
Fabrication of Targets (ST0101010)	$238,800	$79,600	43,330	$1.84
Irradiation of Targets (ST0101020)	$1,556,100	$518,700	43,330	$11.97
Chemical Processing (ST0101040)	$23,550	$7,850	43,330	$0.18
Waste Management (ST0101050)	$10,500	$3,500	43,330	$0.08
Quality Assurance (ST0101060)	$23,100	$7,700	43,330	$0.18
ES&H, Regulatory Compliance & Safety (ST0101070)	$4,050	$1,350	43,330	$0.03
Product Packaging (ST0101080)	$6,600	$2,200	43,330	$0.05
Program Management (ST0101090)	$38,850	$12,950	43,330	$0.30
Production Total (ST01)	**$1,901,550**	**$633,850**	**43,330**	**$14.63**
Customer Sales & Service @ 8% of Processing Cost	$5,100	$1,700		
I-125 GRAND TOTAL		**$635,550**		

(a) Shipments are sent FOB Hanford.
(b) Based on number of curies at production.

Table 5. Summary of Costs for Production at FFTF of Palladium-103

Estimated Budget		Pd-103		
Activity[a]	Estimate 10 Cycles Per Year	FY99 Estimate Per Cycle	Units Produced (mCi Per Cycle)	Production Cost Per Unit ($/mCi)[b]
Fabrication of Targets (ST0101010)	$3,218,000	$321,800	48,000	$6.70
Irradiation of Targets (ST0101020)	$62,500	$6,250	48,000	$0.13
Chemical Processing (ST0101040)	$41,000	$4,100	48,000	$0.09
Waste Management (ST0101050)	$35,000	$3,500	48,000	$0.07
Quality Assurance (ST0101060)	$77,000	$7,700	48,000	$0.16
ES&H, Regulatory Compliance & Safety (ST0101070)	$7,250	$725	48,000	$0.02
Product Packaging (ST0101080)	$22,000	$2,200	48,000	$0.05
Program Management (ST0101090)	$120,250	$12,025	48,000	$0.25
Production Total (ST01)	**$3,583,000**	**$358,300**	**48,000**	**$7.46**
Customer Sales & Service @ 8% of Processing Cost	$13,000	$1,300		
Pd-103 GRAND TOTAL		**$359,600**		

(a) Shipments are sent FOB Hanford.
(b) Based on number of curies at production.

Table 6. Summary of Costs for Production at FFTF of Phosphorus-32

Estimated Budget		P-32		
Activity[a]	Estimate 10 Cycles Per Year	FY99 Estimate Per Cycle	Units Produced (mCi Per Cycle)	Production Cost Per Unit ($/mCi)[b]
Fabrication of Targets (ST0101010)	$40,500	$4,050	700	$5.79
Irradiation of Targets (ST0101020)	$31,000	$3,100	700	$4.43
Chemical Processing (ST0101040)	$39,000	$3,900	700	$5.57
Waste Management (ST0101050)	$35,000	$3,500	700	$5.00
Quality Assurance (ST0101060)	$77,000	$7,700	700	$11.00
ES&H, Regulatory Compliance & Safety (ST0101070)	$9,500	$950	700	$1.36
Product Packaging (ST0101080)	$22,000	$2,200	700	$3.14
Program Management (ST0101090)	$14,500	$1,450	700	$2.07
Production Total (ST01)	**$268,500**	**$26,850**	**700**	**$38.36**
Customer Sales & Service @ 8% of Processing Cost	$15,000	$1,500		
P-32 GRAND TOTAL		**$28,350**		

(a) Shipments are sent FOB Hanford.
(b) Based on number of curies at production.

Phosphorus-32

Phosphorus-32 ($t_{1/2}$ = 14.3 days) is produced by irradiation of a sulfur-32 target in an R3 assembly for 25 days. The product isotope is separated from the sulfur target material by dissolving the target in carbon disulfide and passing the solution through an activated carbon column. The column is then eluted with carbon disulfide to desorb the sulfur, dried, and eluted with warm (75 °C) nitric acid (5 M) to recover the phosphorus-32 product. The product is analyzed for chemical and nuclide purity. The production costs for 700 millicuries of phosphorus-32 are shown in Table 6. The unit production cost is $38.36 per millicurie, which is within the range of market prices of $25 to $85 per millicurie of phosphorus-32.

1.2 Other Examples of Research Isotopes

In this section of the report, cost analyses are presented for the production at FFTF of six isotopes that are of interest for cancer therapy (e.g., copper-67, rhenium-186 and rhenium-188 derived from a tungsten-188 generator), bone pain palliation in patients with advanced metastatic bone cancer (e.g., strontium-89 and tin-117m), and for calibration of gamma imaging systems (gadolinium-153).

Copper-67

Copper-67 ($t_{1/2}$ = 2.58 days) is produced by irradiating a zinc-67 oxide target in an R3 assembly for 10 days. Following irradiation, the zinc oxide is dissolved in sulfuric acid, which is then placed in an electrochemical cell and the copper-67 deposited on a platinum electrode. After 30 min. the solution containing zinc is removed and replaced with fresh acid solution, after which the copper deposition on the platinum electrode is continued for another 30 min. This procedure is repeated twice to ensure a high purity of the deposited copper-67. The platinum electrode is then removed and the deposited copper is dissolved by immersing the electrode in concentrated nitric acid. This solution is evaporated to dryness and the copper-67 product is then dissolved in an acid solution specified by the customer. The final product is analyzed for chemical purity and radionuclide content. The production costs for 1.85 curies of copper-67 are shown in Table 7. The unit production cost is $55.16 per millicurie, which compares favorably with the market price of $93 per millicurie.

Gadolinium-153

Gadolinium-153 ($t_{1/2}$ = 242 days) is produced by irradiation of natural europium-151/153 oxide pellets in a long-irradiation vehicle (LIV) for 100 days. Following irradiation, the target material is dissolved in acetic acid and the solution is contacted with granular zinc metal in an inert argon atmosphere to convert the europium (III) to europium (II). A sulfate salt is then added to precipitate the europium (II), thereby separating it from the gadolinium-153 product. This procedure is repeated three times, at which point the gadolinium-153 has the 99.999% level of purity required for its use as a calibration isotope. The purified gadolinium-153 is then subjected to oxalate precipitation,

Table 7. Summary of Costs for Production at FFTF of Copper-67

Estimated Budget		Cu-67		
Activity[a]	Estimate 25 Cycles Per Year	FY99 Estimate Per Cycle	Units Produced (mCi Per Cycle)	Production Cost Per Unit ($/mCi)[b]
Fabrication of Targets (ST0101010)	$982,500	$39,300	1850	$21.24
Irradiation of Targets (ST0101020)	$777,500	$31,100	1850	$16.81
Chemical Processing (ST0101040)	$230,000	$9,200	1850	$4.97
Waste Management (ST0101050)	$87,500	$3,500	1850	$1.89
Quality Assurance (ST0101060)	$192,500	$7,700	1850	$4.16
ES&H, Regulatory Compliance & Safety (ST0101070)	$33,750	$1,365	1850	$0.73
Product Packaging (ST0101080)	$55,000	$2,200	1850	$1.19
Program Management (ST0101090)	$192,500	$7,700	1850	$4.16
Production Total (ST01)	**$2,551,250**	**$102,050**	**1850**	**$55.16**
Customer Sales & Service @ 8% of Processing Cost	$31,250	$1,250		
Cu-67 GRAND TOTAL		**$103,300**		

(a) Shipments are sent FOB Hanford.
(b) Based on number of curies at production.

followed by filtration and calcination to gadolinium oxide. These procedures are the subject of a U.S. patent application filed in August 1998. The final product is analyzed for chemical purity and radionuclide content. The production costs for 66 curies of gadolinium-153 are shown in Table 8. The unit production cost is $1.04 per millicurie, which compares favorably with the market price of $3.00 per millicurie.

Rhenium-186

Rhenium-186 ($t_{1/2}$ = 3.78 days) is produced by irradiation of rhenium-185 in a hydrided R3 assembly for 25 days. Following irradiation, the target material is dissolved in nitric acid or aqua regia, evaporated to dryness, and redissolved in an acid specified by the customer. No effort is made to separate the rhenium-185 target material from the rhenium-186 product. The final product is analyzed for chemical purity and radionuclide content. The production costs for 15 curies of rhenium-186 are shown in Table 9. The unit production cost is $1.43 per millicurie, which compares favorably with the market price of $7.00 per millicurie.

Tin-117m

Tin-117m ($t_{1/2}$ = 13.6 days) is produced by the irradiation of tin-116 in a hydrided R3 assembly for 25 days. Following irradiation, the target material is dissolved in nitric acid or aqua regia, evaporated to dryness, and redissolved in an acid specified by the customer. No effort is made to separate the tin-116 target material from the tin-117m product. The product is analyzed for chemical purity and radionuclide content. The production costs for 1 curie of tin-117m are shown in Table 10. The unit production cost is $29.75 per millicurie.

Table 8. Summary of Costs for Production at FFTF of Gadolinium-153

Estimated Budget		Gd-153		
Activity[a]	Estimate 3 Cycles Per Year	FY99 Estimate Per Cycle	Units Produced (mCi Per Cycle)	Production Cost Per Unit ($/mCi)[b]
Fabrication of Targets (ST0101010)	$27,000	$9,000	66,000	$0.14
Irradiation of Targets (ST0101020)	$93,000	$31,000	66,000	$0.47
Chemical Processing (ST0101040)	$32,700	$10,900	66,000	$0.17
Waste Management (ST0101050)	$10,500	$3,500	66,000	$0.05
Quality Assurance (ST0101060)	$23,100	$7,700	66,000	$0.12
ES&H, Regulatory Compliance & Safety (ST0101070)	$4,500	$1,500	66,000	$0.02
Product Packaging (ST0101080)	$6,600	$2,200	66,000	$0.03
Program Management (ST0101090)	$9,300	$3,100	66,000	$0.05
Production Total (ST01)	**$206,700**	**$68,900**	**66,000**	**$1.04**
Customer Sales & Service @ 8% of Processing Cost	$6,000	$2,000		
GD-153 GRAND TOTAL		**$70,900**		

(a) Shipments are sent FOB Hanford.
(b) Based on number of curies at production.

Table 9. Summary of Costs for Production at FFTF of Rhenium-186

Estimated Budget		Re-186		
Activity[a]	Estimate 10 Cycles Per Year	FY99 Estimate Per Cycle	Units Produced (mCi Per Cycle)	Production Cost Per Unit ($/mCi)[b]
Fabrication of Targets (ST0101010)	$29,500	$2,950	15,000	$0.20
Irradiation of Targets (ST0101020)	$7,750	$775	15,000	$0.05
Chemical Processing (ST0101040)	$26,750	$2,675	15,000	$0.18
Waste Management (ST0101050)	$35,000	$3,500	15,000	$0.23
Quality Assurance (ST0101060)	$77,000	$7,700	15,000	$0.51
ES&H, Regulatory Compliance & Safety (ST0101070)	$7,500	$750	15,000	$0.05
Product Packaging (ST0101080)	$22,000	$2,200	15,000	$0.15
Program Management (ST0101090)	$9,500	$950	15,000	$0.06
Production Total (ST01)	**$215,000**	**$21,500**	**15,000**	**$1.43**
Customer Sales & Service @ 8% of Processing Cost	$13,000	$1,300		
Re-186 GRAND TOTAL		**$22,800**		

(a) Shipments are sent FOB Hanford.
(b) Based on number of curies at production.

Table 10. Summary of Costs for Production at FFTF of Tin-117m

Estimated Budget		Sn-117m		
Activity[a]	Estimate 10 Cycles Per Year	FY99 Estimate Per Cycle	Units Produced (mCi Per Cycle)	Production Cost Per Unit ($/mCi)[b]
Fabrication of Targets (ST0101010)	$67,750	$6,775	1000	$6.78
Irradiation of Targets (ST0101020)	$35,000	$3,500	1000	$3.50
Chemical Processing (ST0101040)	$38,750	$3,875	1000	$3.88
Waste Management (ST0101050)	$35,000	$3,500	1000	$3.50
Quality Assurance (ST0101060)	$77,000	$7,700	1000	$7.70
ES&H, Regulatory Compliance & Safety (ST0101070)	$7,500	$750	1000	$0.75
Product Packaging (ST0101080)	$22,000	$2,200	1000	$2.20
Program Management (ST0101090)	$14,500	$1,450	1000	$1.45
Production Total (ST01)	**$297,500**	**$29,750**	**1000**	**$29.75**
Customer Sales & Service @ 8% of Processing Cost	$12,500	$1,250		
Sn-117m GRAND TOTAL		**$31,000**		

(a) Shipments are sent FOB Hanford.
(b) Based on number of curies at production.

Strontium-89

Strontium-89 ($t_{1/2}$ = 50.5 days) is produced by irradiation of strontium-88 carbonate in a hydrided LIV assembly for 100 days. The strontium-89 is purified to remove traces of contaminants using a strontium-selective chromatographic resin (Sr-Spec). The column is rinsed with 3 M nitric acid to remove all elements other than strontium, and the strontium is then eluted with 0.3 M nitric acid. The final product is evaporated to dryness and then dissolved in an acid specified by the customer. No effort is made to separate the strontium-89 from other species of strontium contained in the final product. The final product is analyzed for chemical purity and radionuclide content. The production costs for 4.2 curies of strontium-89 are shown in Table 11. The unit production cost is $10.83 per millicurie, which compares favorably with the market price of $113 per millicurie.

Tungsten-188

Tungsten-188 ($t_{1/2}$ = 69.4 days) is produced by irradiation of tungsten 186 in a hydrided LIV assembly for 100 days. The primary use of the tungsten-188 is as a generator material for the rhenium-188 decay product. The target is dissolved in nitric acid or aqua regia, evaporated to dryness, and redissolved in an acid specified by the customer. No effort is made to separate the tungsten-186 target from the tungsten-188 product. The final product is analyzed for chemical purity and radionuclide content. The production costs for 11 curies of tungsten-188 are shown in Table 12. The unit production cost is $12.86 per millicurie, which is higher than the current market price of $4 to $5 per millicurie.

Table 11. Summary of Costs for Production at FFTF of Strontium-89

Estimated Budget		Sr-89		
Activity[a]	Estimate 3 Cycles Per Year	FY99 Estimate Per Cycle	Units Produced (mCi Per Cycle)	Production Cost Per Unit ($/mCi)[b]
Fabrication of Targets (ST0101010)	$21,000	$7,000	4200	$1.67
Irradiation of Targets (ST0101020)	$46,500	$15,500	4200	$3.69
Chemical Processing (ST0101040)	$17,700	$5,900	4200	$1.40
Waste Management (ST0101050)	$10,500	$3,500	4200	$0.83
Quality Assurance (ST0101060)	$23,100	$7,700	4200	$1.83
ES&H, Regulatory Compliance & Safety (ST0101070)	$6,600	$2,200	4200	$0.52
Product Packaging (ST0101080)	$6,600	$2,200	4200	$0.52
Program Management (ST0101090)	$4,500	$1,500	4200	$0.36
Production Total (ST01)	**$136,500**	**$45,500**	**4200**	**$10.83**
Customer Sales & Service @ 8% of Processing Cost	$4,350	$1,450		
Sr-89 GRAND TOTAL		**$46,950**		

(a) Shipments are sent FOB Hanford.
(b) Based on number of curies at production.

Table 12. Summary of Costs for Production at FFTF of Tungsten-188

Estimated Budget		W-188		
Activity[a]	Estimate 3 Cycles Per Year	FY99 Estimate Per Cycle	Units Produced (mCi Per Cycle)	Production Cost Per Unit ($/mCi)[b]
Fabrication of Targets (ST0101010)	$352,800	$117,600	11,000	$10.69
Irradiation of Targets (ST0101020)	$2,700	$900	11,000	$0.08
Chemical Processing (ST0101040)	$16,800	$5,600	11,000	$0.51
Waste Management (ST0101050)	$10,500	$3,500	11,000	$0.32
Quality Assurance (ST0101060)	$23,100	$7,700	11,000	$0.70
ES&H, Regulatory Compliance & Safety (ST0101070)	$2,850	$950	11,000	$0.09
Product Packaging (ST0101080)	$6,600	$2,200	11,000	$0.20
Program Management (ST0101090)	$9,000	$3,000	11,000	$0.27
Production Total (ST01)	**$424,350**	**$141,450**	**11,000**	**$12.86**
Customer Sales & Service @ 8% of Processing Cost	$4,350	$1,450		
W-188 Grand Total		**$142,900**		

(a) Shipments are sent FOB Hanford.
(b) Based on number of curies at production.

2.0 What process, mechanism, and organizational structure do you have for the timely distribution of the produced product?

Response:

Packaging and distribution of isotope products are directly coupled to the isotope production process. Upon preparation of a vial of isotope to the specifications provided by a customer, the vial is transferred into a lead container (pig) with an overpack and taken to an adjacent laboratory. A member of the PNNL isotope production team then packages the pig into a labeled, DOT-approved container and inserts customer-specific data. An offsite Radioactive Shipment Record and other paperwork required by the Department of Transportation are attached to the drum and it is taken to the Richland airport (a distance of about 2 miles) for shipment by Airborne Express to the customer. In addition to Airborne Express, other major express mail carriers such as Federal Express have offices at the three airports located within a 15-mile radius of the Hanford Site, and are used for shipping of isotopes to some international locations. The overall time that elapses between preparation of the customer vial and its delivery to the express mail carrier is typically 2 to 4 hours.

A detailed flowchart showing all of the activities involved in the packaging and shipping of an isotope product is presented in PNNL (1999a) (Section 2.6.1). PNNL has contracts with two subcontractors that assist with the shipping of isotopes: (1) DynCorp transports isotope samples from the production laboratory at the RPL to the 222S Building for ICP analysis, and (2) Waste Management Federal Services transports the isotope shipping containers from the RPL to the airport for delivery to the express mail carrier. All containers that are sent to customers contain A-type quantities of isotopes to minimize shielding requirements and avoid delays in isotope delivery. Shipments are made FOB Hanford, and the customer pays the costs of express mail shipping. In general, the record of Airborne Express and other carriers has been very good, with an average on-time delivery record of 98% for more than 1200 shipments over the past two years.

3.0 What process, mechanism, and organizational structure do you have for customer service?

Response:

The customer sales and service functions are conducted as part of the Hanford Radioisotopes Program at a total level of effort of 1.5 FTE. Customer orders are taken by telephone, E-mail, or FAX and compiled into a spreadsheet that forms the basis for the weekly isotope production campaign. Care is taken to note all customer-specific ordering information, and to compile all of the necessary paperwork such as a copy of the customer's radioactive materials license in advance of shipping (to ensure that the customer can receive the shipment). The sales and service staff also work with PNNL and Waste Management Federal Services transportation specialists to identify the most efficient shipping routes and air carriers for international orders (about 50% of the total isotope sales in 1997-1999). Special efforts are made to accommodate special requests, especially when the isotope is required for the treatment of critically ill cancer patients. The response time under those circumstances can be as little as a few hours. Approximately 350 special requests have been met successfully over the past 10 years.

If FFTF undertakes isotope production in 2004, it is expected that the customer sales and service functions will be increased at that time to a level of effort of approximately 5.5 FTE. In addition, opportunities for privatization of this component of the isotopes program are being explored through ongoing discussions with commercial companies.

4.0 Will you sign contracts that guarantee delivery at the contracted time of delivery, and where the contract has penalty clauses for untimely delivery of the specified product?

Response:

PNNL supplies isotopes under a standard DOE customer service agreement, and handles invoicing and all other aspects of each sales transaction. All isotope products are shipped FOB Hanford, and become the responsibility of the customer at the time of shipment. Accordingly, our service contracts do not have penalty clauses for untimely delivery by the express mail carrier. However, in practice we have routinely waived all charges if the delivery of an isotope product is delayed and the customer is unable to use it. This waiver of charges is subject to DOE approval, but the Isotope Programs Office (NE-70) staff have consistently permitted a waiver to be made under reasonable circumstances. In our opinion, this practice is more "customer friendly" than introducing a penalty clause for untimely delivery in the customer service contract.

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