The U.S. Knowledge Preservation Program for Fast Flux Test Facility Data

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Abstract. An important goal of the U.S. Department of Energy's Office of Nuclear Energy is to preserve the knowledge that has been gained in the United States on Liquid Metal Reactors by collecting, organizing and preserving technical information that could support the development of an environmentally and economically sound nuclear fuel cycle. The FFTF is the most recent LMR to operate in the United States and its 10 years of operation provide a very useful framework for testing the advances in LMR safety technology based on passive safety features. Such information may be of increased importance to new designs after the events at Fukushima. This report describes the knowledge preservation activities related to FFTF legacy information including data from the design, construction, startup, and operation of the reactor and summarizes the current status and accomplishments of the FFTF knowledge preservation activities and lessons learned.

Key Words: FFTF; Lessons Learned; Liquid Metal Fast Reactor; knowledge preservation.

1. Introduction

The Fast Flux Test Facility (FFTF) is the most recent Liquid Metal Reactor (LMR) to be designed, constructed, and operated by the U.S. Department of Energy (DOE). FFTF operated from 1982 to 1992. The technologies employed in designing and constructing this reactor, along with information obtained from tests conducted during its operation, are currently being secured and archived by the Department of Energy's Office of Nuclear Energy. Project efforts to retrieve and preserve critical information related to FFTF have been periodically updated and presented in scientific and technical forums [1][2][3][4][5][6][7][8][9][10]. The engineering knowledge from the design, construction, and operation of FFTF represents a huge investment and cannot be duplicated.

Knowledge preservation at the FFTF is focused on the areas of design, construction, startup, and operation of the reactor. The primary function of the FFTF was to be a test reactor. Therefore, the focus is to preserve information obtained from the irradiation testing of fuels and materials performed in the FFTF. In order to ensure protection of information at risk largely because of aging/degrading storage media and no centralized document repository, the program to date has focused on sequestering of FFTF records, secure retrieval, and compilation of lessons learned.

Located on the Hanford Site in Washington state, the FFTF reactor plant is one of the facilities intended for decontamination and decommissioning consistent with the cleanup mission on this site. The reactor facility has been deactivated and is being maintained in a "cold and dark" minimal surveillance and maintenance mode until final decommissioning is pursued.

2. FFTF Description

A picture of the FFTF plant and its location at the Hanford site in Washington State is shown in FIG. 1. FIG. 2 provides a diagram of the FFTF reactor plant. Since it was designed as a flexible test reactor, the FFTF did not have steam generators but included dump heat exchangers. It was designed to provide a prototypic test bed with respect to temperature, neutron flux level, and gamma ray spectra for fast reactor fuels and materials testing. The FFTF was designed as the most extensively instrumented fast spectrum test reactor in the world, with proximity instrumentation of temperature and flow rate for each core component as well as contact instrumentation and gas and electrical connections for special test positions. FIG. 3 shows an example FFTF instrumented test assembly.

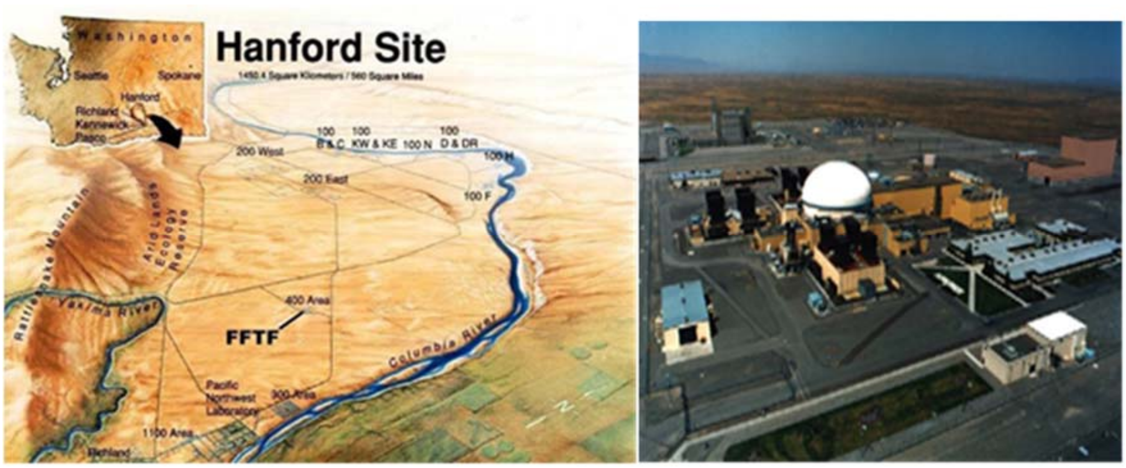

FIG. 1. FFTF at the Hanford Site.

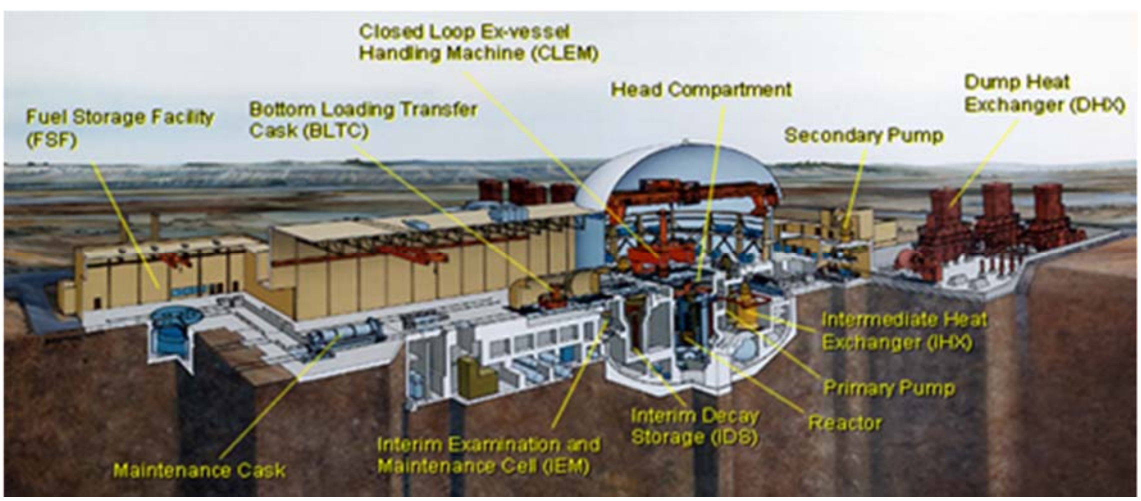

FIG. 2. FFTF Reactor Plant

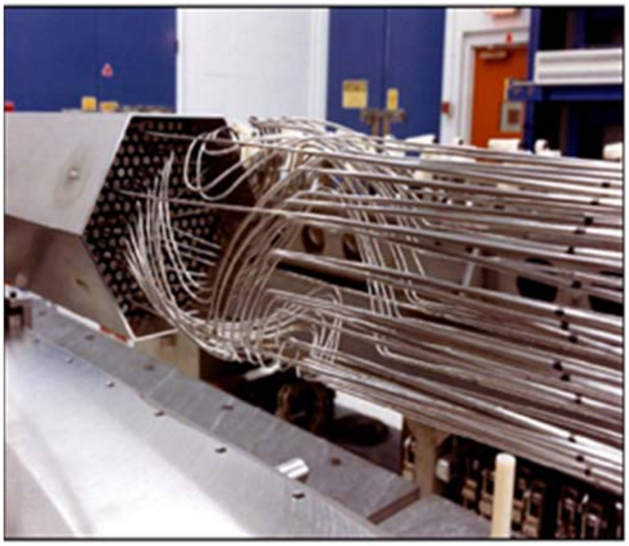

FIG. 3. Instrumented FFTF Test.

Special FFTF data measurement features include:

- Primary and secondary loop hot and cold leg temperatures and flow rates, neutron detectors, pump speed indicators
- Assembly outlet temperatures for each core location with a response time of minutes
- Fast response thermocouples for assembly outlet temperatures for two core locations with a response time of seconds
- Two fuel tests with high response wire wrap thermocouples on fuel pins during the natural circulation tests at startup
- The Plant Data System (PDS) recorded 1300 variables at 1-60 second intervals
- The Experimenters Data System (EDS) recorded several hundred selected parameters at up to 0.1 second intervals

FFTF testing data falls in the following categories:

- Startup Testing: The Acceptance Test Program documented the design and startup process for the reactor. The Reactor Characterization Program provided detailed neutron and gamma ray characterization of the in-core and ex-core environments.
- Passive Safety Testing: The extensive instrumentation and characterization of the reactor and heat transport system supported a wide variety of tests performed to demonstrate the safety characteristics of LMRs. FFTF provided important operational data on the performance of liquid sodium as a heat transport medium and demonstrated the reliability and efficiency of pumps, valves, and other vital components for more than 20 years. During operation, the Passive Safety Test Program included steady state and dynamic measurements of reactivity feedback with changes in power, coolant flow rate, and coolant temperatures.
- Plant Data: Detailed plant data acquired during operation, such as assembly outlet temperatures and flow rates, coolant system temperatures and flow rates, and reactor vessel temperatures, were recorded on magnetic tapes by the Plant Data System (PDS) or Experimenters Data System (EDS). Operational and test data at sub-second frequencies were routinely recorded on magnetic tape by these data acquisition systems.

- Fuels and Materials Irradiation Testing: Irradiation tests were successfully conducted for a wide variety of test assemblies such as advanced fuels (MOX, metal, carbide, nitride), blankets, control and shim absorbers, cladding and duct materials, structural materials, reflectors, and spectral tailoring assemblies for special tests.

3. Startup Testing

3.1.Startup Process

The FFTF underwent a systematic, rigorous, and comprehensive startup of each plant system to verify that the design, documentation, installation, and operation conformed to the design and safety requirements specified in the System Design Documents (SDDs) and the Final Safety Analysis Report (FSAR). Formal testing began in 1978, but some preliminary testing had been conducted as early as 1974. The Startup Test Program was officially completed in 1982 with 166 tests performed. The architect-engineer and prime constructor of FFTF was the Bechtel Corporation, who was also the design contractor for many of the plant's auxiliary systems. The main design contractor for the reactor was the Westinghouse Advanced Reactor Division (ARD) with many of the reactor support systems designed by Atomics International (AI) and Aerojet Manufacturing Company (AMCO). When the AI and AMCO designs were completed, the Hanford Engineering Development Laboratory (HEDL) assumed responsibility for their designs through the construction and startup phases. The overall startup activities were controlled by the Westinghouse Hanford Company (WHC), which managed the HEDL for DOE. DOE project control of FFTF was managed through a local project office.

The startup testing process consisted of three types of tests: construction tests, pre-turnover engineering tests, and acceptance tests. The first two types of tests were conducted prior to formal turnover of a plant system from Bechtel to HEDL and the acceptance tests were then performed after turnover. Because the timing of system turnovers varied, it was not uncommon for all three types of tests to run concurrently during the startup period. The main document for control of the FFTF startup testing was the FFTF Startup Test Plan, which describes the administrative procedures used and the general responsibilities of the various organizations involved. Construction testing was conducted by Bechtel on all portions of the FFTF to assure that construction was completed in accordance with the drawings and specifications. Pre-turnover engineering tests had to be performed at a particular step in the construction sequence before further assembly made later testing and correction of problems impractical or impossible. Turnover was the transfer of custody (responsibility for operation, maintenance and safety) of a portion of the plant from the construction contractor (Bechtel) to the operating contractor (HEDL). The startup testing documents, including QA records, have been identified and preserved.

3.2.Acceptance Testing

The Acceptance Testing Program (ATP) was conducted by HEDL personnel following completion of construction testing and turnover to provide confirmation of design, construction and functional performance of the FFTF. Acceptance Testing was divided into five phases: (1) Pre-operational Tests, (2) System Startup Tests, (3) Hot Functional Tests, (4) Nuclear Startup Tests, and (5) Power Ascension Tests. Each of the five phases included the following documents: (1) Test Resume (used for test planning and includes a summary of test objectives, plant status required, and any special test equipment required), (2) Test Specification, (3) Test Procedure, (4) Test Operating Procedures, (5) Calibration Procedures, (6) Data report, and (7) Evaluation Report.

3.3. Initial Physics Tests

The initial physics testing during the ATP provided the first confirmation of the predictions and prediction techniques developed during the design process. The initial fuel loading was carried out by tri-sector (1/3rd of the core) to accommodate the special fuel handling equipment in FFTF. Data preserved from the initial critical configuration and subsequent full-core critical configuration with fresh fuel prior to any power operation would be invaluable for use as experimental benchmarks in the development of reactor physics/kinetics codes and models. Subcritical reactivity effects were assessed with the Modified Source Multiplication (MSM) technique that was calibrated with inverse kinetics analyses of rod drops. Two different dynamic-testing methods confirmed the basic reactivity feedback model of the FFTF and its wide margin to instability. The first method consisted of scramming a nearly fully inserted rod to initiate a power transient. This “rod drop” technique is similar to that used at EBR-II for many years. The second method, Multi-Frequency Binary Sequence (MFBS), moved a control rod in small, programmed steps about a mean rod position. The reactivity feedback parameter was measured as a function of the driving signal frequency. The agreement between the two methods over the range of frequencies important for FFTF stability evaluations was excellent, especially considering the significant differences in the experimental techniques. FFTF experience with these and other operational physics tests can be found in the archived reports and extracted from the plant data. Initial physics test reports have been identified and archived.

3.4. Reactor Characterization Testing

The primary purpose of the Reactor Characterization Program (RCP) was to ensure that the test conditions supplied to FFTF irradiation experimenters were accurate. It also provided data at the high temperatures encountered in operating LMRs that could be used to adjust the calculational tools used at the FFTF and future LMRs.

Prior to full power operation, zero power testing was conducted in a special ‘In Reactor Thimble’, a special central test assembly with access through the reactor head that provided a controlled environment at ~10°C near the core center for testing. Measurements included both passive and active neutron and gamma detectors, including:

- Absolute fission chambers (^{232}Th, ^{233}U, ^{235}U, ^{238}U, ^{237}Np, ^{239}Pu, ^{240}Pu, and ^{241}Pu)
- Proton recoil proportional counters
- Nuclear research emulsions
- Traversable fission chambers (^{232}Th, ^{233}U, ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, ^{241}Pu)
- Neutron dosimetry including short lived reaction products ^{23}Na(n,γ)^{24}Na, ^{41}K(n,p)^{41}Ar, ^{81}Br(n, γ)^{82}Br
- Gamma ray calorimeters, ionization chambers, Compton recoil spectrometers, Thermo-Luminescent Dosimeters (TLDs)

Special core and reflector assemblies containing approximately 2200 dosimeters up to ± 150 cm from core mid-plane to characterize the neutron flux and reaction rate environment were irradiated at full power in the first 8.6 effective full power days of operation during the startup core characterization tests of the ATP. Burnup measurements were also made on special removable fuel pins irradiated during this test. Absolute fission rate measurements confirmed the accuracy of the thermal-hydraulic power calibration instruments and methods. The data provided detailed neutron spectrum information and spatial reaction rate detail. One of the most significant uses of the data was to validate the cross sections used in FFTF reload designs. This data could be used for the validation of new codes and models. FFTF experience with these physics tests was preserved in the archived reports [8].

4. Passive Safety Testing

Accidents at Unit 4 of the Chernobyl Station and Unit 2 at Three Mile Island changed the safety paradigm of the nuclear power industry. New emphasis was placed on assured safety based on intrinsic plant characteristics that protect not only the public, but the significant investment in the plant as well. Such plants can be considered to be “passively safe” since no active sensor/alarm system or human intervention is required to bring the reactor to a safe shutdown condition. The LMR has several key characteristics needed for a passively safe reactor: reactor coolant with superior heat transfer capability and very high boiling point, low system pressures, and reliable negative reactivity feedback. The credibility of a passively safe LMR design rests on the validity of analytic methods used to predict passive safety performance and the availability of relevant test data to calibrate design tools. Passive safety design requires refined analysis methods for transient events because treatment of the detailed reactivity feedbacks is important. Similarly, analytic tools should be calibrated against actual test experience in existing LMR facilities. The FFTF was intentionally designed to be the most highly instrumented test reactor ever built. Data monitoring capabilities included in-vessel and ex-vessel neutron flux, coolant outlet temperature and flow for every core location, as well as heat transport system temperatures and flows. In addition, eight core locations allowed extensive contact instrumentation for tests. Fast response thermocouples provided an unprecedented level of detail. FFTF experience with all of these passive safety tests can be found in the archived reports and further details can be extracted from the archived plant data as described in the next sections.

4.1.Plant Data

Detailed plant data acquired during these passive safety tests, such as assembly outlet temperatures and flow rates, coolant system temperatures and flow rates, and reactor vessel temperatures, were recorded on magnetic tapes by the normal Plant Data System (PDS) or Experimenters Data System (EDS). During plant operation and testing periods, operational and test data were routinely recorded on magnetic tape by these data acquisition systems. The PDS recorded normal plant parameters (over 1,300 variables) at frequencies up to once per second. The EDS recorded key parameters that were a subset of PDS-recorded parameters, data from instrumented tests in the reactor, plus several reactor parameters used in experiment analysis that were not recorded by the PDS. Recording frequencies on the EDS were as high as once every 0.1 sec., but for the PSTs and related tests, response times did not warrant recording frequencies higher than once per second. The number of parameters recorded by the EDS varied depending on how many instrumented tests were in the reactor. With no instrumented tests, the number of EDS-recorded parameters was normally 100 - 120.

In 2009 the FFTF PST plant data was prioritized for retrieval and processing to ensure that it would be available for future use. These tapes were recovered, copied and converted to ASCII text files. One text file was created for each PDS- or EDS-recorded tape. Documents relevant to PST were recovered, scanned, and catalogued [1] and all PST and related tests, and the time periods they were conducted, were identified. The Passive Safety Testing data has been successfully located, retrieved, extracted, and preserved on modern media. A web-based FFTF PST database is being created for accessing this data.

5. Potential Impact of FFTF Knowledge Preservation On the Design of New LMRs

The future accessibility of information from the design, construction, and operation of the FFTF was in doubt due to media deterioration and the lack of key word linkage to previous programs. In order to ensure protection of information at risk, the program has focused on sequestering unsecured reports, files, tapes, and drawings to prevent loss. Retrieval and processing of information has been selectively based on current DOE/NE program interests and preparation of Lessons Learned Reports. Examples of specific accomplishments include:

- More than 400 boxes of FFTF information, several hundred microfilm reels including Clinch River Breeder Reactor (CRBR) information, and 40 boxes of information on the Fuels and Materials Examination Facility (FMEF) were secured as the FFTF buildings were being cleared.
- Extensive documentation of FFTF design standards, specifications, procedures, and operating experience has been preserved and is retrievable. Examples include Technical Specifications, Control Room Operating Procedures, Reactor Development and Technology (RDT) Standards, Hanford Engineering Development Laboratory (HEDL) Standards, Equipment and Component Procurement Specifications, and Startup Reactor Characterization Reports.
- A process for locating and retrieving Plant and Experimenter Data System (PDS and EDS) tapes in records storage (over 4000 binary tapes generated during plant operations, some more than 30 years old) was developed and applied successfully to retrieve and preserve data from the FFTF Passive Safety Test Program. The Passive Safety Testing data has been successfully located, retrieved, extracted, and preserved on modern media. The binary plant data were decoded and converted to ASCII format for further processing [2].
- An FFTF PST database is being created using a series of web browser HTML pages using Perl scripts that invoke adapted FFTF Fortran programs to produce user-specified data displays.
- The fast reactor fuels testing library contains information related to fuel irradiation testing: the Core Demonstration Experiment, Driver Fuel Evaluation Program, fuel cladding and duct irradiation swelling characteristics, high burnup metal and MOX fuel tests, cladding and duct tests, disassembly records, dimensional profilometry, gamma spectrometry, neutron radiography, fission gas analysis, metallography, photomicrographs, and procurement records. This information has been secured and data packages/Lessons Learned reports prepared for topics of interest to the DOE [10].
- Fuels, neutronics, structural, and thermal hydraulic analysis codes, including correlations from actual test data used to interpret test data and design fuel have been archived.

6. Data Preservation

Information from the design, construction, and operation of the FFTF was at serious risk of being irretrievably lost as the facilities associated with the reactor were being shutdown. Reports, drawings, and data tapes were rescued as the facility was being deactivated. A large quantity of information had been stored on several different systems on the Hanford Site during the design, construction, and operation of FFTF over a period of almost 20 years. Approximately 600,000 FFTF related engineering documents and correspondence are stored in the historical site records system. The Fuels and Materials Library contains over 1155 boxes of information, which translates into 2,100 vertical feet of documents, or ~6.3 million pages. Many of these documents have no electronic counterpart and are difficult to fully digitize. In addition, nearly 800 boxes of records were transported from the FFTF 400 Area QA Vault to Records Holding Storage as the FFTF was closed. The test results information exists in several different formats depending upon the final stage of the test evaluation. Capture of tacit knowledge is necessary to preserve the full value of this information. The collected and stored documentation is more than what is available from other sources. For example, it includes complete sets of drawings for the reactor plant, operations manuals, training manuals, system design descriptions, operations and maintenance manuals, and procurement specifications. As documents and data from these systems are successfully retrieved to meet data requests and program milestones, they are being organized and stored in an electronic database. A disciplined and orderly approach has been developed to respond to client's requests for documents and data in order to minimize the search effort and ensure that future requests for this information can be readily accommodated.

The Lessons Learned approach of capturing the plant experience and knowledge of experts on specific FFTF topics has been successful as a means for preserving FFTF knowledge [10].

Knowledge management activities include ingesting documents into the PNNL Total Records Information Management (TRIM) document management system. TRIM provides "on demand" document identification and prioritization, full test indexing of scanned/OCR'd PDF files, searchable metadata fields, and simple browse and report capabilities.

Some of the lessons learned from efforts to locate, extract, and preserve FFTF data include:

- Documentation of the rigorous and successful testing program at FFTF was thorough and immense, with official records routinely archived.
- Records storage is only useful if the records can be located. A systematic and consistent method for storing non-paper records, such as sequential or special box numbers would have greatly increased the efficiency of locating the boxes containing the data tapes.
- Information critical to interpreting the raw data must be preserved along with the data.
- Difficulties were experienced with a few of the plant data tapes, and paths are being considered to deal with these problematic tapes.

7. Conclusions

The future accessibility of information from the design, construction, and operation of the FFTF has been substantially increased by the development and application of a knowledge management program and methods for locating, retrieving, and processing the historical information. The data from the FFTF startup tests provides a roadmap for a disciplined, organized approach that will be very useful for planning the startup of new LMRs. The ten years of successful operation of the FFTF provided a very useful framework for testing the advances in LMR safety technology based on passive safety features that may be of increased importance to new designs. The FFTF information provides realistic design specifications and experimental results that will be very useful to innovative designers seeking to optimize the design of new LMRs. The United States is emphasizing large-scale computer simulation and modeling. The FFTF reactor characterization program data and passive safety testing data provide the basis for creating benchmarks for validating and testing coupled thermal hydraulic/neutronic/mechanical codes. These could be especially important for LMR beyond design basis accidents and severe accidents. An indication of the value of this information is given by the fact that this information is at a level of detail and depth sufficient to rebuild the reactor plant, or alternatively sufficient to design, construct, and build a similar although not identical reactor.

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