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W. L. Bunch and P. R. Prevo

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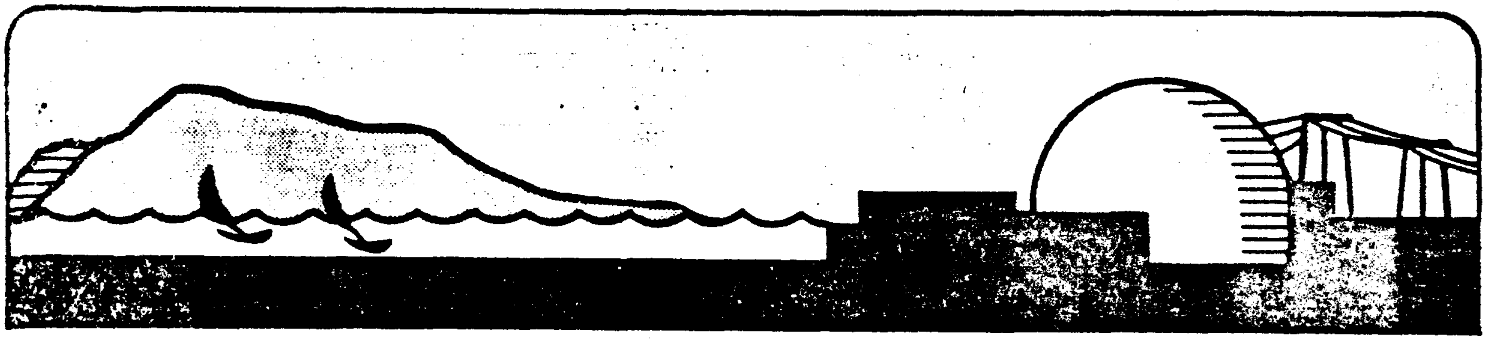

FAST BREEDER SYSTEMS

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W. L. Bunch
P. R. Prevo
Westinghouse Hanford Company
P.O. Box 1970, W/A-34
Richland, Washington USA 99352

ABSTRACT

The Fast Flux Test Facility (FFTF) has been in operation for approximately five years, including over eleven hundred days of full power operation of the Fast Test Reactor (FTR). During that time the collective dose equivalents received by operating personnel have been about two orders of magnitude lower than those typically received at commercial light water reactors. No major contamination problems have been encountered in operating and maintaining the plant, and release of radioactive gas to the environment has been well below acceptable limits. All shields have performed satisfactorily. Experience to date indicates an apparent radiological superiority of liquid metal reactor systems over current light water plants.

INTRODUCTION

The Fast Flux Test Facility (FFTF) is owned by the United States Department of Energy and is located on the Hanford Site near Richland, Washington. The facility features a three loop, 400 MW sodium-cooled, mixed-oxide-fueled reactor that was designed for irradiation testing of fuels and materials to support the commercial development of liquid metal fast reactors.[1] The mission has subsequently been expanded to include a Passive Safety Test program, irradiation of fusion and space reactor materials, and isotope production. Table 1 summarizes key technical parameters for the reactor, whereas Table 2 summarizes its operating history. In addition to the reactor, the containment building also houses the three primary sodium pumps and intermediate heat exchangers, an Interim Decay Storage facility for irradiated core components, and a multilevel hot cell for maintenance and examination of irradiated components. Thus, all major radiation sources are located within the containment building except for sodium sampling cells, cover gas processing equipment, and a long-term irradiated fuel storage facility.

This paper summarizes radiological experience at the facility during more than five years of operation.

TABLE 1. FFTF TECHNICAL PARAMETERS

• Thermal Power	400 MW	
• Maximum Core Outlet Temperature	1100°F	593°C
• Reactor Vessel Inlet Operating Temperature	680°F	360°C
• Reactor Vessel Outlet Operating Temperature	938°F	503°C
• Nominal Core ΔT	300°F	165°C
• Maximum Core ΔT Capability	350°F	195°C
• Primary Sodium Flow Capability	43,500 gpm	2745 lps
• Core Diameter	4 ft	1.2 meter
• Core Height	3 ft	0.9 meter
• Peak Flux	7×10^{15} n/cm^{2}sec	

TABLE 2. FFTF OPERATING HISTORY

	Start	Complete	EFPD
Testing	2-80	12-81	32.7
Cycle One	4-82	11-82	101.6
Cycle Two	1-83	5-83	100.5
Cycle Three	7-83	10-83	101.5
Cycle Four	1-84	4-84	109.5
Cycle Five	6-84	11-84	122.7
Cycle Six	12-84	6-85	134.0
Cycle Seven	8-85	1-86	122.8
Cycle Eight	2-86	7-86	63.0
Cycle Nine-A	9-86	2-87	137.7
Cycle Nine-B	3-87	6-87	-100

PLANT SHIELD TESTS

A relatively extensive shield measurements program was completed during early power operation of the facility.[2] These measurements were made to assure that no major defects had been introduced by construction, to establish radiation zones, to compare the results with the design calculations, and to establish the radiation environment associated with reactor structural components.

A four part program was established to assure that plant shields performed satisfactorily. First, individual components of engineered systems were evaluated, primarily by the use of radioactive sources. Second, a one-tenth megacurie cobalt source was used to survey the walls, floor and ceiling of the hot cell prior to the installation of major equipment. Third, walk-through surveys were made in all accessible areas during the initial low power operation to assure that no major shield deficiencies existed. Fourth, detailed radiation surveys of all accessible plant shields were made during the initial extended power run.

Several radiation streaming problems were detected and corrected as a result of the hot cell measurements.[3] The fact that the hot cell contains several operating levels contributed to one of the problems, but the major finding was that interfaces between engineered shields were not adequately controlled. Some examples of the problems identified include: (1) the manufacturer of the windows created a step to match the offset in the frame by welding an additional plate rather than using a solid piece, thereby creating a streaming path; (2) standard master slave manipulator penetrations do not contain adequate shielding for use in multi-level hot cells; (3) although the ceiling valve and cell walls each contained adequate shielding, the interface did not; (4) a design change was made because of seismic considerations in which a shield plug was used in an access port rather than inner and outer doors, thus creating a streaming path without the approval of the shielding analyst. On the positive side, it should be noted that the high density concrete walls contained no detectable voids.

Most of the major shield walls within the containment building surround the piping and equipment associated with the primary sodium system. Saturated activity of the primary sodium is about 11 millicuries of ^{24}Na per gram. The large pipes and components containing sodium at this activity level require the equivalent of about seven and a half feet of ordinary concrete to reduce the field to negligible levels. High density concrete was used in some places because of space limitations. No measurable imperfections in the bulk shield were detected; however, beams of small size and low intensity were found at some shield interfaces that required the installation of small patches. Details of these interface findings are contained in Reference 2.

REACTOR SHIELD MEASUREMENTS

Shield measurements were made as part of the overall reactor characterization program to define accurately the test environment to support the plant mission. Only a limited number of locations could be accessed to obtain data for evaluating shield performance. Passive sensors (radioactivants) were irradiated in special assemblies placed in the core, reflector and in-vessel storage modules, within a dry in-reactor thimble that permitted measurements above the core, and within a thimble in the reactor cavity. The threshold and resonance energy detectors provide a basis for defining the variation in the intensity and spectral distribution of the neutron flux. The results of the measurements are in relatively good agreement with two-dimensional diffusion theory calculations; therefore, the calculations are used to interpolate between measurement points. Interpolation is required to define damage (displacement per atom) rates associated with structural components. The use of diffusion theory was also justified by an analytical study comparing different methods.[4] Although the inner radial shield and the core basket (central portion of the core support structure) were designed to be replaceable, such an effort would be time consuming and costly. The shield measurements provide a relatively accurate determination of the neutron environment in which these components reside; therefore, the lifetimes of these components can now be established with greater confidence.

Neutron measurements were also made in the head compartment above the reactor using Bonner balls. One of the primary purposes of these measurements was to determine the effect of stored fuel. There are three In-Vessel Storage Modules (IVSM) located within the reactor vessel but outside the radial shield. Design calculations indicated that fission events induced in fuel located in these storage modules would convert the low energy neutrons that penetrate the radial shield into high energy fission neutrons. The higher energy neutrons have a higher probability of reaching the head compartment. As shown in Table 3, the measurements confirmed that design prediction.

TABLE 3. HEAD COMPARTMENT DOSE RATES

Stored Fuel Per IVSM	Flux (n/cm^2sec)	Dose Rate (mrem/hr)
0	0.1	0.0007
1	1.2	0.008
4	3.5	0.025
9*	8.8*	0.06*
19*	17*	0.1*

* Extrapolated

HEAT TRANSPORT SYSTEM CELLS

The dose rate within the FFTF primary heat transport system cells is being measured during extended outages to determine the buildup of radioactivity. There are at least three sources of radiation that are of concern: the activity induced in the sodium and its impurities, the activity associated with fuel and fission products that might get into the sodium as a result of cladding failures, and the transport and deposition of radioactive corrosion products generated in reactor components.

The primary radioactivant induced in sodium is ^{24}Na, which has a 15 hour half-life and reaches an equilibrium activity in FFTF of about 11 millicuries per gram of sodium. This isotope emits high energy gamma rays as it decays, requiring in excess of seven feet of structural concrete to reduce the dose rate to background levels on the operating floor. When the reactor is shut down, this isotope decays to negligible levels within a few weeks and ^{22}Na, with a half-life of 2.6 years, becomes an important source of radiation in the sodium. This isotope reaches a maximum activity in FFTF of about 0.8 microcuries per gram of sodium and generates a radiation field of several hundred millirem per hour near the large pipes in the Heat Transport System (HTS) cells. In theory, the radiation source associated with the sodium could be removed from the HTS cells by draining the system; however, this is not considered to be practical in FFTF.

Although FFTF is designed to operate continuously while up to 1% of the fuel pins have failed, only ten cladding breaches have been detected to date. Measurements of grab samples of sodium taken from the primary system indicated that cesium isotopes entered the sodium as a result of cladding breaches that occurred in 1984 and 1985. Although other fission products might have entered the sodium at the same time, none were sufficiently abundant to be detected or important over an extended time period. Also, no plutonium or uranium isotopes have been found in the primary sodium. Although ^{134}Cs and ^{137}Cs combined to a total activity of about 0.3 microcuries per gram of sodium following the 1985 cladding breach, they did not make a major contribution to the cell dose rate compared to ^{22}Na because of spectral differences. The presence of the cesium did create an operational problem because of its propensity to concentrate in the sodium frost. Thus, patches of sodium frost that are invisible to the eye are now detectably radioactive. Prior to the entry of the cesium into the sodium, the frost buildup was visible to the naked eye before being sufficiently radioactive to be detectable.

The third source of radioactivity within the HTS cells is the plateout of corrosion products that are transported from the reactor. Predictions based on laboratory measurements indicated that ^{60}Co would plate out on hot surfaces and ^{54}Mn on cold surfaces. Gamma ray spectrometer measurements of the primary sodium pipes in the HTS cells confirm the presence of ^{54}Mn and indicate that the concentration on cold leg piping is over an order of magnitude greater than that on the hot leg piping. To date, it has not been possible to detect the presence of ^{60}Co on any of the HTS cell piping. About two-thirds of the dose rate near cold leg piping in the HTS cells is now attributed to the presence of the ^{54}Mn that has plated out. Near the hot leg piping, only about one-fourth of the dose rate is attributed to the presence of the ^{54}Mn. Although the manganese plateout activity was believed to be approaching equilibrium values for the initial fuel and operating conditions, future changes are anticipated because of the new fuel currently being tested. Continued measurements will be required to track the effect of the present fuel loading and operating conditions.

PERSONNEL RADIATION EXPOSURE

Plant personnel radiation doses have been very low, as shown in Table 4. These radiation dose results are for about 300 radiation workers at the plant. In addition to operation and maintenance of the reactor, these doses include operation of the hot cell and a decontamination and maintenance facility located in an adjacent building. Replacement of an electromagnetic pump during the fourth quarter of 1984 caused the largest collective dose to date.[5] This work involved cleanup of a few hundred pounds of primary sodium which leaked from the failed pump. Collective dose from this single event was about 4 man-rems (0.04 person-Sv), with the highest individual dose being 250 mrems.

TABLE 4. PERSONNEL EXPOSURE SUMMARY

	Year				
	1982	1983	1984	1985	1986
Average Dose Per Person (mrem)	36	11	37	4	10
Highest Individual Dose (mrem)	200	200	250	110	290
Collective Dose (man-rem)	10	5	13	1	2

It should be noted that radiation workers at FFTF receive more dose from the natural background than from work. The average annual local dose is about 100 mrems, which exceeds the working doses by a significant amount. The low operating doses at FFTF are consistent with experience at other sodium cooled fast reactors. For example, the French report collective doses of about 5 man-rems per year at Phenix, with a high of 17 man-rems in the year an intermediate heat exchanger was replaced. By comparison, personnel doses at a typical commercial light water reactor approach 1000 man-rems. Average personnel dose in 1982 at USA pressurized water reactors was 530 mrems, and at boiling water reactors it was 760 mrems. The low personnel doses at sodium cooled reactors is associated with pressure and chemical differences between metal and water systems.

Radiation levels in areas normally accessed to operate the plant are essentially at background levels. Thus, almost all doses are associated with nonroutine maintenance and recovery operations. Such operations are governed by ALARA principles with appropriate preplanning and training.

CONTAMINATION CONTROL

Contamination has been effectively controlled by employing standard nuclear industry monitoring instruments and procedures. Control is so effective in FFTF that access to the containment building is permitted in street clothes; i.e., no protective clothing. Local contamination control is required during refueling, during removal of hot cell equipment, and during maintenance activities on radioactive equipment. Much of the contamination is associated with the primary sodium and its cesium content. In addition, the radioisotopes ^{110m}Ag, ^{124}Sb and ^{182}Ta have been detected. These are believed to be associated with activation of bearing material or impurities in the sodium and structural material in the reactor. Metal fines produced during the cutting of irradiated stainless steel ducts in the hot cell contain significant quantities of ^{60}Co. Because the hot cell is contaminated by such material, special care is taken during the transfer and repair of hot cell equipment. Although there have been a number of cases of skin contamination through the years, all were minor with the highest being 30,000 dpm and with decontamination being readily accomplished. There have been no instances of internal deposition.

ENVIRONMENT PROTECTION

The release of radioactive material to the environment has been extremely low. There are no radioactive liquid releases from FFTF. Radioactive liquid wastes are associated primarily with the sodium-cleaning process that takes place in the hot cell. These are collected, transferred to a railroad tank car, transported to the Hanford storage site, and placed in large double-walled tanks. Generation of solid waste is also minimal. Again, the waste is transported to the Hanford storage facility.

Total release of airborne radioactive materials through 1986 has been about 39 curies of noble gases. These releases result in a dose of less than 0.01 mrem to the maximally exposed off-site individual and are so low that they are not detectable off-site. A summary of these releases is given in Table 5. The first release was attributed to leaks in instrument tubing connections that were subsequently repaired. The second release was associated with a planned release of ^{41}Ar for test purposes. The later releases were associated with test fuel cladding breaches. A comparison of releases from commercial light water plants and FFTF is given in Table 6.

TABLE 5. SUMMARY OF ENVIRONMENTAL RELEASES

Date	Curies Released*	Principal Radionuclide
May 1982: Cycle 1	0.5	^{33}Xe
Oct 1983: Cycle 3	1.5	^{41}Ar
Nov 1984: Cycle 5	10	^{85}Kr and ^{133}Xe
Dec 1984: Outage following Cycle 5	10	^{85}Kr and ^{131m}Xe
April & May 1985: Cycle 6	8	^{85}Kr
June 1985: Cycle 6	1.2	^{85}Kr
July 1985: Cycle 6	1.2	^{85}Kr
Dec. 1985: Cycle 7	2.7	^{85}Kr
Oct. 1986: Cycle 9A	3.7	^{85}Kr

* 1 curie = 3.7×10^{10} Bq

TABLE 6. RADIOACTIVE MATERIALS RELEASED PER LIGHT WATER REACTOR IN 1981 AND FFTF IN 1984

(Activity in Curies*)

Reactor Type	Airborne Fission & Activation Gases	Airborne Partic- ulates	Liquid Tritium	Liquid Fission & Acti- vation
BWR	50,000	1	25	1
PWR	4,000	0.1	500	2
FFTF	20	0	0	0

* 1 curie = 3.7×10^{10} Bq. Values for BWR and PWR are averages; no power correlation has been established.

Release of airborne radioactivity to the environment is minimized at FFTF by the two gas processing systems. The Radioactive Argon Processing System (RAPS) handles the reactor cover gas system; whereas the Cell Atmosphere Processing System (CAPS) handles air, nitrogen and argon from the hot cell and from inerted cells that contain radioactive sodium. Both systems process the gas by holdup to permit radioactive decay. This is effective for all radioisotopes encountered except for ^{85}Kr, which has a half-life of 10.5 years. Holdup is accomplished by a series of tanks and liquid-nitrogen-cooled charcoal beds. Although CAPS routinely handles about ten times the flow handled by RAPS, the argon cover gas contains more radioactivity. CAPS also serves as a backup to RAPS. The successful operation of these systems is demonstrated by the tabulated results over the plant lifetime.

SUMMARY

Radiological safety at FFTF has been demonstrated by over five years of operation. The philosophy in the design of the plant layout and shields has assured that operating personnel receive negligible doses during normal routine operation of the plant. The primary sodium system has operated efficiently and required very little maintenance. The electromagnetic pump failure that did occur was replaced with personnel receiving relatively small doses. Accepted practices and procedures are employed to control contamination and to assure that doses are minimized when breakdown maintenance is required. Release of radioactive material to the environment has been minimal and below the level of detectability at the site boundary. Although current light water reactor plants meet all established radiological safety requirements, the operating experience gained in over five years of operation of the FFTF indicates that even better radiological performance can be achieved using liquid metal reactors.

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