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DEVELOPMENT AND TESTING OF SODIUM COMPONENTS

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INTRODUCTION

Sodium component experience in the USA has progressed from the development of the small components for EBR-I through plants of substantial thermal capacity. Development of pumps, valves, heat exchangers, steam generators, and fuel handling systems for large economic liquid-metal fast breeder reactors (LMFBR's) will progress from the existing operating experience and technology base, through several stages, to commercial plants.

Performance targets for commercial power-plant components have been identified in the USAEC's 1000-MW(e) plant studies. [1-4] Translation of these targets into specific component designs is the object of a number of contracts to component vendors under the AEC's LMFBR Program. These contracts are pointing toward test evaluation of prototype components in USAEC facilities, principally the Liquid Metal Engineering Center (LMEC). The LMEC provides capability to test prototype sodium pumps, heat exchangers and steam generators, and auxiliary system components in a sodium environment. These prototype components will be further tested and improved in the FFTF and demonstration plant programs of the USA.

SUMMARY OF COMPONENT EXPERIENCE

Past experience with components for liquid metal systems spans a wide range of operating conditions and sizes. Small components have been operated at temperatures well above the range of interest for economic

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LMFBR's; however, even today's largest components are much smaller than those required for demonstration and commercial plants. The present technology of sodium components is summarized later in this paper, in Tables II to VI.

REQUIREMENTS FOR 1000-MW(e) PLANTS

The USAEC sponsored a series of design studies of 1000-MW(e) LMFBR's, completed in 1969, to define the performance objectives and development programs for commercial LMFBR's. These studies establish targets for commercial plant components which are summarized in Table I. For almost all parameters, there is a wide span of characteristics, indicating flexibility in design choices and optimization. As detailed designs are completed and component development experience provides further basis for judgment, one can expect variations in optimum plant designs. The major design choices that influence the component requirements are: (1) pot vs loop configuration, (2) outlet temperature, (3) number of heat transfer circuits, (4) hot vs cold leg location for the primary pump, (5) under-the-plug vs hot cell refueling, (6) plant control philosophy, with respect to transients imposed, and (7) provisions for decay heat removal.

DEVELOPMENT APPROACH FOR COMPONENTS FOR COMMERCIAL PLANTS

Commercial plants will require component capabilities in heat transfer and sodium flow volume, up to ten times greater than current experience. To this physical size increase must be added the additional complication of higher sodium temperature ($\sim 950^{\circ}\text{F}$ current to $1000\text{--}1150^{\circ}\text{F}$ future). These increases in sodium component capabilities place severe requirements on component engineering, with particular emphasis on materials selection and performance.

Comparison of present technology for sodium components with the desired performance of commercial plants shows the importance of further development, to provide manufacturers and utilities with assurance of successful operation of large LMFBR's. One approach is to perform full-scale component testing in synthesized environments, simulating plant operation. This approach could provide the most realistic basis for confidence, but is generally impractical, due to the large capital investment in test facilities and difficulty in predicting and simulating all operating conditions. Further, since life tests would not be practical, because of the long times involved, both accelerated tests and elaborate instrumentation would be required. Accelerated tests require extrapolation, which limits confidence; elaborate instrumentation may well interfere with achieving a prototypical test.

Near the other end of the scale in time and effort are tests in which particularly sensitive portions of components may be tested under simulated conditions, to yield performance data on subcomponents which, when assembled into the whole, could provide reasonable assurance of reliability in the full-sized assembly. This latter course requires a substantial amount of engineering judgment in selecting the critical components, planning and performing tests which are truly representative of conditions in actual service, and interpretation of test data to determine suitability. Subcomponent testing is vulnerable to unanticipated interactions. Particular care is required to assure that subcomponent tests are independent, or that interdependences have been anticipated and taken into account.

TABLE I
1000-MW(e) PLANT COMPONENT CHARACTERISTICS

	AI ^(a)	B&W ^(b)	GE ^(c)	W ^(d)
Primary Pump				
Flow (gal/min)	62,800	37,000	63,800	150,200
Operating Temperature (°F)	1,140	800	809	770
Valve	Butterfly			None
Diameter (in.)	36	26		
Operating Temperature (°F)	905	1,000	809	
Intermediate Heat Exchanger				
Duty [MW(th)]	800	408	808	1,300
Surface Area (ft ²)	29,900	10,500	25,800	49,800
Maximum Sodium Temperature (°F)	1,140	1,100	1,150	1,000
Evaporator	Hockey Stick, Shell & Tube	Combined Evaporator- Superheater, Helical Coil	U-Tube	J Module, Shell & Tube
Duty [MW(th)]	78.5	688	280	
Surface Area (ft ²)	3,640	53,820	17,880	
Tube Material	2-1/4 Cr - 1 Mo	2-1/4 Cr - 1 Mo	2-1/4 Cr - 1 Mo	Incoloy 800
Maximum Sodium Temperature (°F)	905	1,000	942	
Superheater	Hockey Stick, Shell & Tube	Combined Unit (See evaporator data)	U-Tube	J Module, Shell & Tube
Duty [MW(th)]	49		118	
Surface Area (ft ²)	2,800		8,040	
Tube Material	Type 321 Stainless Steel		Type 316 Stainless Steel	Incoloy 800
Maximum Sodium Temperature (°F)	1,070		1,071	1,040
Fuel Handling				
Type	Under Plug	Under Plug	Hot Cell	Hot Cell
Plug Diameter (in.)	294	385	-	-

(a) Atomics International

(b) Babcock & Wilcox

(c) General Electric

(d) Westinghouse

Between these two approaches lies a continuous spectrum of compromises, set by technical, financial, and schedule considerations. These may involve the testing of prototype components, though not necessarily full size, with critical areas identified in advance from full-scale designs and past experience. The critical areas are mocked up to simulate the full-scale design, but the whole apparatus need not be in full scale. However, associated with these compromises is a continuous gradation of confidence level in achieving component performance goals.

It is apparent that there is no one method of development and testing for components which meets the engineering, financial, and schedule requirements simultaneously; there must be a mix, based on engineering and management judgment, which takes into account the conflicting forces entering into a final decision.

The program being undertaken by the United States, to bridge the gap between today's technology and the commercial plants, follows a composite approach, starting with conceptual design of large components based on overall system requirements and past component experience, followed by sub-component testing to verify selected materials, mechanical, and hydraulic characteristics leading to model and prototype component testing, prior to inclusion in FFTF and the demonstration plant(s). Each demonstration plant will have a supporting test program to prove the particular features of the specific plant design. Operating experience with large components in the demonstration plants and FFTF provide verification of system environmental requirements, validity of prototype extrapolations, maintenance experience, and life information for application to larger commercial plants. The program involves the USAEC, the national laboratories, and the reactor and component manufacturers. The fast reactor progress of other nations also will be considered in the design and testing of U.S. components.

In the remainder of this paper, key technical uncertainties relating to sodium system pumps, valves, heat exchangers, steam generators, and fuel handling equipment will be identified, and the actions required to reduce the uncertainties to acceptable levels will be discussed. The FFTF development and test program will be described, and a summary description of U.S. LMFBR test facilities will be given.

Before reviewing individual component areas, some general discussion of the high-temperature structural design problems is appropriate. It should be kept in mind that these problems are not equally applicable to all LMFBR plant designs. System design and operating conditions can be specified, to mitigate or even eliminate those problem areas which begin to manifest themselves as temperatures approach the creep range (900 to 1000°F), indicating the critical problems will be in the hot leg of the system.

Higher temperature brings the stainless steels commonly used for LMFBR components into the creep range. Thermal transients and structural discontinuities may introduce plastic deformation, which interacts with creep effects. This can result in thermal ratchetting and accelerated structural damage, due to interaction of creep and fatigue. Lowering membrane stresses through increasing material thickness does not evade these problems, because the increase in thickness may aggravate the internal strains set up by thermal gradients, to the point where these cyclic stresses can contribute more to material damage than ordinary pressure and bending strains.

The complex geometries of some components, coupled with the need to account for stress and strain redistribution from plastic deformation and creep, greatly complicates the structural analysis. This has given impetus to a state-of-the-art extension of the application of structural mechanics to three-dimensional creep analyses. A major effort for validation of high-temperature design criteria, based on an elastic-plastic-creep analysis, is required. A companion problem is the definition and analysis of thermal transients.

The current approach in high-temperature structural design provides two paths for the evaluation of structural integrity. One path is derived from conservative adaptations and extensions of previous criteria based on elastic analysis. The other path is based on comprehensive elastic-plastic-creep analyses. Since it will not always be practical and/or economic to design for the simpler, more conservative elastic criteria, developmental testing is required to generate information on the properties of materials in the creep range, and to better understand the relationships between the mechanical properties, failure mechanisms, and behavior of representative components.

Another area of major importance to the development of reliable components for the commercial plants is the establishment of comprehensive quality assurance programs by the component suppliers. The design and testing of prototypes can provide the necessary quality assurance experience, as well as the technology for extrapolation to larger size components. The importance of quality assurance to the success of the commercial plants cannot be overstated.

Sodium pumps

There is good experience with sodium pumps of the general configuration to be used in the commercial plants, but of lower capacity (HNPf, EBR-II, and Fermi). The largest capacity operating units in the U. S. are the Fermi pumps, with a flow rate of $\sim 12,000$ gal/min; thus, the flow scaleup required for the 1000-MW(e) plants ranges from about a factor of ~ 3 to a factor of ~ 10 . Additional extrapolation in discharge head and operating temperature will be required, as shown in Table II. Similar centrifugal pump designs are used in many LWR plants, providing additional experience in manufacturing and operating large-capacity pumps that approximate the LMFBR size. Major differences for LMFBR pumps are higher operating temperatures, thermal transients, and longer pump assembly and shaft. The main technical uncertainties in large pumps are: (1) long-term performance and reliability, (2) distortion effects due to temperature and temperature transients, (3) shaft dynamics, (4) alignment control during fabrication, and (5) maintainability.

The on-going AEC LMFBR development and test program, FFTF development, and the demonstration plants will provide the technology and experience needed for commercial plants. LMEC is testing shaft seals and hydrostatic bearings developed by component suppliers in support of the FFTF and the demonstration plants. The next step will be testing of an FFTF prototype pump in the Sodium Pump Test Facility (SPTF) at the LMEC, which will be available to test demonstration plant pumps after completion of the FFTF testing.

Table II shows the anticipated technical evolution of the pumps, from the present technology base to pumps required for commercial LMFBR's. There is a broad range of requirements for commercial LMFBR's, reflecting the

TABLE II
PUMP EVOLUTION

	Present Technology						FFTF	Demonstration Plants	Commercial Plants
	SRE-PEP	SCTI Primary	EBR-II	HNPF	Fermi	LWR's			
Type	Free Surface, HNPF Type	Free Surface, HNPF Type	Free Surface, Sump Type	Free Surface, HNPF Type	Free Surface, Fermi Type	Centrifugal	Free Surface	Free Surface	Free Surface
Flow (gal/min)	2700	3200	5500	7200	11,800	80-100,000	14,500	25-60,000	40-150,000
Head (ft sodium)	180	235	200	160	310	250-300	500	~400	120-430
Operating Temperature (°F)	1000	900	700	945	600	~650	1050	720-1060	770-1140
Pump Shaft Length (ft)	12	5	11	16	14	~15	~30	~30	~30
Seal Type	Face, Oil Lubricated	Face, Oil Lubricated	Hermetic Motor	Face, Oil Lubricated	Face, Oil Lubricated	Face, Water Lubricated	Face, Oil Lubricated	Face, Oil Lubricated	Face, Oil & Gas Lubricated
Hydrostatic Bearing, Diameter x Length (in.)	10 x 7	6.5 x 8.5	12 x 12	12 x 12	12 x 12	24 x 17	12 x 12 ^(a)	~24 x ~15	~24 x ~15
Impeller Diameter (in.)	23	16	26	27	37	30-45	41 ^(a)	40-70	30-90

(a) Estimated

TABLE III
VALVE EVOLUTION

	Present Technology								FFTF		SPTF	Demonstration Plants			Commercial Plants		
	SRE-PEP	SCTI	EBR-II	HNPF		Fermi											
Service	Throttle	Throttle	Throttle	Check	Throttle	Block	Throttle	Check	Block	Check	Throttle	Block	Throttle	Check	Block	Throttle	Check
Type	Modified Plug	Butterfly	Angle	Swing Disc	Ball	Split-Wedge Gate	Plug	Swing Disc	Swing Gate	Swing Disc	Butterfly	Split-Wedge Gate & ?	Butterfly	?	Split-Wedge Gate	Butterfly & ?	?
Diameter (in.)	8	8	4	16	14	16	6	16	28	16	18	36-?	36	?	26-34	22-38	?
Operating Temperature (°F)	650	900 & 1200	700	610	610	945	600	600	1050	830	1100	~700-1025	760	720-750	670-1000	780-1000	809-?
Stem Seal Type	Torque Tube	Freeze	Close Clearance	None	Freeze	Freeze	Double Bellows	None	Freeze	None	Freeze	Freeze & ?	Freeze	None	Freeze & ?	Freeze & ?	None

design approach of each manufacturer. The FFTF and demonstration plants, coupled with on-going development, provide an orderly evolution of pumps from the present state to the large commercial plants. A comparison of detailed parameters, such as bearing loads, specific speed, and linear velocities of the seal, bearing, and impeller, shows that they are within the range of existing sodium pump designs; the major extrapolations required from today's sodium pump designs are the physical size of the components, higher discharge head, and, for hot-leg pumps, higher operating temperature.

The development of manufacturing skill, testing, and operating experience is needed for extrapolation to commercial plant requirements. This experience will be obtained from the prototype pumps to be developed and tested in the SPTF, and the construction and operation of the FFTF and demonstration plant units.

Valves

There is no past experience with sodium valves of the size specified for the 1000-MW(e) plants, although many expected design features have been used previously. The main uncertainties are size scaleup, stem seals, vibration, and thermal transient effects on materials and structures. Valve development and testing is being pursued under the AEC's LMFBR program, to provide information needed to supply the valves for FFTF and SPTF. These valves (see Table III) will provide additional technology needed to permit extrapolation to the demonstration plant valve sizes. Operation of the demonstration plants will provide further information, useful for design of reliable valves for commercial plants.

Intermediate heat exchanger (IHX)

Although no sodium heat exchangers as large as those to be used in the demonstration plants and 1000-MW(e) plants have been built to date, there has been considerable applicable experience with smaller units. Past experience and analysis of LMFBR design work indicate that the principal areas of uncertainty are: (1) shell and tube side flow distributions, (2) tube vibration and wear, (3) maintainability, and (4) thermal transient effects.

A combination of development testing and operating information from the FFTF and demonstration plants is expected to provide sufficient hydraulics design information for the 1000-MW(e) units, as the scaleup from the demonstration plants is not great. Table IV shows the relationship of present technology, demonstration plants, and commercial plants. The Fermi experience to date is up to about one-half rated power.

Maintainability must be carefully considered, because IHX's may become sufficiently radioactive, due to corrosion product deposition, to require semi-remote maintenance. Removable tube bundles permit repairs to be made in a maintenance area. Maintenance on fixed-bundle shell-and-tube units will be performed in place. Development of semi-remote techniques potentially will be required for either type, in the event radioactivity levels are too high to permit contact maintenance.

Steam generators

Of all the sodium system components, the steam generators are generally regarded as the most critical. Some of the past experience has been

TABLE IV
INTERMEDIATE HEAT EXCHANGER EVOLUTION

Type	Present Technology						FFTF	Demonstration Plants	Commercial Plants
	SRE	SEFOR	SCTI	EBR-II	HNPT	Fermi			
	U-Tube	U-Tube	Shell & Tube, Sine Wave Tube	Shell & Tube, Removable Bundle	Shell & Tube Bellows in Shell	Shell & Tube Floating Head, Removable Bundle	Shell & Tube Removable Bundle	Shell & Tube, Removable Bundle, & Fixed Shell & Tube	Shell & Tube, Removable Bundle, & Fixed Shell & Tube
Duty [MW(th)]	20	20	30	63	43	143	133	263 - 625	400 - 1300
Surface Area (ft ²)	1155	483	1393	4540	2875	5840	8800	? - 24,000	10,000 - 50,000
Number of Tubes	316	161	462	3026	1395	1860	1550	? - 2900	3400 - 7400
Maximum Sodium Temperature (°F)	960	809	1200	883	945	900	1050	1000 - 1060	1000 - 1150
Log Mean Temperature Difference (deg F)	60	144	62	48	50	80	92	64 - 80	65 - 120

poor; however, there has been satisfactory experience for the relatively short periods of operation in SRE and HNPF, and, for a longer operating period, in EBR-II. The early problems with the single-wall-tube Fermi units appear to have been corrected. Recent testing of the ALCO unit in the SCTI resulted in severe tube sheet cracking. An investigation of the cause of failure is in progress. The concerns regarding steam generators can be broadly classified into the following categories: (1) structural integrity and reliability, (2) operational stability, (3) hydraulic performance and flow distribution, (4) accommodation of tube leaks and sodium-water reactions, and (5) rapid and reliable leak detection.

The steam generator experience which is applicable to the demonstration plants or the commercial plants is with small units. The key steps in developing steam generators for the commercial plants are the testing of models in the SCTI and the construction and operation of demonstration plant units. This evolution is summarized in Table V. The Fermi experience to date is up to about one-half rated power. It is seen, from this table, that there is still a significant extrapolation in unit size and temperatures from the demonstration plant, for some of the designs of 1000-MW(e) plants. An example of the important role of testing is provided by the Atomic International program, in support of their demonstration plant, wherein a steam generator module has been supplied to the AEC for testing in the SCTI.

Fuel handling

The fuel handling systems being considered by LMFBR manufacturers in the United States are of two basic types: (1) the under-plug system, using rotatable plugs, and (2) the hot-cell type (see Table VI). There are wide variations in the design details of these systems.

There is substantial satisfactory experience with under-plug systems at EBR-II and Fermi; however, the diameters of the rotatable plugs must be increased, by factors of 2 to 3, for large plants. There is a great deal of experience with both in-vessel and ex-vessel fuel transfer machines, similar to those planned for commercial plants. The experience with the hot cell refueling system at SEFOR also has been quite good, lending confidence to the selection of that type for large systems as well.

Because of the variation of design details between manufacturers, each organization plans development work for their demonstration plant. In general, these programs will involve mockups and proof tests, as well as component-level tests. The FFTF will provide important additional experience relevant to under-plug mechanical equipment, as well as overall system data.

The most important technical uncertainties associated with fuel handling systems are: (1) the effect of irradiation-induced swelling and bowing of core components on fuel handling, (2) sodium frost, (3) possible plutonium contamination from leaking or failed fuel rods, and (4) the capability to accommodate failures in a safe manner. None of these appear to involve questions of basic feasibility. The FFTF and demonstration plants and their associated test programs will provide proven systems for the commercial plants, as there is essentially no scaleup required.

TABLE V
STEAM GENERATOR EVOLUTION

	Present Technology					AI Module SCTI	Demonstration Plants	Commercial Plants
	SRE	ALCO Unit SCTI	EBR-II	HNPf	Ferna			
Type	Combined Superheater-Evaporator, Once-Through Duplex U-Tube, Mercury Third Fluid	Once-Through Shell & Tube, Sine Wave	Shell & Tube, Duplex Bonded	Bayonet Duplex Tube, Helium Third Fluid	Combined Superheater-Evaporator, Once-Through Serpentine Tube	Hockey Stick, Shell & Tube	Separate Superheater, Evaporator, & Reheater, Once-Through & Recirculating Shell & Tube, & Bayonet Tube	Separate Superheater, Evaporator, & Reheater, & Combined Superheater, Evaporator, & Reheater, Shell & Tube Hockey Stick, J Module, U-Tube, & Helical Coil
Duty/Module [MW(th)]								
Evaporator	30	30	5.7	69	143	26	76-263	80-690
Superheater			4.2	16			73-82	50-120
Surface Area/Module (ft ²)								
Evaporator	2790 Sodium Side, 1580 Water Side	1260	620	3,680	10,800	1,475	4,400-20,000	4,000-54,000
Superheater			620	2,150			4,400-8,300	2,800-8,000
Number of Tubes/Module								
Evaporator	199	300	73	679	1,200	158	475-1,240	340-760
Superheater			73	560			250-475	380-440
Maximum Sodium Temperature (°F)	900	1175	866	895	820	950	935-1000	1,040-1,070
Steam Conditions								
Pressure (lbf/in ²)	600	2,200	1,250	850	885	2,400	1,450-2,400	2,500
Temperature (°F)	825	1,050	850	850	780	900	900-950	950-1,000
Materials	Type 304 Stainless Steel	Type 316 Stainless Steel & Type 316 - Inconel	2-1/4 Cr - 1 Mo	2-1/4 Cr - 1 Mo & 5 Cr - 1/2 Mo - 1/2 Ti	2-1/4 Cr - 1 Mo	2-1/4 Cr - 1 Mo	2-1/4 Cr - 1 Mo & ?	2-1/4 Cr - 1 Mo, Stainless Steel & Incoloy

TABLE VI
FUEL HANDLING EVOLUTION

	Present Technology					FFTF	Demonstration Plants	Commercial Plants
	SRE	SEFOR	EBR-II	HNPF	Fermi			
Type	Through Plug	Hot Cell	Under Plug	Through Plug	Under Plug	Under Plug	Under Plug & Hot Cell	Under Plug & Hot Cell
Plug								
Type	Rotation for Maintenance		Double Rotatable	Rotation for Maintenance	Single Rotatable	Three Rotatable	Double Rotatable	Double & Triple Rotatable
Diameter (Large) (in)	142		142	230	112	75		294-385
Seal	Frozen Metal		Liquid Metal Trough	Frozen Metal	Silicone Rubber	Silicone Rubber	Silicone Rubber, Liquid Metal Trough	Silicone Rubber, Liquid Metal Trough
In-Vessel Transfer								
Function	None	See Below	Transfer & Rotate	None	Transfer	Transfer & Rotate	Transfer & Rotate	Transfer & Rotate
Type			Screw Driven, Vertical Grapple & Rotating Horizontal Transfer Arm		Offset Arm, Ball Screw Vertical Drive, Gear Rotation Drive	Offset Arm, Chain Hoist Vertical Drive, Gear Rotation Drive	Chain & Telescoping Drives, Vertical Grapple, & ?	Chain & Telescoping Drives, Vertical Grapple
Cooling			Under Sodium		Under Sodium	Under Sodium	Under Sodium	Under Sodium
Ex-Vessel Handling								
Function	Ex-Vessel Transfer	Ex-Vessel & In-Vessel Transfer, Rotation	Ex-Vessel Transfer	Ex-Vessel Transfer	Transfer From Reactor Building to Fuel Building	Ex Vessel Transfer	Ex-Vessel Transfer	Ex-Vessel Transfer
Type	Steel Cable, Vertical Grapple	Bridge Crane, Steel Cable, Vertical Grapple	Link Chain, Vertical Grapple	Roller Chain, Vertical Grapple	Steel Tape, Vertical Grapple	Roller Chain, Vertical Grapple	Steel Tape, Cable, & ?	Steel Tape, Cable, & Telescoping Tube, Vertical & Horizontal Grapple
Cooling	Natural Convection	Cell Atmosphere	Forced Argon	Forced Helium	Forced Argon	Air-Cooled Sleeve	Cooled Sleeve & Forced Gas	Cooled Sleeve, Forced Gas, & Cooled Dip Tube
Heat Removal [kW(th)]			3	~10	4	10	15-45	20-50
Fuel Assembly Container	None	None	None	None	Na-Filled Pot	Na-Filled Pot	Na-Filled Pot & Transfer Tube	None & Na-Filled Pot

DEVELOPMENT AND TESTING FOR FFTF COMPONENTS

Development of reliable components for use in the FFTF assumes top priority in the present LMFBR program. A joint industrial-USAEC coordinated effort is being followed. Contracts covering development, design, and fabrication of major FFTF components were awarded to industrial suppliers, following extensive conceptual design studies.

To the maximum extent practicable, FFTF components utilize modest extrapolations of design features proven through previous plant operating experience. The FFTF 1050°F reactor outlet sodium temperature, coupled with a 20-year plant design life, requires an extension of today's technology for sodium system components. Consequently, special emphasis is placed upon developing high-temperature structural design criteria, including stress analysis techniques. The USAEC standards program being implemented for procurement of FFTF components is expected to provide sound bases for specifying design and fabrication procedures consistent with needs of demonstration and commercial plant equipment. Major design parameters for the FFTF components were included in Tables II to VI.

Primary sodium pumps

The pumps are centrifugal, tank-type pumps, with many features similar to the units used in the Fermi plant, except that the impeller inlet is ducted. Model testing is being performed to substantiate the analysis of the pump suction inlet geometry. Other developmental testing is being conducted to establish the design adequacy of: (1) the hydrostatic bearing, (2) the hard-facing materials used in the hydrostatic bearing, and (3) the pump shaft cover gas seal. A full-scale prototype of the FFTF primary pump will be tested in a water test facility and in the SPTF, to verify performance characteristics prior to FFTF plant operation.

Valves

FFTF sodium system valves range in size from 1/2 to 28 in. in diameter; the small sizes are of conventional design. The large primary system isolation and check valves are of unconventional design, because there are none available that can meet system requirements with respect to the combination of design temperatures, thermal transients, sealing capability, and allowable pressure drop.

The test program planned, or in progress, for these valves includes scaled-down air and water loop flow tests of both types of valves. These tests will verify calculated pressure drops and flow characteristics. The isolation valve stem freeze seal concept is based on highly localized heat removal, using a comparatively short axial cooling section. Since the concept has not previously been demonstrated, a subcomponent test of the principle is being considered. Finally, full-scale prototypes will be tested in sodium, to evaluate overall performance of the entire valve.

Intermediate heat exchangers

The IHX's are vertical, shell and tube type, having removable tube bundles, similar to units used in the Fermi plant. Water testing of models is being performed, to substantiate hydraulic and vibration analysis results. Models of highly stressed structural members, typical of tube - tube sheet

joints, are being subjected to fatigue cycle testing under prototype sodium temperature transients. A full-scale prototype of the FFTF IHX will ultimately be tested in the SCTI at reduced power conditions, to characterize performance and to demonstrate proposed maintenance techniques, prior to FFTF plant operation.

Fuel handling equipment

In general, the fuel handling and interim examination and maintenance cell equipment designs are "state of the art." However, some design features are unique in application, and have been selected for "feature testing." Examples of the feature tests are In-Vessel Handling Machine (IVHM) guide roller tests in sodium, and sodium removal process equipment for the Interim Examination and Maintenance Facility.

The full-scale tests at the High-Temperature Sodium Facility (HTSF) will be performed to demonstrate the technical feasibility of the design concept, to verify the design, and to furnish data for design refinements. These tests will further demonstrate that all interfaces and operational and maintenance requirements have been satisfied. Prototypic and/or actual plant hardware will be tested. Tests will be performed dry, using the Core Mechanical Mockup (CMM), and in sodium, using the Composite Reactor Components Test Activity (CRCTA).

TEST FACILITIES

There is a wide variety of test facilities available in the United States. The characteristics of these facilities, and facilities under construction, are summarized in Table VII.

REFERENCES

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- [2] Babcock and Wilcox, 1000-Mwe LMFBR Follow-on Study, USAEC Rep. BAW-1328 and BAW-1331 (1969)
- [3] General Electric, 1000-Mwe LMFBR Follow-on Study, USAEC Rep. GE-5678 and GE-5769 (1969)
- [4] Westinghouse, 1000-Mwe LMFBR Follow-on Study, USAEC Rep. WARD-2000-97 and WARD-2000-90 (1969)

TABLE VII
SUMMARY OF TEST FACILITY CAPABILITIES AND CHARACTERISTICS
(Sheet 1 of 2)

Facility	Year Con- structed	Design & Operating Conditions			Material (piping)	Comments
		Pressure (lbf/in ²)	Temperature (°F)	Flow (gal/min)		
Argonne National Laboratory (ANL)						
Core Component Test Loop (CCTL)	1965	150	1200	800	304SS	Hydraulic flow test of fuel subassemblies and instruments
Sodium Flow Sensor Calibration Facility	1965	30/10	900/800	100	304SS	Intended only for sodium flow sensor calibration
Component and Materials Evaluation Loop (CAMEL)	1967	150/100	1200	200	304SS	Isothermal testing of components and materials
Fuel Failure Detection Loop	1965	30/30	1300/1200	30	304SS	Test fission gas detector devices
Experimental Breeder Reactor II (EBR-II)	1957	90/80	900/880	9000/5890	304SS & Croloy	This is an active FBR power plant
FBR-II Out-of-Core Nuclear Instrument Test Loop (NITL)	1970	—	700-1200	—	SS	Test experimental neutron detectors and cable
Large TRFAT Sodium Loop	1968	150/75	1025/932	160	304SS	Fuel meltdown studies under flowing sodium
High Temperature Furnace Facility	—	—	5070	—	—	Test components at ultrahigh temperatures
Atomic Power Development Associates, Inc (APDA)						
APDA Sodium Endurance Loop	1959	120/130	1000/1000	350	304SS	Test reactor subassemblies in flowing sodium
APDA Sodium Technology Loop	1961	175/35	1200/1000	200 main 7.5 side	316 SS	Evaluate in-line instruments and purification devices
APDA Rig 10	1965	125/7.5	800/610	400	C steel	Investigate small water leaks into sodium
Enrico Fermi Atomic Power Plant (EFAPP)	1965	125	1000	20,000	304SS	Full-scale industrial fast reactor power plant
Atomics International (AI)						
High-Temperature Sodium Supply System	1969	100/30	1200/1200	60, each of 2 pumps	304SS	Tests on control rod components at reactor operating conditions
Reactor Sodium Environment Chamber	1969	50/20	1200/1200	20	304SS	Simulated reactor environment, especially sodium vapor
Low-Temperature Sodium Supply System	1969	100/20	1200/600	20	304SS	Testing components at reactor refueling temperatures
LMFBR 2-in. Flowing Sodium Loop	1967	21	1300/1200	40	304SS	Effects of environmental factors on mechanical properties of fuel cladding materials
Babcock & Wilcox Co (B&W)						
Model Sodium Heated Steam Generator	1964	Na 60/30 H ₂ O 2400	Na 1200/1100 H ₂ O 1050 (op)	Na 25 H ₂ O 115	316SS	Steam generator and corrosion studies
Brookhaven National Laboratory (BNL)						
Sodium Heat Transfer Facility	1968	100/80	1600/1600, 1000	35	316/ 304SS	Tests of core design and safe operation
General Electric Co (GE)						
Loop No. 11 Thermal-Hydraulic, Fuel and Flow Test Loop	1965	300/60	1300/1000	80	SS	Thermal and hydraulic testing of LMFBR components
Steam Generator Test Rig	1969	250/125	1100/1000	180	304SS	Heat transfer studies
Southwest Experimental Fast Oxide Reactor (SEFOR)	1968	100	1050	5000	304SS	A 20-MW(th) fast breeder reactor, fueled with sodium and uranium oxides. Owned by utilities, GE, Furatom, etc
SEFOR Refueling Cell Mockup	—	10	1000/400	20/10	—	Temperature study, demonstrate refueling system and training

TABLE VII
SUMMARY OF TEST FACILITY CAPABILITIES AND CHARACTERISTICS
(Sheet 2 of 2)

Facility	Year Constructed	Design & Operating Conditions			Material (piping)	Comments
		Pressure (lb/in ²)	Temperature (°F)	Flow (gal/min)		
Hanford Engineering Development Laboratory (HEDL)						
Core Segment Development Facility (CSDF)(a)	1971(b)	50	1200	Static	304SS	Vessel 2-1/2 ft diameter x 42 ft long Operational environment for testing full-length LMFBR components
Fast Reactor Thermal Engineering Facility (FRTEF)(a)	1971(b)	300	1200	600 at 200 lb/in ²	304SS	For design and safety testing of heated FFTF fuel subassemblies Loop test section to 1800°F, 39-pin assembly can be tested at 106 Btu/hr-ft ² heat flux
High-Temperature Sodium Facility (HTSF)(a)	1971(b)	—	—	—	—	High-bay sodium facility, 45,000 gal sodium storage Will house CRCTA and future facilities
Composite Reactor Component Test Activity (CRCTA)(a)	1972(b)	50	1100	Static	304SS	"Quasi-static" sodium system for full-scale testing of FFTF in-vessel & ex-vessel equipment, including IVHM, Instrument Tree Core Restraint, Closed Loop Ex-Vessel Machine, & Floor Valves Test Vessel 15 ft ID x 36 ft 4 in length
Liquid Metal Engineering Center (LMEC)						
Sodium Components Test Installation (SCTI)	1964	125/90	1300/1200	3000	304SS	Tests of heat exchangers and steam generators
Large Components Test Loop (LCTL)	1958	25	1000	2000	2 1/4 Cr 1 Mo	To be succeeded by the Small Components Test Loop (SCTL)
Pump Seal Test Facility (PSTF)	1969	55/50	1400/1200	0 to 55	304SS	Tests of pump seals and mechanisms not necessarily related to pump, such as control rod drives
Sodium Mechanisms Test Installation (SMTI)	1966	25	1200	—	304SS	Tests of materials and mechanisms in sodium liquid and/or vapor
PMIS Loop II	1970	15	1200	20	304SS	Static sodium environment for mechanism testing Four test vessels
Sodium Pump Test Facility SPTF)(a)	1972(b)	250	1200	18 000 (initial)	304SS	Flow and thermal shock capability for pump, valve, and instrument testing and calibration
Small Components Test Loop (SCTL)(a)	1972(b)	225	1200	3500 at 220 lb/in ²	304SS	10-in loop, environmental & transient testing of piping, valves, instruments, small components, & subsystem inserts
Pump Bearing Test Facility (PBTF)(a)	1972(b)	210 (bearing) 300 (piping)	1050	600	304H SS	Proof & performance tests of sodium-lubricated main-shaft radial bearings
Mine Safety Appliance Research Center (MSAR)						
MSAR Loop-1 (High-Carbon System)	1961	50/30	1400/1200	25	316SS	Test mechanical properties, calibrate carbon meters Conduct stress-free excursions in C- or O ₂ -contaminated systems
MSAR Loop-2 (High-Oxygen System)	1961	50/30	1400/1200	25	316SS	
MSAR Loop 3 (Clean Sodium, Mechanical Properties)	1968	100/55	1400/1200	85	316SS	Mechanical properties tests with clean sodium and high-velocity conditions
MSAR 4-in Pump Test Loop	1965	250/200	1600/1500	800	316SS	Test experimental linear induction pump
Oak Ridge National Laboratory (ORNL)						
LMFBR — Failed Fuel Mockup	1970	100/90	1300/600 to 1200	260	304H SS	Investigate LMFBR fuel pin failures
LMFBR — Heater Test	1969	30/25	1200/1200	5	316SS	Determines performance of electric heaters used in Failed Fuel Mockup
Westinghouse Electric Corp						
General Purpose Loop-1 (GPL-1)	1967	330/230	1200/1200	200	304SS	Heat transfer, hydraulics, sodium technology, and component tests
General Purpose Loop-2 (GPL 2)	1968	300/219	1200/1200	2000	304SS	Test full-size fuel assemblies, control rods, and large components

(a) Under construction

(b) Year operational