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THE EXPERIMENTAL BREEDER REACTOR (EBR-II) FUEL-PERFORMANCE FACILITY (FPTF)*

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THE EXPERIMENTAL BREEDER REACTOR-II (EBR-II) FUEL-PERFORMANCE TEST FACILITY (FPTF)

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ABSTRACT

The Fuel-performance Test Facility (FPTF) is the latest in a series of special EBR-II instrumented in-core test facilities. A flow control valve in the facility is programmed to vary the coolant flow, and thus the temperature, in an experimental-irradiation subassembly beneath it and coupled to it. In this way, thermal transients can be simulated in that subassembly without changing the temperatures in surrounding subassemblies. The FPTF also monitors sodium flow and temperature, and detects delayed neutrons in the sodium effluent from the experimental-irradiation subassembly beneath it. This facility also has an acoustical detector (high-temperature microphone) for detecting sodium boiling.

INTRODUCTION

The first EBR-II instrumented in-core test facilities were Instrumented Subassembly Tests (INSAT's) that consisted of an experimental subassembly, extension tube, and terminal box. The subassembly contained fission-gas-pressure transducers, flux monitors, fuel elements with integral thermocouples, and flowmeters. Instrument leads were routed out of the reactor through the extension tube and were connected to external readouts at the terminal box.

The second-generation facilities, In-Core Instrument Test Facilities (INCOT's) did not contain fuel elements. These facilities contained various instruments and materials for evaluation in a reactor environment. A sodium-flow control valve permitted operation at various coolant temperatures.

These INCOT facilities were followed by a more sophisticated Breached-fuel Test Facility (INCOT-BFTF). This facility consists of an instrumented thimble seated on a fueled Run-beyond-cladding-breach (RBCB) type of experimental subassembly. The BFTF provides more detailed experimental data than previous facilities. Instrumentation consists of a delayed-neutron detector, flowmeters, thermocouples, and a removable deposition sampler to collect debris from a failed subassembly element. The BFTF experimental subassembly--and also the FPTF subassembly--may be replaced without removing the facility, whereas the experimental subassembly is an integral part of the INSAT's and the original INCOT's, so these complete facilities must be replaced when the subassembly is removed.

The FPTF is part of the EBR-II Operational-reliability-testing (ORT) program established to perform safety research and to improve reactor operational reliability. By varying the flow through its experimental subassembly, the facility provides the capability for simulating temperatures accompanying power transients and thus allows fuel qualification in advance of whole-core transient operation without disturbing flow or fluence of other subassemblies. It also prevents thermal shock to the reactor that could result from power-cycling transients.

DESCRIPTION OF SYSTEM

GENERAL

The FPTF is installed in EBR-II control rod position No. 6 (reactor grid location 5F3); it utilizes the existing elevator drive assembly, bellows seal, and support platform used for the original INCOT facility previously installed in this position.

The FPTF consists of a thimble, an instrument carrier, an extension tube, and a terminal box. The thimble extends downward from the support station through the small rotating plug and the reactor-vessel cover, and terminates in the reactor-vessel upper plenum. The thimble is seated onto the top of an experimental-irradiation subassembly that is locked into a special guide tube in the reactor grid. A relatively leak-tight coupling is assured by a ball seat coupling assembly that is held captive to the lower end of the thimble. Figure 1 is a schematic diagram of the FPTF assembly.

The instrument carrier assembly is supported in the top of the thimble by a ball bearing. It contains thermocouples, flowmeters, an acoustical sensor, and a delayed-neutron detector (DND) assembly. The inner portion of the flow control valve is an integral part of the instrument carrier. The instrument carrier is routed within the thimble to control sodium flow through the valve.

Sheathed instrument leads are routed through the center of the instrument carrier tube attached to the flowmeters, which in turn are attached to the bottom end of the inner portion of the valve. These leads then pass through the center of the valve, go along the side of the lead support rod which extends up to the shield, pass along the outside wall of the shield tube, and then pass through the sodium seal bulkhead. The instrument leads are brazed into the bulkhead to provide a sodium-tight seal. The leads then pass through an annulus between the DND drywell and instrument carrier outer tube and enter the terminal box. At this point the sheathed leads are connected to flexible cables that are routed to hermetically sealed connectors on the terminal box cover. All of the instruments except the DND are a permanent part of the thimble assembly. The DND can be replaced through the top of the terminal box.

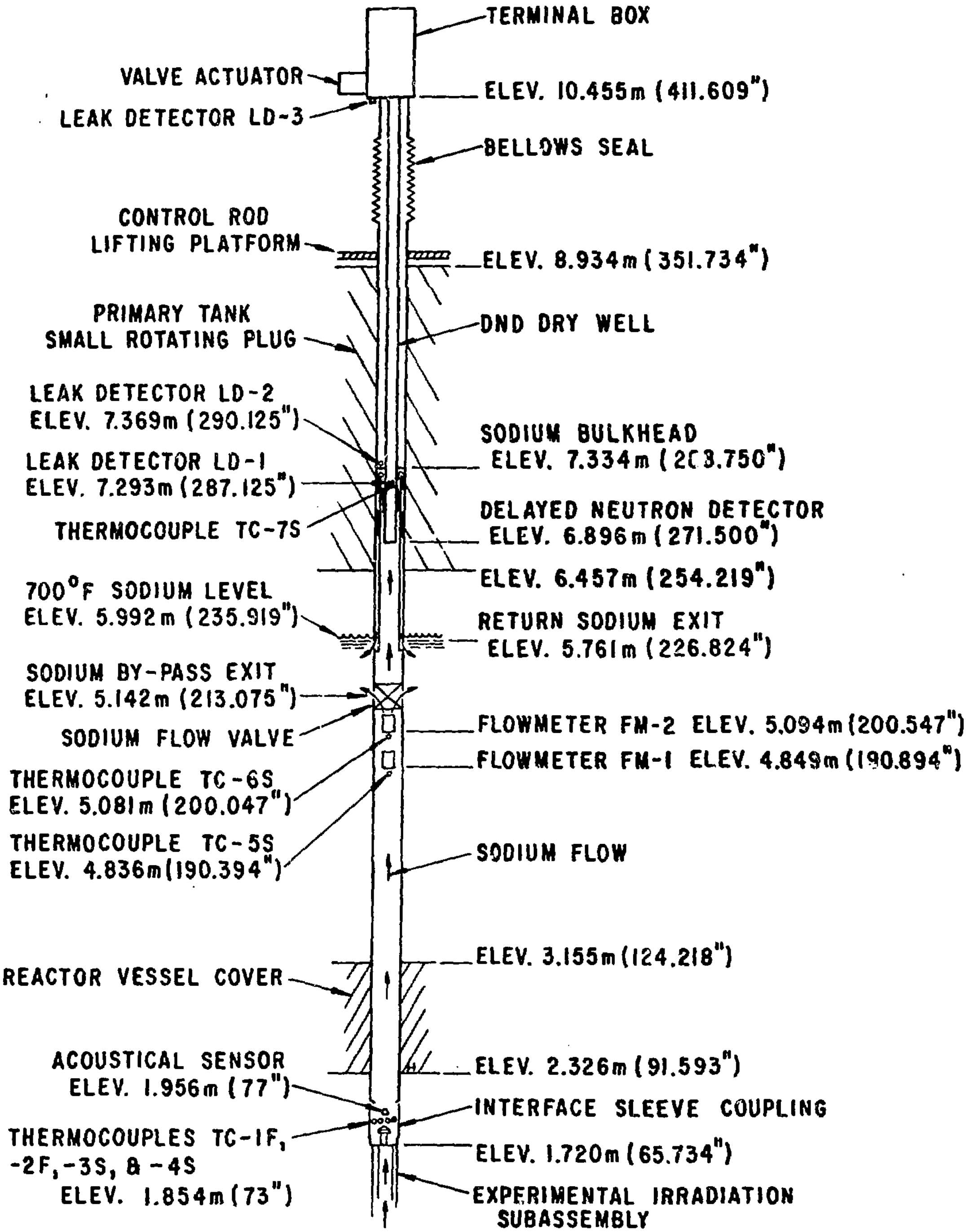

FIG. 1 FUEL PERFORMANCE TEST FACILITY (FPTF)

SODIUM FLOW THROUGH THE FPTF

During reactor operation, sodium flows up through the experimental subassembly and enters the FPTF thimble. The flow then passes four thermocouples and the acoustical sensor and flows between the thimble and instrument carrier into the flow control valve, a total distance of about 3.66 m (12 ft). Tandem flowmeters, mounted just below the flow valve, monitor sodium flow.

With the valve closed, there is a minimum leakage flow. This is allowed by the diametral clearance between the valve inner cylindrical portion and valve body and by the small clearance along the instrument leads that pass through the upper cylindrical portion of the valve. The flow then passes through ports in the upper cylindrical portion of the valve and enters the inside of the instrument carrier tube. At this point the sodium flows through the annulus formed by the inside of the instrument carrier flow divider tube and the outside of the DND dry well tube and flows past the DND to the sodium seal bulkhead. The flow then reverses and passes down an annulus between the instrument carrier flow divider tube and the instrument carrier outer tube, passes through outlet flow holes in the thimble, and returns to the primary tank bulk sodium.

As the valve is partially opened flow ports in the valve cylinder and the valve housing begin to align and permit additional sodium flow through the subassembly. This flow passes from the inside of the valve, enters the inside of the instrument carrier tube, and then flows up past the DND.

As the valve is opened further, the flow port openings gradually increase. The lower ports in the valve and housing also begin to open and eventually become fully aligned (100% open) and communicate directly with the primary tank bulk sodium. This sodium bypassing is necessary because the relatively small annuli around the DND would restrict the flow through the subassembly. A labyrinth seal forms a part of the upper portion of the valve to minimize flow leakage to the bulk sodium.

The cylindrical inner portion of the valve connects to the instrument carrier drive tube through a bellows. The bellows provides a flexible connection to minimize valve binding due to slight drive tube misalignment; it also provides a seal to prevent sodium from leaking into the annulus between the instrument carrier and thimble. An outer sleeve surrounding the bellows is welded to the bottom of the instrument carrier drive tube. The bottom of the sleeve is held captive in a groove in the extension of the cylindrical portion of the valve. Pins in the valve cylinder engage grooves in the bottom of the sleeve to transmit the torque required for valve rotation. This sleeve holds the inner portion of the valve at the proper elevation, limits torsional deflection of the bellows; it also transmits rotation of the drive tube to the valve. Valve travel is limited to 90°.

FLOW VALVE CONTROL SYSTEM

The FPTF flow valve control system comprises a rotary valve actuator, a manual control station, and a programmable valve controller. This arrangement permits complete manual control of the valve, or sequential automatic operation in accordance with predetermined programs.

The sodium flow valve is driven by a servo-controlled rotary actuator mounted on the outside of the FPTF terminal box. Inside the terminal box the actuator output shaft connects to the valve extension tube assembly through a right-angle gear drive (3:1 ratio). This translates the 270° rotation of the actuator in to the required 90° rotation of the valve.

The rotary valve actuator contains a servo motor, a feedback tachometer for smooth control, reduction gears that provide a maximum speed of 9 rpm at the output shaft, a precision feedback potentiometer, and limit switches that stop overtravel. These electrical components are interconnected to a servo amplifier. The amplifier compares the feedback potentiometer signal with an input signal and transmits a drive signal to the servo motor. The servo motor repositions the actuator until the comparison is "null." The servo amplifier control signal is supplied by an auto-manual station. This station allows the actuator position to be manually controlled or switched to the "auto" position for relaying control signals from a setpoint programmer. In "auto," the setpoint programmer applies a predetermined program to sequentially control the valve.

The setpoint programmer may be adjusted to incrementally position the valve and to cycle it between the full-closed and full-open positions. A full cycle ofthe valve covers 84° of travel and it is represented as 0% or 100% on the valve position indicator. Should the valve rotate past the 0% or 100% position by one degree, a limit switch will interrupt power to the actuator. If rotation continues one degree past either limit switch position (due to failure of a limit switch or to inertia) a mechanical stop will prevent further rotation. Interlock circuits are provided to drive the valve to the open limit (1° past 100%) in the event of a reactor scram or sodium over-temperature indication. The valve may also be tripped from the control room or from the valve control console. A valve-open limit indication is provided in the control room when the 1°-past-100% position is reached. An integral current limiting device prevents damage to the actuator if power is not interrupted when the mechanical stops are reached, or if binding should occur. An electronic torque limiting feature is also included. This device senses valve actuator current and prevents it from rising above its preset value. This circuit eliminates the requirement for a shear pin in the valve drive train; it is adjusted to limit the driving torqe to 11.3 N·m (100 lb-in.).

An electrically operated brake is also included in the valve actuator. This brake locks the valve in position when the servo system is denergized. A clamp is provided to permit the valve to be locked at any selected position. This would be used in the unlikely event that facility operation would continue with the drive actuator removed. A dedicated electrical feeder from the uninterruptible power system is provided to ensure continuous operation of the valve.

FPTF SENSORS

Thermocouples

Seven thermocouples monitor temperatures in the FPTF. These thermocouples are of two types; a fast-response type and a standard-response type. Two fast-response and two standard-response thermocouples are located at the bottom end of the sensor assembly (the point where subassembly outlet sodium enters the FPTF). Standard-response thermocouples are also located at each of the two flowmeters and at the delayed-neutron detector. All thermocouples are type K, chromel-alumel.

High-Temperature Microphone (Acoustical Monitor)

A high-temperature microphone system is provided to monitor noise in the sodium entering the FPTF. The high-temperature microphone is located near the bottom of the instrument carrier tube, out of the main sodium flow. Holes in the tube allow noise to be transmitted directly through the sodium.

A small vent tube supplies oxygen to the microphone from a reservoir to maintain high electrical resistance.

Flowmeters

Total flow from the subassembly through the FPTF is measured by eddy-current-type flowmeters. Two flowmeters are provided to ensure continued flow monitoring should one unit fail. Before installation, the flowmeters were calibrated in a sodium loop.

Delayed-neutron Detection (DND) System

The DND system functions to detect fuel cladding failures that expose fuel to the sodium coolant. This system comprises a fission counter, charge-sensitive preamplifier. linear-pulse amplifier, single-channel analyzer, count-rate meter, high-voltage power supply, and monitor circuits.

The FPTF delayed-neutron detector is located in a drywell at an elevation within the shielded portion of the small rotating plug. Sodium flows through an annulus surrounding the DND. DND signals are routed out of the primary tank via a sheathed cable. To improve signal-to-noise ratio, the detector is electrically insulated from the remainder of the facility.

A shield of boron carbide encloses the drywell. This shield absorbs the background neutron flux while permitting delayed neutrons in the flowing sodium to react with the detector.

The DND fission counter has a thermal neutron sensitivity of 0.1 cps/nv; it is rated for operation at 427°F (800°F). Because of heat transfer from the facility to the bulk sodium, the detector temperature remains nearly constant regardless of the flow valve position.

Leak Detectors

The FPTF is equipped with three sodium leak detectors. One detector is located in the terminal box, another is near the DND, and the third is just above the bulkhead. The leak detectors consist of a length of mineral-insulated sheathed thermocouple wire that is squared off and sealed to expose the two separate wires at the sensing end. Sodium contacting the wires would complete an electrical circuit and activate the leak detector alarm.

FPTF-TO-SUBASSEMBLY INTERFACE SLEEVE COUPLING

The sleeve coupling by which the experimental subassembly is attached to the FPTF is unique. It allows the experimental subassembly to be easily separated from and reconnected to the facility during fuel handling while sealing the interface during reactor operation, so that sodium leakage is minimal.

Because of the long length of the FPTF tubes, 9.25 m (30 ft), and the possible bowing of EBR-II subassemblies, misalignment could occur at the mating point. To compensate for this misalignment and still prevent leakage, the lower end of the FPTF thimble has a sleeve coupling that will accommodate a maximum misalignment of 11.11 mm (0.437 in.). This coupling has spherical ends that mate with concave conical seats on the thimble and on the subassembly (see Figure 2). The ball seats establish a seal along an annular line of contact to minimize leakage.

A restraining collar in the coupling limits swivel action to ensure that a seal is always maintained and that the system does not become mechanically unstable. A thermal liner is incorporated in the sleeve coupling to moderate effects of sodium temperature changes on the thimble wall.

The FPTF weight, 113 kg (250 lb) and the weight of the terminal box and extension rod, 45 lb (100 lb) provide the seating force for the sleeve coupling.

A further design consideration was material selection for the sleeve coupling and subassembly upper adapter interface. This material must exhibit the least possibility of sticking or self-welding; it must also be compatible with high temperature sodium, and radiation exposure. The metal-to-metal line contact of the ball seals operating at temperatures between 560 and 663°C (1040 and 1225°F) for extended periods introduces the potential for diffusion welding of the mating surfaces. This would complicate separation of the FPTF from the subassembly. Further, any roughing of the mating surfaces would cause undesired leakage in subsequent experiments. Therefore, an engineering test program was undertaken to determine the most desirable combination of materials for this seal.

OPERATING EXPERIENCE

The facility was installed in the reactor in June 1981. The bulk sodium temperature in the primary tank was 371°C (700°F). Operational checkouts were conducted on the flow control valve, programmable valve actuator, DND, thermocouples, and acoustical sensor, and their performance was satisfactory. However, the two fast-response thermocouples gave erroneous readings after having been in the reactor a few months. It appears that these thermocouple leads were shorted by inleakage of sodium through the sheath closure weld at the thermocouple junction. Evaluation of the flow distribution is being made to determine if the leakage at the sleeve coupling is as expected.

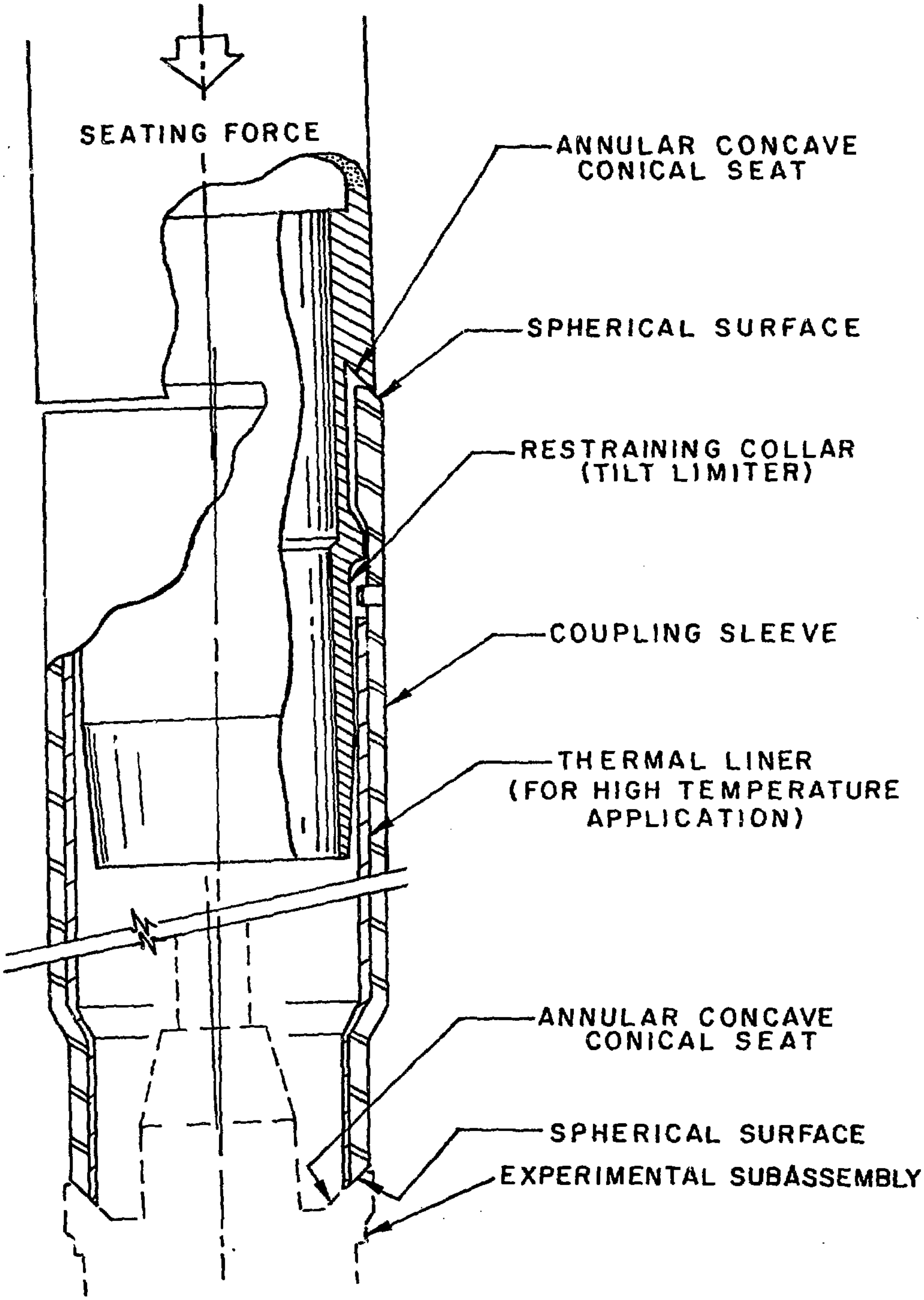

FIG. 2 SEALING COUPLING