HEDL-SA-2107-FP

CONF-800401--27

MASTER

SODIUM FILL OF FFTF

J. B. Waldo,
R. K. Greenwell, T. A. Keasling,
J. R. Collins, D. B. Klos

February, 1980

Second International Conference on Liquid
Metal Technology in Energy Production

April 20-24, 1980

Richland, WA

HANFORD ENGINEERING DEVELOPMENT LABORATORY
Operated by Westinghouse Hanford Company, a subsidiary of Westinghouse Electric Corporation, under the Department of Energy Contract No. DE-AC14-76FF02170

DISCLAIMER

SODIUM FILL OF FFTF

J. B. Waldo, R. K. Greenwell, T. A. Keasling
J. R. Collins, D. B. Klos

ABSTRACT

With construction of the Fast Flux Test Facility (FFTF) completed, the first major objective in the startup program was to fill the sodium systems. A sodium fill sequence was developed to match construction completion, and as systems became available, they were inerted, preheated, and filled with sodium. The secondary sodium systems were filled first while dry refueling system testing was in progress in the reactor vessel. The reactor vessel and the primary loops were filled last. This paper describes the methods used and some of the key results achieved for this major FFTF objective.

INTRODUCTION

Basically, the systems requiring sodium are; the primary and secondary heat transport systems (HTS), primary and secondary sodium purification and sampling systems, and their respective drain tanks and storage vessels. A flow schematic of the plant is shown in Fig. 1. The primary HTS consists of the reactor vessel and three loops with an intermediate heat exchanger (IHX) in each loop to reject the heat to the secondary HTS.

The secondary HTS consists of three individual loops, each taking heat from the primary at its respective IHX and rejecting it to atmosphere through four dump heat exchangers (DHX) per loop. The sodium in each loop (primary and secondary) is circulated by a vertical, single-stage centrifugal pump.

Separate subsystems are provided in both the primary HTS and for each of the three secondary HTS loops for on-line sodium purification and sampling. Each subsystem consists of a small loop containing an electromagnetic (EM) pump, a cold trap for removing impurities, and a sodium sampling and monitoring package.

The plant is also provided with three large sodium storage vessels which were filled repeatedly from tank cars and used as reservoirs during the fill sequence.

SECONDARY HTS SODIUM FILL

Inerting

Due to the chemical reaction of sodium with oxygen and water, it is necessary to provide an inert atmosphere in all components prior to introducing sodium. The secondary HTS and supporting systems were inerted on a loop-by-loop basis, by system evacuation through high point vents and then by successively pressurizing with argon gas (the inert atmosphere used as a cover gas for FFTF) and venting back to atmospheric.

The secondary HTS was inerted by starting with Loop #3 and progressing to Loop #2 and then Loop #1. Each loop was successfully evacuated to 700 Pa (0.1 psia). Loop #3 included the secondary sodium storage vessel for a total system volume of approximately 179 m^3 (6340 ft^3). Loops #2 and #1 each had a system volume of approximately 68.2 m^3 (2410 ft^3). Evacuation was accomplished with plant vacuum pumps, each rated at 0.033 m^3/s (70 scfm). Loop #3 and the storage vessel were pumped down utilizing four pumps. Three vacuum pumps were used on the other two loops. Evacuation time to 700 Pa (0.1 psia) was 10 to 15 hours for each loop.

Immediately after evacuation, each loop was monitored for vacuum decay for at least 24 hours to evaluate system leak tightness. At the completion of the vacuum test, each loop was then rapidly backfilled with the plant argon system. Each loop was pressurized to 380 kPa (40 psig) and then vented back to atmospheric pressure three times, each time using different vent locations to promote good mixing. Final system purity was verified by portable gas analyzers and gas grab samples. The inerting method used was successful in achieving oxygen levels of 5 - 20 ppm (50 ppm limit) and moisture readings of 30 - 85 ppm (100 ppm limit).

Throughout inerting, the systems were continuously monitored for leakage. During evacuation, portable ultrasonic detectors (to detect leak noise) were used with little success. After the systems were pressurized with argon, much better success was achieved with portable argon leak detector units, and in several instances, mechanical packing joints in the argon piping were found to be leaking and were repaired.

Secondary HTS Preheat

Prior to introducing the reactor-grade molten sodium, the systems were preheated to approximately 177°C (350°F). The piping and most components are preheated using Calrod-type electrical resistance heating. Indirect oil-fired preheaters are provided for each DHX tube bundle.

The electrical preheating proved to be the most difficult to control due to the vast number of control loops (∿2,500 for overall plant) and the associated control and insulation problems. A microcomputer system was employed to monitor all of the control loops. The poor thermal conductivity of dry inerted pipe resulted in poor temperature distribution and was the source of many of the control problems. The resulting poor temperature distribution was also the reason for the final agreed-to temperature tolerance of 177^{+83}_{-28}°C (350^{+150}_{-50}°F). The DHX tube bundles were externally heated using oil-fired preheaters which circulated heated air over the sodium tube bundle and successful preheating was achieved with little difficulty.

As during inerting, the preheating was done on a loop-by-loop basis for the secondary HTS. During heatup, the loop atmosphere was monitored for moisture utilizing a portable hygrometer. The moisture levels rose with temperature and an argon purge was required to maintain the levels within the acceptance criteria of less than 100 ppm.

Preheat of the secondary HTS Loop #3 and the secondary sodium storage vessel took approximately twenty days with a five-day "hold" encountered for piping snubber work. The secondary HTS Loop #2 took approximately eight days and Loop #1 took approximately twelve days.

Secondary Fill and Initial Circulation

For sodium fill of all plant systems, the sodium was pressure-transferred from railroad tank cars into the various plant storage vessels. Each tank car had a capacity of approximately 39.7 m^3

(10,500 gallons) of sodium. A hot-oil heating and circulating system was provided at the tank car station to melt the sodium and establish the transfer temperature of 149 $\pm$ 8°C (300 $\pm$ 15°F). Only one tank car could be heated and unloaded at a time, with a minimum "turn around" time of approximately 26 hours.

The first sodium fill of an FFTF system was initiated in June 1978 with the transfer of approximately 102 m^3 (27,000 gallons) into the secondary HTS storage tank. After heating this sodium to 177°C (350°F), the secondary Loop #3 sodium processing system was pressure-filled and the storage vessel inventory was circulated through the processing system to obtain a plugging temperature indication (PTI). The initial PTI reading was 143°C (290°F) and this was judged acceptable for fill of the loop. The acceptable range was defined as a PTI reading of 17°C (30°F) less than system temperature.

On July 2, 1978, the first secondary HTS loop was filled with about 68 m^3 (18,000 gallons) of sodium, over a period of 15 hours. The sodium was transferred into the loop via the fill/drain header (Fig. 2) by gradual pressurization of the storage tank. The sodium fill progress was monitored initially by observation of piping and component trace heat temperature changes, and the drop in level of the storage tank. As the sodium elevation reached the higher portions of the loop, installed level sensors in the pump and the loop expansion tank started indicating. As a "backup" to the installed level probes, portable manual eddy current probes were utilized in spare level wells in both the storage and expansion tanks. These manual probes were invaluable in providing reliable level indication during initial fill until the installed probes could be calibrated in place (these manual probes were also used in the reactor and primary storage tanks to monitor levels accurately). A final storage tank pressure of 253 kPa (22 psig) was required to raise the sodium level to the required height.

Sodium plugs were established in the freeze traps connected to the high points on either side of the processing loop cold trap and at the dump heat exchanger (DHX) inlets by system pressurization. The loop fill was completed by initiation of sodium circulation through the processing system cold trap, and PTI, by EM pump, and circulation through the HTS loop by operation of the main pump on pony motor (10% full flow).

The initial PTI readings on secondary Loop #3 were 149°C (300°F) which indicated excellent system purity control. The loop was then heated to 204°C (400°F) and the cold trap placed on-line.

The second and third secondary HTS loops were filled in September 1978 utilizing similar procedures to those used to fill the first loop. The storage tank was refilled prior to each loop fill. Approximately 238 m^3 (63,000 gallons) of sodium were unloaded from six tank cars for filling all the secondary HTS loops.

PRIMARY HTS SODIUM FILL

Inerting

The inerting of the primary HTS was performed in three stages, dictated primarily by system readiness.

The first stage consisted of closing the isolation valves in each primary loop and inerting the loops separately from the reactor vessel. This inerting operation was done in support of secondary HTS sodium fill as a precaution taken to minimize the consequences of a secondary-to-primary sodium leak (if an IHX leak problem were to occur during secondary fill). The entire primary system (i.e., reactor vessel), could not be inerted at this time due to repair operations being performed on in-vessel refueling equipment. Since loop inerting would be repeated later, and the in-containment argon system was not yet operational, a simple displacement purge, using argon bottles as a gas source, was performed on each loop. The desired purity of $\leq$300 ppm O_2 was reached without difficulty.

The second stage of inerting consisted of placing the in-containment argon system in operation and inerting the primary sodium drain vessel (T-43). These systems were easily inerted by evacuation and backfill to O_2 levels less than 10 ppm.

The third and final stage was to evacuate and inert the overall primary system which included the three primary HTS loops, reactor vessel and the reactor overflow vessel. The total system volume for this inerting operation was 623 m^3 (22,000 ft^3). Five vacuum pumps (each rated at 70 scfm) were used connected to system high point vents.

Two evacuations were required due to leakage problems encountered with the temporary argon preheat adaptors installed through the reactor head. After the leakage problem was fixed, it took 21 hours to achieve a vacuum of less than 0.1 psia. A rapid backfill method was used to minimize the inleakage time; a previously inerted tank (~215 m^3) (~7,600 ft^3) was pressurized (276 kPa) (40 psig) with argon and then used to assist in backfilling the evacuated system. Total backfill time to atmospheric pressure was 1 hour and 25 minutes. Final system purity was less than 5 ppm O_2 which was well below the stipulated 100 ppm O_2 maximum. Approximately nine days elapsed from the start of the first evacuation until acceptable O_2 levels were achieved in the primary system. Following evacuation and backfill of the primary HTS, the final connection of the reactor internal preheat equipment was made to the reactor vessel.

Primary HTS Preheat

The primary HTS piping and all components, except the reactor vessel shell and internals, were preheated using permanent Calrod-type electrical resistance heating similar to that provided for the secondary HTS. Again, a number of temperature control problems were encountered, primarily due to insulation problems and the poor thermal conductivity of dry piping and components. A similar preheat tolerance of 177 $^{+83}_{-28}$°C (350 $^{+150}_{-50}$°F), was necessary for all piping, with different specific tolerances required for the reactor vessel head and the main-loop isolation valves.

The reactor vessel was heated externally from ambient to 177°C (350°F), using a portable nitrogen blower heater unit (NBHU) to circulate hot air in the annulus between the reactor vessel and the reactor guard vessel. The reactor internals were also heated in conjunction with the external vessel heating, using a portable argon blower heater unit (ABHU), which circulated heated and pressurized argon gas in a closed cycle through the reactor internals. Preheating the reactor vessel and the reactor internals was successfully completed following predescribed heating rates, without difficulty. Actual heatup rate data are presented in Fig. 3. Thermocouples installed in the low level flux monitor (LLFM) were used to determine completion of reactor internals preheat (149°C) (300°F). Following the initial heatup, the

ABHU was shutdown, and the associated equipment removed. The NBHU continued to operate to maintain the reactor vessel temperatures throughout the sodium fill evolution.

The preheat of the primary HTS support systems was sequenced to meet the overall fill schedule. The three primary HTS loops and the reactor vessel were preheated essentially simultaneously. Preheat of the entire primary HTS and reactor vessel was successfully completed in approximately 33 days.

Primary Fill and Initial Circulation

In preparation for fill of the primary system, all storage tanks in the plant were sodium filled from tank cars. The secondary storage tank was simply refilled and no attempt was made to obtain a PTI reading before moving the sodium to the primary loops. The in-containment primary storage tank and the reactor overflow tank were filled initially, and their separate processing systems started to obtain PTI readings. Initial PTI readings were approximately 152°C (305°F) in both tanks, so cold trapping was not required before sodium transfer to the primary HTS.

The first major phase of fill of the FFTF primary heat transport system started on December 15, 1978, with the pumped transfer of sodium from the reactor overflow vessel to the primary HTS. Over a period of 31 hours, a total of 279 m^3 (73,880 gallons) of sodium (total available sodium in all three plant storage vessels) were transferred into the primary HTS by pressure and pumped transfer. The fill path (shown in Fig. 4), was through the Loop #1 IHX fill/drain line. Sodium partially filled the IHX, then "spilled over" through the pump discharge line to partially fill the pump until the level reached the bottom of the elevated piping; at this point, sodium spilled over through the cold leg piping (hot leg valve closed) to start filling the reactor vessel from the low point up, thus helping to displace any gas in the reactor internal structures and core region. Spillover from the IHX to the pump was detected using an amplifier and loud speaker arrangement, connected to one of the pump discharge pipe accelerometers. This arrangement worked quite well and proved to be extremely sensitive. At the completion of the transfer, the hot leg isolation valve was opened. Reactor and loop levels were then as depicted in Fig. 5.

The elevated piping for primary HTS Loop #1 was then filled to allow the pump in that loop to be started on pony motor. The loop elevated piping, and associated freeze vents, were filled by very carefully applying a gradually increasing vacuum (see Fig. 5) to the loop high-point vents, to transfer sodium from the reactor vessel up into the loop. Due to the hydraulic profile of the primary HTS loop, a gas pocket will be trapped in the top of each IHX on initial completion of loop fill. This gas pocket, which is not a hindrance to main pump operation, could have been large enough to prevent circulation on first starting the pump on pony motor. To minimize the amount of gas remaining in the loop, the vacuum was applied in small steps using special temporary equipment designed and built for this purpose. Fill of the elevated piping progressed exactly as planned with sodium levels responding as predicted. On first starting the pump pony motor, flow was indicated on the loop flowmeter almost immediately, indicating that the fill method was satisfactory in limiting the gas bubble in the IHX. While Loop #1 was being filled, refill of the storage vessels was initiated, in preparation for the fill of the remaining loops.

Fill of the other two primary HTS loops, fill of the reactor vessel to the overflow level, and the initial startup of the other two primary HTS pumps was completed with no significant problems encountered. The second and third primary loops were filled in the same manner as the first loop. A total of 456 m^3 (120,680 gallons) of sodium was required to fill the three primary HTS loops and reactor vessel to the normal level and was completed over a 14-day period.

Shortly after filling the reactor to the overflow level, normal reactor makeup flow was established. This was the first opportunity to obtain an indication of the purity of the sodium in the reactor system. The first plugging temperature obtained for this sodium was 159°C (319°F) at a nominal system temperature of 198°C (388°F).

Throughout primary HTS fill, a 25.4 cm (10 inch) diameter view-port was installed on one of the reactor fuel transfer ports to permit visual observation of the interior of the reactor vessel. The surface of the sodium during and following fill was observed to be very shiny and mirror-like, again indicating a very clean system.

LESSONS LEARNED FROM FFTF SODIUM FILL

Preheat Temperature Limits

Initially, FFTF preheat requirements of 177 ± 8°C (350 ± 15°F) were overly restrictive and could not be achieved. The temperature limits on preheated piping and components must be realistic and take into account the realities of heating dry pipe, insulation irregularities, wall penetrations, readout accuracy, etc. The final limits of 177 $^{+83}_{-28}$°C, (350 $^{+150}_{-50}$°F) were workable and resulted in only a few areas which had to be addressed on a case-basis. In each of these areas, stress analyses were performed, taking into account the actual pipe/component temperature conditions, before introduction of sodium was permitted.

Reactor Vessel Preheat

The combination of the reactor vessel/guard vessel external heater and an internal argon circulating/heating unit was quite effective. The vessel could probably have been preheated entirely with the guard-vessel unit only, but the time required would have been increased. The internal gas circulating unit increases the heating rate of the core region and also promotes excellent inerting of the system when a purge is utilized during the entire preheat. Strategically located temporary or permanent thermocouples should be provided in the slowest heating regions to permit completion of preheat based on data rather than calculations or extrapolation.

Cold Trapping During Fill Operation

Experience at FFTF with over 752 m^3 (200,000 gallons) of sodium showed that cold trapping in the storage tanks is not required before filling of the systems, if the systems are clean and well inerted. This can be a significant time saver during a complicated fill evolution and justifies extra care during construction and inerting.

Need for Additional Sodium Level Wells

One of the key factors in successfully completing the sodium fill evolution, was in knowing the precise location of the sodium level in the various pumps, expansion tanks, storage tanks, and the reactor vessel during the initial filling operations. Our experience shows that in future plants, additional level wells should be provided in all sodium pumps and vessels to permit manual level measurement with portable eddy current level probes. These wells are invaluable, not only for initial fill, but also during later plant operation, when in-place calibration of the permanent level units is desired.

In FFTF, unused level wells were available in all of the sodium storage tanks and the secondary expansion tanks; however, they were not provided in the main HTS pumps or the reactor vessel. For sodium fill, a special 14 m (46 ft) long "level thimble" was built and temporarily installed in the reactor vessel to permit manual level measurements over an extended range. This thimble has been used repeatedly during the startup program to monitor all primary fill and drain operations.

EM Pumps and Flowmeters

The electrical phasing problems related to EM pumps and EM flowmeters make them difficult to interpret during initial fill. More often than not, they pump or indicate in reverse, and procedures and hardware should be provided to anticipate these problems in future plants. Installed system differential pressure indicators are often the only tool available for determining actual flow direction in an isothermal sodium system.

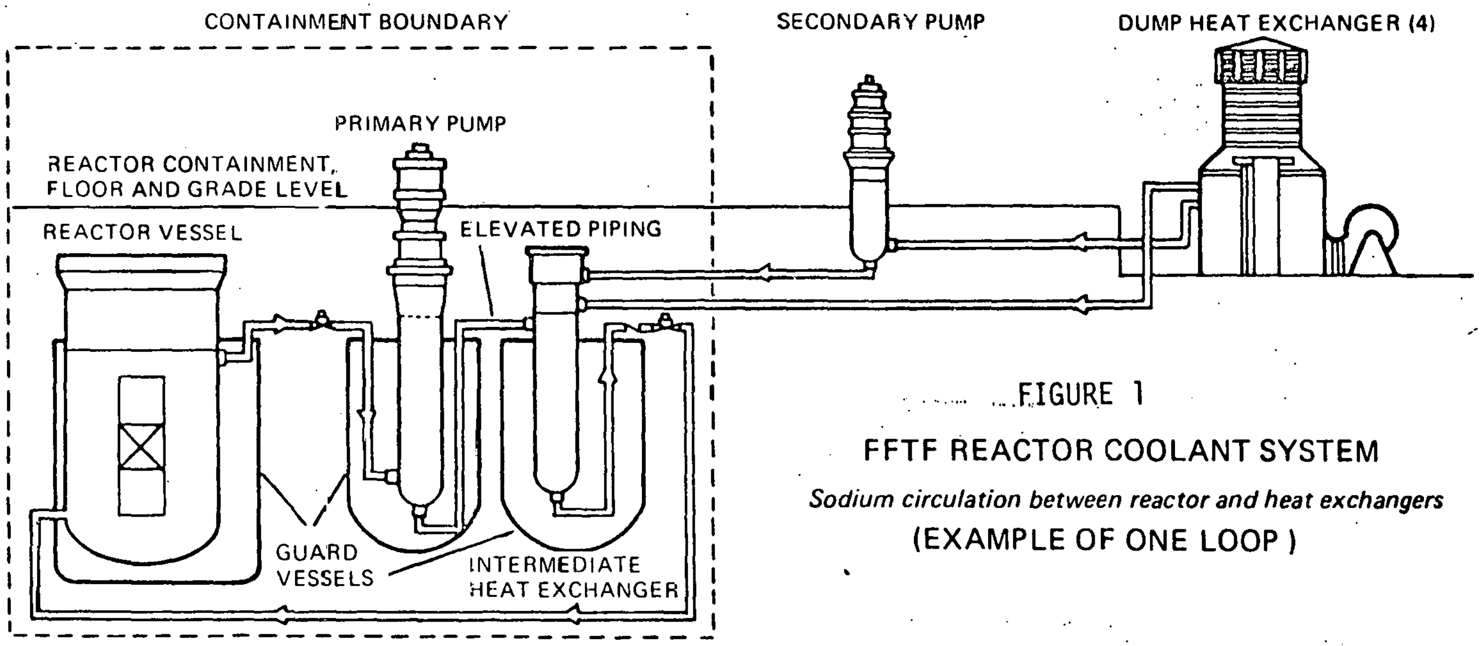


FIGURE 1

FFTF REACTOR COOLANT SYSTEM

Sodium circulation between reactor and heat exchangers

(EXAMPLE OF ONE LOOP)

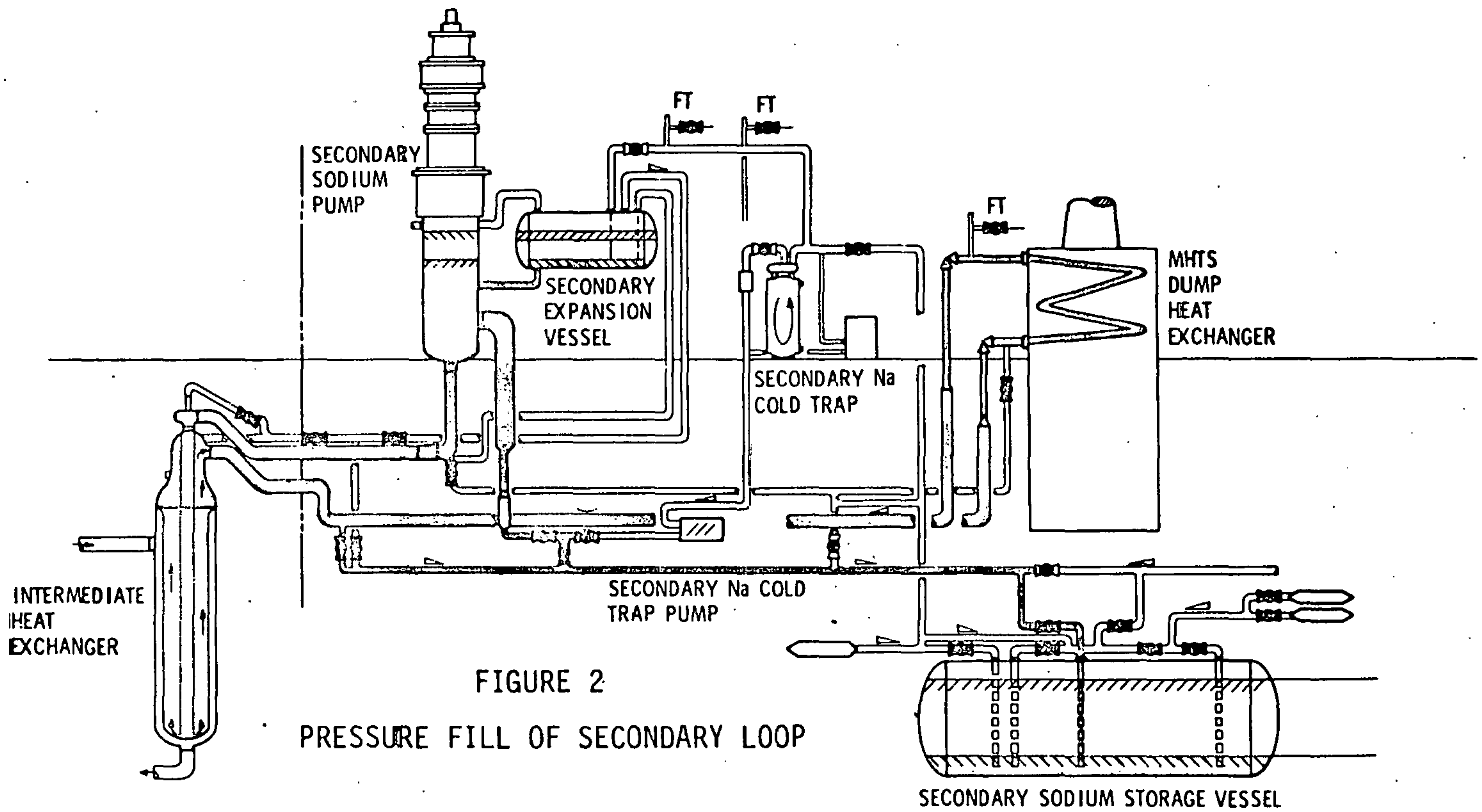
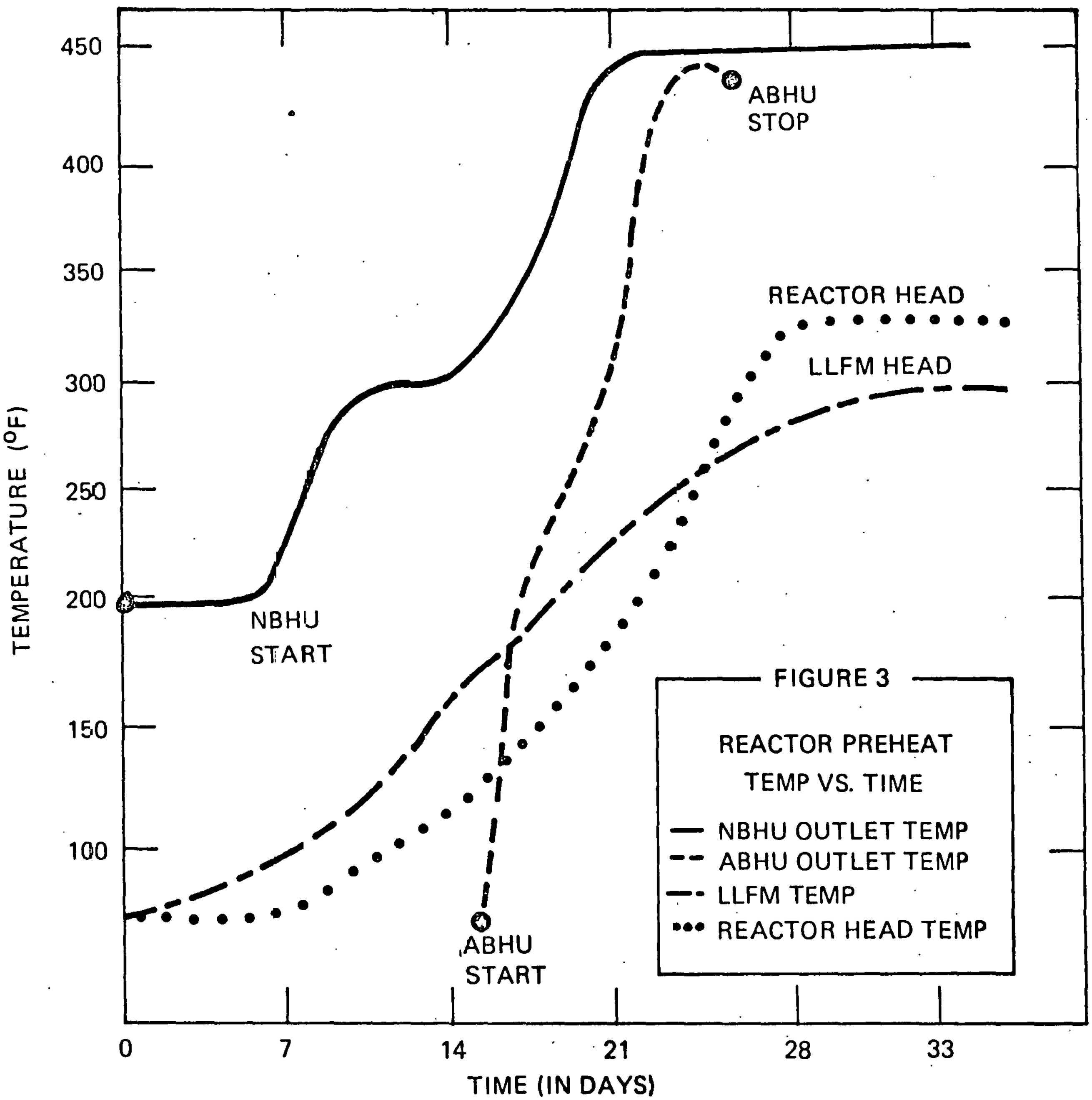


FIGURE 2

PRESSURE FILL OF SECONDARY LOOP

HEDL 7803-110.3


450
400
350
300
250
200
150
100
TEMPERATURE (°F)
0
7
14
21
28
33
TIME (IN DAYS)
NBHU START
ABHU START
ABHU STOP
REACTOR HEAD
LLFM HEAD
FIGURE 3
REACTOR PREHEAT TEMP VS. TIME
NBHU OUTLET TEMP
ABHU OUTLET TEMP
LLFM TEMP
REACTOR HEAD TEMP

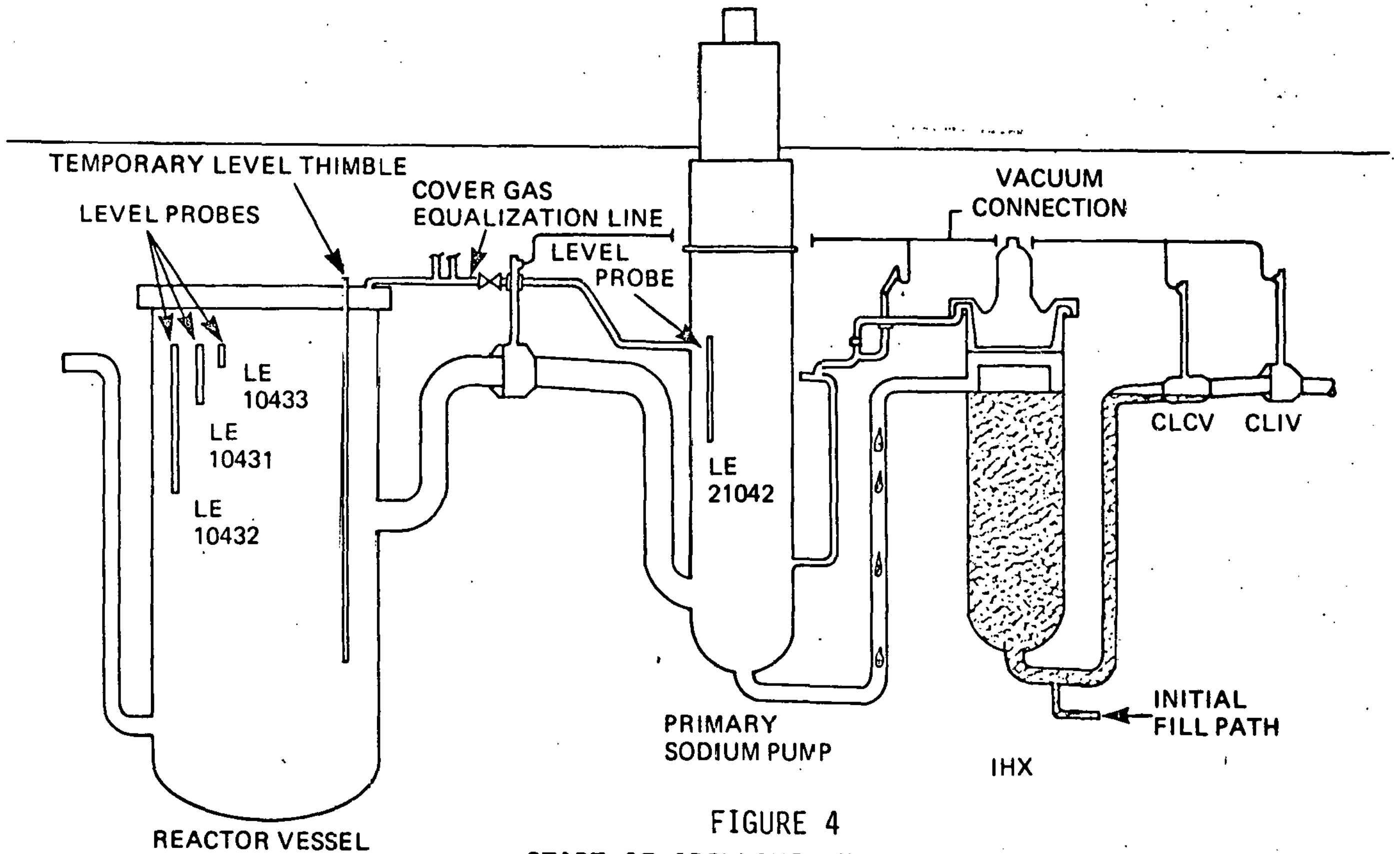


FIGURE 4
START OF SPILLOVER FROM IHX TO PUMP

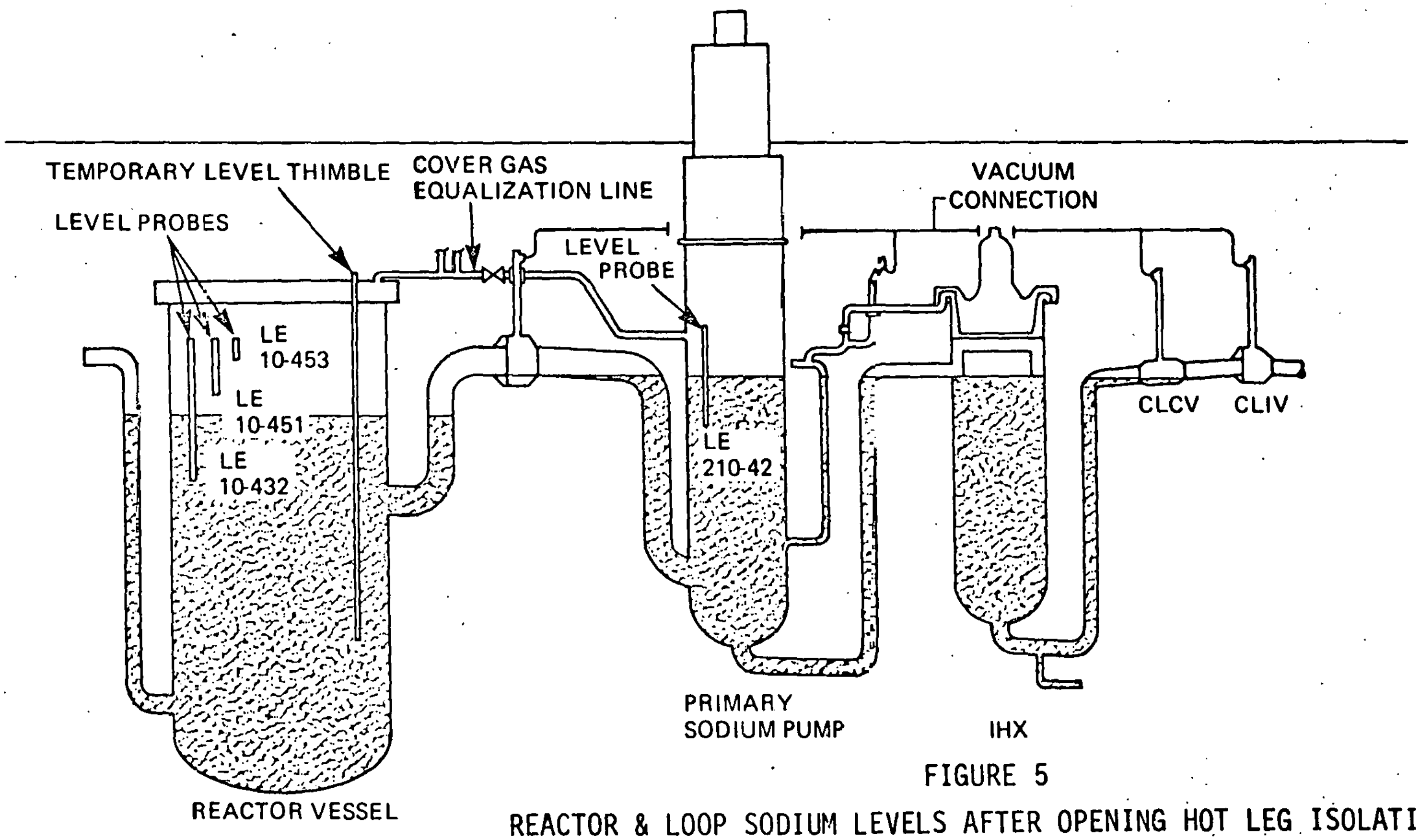


FIGURE 5

REACTOR & LOOP SODIUM LEVELS AFTER OPENING HOT LEG ISOLATION VALVE