FFTF PURIFICATION SYSTEM PERFORMANCE DURING
FILL AND INITIAL TEMPERATURE ASCENSION

MASTER

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ABSTRACT

Design parameters of the sodium purification systems on the Fast Flux Test Facility are given. Sodium and argon cover gas impurity changes observed during initial sodium fill and initial reactor heatup to 800°F are discussed. Sodium Purification System operation during these critical sodium impurity control periods is described.

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INTRODUCTION

The Fast Flux Test Facility (FFTF) is the major U.S. test facility in support of the Breeder Reactor Program. The FFTF is operated for the U.S. Department of Energy by the Westinghouse Hanford Company and is located a few miles north of Richland, Washington, U.S.A.

The FFTF Reactor which produces 400 megawatts is sodium cooled by three separate primary cooling loops with a maximum flow of 14,500 gpm. The Primary Sodium System contains 150,000 gallons of sodium in the reactor vessel and three primary cooling loops. Each Primary Heat Transport System (HTS) loop is cooled by a single Reactor Secondary HTS loop containing 17,500 gallons of sodium which are also circulated at a maximum flow of 14,500 gpm.

Cold traps are used for FFTF sodium purification. FFTF cold trap designs and thermal performance test results have been described previously by Bloom and McPheeters.⁽¹⁾

The reactor primary and secondary cold traps are shown schematically in Figures 1 and 2. The Reactor Primary Sodium Processing System shown schematically in Figure 3 gives the location of the cold trap. The sodium flows from the reactor vessel overflow weir to the primary sodium overflow vessel, the make-up pumps, the reactor primary cold trap and then back to the reactor vessel.

The Reactor Secondary Sodium Processing System shown schematically in Figure 4 shows the location of the secondary cold trap. The sodium flow path is from the dump heat exchanger outlet line through the electro-magnetic pump and cold trap then returns to the expansion tank and then

FIGURE 1: FFTF Reactor Primary Cold Trap.

HEDL 7701-125.3

FIGURE 2: FFTF Reactor Secondary Cold Trap.

HEDL 7910-284.1

FIGURE 3: Reactor Primary Sodium Processing System.

FIGURE 4: Reactor Secondary Sodium Processing System.

to the Secondary HTS pump.

FFTF sodium sampling equipment for both the reactor Primary and Secondary HTS was described by McCown and Olson.⁽²⁾ Keough and Ebersole⁽³⁾ have presented the vanadium, scandium and iron-manganese equilibration methods used in FFTF for oxygen, hydrogen and carbon, respectively. Keough and Ebersole⁽³⁾ also described the metal analysis methods and the argon impurity analysis methods used for FFTF.

FFTF Sodium Purification System characteristics are summarized in Table 1. The Reactor Primary Sodium Purification System has a 60-80 gpm sodium flow rate which provides one primary system turnover through the cold trap in about 40 hours. Theoretically, four system turnovers through the cold trap are required for 95% recovery from an impurity transient if the cold trap is 100% efficient. Therefore, 160 hours or seven days would be required for the cold trap to reduce the sodium plugging temperature to the cold trap trapping temperature. In real operating systems, the cold trap is not 100% efficient and about six turnovers are required to recover from an impurity spike. Experimental Breeder Reactor (EBR)-II cold trap efficiencies have been reported at 30% to 90% by Osterhout.⁽⁴⁾

The nominal 15 gpm reactor secondary cold trap provides a 19-hour turnover time which theoretically should give a three-day recovery time from an impurity spike for a 100% cold trap efficiency.

Estimated cold trap maximum capacities listed in Table 1 are calculated assuming the crystallizers will plug with impurities when about 10 volume percent of the packed section is taken up with either sodium oxide (Na_2O) or sodium hydride (NaH). The cold traps will collect both Na_2O and NaH so the actual capacity will be some fraction of the maximum weights listed.

TABLE 1

FFTF SODIUM PURIFICATION SYSTEMS

	<u>Reactor Primary</u>	<u>Reactor Secondary</u>
System Volume (gal)	150,000	17,500 per loop
Cold Trap Flow Rate (gpm)	60-80	12-17
Turnover Time (hr)	~40	~19
Max. Cold Trap Inlet Temp (°F)	1050	750
Min. Cold Trap Trapping Temp (°F)	230	230
Cold Trap Packed Volume (gal)	400	190
Cold Trap Capacity	770 lbs Na ₂ O or 470 lbs NaH	370 lbs Na ₂ O or 230 lbs NaH

INITIAL SODIUM FILL AND LOOP OPERATION AT MAXIMUM ISOTHERMAL SYSTEM TEMPERATURE (MIST)

A major goal has been the sodium fill and operation of the Reactor Primary and Secondary HTS. Sodium fill of the Reactor Secondary Loop 3 was started July 2, 1978. Reactor Secondary Loop 2 sodium fill was started September 11, 1978 and Reactor Secondary Loop 1 sodium fill was started September 24, 1978. Sodium fill of the reactor primary was started December 11, 1978 and completed December 29, 1978. Methods and procedures for FFTF sodium fill from the tank cars to the FFTF systems were described by Ballif and Meadows.⁽⁵⁾

Argon cover gas analysis, sodium plugging temperature and cold trap temperature are compared with loop operating temperature as a function of time. Figures 5 and 6 show these data for the Reactor Primary and the Reactor Secondary Loop 1, respectively. The Reactor Secondary Loop 2 and 3 behaved very similarly to the Reactor Secondary Loop 1.

Equilibration data for oxygen, hydrogen and carbon taken during the first several months of loop operations are given in Table 2 and Table 3 for the Reactor Primary and Reactor Secondary Loop 1, respectively. The trace metal analysis for the same period is summarized in Table 4 for the reactor primary and in Table 5 for the reactor secondary.

Reactor secondary argon cover gas analysis was provided by periodically taking a gas sample of the surge tank cover gas and analyzing the sample with a gas chromatograph. The reactor primary argon gas was sampled by three different methods. Gas samples prior to December 16 were analyzed similar to the method used for the secondary system and were taken from a temporary argon recirculation blower system used for preheating the reactor vessel. Reactor primary gas samples after December 30, 1978 were analyzed continuously by an on-line gas chromatograph, first by a temporary unit, then by a permanent unit after January 30, 1979. The on-line gas chromatograph samples the gas from the 1 scfm reactor vessel cover gas argon system

HEDL 7910-284.3

FIGURE 5: Reactor Primary Operating History.

FIGURE 6: Reactor Secondary Loop 1 Operating History.

TABLE 2

FFTF REACTOR PRIMARY HTS SODIUM ANALYSIS BY EQUILIBRATION

<u>Date</u>	<u>O (wppm)</u>	<u>H (wppm)</u>	<u>C (wppm)</u>
1/25/79	2.0	-	-
2/07/79	2.6	0.13	0.19
2/12/79	2.8	0.21	0.43
2/25/79	1.6	0.27	0.09
4/02/79	1.0	0.10	0.05
4/29/79	-	0.08	0.05
5/21/79	0.54	0.11	-

TABLE 3

FFTF REACTOR SECONDARY HTS LOOP 1 SODIUM ANALYSIS BY EQUILIBRATION

<u>Date</u>	<u>O (wppm)</u>	<u>H (wppm)</u>	<u>C (wppm)</u>
11/21/78	1.8	0.15	0.04
12/04/78	2.1	-	-
12/05/78	1.9	-	-
12/19/78	1.4	-	-
1/07/79	1.9	0.14	0.05
1/26/79	2.4	-	-
2/12/79	2.4	0.13	0.12
2/26/79	2.3	0.21	0.13
3/28/79	1.1	0.07	.05
4/16/79	1.0	0.17	0.05
5/04/79	0.79	0.09	0.18

TABLE 4

FFTF REACTOR PRIMARY HTS OVERFLOW CUP SODIUM ANALYSIS

	11/16/78	11/27/78	12/01/78	12/06/78	12/12/78	12/15/78	12/29/78	1/02/79	1/18/79	1/24/79	2/27/79	3/11/79	4/03/79	4/11/79
Al			.04	.14							.04	.23		
Au				.02							.01	<.01		
Ag				<.01							<.01	<.01		
B						.3								
Ba				.01										
Bi			<.01	<.01							<.01	<.01		
Ca	.02	.01	<.01	<.01	<.01						<.01	<.01		
Cd					<.1		.05				.02	.02		
Cs							<.3							
Cl						.05			.5					
Cr		.03	.10	.02	.03			0.4		.02	.02	.10		
Co			<.01	.01	.02						<.01	.02		
Cu	.03	.01	<.01	<.01	.02						<.01	.05		
F					<.01				<.02					
Fe	12.3	0.8	.58	1.6	15.0			.17		.2	.18	.14		
Pb		<.01		<.01							.03	.04		
Li		<.01		<.01										
Mg		<.01	.04	.02	.03						<.01	.04		
Mn	.24	.06	.05	.10	.10			.01		<.01	<.01	.2		
Mo			.01	<.01	.01						.01	<.01		
Ni	.56	.08	.08	.2	1.9			.04		.02	.02	2.8		
P														
K			282										< 0.05	
Rb						.1								
Si					2				.4					
S														
Sn				<.01									< 0.5	
Sr				<.01							<.01	<.01		
Ti				.01							<.01	<.01		
U											<.01	<.01		
V				<.01										<.001
Zn					.15		.1				<.01	<.01		

TABLE 5

FFTF SECONDARY HTS LOOP 1 OVERFLOW CUP SODIUM ANALYSIS

	1/23/79	1/23/79	2/02/79	2/25/79	2/28/79	2/28/79	3/01/79	3/24/79	4/27/79	
Al	<.01	<.01	0.1	.17				0.01		
Au	.07	.01		.07				<.01		
Ag	.01	<.01	<.01	<.01				<.01		
B							<.002			
Ba	.01	<.01	<.01	<.01				<.01		
Bi	.03	<.01	<.01	<.01				.01		
Ca	<.01	<.01		.19				.02		
Cd							<.01			
Cs							<.02			
Cl							.03			
Cr	.4	.8	1.8	.7				.37		
Co	<.01	<.01	.02	<.01				<.01		
Cu	.01	.02	.02	.01				<.01		
F										
Fe	1.2	3.7		2.8				2.9		
Pb	.02	.02	.01	.3				<.01		
Li	<.01	<.01								
Mg	.01	.01	.02	<.01				<.01		
Mn	.3	.1	.2	.07				.03		
Mo	<.01	<.01	.01	<.01				.13		
Ni	.2	.4	1.0	.5				.27		
K						310				
Rb							<.02			
Si						.02				
S									0.1	
Sn	.2		<.01	.05				<.01		
Sr	.01	<.01	<.01	<.01				<.01		
Ti	.03	.01	<.01	<.01				.01		
U					.002					
V	.01	<.01	<.01	.01				<.01		
Zn							<.01			

which vented to atmosphere during this period.

Reactor grade sodium was used to fill the FFTF and the vendor analysis of the tank cars is given in Table 6. The sodium in the tank cars was heated to 300°F and passed through a 20 micron sintered stainless steel metal filter. A plugging temperature of 300°F was measured for one of the tank car sodium batches after transfer to a reactor tank.

Following transfer, the Loop Processing System was started and an oscillating plugging temperature indicator reading was taken on the sodium as soon as possible. The Reactor Secondary Loop 1 had the highest plugging temperature at 350°F prior to cold trapping. The reactor primary sodium plugging temperature reached 325°F prior to cold trapping. The source of the impurities during this fill and recirculation phase was probably oxygen and water absorbed on the steel surfaces.

Cold trap flow was started with the cold trap isothermal with the loop sodium. The cold trap trapping temperature was then reduced to a temperature 25°F below the sodium plugging temperature.

The cold trap temperature reduction was limited to no more than 25°F below the sodium plugging temperature and to a minimum of 280°F to protect the cold trap from plugging. The 280°F limit was in effect until after initial loop heatup to 800°F. Impurity burden releases were expected from the new steel surfaces during initial heatup of the systems. Excessive differences between the cold trap trapping temperature and sodium plugging temperature were to be avoided to prevent premature cold trap plugging. The data reported by Bloom and McPheeters⁽¹⁾ demonstrated a small top to bottom temperature difference exists in the crystallizer for the FFTF cold traps when operating at 400°F. Therefore, under these conditions, cold trap temperatures greater than 35°F below the plugging temperature could cause plugging of the crystallizer inlet piping.

TABLE 6

VENDOR ANALYSIS OF FFTF SODIUM
(wppm)

<u>Tank Car Number</u>	<u>(Assay. % Na+K)</u>	<u>Ca</u>	<u>Cl</u>	<u>K</u>	<u>C</u>	<u>B</u>	<u>Li</u>	<u>S¹</u>	<u>U</u>
78505	99.98	1.0	3	210	15.1	2.4	0.3	.06	.001
67984	99.98	1.0	3	250	3.9	1.8	<0.1	.02	.003
67980	99.98	1.0	3	300	1.6	2.5	<0.1	0.4	.006
67983	99.98	1.0	3	225	2.2	<0.1	<0.1	.06	.007
67985	99.99	1.0	3	265	2.6	3.2	<1.0	.22	.003
67987	99.97	1.0	3	270	7.9	3.3	<1.0	.06	.003
77806	99.98	1.0	3	260	0.8	0.7	<1.0	0.1	.008
67904	99.98	1.0	3	260	0.7	0.8	<1.0	0.1	.010
37210	99.96	1.0	3	280	0.5	0.47	<1.0	0.1	.010
77807	99.96	1.0	3	275	1.2	0.67	<1.0	0.05	.008
78504	99.98	1.0	3	240	1.5	0.46	<1.0	0.1	.03
67901	99.96	1.0	3	280	1.1	0.1	<1.0	0.1	.008
78904	99.98	1.0	3	270	2.8	0.1	<1.0	0.1	.006
37209	99.97	1.0	3	270	2.5	0.08	<1.0	0.1	.008
67986	99.97	1.0	3	285	4.9	0.20	<1.0	3.0	.007
78500	99.98	1.0	3	280	1.0	0.2	<1.0	0.1	.008
78506	99.97	1.0	3	300	1.9	0.2	1.0	0.2	.005
77811	99.97	1.0	3	280	3.8	0.2	1.0	1.0	.007
78503	99.96	1.0	3	300	1.7	0.2	1.0	1.0	.007
37208	99.96	1.0	3	235	1.6	2.0	1.0	.17	.004
77805	99.96	1.0	3	270	1.9	0.2	1.0	.13	.003

The reactor primary and secondary plugging temperatures were quickly reduced to the cold trap trapping temperatures as shown in Figures 5 and 6 after cold trap startup. The Reactor Secondary Loop 1 plugging temperature was reduced from 350°F to 275°F in five days. The reactor primary cold trap reduced the sodium plugging temperature 25°F from a high of 325°F in two days. The primary cold trap was then reduced in temperature over several weeks to 280°F.

The reactor sodium systems were heated to MIST at 800°F in February 1979 to perform reactor equipment tests and remove metal surface impurities. The heatup was controlled at 2°F/hr from 400°F to 600°F and 1°F/hr from 600°F to 800°F. Higher impurity release rates from the steel were expected above 600°F, thus, the reason for the slower heatup rate. A four-day hold was in effect at 600°F to assure that the cold traps were controlling the sodium impurity levels. A reactor heatup hold was to occur if the sodium plugging temperature exceeded 325°F but none was necessary.

The reactor primary sodium plugging temperature increased the most during temperature ascension. The initial plugging temperature of 280°F increased to 307°F during system heatup from 400°F to 600°F, held constant during the 600°F hold, and then increased to a high of 316°F during heatup to 790°F. The reactor primary cold trap temperature was increased to about 290°F during the period of high plugging temperature and then was decreased as the sodium plugging temperature allowed.

The reactor secondaries had plugging temperatures between 265 to 270°F when sodium temperatures were at 400°F prior to heatup. The plugging temperatures increased to $288 \pm 4^\circ\text{F}$ during heatup to 600°F, held relatively constant at the 600°F system temperature plateau, and increased to a maximum of 302°F during heatup to 790°F.

All sodium system plugging temperatures were decreased at least 10°F prior to system cooldown from 790°F to 400°F. The 10°F plugging temperature decrease indicated heat impurity removal rates were greater than impurity

source rates and the impurity levels in the four reactor sodium systems were being controlled by the purification systems.

After reactor cooldown from 800°F MIST temperature to 400°F, the sodium plugging temperatures decreased to the cold trap temperature within a few days. The cold trap temperatures were decreased to 230 to 240°F over the next six weeks' operation at 400°F. There was no increase in sodium plugging temperature during the short three-day heatup to 700°F one week after MIST.

COVER GAS IMPURITY TRENDS DURING REACTOR OPERATION

Prior to sodium fill, the systems were evacuated and backfilled with high purity argon several times until the oxygen level was below 50 vppm O_2 . The systems were then heated to $350^\circ F \pm 50^\circ F$ in preparation for sodium fill. Typically the hydrogen level started increasing in the cover gas as the system was heated above $350^\circ F$ as shown in Figures 5 and 6.

In the Primary System, the hydrogen increased to 36 vppm H_2 only to decrease again to near 0 as the vessel temperature decreased from $400^\circ F$ to $300^\circ F$ when the temporary argon blower heat unit (ABHU) was turned off. The hydrogen concentration remained near zero during the period the vessel remained at $300^\circ F$. The hydrogen source was apparently gaseous hydrogen diffusing out of the steel surfaces and the diffusion rate was very slow below $350^\circ F$. Oxygen, nitrogen and methane increases were not detected during heatup from 400 - $800^\circ F$ and remained less than 20 vppm during preheat.

After reactor primary sodium fill, the reactor vessel temperature was increased to $375^\circ F$ and the primary cover gas showed 30 vppm H_2 . As the Primary System was heated to $400^\circ F$, the hydrogen level increased to 63 vppm H_2 and then decreased to 40 vppm over the following month.

During initial temperature ascension from $400^\circ F$ to $600^\circ F$, the reactor primary cover gas hydrogen increased from 40 to 120 vppm H_2 , then started decreasing. As the reactor temperature was increased from $600^\circ F$ to $800^\circ F$, the hydrogen concentration held near 95 vppm H_2 , but again decreased as the $800^\circ F$ temperature plateau was held during MIST. The hydrogen concentration had decreased to about 40 vppm H_2 at the end of MIST testing and quickly decreased to near 5 vppm H_2 once the reactor temperature was decreased to $400^\circ F$.

The diffusion rate of gaseous hydrogen out of the steel surfaces was increased by increasing system temperature. The hydrogen was being removed from the cover gas by reaction with the sodium. Eventually the hydrogen

level in the cover gas was decreased by reaction with the sodium as the steel source was depleted.

The reactor primary cover gas hydrogen concentration again increased from 5 to 30 vppm H_2 during a system heatup to 700°F over a three-day period about one week after MIST test completion. The hydrogen decreased to about 5 vppm H_2 after cooldown to 400°F.

New steel surfaces will be introduced into the reactor vessel core components and will be a future source of hydrogen. Insertion of the core components into the reactor vessel will also cause introduction of air and water vapor. The on-line gas chromatograph will provide valuable cover gas impurity measurements to detect and help prevent large unintentional impurity introductions into the Cover Gas System which must eventually be removed by the primary cold trap.

The Reactor Secondary Loop 1 cover gas showed a high hydrogen level (180 vppm H_2) after preheat to 350°F, but the hydrogen decreased first to 20 vppm within four days after sodium fill, then reduced further to about 5 vppm H_2 after about one month. The hydrogen then stayed below 6 vppm H_2 except during MIST when the level increased to only 13 vppm H_2 . Evidently the relatively small amount of hydrogen released from the smaller steel surface area in the reactor secondary expansion tank cover gas region reacted with the sodium present and did not build up as observed in the Reactor Primary System. The Reactor Primary System has a much higher surface area due to core components and equipment and has a much greater potential hydrogen source rate.

CONCLUSIONS

Sodium fill and heatup to MIST of the FFTF Sodium Systems provide the basis for the following conclusions.

1. The FFTF cold traps have maintained high purity sodium in both the Reactor Primary and Reactor Secondary Sodium Systems through initial sodium fill and heatup to MIST.
2. FFTF impurity burdens have been relatively low and are attributed to internal system cleanliness, purchase of reactor grade sodium, and low temperature filtering during sodium fill.
3. Hydrogen gas evolution can be expected from new stainless steel surfaces heated above 350°F and the rate is proportional to temperature.
4. Impurity release rates from new stainless steel surfaces can be controlled at low levels and sodium plugging temperatures can be controlled below 325°F during initial temperature ascension. Recommended initial heatup rates are 2°F/hr below 600°F and 1°F/hr above 600°F with plateaus at 600°F and 800°F.
5. Impurity releases from new fuel steel surfaces to the reactor cover gas and primary sodium system will have to be monitored closely to assure maintenance of required reactor sodium purity for operation above 800°F.
6. Cover gas and sodium purity levels need to be monitored closely during initial reactor fueling to obtain estimates of impurity source rates to be expected during future fuel and core component loading to the reactor vessel.

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