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Revision 0

Fast Flux Test Facility Sodium Volume Reconciliation

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

FLUOR®
P.O. Box 1000
Richland, Washington

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M. R. Galvin
Fluor Hanford, Inc.

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ACRONYMS, LABELS AND DEFINITIONS

Bottom Loading Transfer Cask	Used to transfer short core components in and out of containment.
Cesium Trap	Installed in Heat Transport System-South. Cesium trap is used to capture cesium from primary sodium. Similar to a cold trap.
Cold Trap	A crystallizer vessel and economizer operated at a lower temperature to encourage sodium impurities to precipitate out and purify the system sodium.
Core Component Pots	Pots used to hold reactor assemblies in Interim Decay Storage. All 108 pots were plunged and pulled from Interim Decay Storage prior to drain.
Crystallizer	Larger tank of a cold trap or the cesium trap to collect impurities.
DHX	Dump Heat Exchanger. The Fast Flux Test Facility has three dump heat exchangers each having four modules/tube bundles. Each module in turn has 66 tubes.
Economizer	Regenerative heat exchanger attached to a cold trap or cesium trap crystallizer to use energy from incoming sodium to raise the temperature of the outgoing sodium.
EM	Electromagnetic
FFTF	Fast Flux Test Facility
FSF	Fuel Storage Facility
Hallam Sodium	Sodium recovered from the Hallam, Nebraska test reactor. Placed in the Fuel Storage Facility fuel storage vessel during sodium fill.
HTS-S	Heat Transport System - South. Building south of Containment containing primary multipurpose samplers and the Cesium Trap.
IDS	Interim Decay Storage (T-62). The in-containment vessel designed to hold assemblies removed from the reactor vessel.
IHX	Intermediate Heat Exchanger. Three, one in each loop, in-containment vertical tube and shell heat exchangers used to transfer heat from the primary to the secondary Main Heat Transport System loops.

ACRONYMS, LABELS AND DEFINITIONS (continued)

MHTS	Main Heat Transport System. Loops, pumps, heat exchangers and piping intended to deliver heat from the reactor core to the atmosphere.
N-5	The primary cold trap.
NaK	Sodium Potassium eutectic which remains liquid down to approximately 9°F. Used in intermediate heat exchanger loops and, in small quantities in liquid metal systems pressure instruments.
Overflow Weir	A standpipe that kept the reactor vessel from overflowing by allowing excess sodium to drain back to T-42.
P-38	Primary sodium makeup electromagnetic pump. Took suction from T-42 and delivered sodium through N-5 to the reactor vessel.
P-39	Primary sodium makeup electromagnetic pump. Took suction from T-42 and delivered sodium through N-5 to the reactor vessel.
PTI	Plugging Temperature Indicator. Used to measure the purity of sodium in primary, secondary, Interim Decay Storage and Fuel Storage Facility sodium systems.
SSF	Sodium Storage Facility. Building southwest of containment. Holds storage tanks containing drained liquid metals.
T-42	Reactor sodium overflow tank. Sodium from the reactor vessel would run to T-42 via the overflow weir. Provided an expansion and contraction volume.
T-43	Primary sodium storage vessel. In-containment vessel that held a reserve of primary sodium. Used extensively to fill and drain in-containment systems.
T-44	Secondary storage vessel. Ex-containment tank that held excess secondary sodium and provided a drain volume for secondary sodium leak fire protection. Used to transport secondary sodium to the Sodium Storage Facility.
T-88	Electromagnetic Pump (P-38) drain tank. Intended to be a low point to drain sodium if the electromagnetic pump needed replacement.
T-89	Electromagnetic Pump (P-39) drain tank. Intended to be a low point to drain sodium if the electromagnetic pump needed replacement.

ACRONYMS, LABELS AND DEFINITIONS (continued)

T-98	Storage tank for the Interim Decay Storage NaK cooling system. Formerly contained NaK but was flushed with sodium.
T-99	Storage tank for the N-5 NaK cooling system. Formerly contained NaK but was flushed with sodium.
T-914	NaK settling tank for the Fuel Storage Facility. Was drained and cleaned.
T-932	Fuel Storage Facility fuel storage vessel. Previously held approximately 31,000 gallons of sodium and fuel assemblies from the reactor.
T-3001	Sodium storage tank in the Sodium Storage Facility. Holds secondary sodium.
T-3002	Sodium storage tank in the Sodium Storage Facility. Holds primary sodium.
T-3003	Sodium storage tank in the Sodium Storage Facility. Holds primary sodium.
T-3004	Sodium storage tank in the Sodium Storage Facility. Holds secondary Intermediate Heat Exchanger, Fuel Storage Facility, and Interim Decay Storage sodium.

FAST FLUX TEST FACILITY SODIUM VOLUME RECONCILIATION

1.0 EXECUTIVE SUMMARY

The following report summarizes the Fast Flux Test Facility (FFTF) sodium volumes, reports the fill and drain data, and estimates the quantity of residuals. Brief descriptions are provided of the fill and drain processes.

Review of sodium and sodium potassium eutectic (NaK) fill reports and completed procedures indicates approximately 253,000 gallons were added to the facility. Applying a Student-T distribution for a 95% confidence level indicates the liquid metal fill was between 249,300 and 257,400 gallons.

Drained liquid metal accumulated in the Sodium Storage Facility (SSF) tanks is approximately 242,850 gallons. Applying an estimated uncertainty gives the range for drain of 242,100 gallons to 243,600 gallons.

Comparing the fill and drain results indicate the residual liquid metal volume is between 6,000 and 15,300 gallons. An effort has been made to identify the locations of the main residual volumes and estimate their magnitudes; the result is a total of 6,400 gallons. This indicates that the actual residual volume is most likely near the low end of the 6,000 to 15,000 gallon range.

2.0 BACKGROUND

Liquid metal fill at the 400 Area was initiated in late May 1978 with the transfer of approximately 10,000 gallons to Secondary Storage Vessel T-44. The last fill activity was completed with the NaK addition to the Fuel Storage Facility (FSF) NaK Cooling Loop #2 in October 1984.

The drain activities began on April 7, 2003 with the drain of Secondary Loop 1 to T-44. The final drain work, removing approximately 700 gallons of sodium from the Primary Main Heat Transport System (MHTS) valves, is planned for late fiscal year 2007.

For both fill and drain, transfers were accomplished by pressure transfers; using cover gas to raise the internal pressure of the source vessels and opening intervening valves to permit flow. The final phase of the primary sodium drain (Phase 3-reactor) used a pump inserted in the reactor vessel. This pump used a vacuum to draw sodium into the pump chamber and nitrogen gas to push the sodium out to the SSF. In a few cases, where elevation differences were extreme, the receiving vessel was evacuated to permit and enhance flow.

During early planning for drain and construction of the SSF a range of estimates for the drain volume was established. 260,000 gallons was chosen as a bounding value and published. Similarly an estimate of plant residuals of 3,580 gallons was published in HNF-SD-FF-SSP-004, *Fast Flux Test Facility Closure Project - Project Management Plan*. Both numbers are revised in this document.

3.0 FILL REPORT DATA

A. Secondary

Each secondary loop was filled under Test Procedure TP-00-3A022. Loop 3 was filled on July 2, 1978. Loop 2 was filled on September 11, 1978. Loop 1 was filled on September 25, 1978. The test report for the procedure was issued March 13, 1979. The loop volumes averaged 17,650 gallons giving a total of 52,950 gallons.

B. Primary

The primary Heat Transport System (HTS) piping, reactor vessel, and overflow vessel T-42 were filled by Test Procedure TP-00-3A021. These volumes and the primary Auxiliary Liquid Metal systems were filled and sodium circulation was established between November 11, 1978 and January 29, 1979. The test report was issued on August 16, 1979. Total sodium volume required to initially fill the in-containment storage vessels to the 90% level and reactor vessel to normal operating level was 175,380 gallons. This figure should not be taken to represent the primary systems volume as excess sodium in the storage tanks at this point was used to fill other systems.

C. Interim Decay Storage

The Interim Decay Storage (IDS) vessel was filled using Test Procedure TP-00-3A021-IDS on April 9, 1981. The fill required approximately 10 hours and used 15,250 gallons to fill IDS (T-62) from T-43.

D. Fuel Storage Facility

The FSF fuel storage vessel and its purification loop were filled with sodium salvaged from the Hallam reactor. Three tanks were delivered to the 400 Area, modified and connected to the FSF. According to TP-FSF-02315, approximately 31,000 gallons of sodium were added to the FSF from the Hallam tanks. The first transfer was initiated on January 16, 1984 and the final transfer from the Hallam tanks was completed on February 15, 1984. Initial circulation of the sodium processing loop was completed on April 13, 1984.

E. NaK

Three quantities of bulk NaK (eutectic of sodium and potassium) were added to the facility. Two in-containment cooling loops, IDS cooling and N-5 (primary cold trap) cooling, were filled by Test Procedure TP-81-3C039 from October 3, 1978 through October 6, 1978. Finally, NaK was added to the FSF Natural Draft Heat Exchanger Loop #2 by procedure TP-FSF-02313. This was done on October 16, 1984. The total quantity of NaK introduced to the plant was 872 gallons.

F. Fill Data Summary

The individual system sodium fill reports (e.g., secondary, primary, IDS) do not consistently total and summarize the sodium added to the facility. This deficiency has been largely responsible for the previous variances of published volumes. The most accurate estimate for liquid metal comes from the sodium rail car fill results and is presented in Table 1. Adding the FSF sodium and NaK volumes gives the estimate of total bulk liquid metal.

During fill, rail cars were connected to the plant sodium fill piping and heated to melt the frozen sodium. Sodium was then delivered to one or more of the three in-plant storage vessels (T-44, T-43 and T-42). For FSF, the Hallam sodium tanks were similarly emptied to the FSF Fuel Storage Vessel.

NaK was brought into the facility in drums and transferred to the in-containment systems and the FSF cooling loop in a similar pressure transfer procedure.

TABLE 1 - SODIUM FILL DATA (All Volumes in Gallons)					
Tank Car Unload Order	Tank Car/Tank ID Number	Unload Date	Gallons Out of Tank	Received By	Gallons Received
1	67987	06/18/78	10,125	T-44	10,050
2	78506	06/20/78	10,450	T-44	11,200
3	77811	06/21/78	6,150	T-44	6,200
3	77811	08/29/78	4,400	T-44	4,250
4	78500	08/31/78	10,650	T-44	10,250
5	78503	09/02/78	5,150	T-44	5,300
5	78503	09/16/78	5,550	T-44	5,350
6	37209	09/22/78	10,025	T-44	9,300
7	78904	11/03/78	11,550	T-44	11,550
8	67901	11/07/78	8,450	T-44	8,450
8	67901	11/08/78	2,150	T-44	2,150
9	78504	11/11/78	10,375	T-43	10,500
10	67986	11/14/78	9,600	T-43	9,650
10	67986	11/14/78	450	T-44	450
11	67904	11/27/78	10,525	T-42	10,200
12	77806	11/29/78	3,175	T-42	3,050
12	77806	11/29/78	7,200	T-44	7,500
13	77807	12/01/78	10,500	T-44	10,500
14	78505	12/04/78	8,850	T-44	9,100
15	67984	12/20/78	10,525	T-42	10,350
16	67985	11/22/78	10,850	T-42	10,400
17	37208	12/23/78	10,650	T-42	10,600
18	77805	12/25/78	10,475	T-42	10,950
19	67983	12/29/78	10,350	T-42	10,400
20	37210	01/04/79	3,550	T-43	3,380
20	37210	01/04/79	6,950	T-44	7,245
21	67980	03/27/81	10,660	T-43	11,030
14	78505	03/29/81	1,750	T-43	2,250
Sodium added to Reactor Systems:			221,085		221,605
FSF Sodium:					
1st Hallam Tank		01/16/84	11,750	T-932	11,750
2nd Hallam Tank		02/03/84	13,100	T-932	13,000
3rd Hallam Tank		02/15/84	6,100	T-932	6,000
Sodium added to FSF:			30,950		30,750
Sodium in the FFTF Plant:			252,035		252,355

TABLE 1 - SODIUM FILL DATA (All Volumes in Gallons)

Tank Car Unload Order	Tank Car/Tank ID Number	Unload Date	Gallons Out of Tank	Received By	Gallons Received
NaK:					
NaK In-Containment (IDS):		10/03/78	104	T-98	104
NaK In-Containment (N-5):		10/06/78	388	T-99	388
NaK to FSF Cooling Loop #2		10/16/84	380	T-914	380
Bulk NaK			872		872
Total Bulk Liquid Metal:			252,907		253,227

4.0 ESTIMATING THE SODIUM FILL VOLUME MEASUREMENT ERROR

Two approaches have been used to estimate the error in the above totals and are presented here.

A. Using the Minimum and Maximum Measurements

Looking at the tank car transfer data, two figures are available for each transfer. First is the volume removed from the supplying vessel and second that delivered to the receiving vessel. A simple estimate of total volume range can be obtained by summing all the lower values (minimum) and higher values (maximum) for each transfer separately. Doing this results in a minimum sodium volume of 249,900 gallons and a maximum of 256,300 gallons (with an average of 253,100 gallons).

B. Statistical Analysis of the Fill Data

A more sophisticated statistical analysis of the FFTF sodium fill volume was performed using the Student-T distribution and the 28 tank car to FFTF transfer data points listed in Table 1. The result shows a "best-estimate" value of 221,300 gallons with a 95% confidence level range of 217,900 to 225,700 gallons. Adding the FSF sodium and NaK volumes yields a best estimate of 253,000 gallons with a 95% confidence level range of 249,300 to 257,400 gallons.

C. Sodium Volume Measurements

Sodium volumes are difficult to calculate with precision from the level measurements due to the following factors:

i. The process employed to obtain most level measurements in a liquid metal storage tank uses a dual-coil inductive probe. This probe is inserted into a narrow sealed thimble reaching to the bottom of each vessel. When the probe passes the sodium level it indicates so on a connected meter.

Consistency of practice is necessary to obtain correct results and was largely obtained by procedure compliance and operator training. Even so, errors are introduced by the following:

a. Allowing the level probe and its metal tape or cable to remain in the thimble for too long, creating thermal expansion (elongation) which disappears when the probe is removed for measurement.

b. Discontinuities in the level thimble wall thickness (such as a weld) will provide false indications of liquid metal level. Similarly, level thimble supports or adjacent tank internals will give a false reading. If these discontinuities are near the expected liquid metal level an error may be introduced. It is believed thimble discontinuities were usually the reason for gross differences between supplied and received volumes.

c. Due to separation and shielding needs level measurements for most vessels were made through a floor penetration into the thimble. These measurements and calculations assume the floor elevations and tank position are as designed and do not change due to thermal expansion.

d. Despite training, procedures and experience, variations between operators did and will exist. Locating the precise location of maximum meter deflection required practice and touch.

ii. Volume calculations depend on as-built and construction drawings truly representing the vessels.

a. Most sodium storage vessels have semi-elliptical heads. Some of the vessels (i.e., T-42 and T-3001) vessels have non-elliptical heads, rather they have heads with a crown radius and knuckle radius making them somewhat flatter than elliptical heads. In these cases, the volume equations employ elliptical heads and were back fitted to have an identical total volume. The volume tables are most accurate at the empty, mid-vessel and full volumes. Intermediate level measurements will have a few gallons error.

b. There are differences between the actual tanks and design drawings. This is in the form of not only location dimensions as discussed above but also in tank geometry. For instance, the as-built drawings for the SSF tanks indicates one tank is as much as 2 inches taller than its companions. This has been investigated and cannot be confirmed. The 2 inches, if applied to the cylindrical section of the tank would result in a 770 gallon error.

iii. Sodium temperature impact. During most drains the loops and vessels to be drained were maintained at higher temperature than the receiving vessels, usually above 400°F. This was to reduce the impact of heat loss and the corresponding possibility of plugs. Most receiving storage vessels were controlled closer to 300°F. If the level measurements were separated by a significant block of time a volume error would be created by decreasing temperature and increasing density. Accounting for the temperature differences was deemed too difficult and not necessary given the other inaccuracies in level measurement. Sodium density decreases only by 1.5% from 300°F to 400°F.

5.0 DRAIN RESULTS

The liquid metal drains after reactor shutdown in chronological order were as follows. Each is described in more detail below.

Drain	Description	Date Completed
A.	Early Vessel Transfers (preparation for early secondary loop drain)	November 7, 1995
B.	Secondary loop drain to T-44 and transfer to the SSF	April 21, 2003
C.	Intermediate Heat Exchanger (IHX) Secondary sodium drain	November 12, 2003
D.	FSF NaK drain into the FSF Sodium System	July 28, 2004
E.	In-containment NaK cooling systems flush and drain into the Primary MHTS.	September 25, 2004
F.	Primary Drain, Phase I (Loops and partial reactor vessel drain)	August 23, 2004
G.	Primary Drain, Phase II (HTS-S, auxiliary piping and T-42)	November 1, 2004

Drain	Description	Date Completed
H.	Primary Drain, Phase III (Remainder of reactor vessel)	June 20, 2005
I.	FSF sodium drain	September 16, 2005
J.	IDS sodium drain (IDS and T-43)	October 5, 2006
K.	Primary MHTS large valve drain	Yet to be completed. Planned before September 2007

A. Early Vessel Transfers

Secondary sodium transfers to in-containment vessels in 1995.

During standby, the secondary MHTS loops constituted the majority of heat losses from the sodium systems and hence plant power demands. Early in the FFTF shutdown period it was decided to reduce costs by draining the secondary sodium to the in-plant sodium storage vessels (T-44, T-43 and T-42) while the SSF construction was underway. The procedure was completed to the point of transferring most T-44 sodium to T-43 and then transferring most T-43 sodium to T-42. Prior to the first secondary loop (Loop 1) drain the activities for drain were suspended by Department of Energy direction.

Secondary sodium transferred from T-44 to T-43 in 1995:

Gallons using T-44 levels	Gallons using T-43 levels
7,235	7,572

From there sodium was transferred from T-43 to T-42:

Gallons using T-43 levels	Gallons using T-42 levels
10,704	10,811

After the transfer the vessel sodium volumes were:

Vessel	Sodium Volume, Gallons
T-44	3,228
T-43	12,839
T-42	16,692

B. Secondary Loop Drain

Each secondary loop was sequentially drained to storage vessel T-44 and pressure transferred to T-3001. Note these quantities are not secondary loop volumes (e.g., does not include the sodium trapped in the IHXs).

	Secondary Loop Sodium Quantities Transferred to SSF	
	Using T-44 Measurements	Using T-3001 Measurements
Loop 1	16,982	17,099
Loop 2	16,772	16,229
Loop 3	16,283	16,050

The vessel volumes before and after the MHTS secondary loop drain were:

	Sodium Volumes	
	T-44	T-3001
Initial Volume, gallons	3,204	0
Final Volume, gallons	3,426	49,378

The secondary loop drain filled T-3001 to 94.4% volume. Trace heat was then secured to permit the sodium to freeze.

C. IHX Secondary

The IHX secondary sides (tubes, downcomer, upper and lower plenums) constitute secondary loop low points and retained approximately 2,000 gallons during loop drain. This sodium was maintained at temperature by the circulating primary system. Dip tubes were inserted in each IHX downcomer pipe and connected to the System 81 drain piping. Cover gas pressure was increased in the respective loop and valves were opened to deliver the sodium to T-44. After all three IHX drains, approximately 3,000 gallons were sent to T-43 for the then upcoming in-containment NaK flush. T-44 was then emptied as much as possible to T-3004.

The transfer data for E-1 drain is shown in the following table:

T-44 Before E-1 Drain	T-44 After E-1 Drain	Drained Quantity
3,426 gal	5,577 gal	2,151 gal

For E-2:

T-44 Before E-2 Drain	T-44 After E-2 Drain	Drained Quantity
5,577 gal	7,847 gal	2,270 gal

For E-3:

T-44 Before E-3 Drain	T-44 After E-3 Drain	Drained Quantity
7,847 gal	10,008 gal	2,161 gal

Approximately 3,000 gallons were transferred T-44 to T-43 to provide sodium for the planned in-containment NaK systems flush (with sodium):

	Sodium Volume Transferred from T-44 to T-43		
	Sodium Volume Before	Sodium Volume After	Transferred
Using T-44 Levels	9,910 gal	6,899 gal	3,011 gal
Using T-43 Levels	2,364 gal	5,579 gal	3,215 gal

T-44 was then emptied as much as possible to T-3004:

	Sodium Volume Transferred from T-44 to T-3004		
	Sodium Volume Before	Sodium Volume After	Transferred
Using T-44 Levels	6,899 gal	30 gal*	6,869 gal
Using T-3004 Levels	0 gal	6,362 gal	6,362 gal
*Estimated, based on tank configuration.			

At this point T-44 and T-3004 trace heat was secured to permit the vessels to cool. No additional secondary sodium was placed in T-3004 and this transfer constituted the final use of T-44.

i. Summary of Secondary Sodium Drained and Transferred

Description	Quantity using T-44 levels, Gallons	Quantity using the receiving vessel levels, Gallons
Transferred from T-44 to T-43, November 1995	7,235	7,572
Transferred from T-44 to T-3001 after Loop 1 drain, April 2003	16,982	17,099
Transferred from T-44 to T-3001 after Loop 2 drain, April 2003	16,772	16,229
Transferred from T-44 to T-3001 after Loop 3 drain, April 2003	16,283	16,050
Transferred from T-44 to T-43 after IHX drain, September 2003	3,011	3,215
Transferred from T-44 to T-3004 after IHX drain, September 2003	6,689	6,362
Total secondary sodium transferred	**67,032**	**66,527**
Total secondary sodium transferred to SSF	**56,786**	**55,740**

D. FSF NaK Transfer into the FSF Sodium

Prior to FSF sodium drain the bulk FSF NaK was disposed of by transferring it into the FSF fuel storage vessel. Approximately 380 gallons of NaK were transferred, leaving approximately 32 gallons behind in the NaK storage tank and cooling loop. This latter amount was subsequently removed by a superheated steam cleaning process.

E. NaK flush

The two NaK cooling systems were used in-containment to cool the primary cold trap and IDS during reactor operation. In order to eliminate the bulk and residual NaK in these systems they were flushed with sodium from T-43. The sodium was drawn from T-43 in batches, circulated through the NaK cooling systems, and delivered to the suction of the primary electromagnetic (EM) pumps (P-38 and P-39). At the completion of the flushes the NaK cooling systems were drained as much as possible and allowed to cool. The NaK cooling systems have no installed trace heat. Throttled EM pump operation was used to achieve and maintain elevated temperatures. Approximately 490 gallons of NaK were added to the primary system.

F. Primary Phase 1

Primary Drain Phase 1 involved lowering reactor vessel sodium level, breaking siphon in each of the loops and draining the sodium to the reactor vessel and T-43. From T-43 the sodium was delivered to SSF T-3002. Due to the sodium volume involved this drain required batch transfers to and from T-43.

Primary Phase 1 Sodium Delivered to the SSF	
	Sodium Volume, Gallons
T-3002	74,860

G. Primary Phase 2 and HTS-S

Primary Drain Phase 2 involved draining primary sodium previously frozen in HTS-S for standby back to the reactor vessel. No attempt to reheat the piping to the Multi-Purpose Samplers or the Cesium Trap was made. Likewise, the Cesium Trap was frozen early in the FFTF standby period and was not drained. Phase 2 also drained as much sodium as possible from T-42 by siphoning it back to T-43 and sending it out to SSF T-3003 from T-43. T-42 was then allowed to cool to ambient temperatures.

Primary Phase 2 Sodium Delivered to the SSF	
	Sodium Volume, Gallons
T-3003	20,632

H. Primary Phase 3

The final primary drain required drilling through the reactor core support structure and installing a pump to remove the remaining sodium from the reactor vessel. Sodium was then pumped directly to the SSF T-3003 via the installed drain lines.

Primary Phase 3 Sodium Delivered to the SSF	
	Sodium Volume, Gallons
T-3003	42,005

i. Summary of Primary Sodium Transferred

Primary Sodium Delivered to the SSF		
	SSF Vessel	Sodium Volume, Gallons
Phase 1	T-3002	74,860
Phase 2	T-3003	20,632
Phase 3	T-3003	42,005
Total		**137,497**

I. FSF Sodium Drain

Liquid metal was drained from the FSF fuel storage vessel by batch transfers into and out of a small tank located on the 550-foot elevation of FSF. Each complete batch transferred approximately 330 gallons with 95 batches required to empty the vessel. Totaling the batches, the amount of liquid metal transferred out of the FSF vessel was approximately 30,909 gallons. The pre-transfer T-3004 volume was 6,361 gallons whereas the post transfer volume was 37,329 gallons, making the amount transferred 30,968 gallons. The difference between the batch volume estimate and the T-3004 dip results was only 59 gallons. It is important to note this drain included the approximately 350 gallons of NaK that had previously been transferred from the FSF NaK cooling loop #2 to the FSF Fuel Storage Vessel.

FSF Sodium Drain	
Gallons using T-38 levels (accumulative)	Gallons using T-3004 levels
30,909	30,968

J. IDS

i. IDS 2004 Level Lowering

In March 2004 the IDS sodium level was lowered to preclude Bottom Loading Transfer Cask grapple immersion in sodium while handling assemblies. Approximately 1,288 gallons of sodium were removed to T-43.

ii. IDS 2006 Drain

The IDS vessel, IDS processing loop and T-43 were emptied to the SSF T-3004. Prior to IDS vessel drain to T-43, T-43 sodium level was lowered by transferring sodium to T-3004. Prior to the IDS vessel drain the 108 core component pots (CCP) were plunged to remove as much sodium as possible and pulled from the vessel storage basket. The pots retained approximately 3.7 gallons of sodium each. Then IDS vessel sodium was drained to T-43 and T-43 was in turn emptied as much as possible to T-3004. Trace heat to T-43 and the IDS vessel was then secured.

Using T-43 levels the sodium transfer went as follows:

Description	+/-	T-43 Volume, Gallons	Using T-3004 Levels, Gallons
T-43 volume prior to IDS drain		3,309	
T-43 sodium volume reduced to ensure space for IDS drain	-1,580	1,729	
IDS vessel drained to T-43	+14,624	16,353	
T-43 emptied as much as practical to T-3004	-16,353	20*	
Total transferred to SSF using T-43 levels	**17,933**		**17,945**

*Estimated, based on tank configuration.

The two measurements (17,945 gallons using T-3004 and 17,933 gallons using T-43) are in good agreement with only a 12 gallon difference.

K. Main Heat Transport Large Valve Drain

When the primary loops were drained approximately 700 gallons of sodium were retained in the bodies of the nine primary MHTS valves (one 28 inch isolation valve, one 16 inch isolation valve, and one 16 inch check valve in each loop). This sodium will be removed by draining it to T-43 and sending it from T-43 to SSF. Though not previously planned it became clear that using T-43 to remove the sodium was the simplest and least costly alternative. It is anticipated that nearly all of the 700 gallons will be removed during the upcoming drain work.

L. Summary of Drain Activities

The table below shows the volume of liquid metal received by the SSF vessels. Nearly 243,000 gallons were drained from the FFTF plant and FSF.

SSF Vessel	Secondary Loops	Secondary IHXs	Primary	FSF	IDS & T-43	MHTS Valves*	Total Each Vessel
T-3001	49,378						49,378
T-3002			74,860				74,860
T-3003			62,637			700	63,337
T-3004		6,362		30,968	17,945		55,275
Total	49,378	6,362	137,497	30,968	17,945	700	**242,850**

*Estimated, based on valve configuration.

M. Estimating the Drain Volume Error

The error that may have occurred in the drained volume is dependent upon the final dips of each of the SSF tanks. Again it is expected that a typical operator, following established procedures would be able to measure the level in the tanks with a maximum error of 1/4 inch. However other possible errors, such as building structural and vessel variations increase that possible error to a total of 1 inch. T-3001 is a horizontal tank, unique in the SSF. At mid-section T-3001 a variance of 1 inch would result in a volume error of 319 gallons. T-3002, T-3003 and T-3004 are identical vertical tanks and the maximum error in the cylindrical section would be 384 gallons. Statistically combining all these errors:

$$((319 \text{ gallons})^2 + 3(384 \text{ gallons})^2)^{0.5} = 738 \text{ gallons (round to 750 gallons)}$$

Applying the error range the liquid metal drained would be:

242,850 gallons ± 750 gallons (242,100 gallons min, 243,600 gallons max)

6.0 RESIDUALS ESTIMATE

Table 2 lists the expected liquid metal residual volumes retained in the plant and FSF.

Most estimates in Table 2 are based on known geometrical constraints. Liquid metal transfer from storage vessels involved adding cover gas to the top of the vessels which forced flow from the bottom up through dip tubes. The single assumption for vessels (liquid metal storage, reactor, IDS, and fuel storage) is that sodium transfer ceased once the sodium level reached the level that cover gas could migrate up the dip tube and break the siphon.

For cold traps, the crystallizers were frozen prior to the respective system drains. With exception of the Cesium Trap and the FSF cold trap the economizers were retained hot and blown through during the drains, though it is assumed and expected that very little economizer sodium was removed by the small gas flow through the tube sheet bypass hole. The FSF cold trap economizer is on a common trace heater string with the crystallizer and cannot be cooled independently. It was frozen along with the crystallizer. The Cesium Trap was frozen early in the FFTF shutdown and was not drained at all. In each calculation the cold trap economizers were assumed full.

Piping residuals are difficult to estimate. First, the total lineal foot of each pipe size is not precisely known and has been herein estimated from isometric drawings. Secondly, it is not known how much sodium was retained by the piping. By design, all sodium piping was to be sloped toward adjacent storage vessels creating the expectation the piping did drain well. Experience at other facilities however does not support this assumption. It is expected that while the smaller piping may have drained or been blown down completely, sufficient dripping and settling may occur before the freezing temperature was reached to refill some of the pipe. Further, all valves in sodium lines are globe style and have retained a small volume. For this estimate it was decided that all the small bore (6 inches and below) piping would be assumed 20% full after the drain evolutions. The 20% figure was selected through engineering judgment with information from other facilities that have begun removing small bore sodium bearing piping. Feedback in one of these cases indicated this number could be as high as 35%. The 400 area volume retention is not expected to be that high because of the level of effort taken to blow each pipeline down with cover gas at the completion of each drain. Larger bore piping, which is present only in the primary and secondary MHTS piping, is assumed to have fully drained.

Sodium retained by the Dump Heat Exchanger (DHX) modules constitutes the greatest single volume of estimated residuals. For this estimate it has been assumed that the DHX tube bundles are 25% full and given the considerable length (approximately 108,000 feet) of tubes this creates a large sodium volume. The higher percentage volume for the DHXs was taken due to two factors. One is the DHX drain did not involve an active 'blow down' where gas would force the sodium down the pipe or tube to the storage vessels. Rather, the DHXs were drained by gravity when the argon gas migrating from the loops' pump and expansion tanks reached the DHX high points. It is expected (and would have similarly have happened in a blow down) that a handful of tubes provided sufficient passage for gas migration and module drain. The remaining tubes, as parallel paths, may not have drained as completely. Secondly, drawings indicate the tube bundles have less slope than the installed piping and therefore have less propensity to drain. In addition, given the hanger spacing there is a greater likelihood for variations in the slope.

All liquid metal piping removed from the plant has had an interior surface liquid metal film. In two locations, the NaK fill line in lower Containment, film thickness was measured using an ultrasonic tester. Thickness varied but reached as great as 0.005 inches. This pipe had a standing column of NaK for the plant life and at these locations never ventured far from ambient temperature. Calculation of total exposed surface area of all systems is beyond the scope of this document, but given the enormous surface areas in the reactor vessel and storage vessels liquid metal films and droplets may constitute a significant quantity of liquid metal.

TABLE 2		
TOTAL ESTIMATED RESIDUAL (GALLONS):		**6,416**
Secondary		**Gallons**
Cold Traps:		
Secondary Loop 1 (N-7)		300
Secondary Loop 2 (N-40)		300
Secondary Loop 3 (N-41)		300
DHX module tubes and headers		1,805
IHXs (3)		10
T-44		30
Multipurpose Samplers		3
Main Coolant Pumps		10
Plugging Temperature Indicators (PTI)		3
Venturi Flowmeters		36
Piping and Valves		221
Primary		**Gallons**
Cold Traps:		
Primary (N-5)		675
Cesium Trap (N-3)		60
Reactor Vessel		
Outside Core Basket		23
Pockets Periphery of Core Support		43
Instrument Trees and In-vessel Handling Machine		50
Reflector Assemblies		25
Other Core Assemblies		8
Bottom of Vessel		7
Horizontal Surfaces		336
Main Coolant Pumps		10
IHXs		5
T-42		20
T-43		20
T-88 and T-89		4
Big MHTS Valves		7
PTIs		3

TABLE 2		
Primary Cont'd		**Gallons**
Overflow Weir		3
HTS-S/P-52		10
T-99 (now containing sodium)		3
E-137		1
Multipurpose Samplers		3
Piping and Valves		215
IDS		**Gallons**
IDS Vessel		20
Horizontal Surfaces		20
E-79		1
Cold Trap:		
IDS (N-46)		300
P-40 and P-41		5
T-98 (now containing sodium)		2
PTI		3
Core Component Pots		400
E-133		3
E-134		1
FSF		**Gallons**
Cold Traps:		
Permanent (N-932)		140
Temporary (in Maintenance and Storage Facility)		300
EM Pump		2
FSF Vessel		10
Tubes		600
Horizontal Surfaces		50
Piping, Valves and In-Line Heater		10

7.0 CONCLUSIONS AND RECONCILIATION

A. Using the base numbers, a difference of approximately 10,000 gallons exists between fill and drain (fill: 253,000 gallons, drain: 243,000 gallons in SSF). 10,000 gallons constitutes approximately 4% of the total sodium fill. Applying the statistical analyses the fill volume becomes 249,300 gallons to 257,400 gallons with a 95% confidence level. With uncertainty estimation, the drained volume becomes 242,100 gallons to 243,600 gallons. The minimum and maximum difference between fill and drain volumes are then 5,700 gallons and 15,300 gallons.

B. Quantified residual volume totaled to just over 6,400 gallons retained. This figure assumes all small bore piping (< 6 inch diameter) remained 20% full by volume. The residual sodium volume contributed by small bore piping is small compared to other sources of residual.

Similarly the DHX tube bundles are assumed to be 25% full. This estimate is the largest single contributor to the sodium residual volume. The higher figure was used due to the nature of the DHX configuration.

Not included in this figure are:

i. Sodium film/droplets present throughout the systems. Given that the total surface area exposed to liquid metal is enormous even a thin film would constitute a significant volume, certainly in the order of hundreds of gallons.

ii. Sodium vapor deposits present in the cover gas spaces above sodium vessels and vapor traps.

iii. Sodium drip pots from the refueling machines.

iv. Sodium removed by periodic sampling.

v. Sodium removed from fuel assemblies washed in the Interim Examination and Maintenance Cell Sodium Removal System.

With the possible exception of the sodium films none of these neglected sodium quantities is believed to accumulate to a significant volume.

C. Though significant uncertainty/discrepancy remains, the actual residual volume is likely to be in the low end of the 6,000 to 15,300 gallon range.

8.0 REFERENCE

HNF-SD-FF-SSP-004, *Fast Flux Test Facility Closure Project - Project Management Plan,* Revision 5.