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SUBJECT: A Review of the Data and Observations Taken for
the Purpose of Locating and Estimating the Size
of the Hole in the Core

To: S. E. Beall

From: R. Van Winkle and R. H. Guymon

SUMMARY

Two different measurements of the weight of D_2O required to fill the blanket to the level at which spill-over into the core occurs and visual observation of this water level, using a periscope, places the elevation of the hole (or crack) in the core vessel within about $1/2"$ of $812'-5"$, or approximately 1 to $1-1/2"$ below the intersection of the 30 and 90° cones.

The inherent errors involved in estimating a liquid level in the high-pressure system by weighing the liquid drained to the low-pressure system and referring to a calibration of volume vs. elevation are greater for the core than for the blanket.

An indication of the approximate size of the hole in the core was obtained by measuring the difference in liquid levels between the core and blanket, using bubbler probes, as D_2O was caused to flow at measured rates from core to blanket, or vice versa. Heads of approximately $1/8$ to approximately $3/4$ inch were observed for flows in the range 19 to 65 lb/min, indicating a flow area of about 1.4 square inches, assuming a sharp-edged submerged orifice.

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I. PROCEDURES

The several attempts to determine the elevation of the core hole and the estimate of its size are described:

A. Locating elevation of hole in core vessel.

1. In Run No. 14 after it had been definitely established that there was an interconnection between the core and blanket which permitted the transfer of solution in either direction, the high-pressure system was cooled to less than 100°C, the blanket high-pressure system was drained with the fuel dump valve kept closed. By completely draining the blanket high-pressure system, the fuel system was permitted to drain itself down to the level of the hole in the core; this level was then determined by completely draining the core, weighing the amount drained. From the liquid level vs volume calibration of the fuel high-pressure system, the approximate elevation of the hole in the core was ascertained. Complete draining of each side was insured by pressurizing the high-pressure system to a higher pressure than the dump tank, using oxygen introduced to the high-pressure system through Line 167 from the chem plant; the appearance of gas in the dump tank, as indicated by a sudden increase in dump tank pressure when the dump valve is open, indicated that the high-pressure system was empty of liquid.
2. The findings of the initial draining of the fuel high-pressure system were verified by repeated drainings and weighing of the quantity required to fill (separately) the fuel and blanket high-pressure systems; thus tests were performed in which the fuel high-pressure system was filled sufficiently to transfer D₂O to the blanket. The blanket high-pressure system was drained, and then the fuel high-pressure system drained and contents weighed. The blanket high-pressure system was also filled sufficiently to transfer D₂O through the hole to the core, the core drained, and then the blanket high-pressure system was drained and its contents weighed.
3. Additional data were obtained in which it was established that the hole could not be below given levels by pumping certain weighed amounts of D₂O into the blanket high-pressure system with no transfer of D₂O to the core, as indicated by the fact that the fuel dump tank weight remained unchanged when the fuel dump valve was opened.
4. The approximate level at which spill-over from the blanket to the core occurred was determined visually with a periscope focussed on the core in the vicinity of the intersection of the 30-90° cones. In this test it was determined that the core was empty by leaving the fuel dump valve open until the pressurizing gas caused the fuel dump tank pressure to rise rapidly with no change in dump tank weight.
5. The level at which leakage from the core to the blanket occurred was determined by looking for water spilling from the side of the core into the empty blanket space with the fuel feed pump delivering its maximum output to the core (> 20 lb/min).

6. An unsuccessful attempt was made to locate the level of the hole in the core by illuminating the inside of the core and looking for light streaming through the hole into the darkened blanket space.

B. Estimating the size of the hole in the core vessel.

1. The size of the hole in the core vessel was determined by measuring the difference in elevation between fuel and blanket liquid levels for various known flows of D_2O through the hole in the core. The difference in head was determined by the use of bubbler probes inserted into the core and the blanket. It was intended that the ends of each probe be at elevation $812'-0"$ (at least below $812'-5"$), but the probe in the core could not be threaded through the several screens above that elevation. It rested on the second screen from the top at about $812'-10-3/4"$.

Pressure drop measurements were taken with both liquid levels above $812'-10-3/4"$. Flow through the hole was induced by: (a) raising the level in the core by pumping up with the fuel feed pump; (b) with the level above $814'$, dumping from the fuel high-pressure system, and (c) with the level above $813'-5"$, dumping out of the blanket high-pressure system.

II. EVALUATION OF RESULTS

A. Sources of error.

1. Using volume vs. elevation calibration.--The original volume calibrations of the fuel and blanket high-pressure system were made by filling through the respective dump valve flanges and venting the back of the circulating pumps and the pressurizers to atmosphere.

- a. The volumes of the dump lines between the dump valves and the dump tanks were not included in the volume calibrations.

These dump lines (downstream of the dump valves) are constituted as follows:

Line 106 (fuel dump line)

$1'-2-1/2"$ of $1/2"$ Sch. 80 pipe

$25'-1"$ of $1"$ Sch. 80 pipe

Volume: 3.7 liters (≈ 9.0 lb D_2O at $20^\circ C$)

Line 206 (blanket dump line)

$2'$ of $1"$ Sch. 80 pipe

$29'-11-1/2"$ of $1-1/2"$ Sch. 80 pipe

Volume: 10.68 liters (≈ 25.9 lb D_2O at $20^\circ C$)

- b. The circulating pumps and their inlet and discharge lines form an inverted U which permits gas to be trapped in a volume of about 38 liters and 35 liters when the high-pressure systems are being filled and the liquid level rises above elevation $\sim 809'5\frac{1}{2}"$ and $809'6\frac{1}{2}"$ on the fuel and blanket sides, respectively. The maximum error that could result would be that the pump inlet and discharge nozzles would not be filled between elevation $\sim 809'6"$ and the elevation of the hole in the core. The resulting error (if the hole is at $\sim 812'5"$) would be less than the amount required to fill ~ 6 feet of $3\frac{1}{2}"$ pipe (I.D. = 3.062"), or less than ~ 20 lb of D_2O . An error this great would place the indicated elevation of the hole low by about 10 inches on the fuel side in the neighborhood of and below $812'5"$; on the blanket side a 20 lb error changes the indicated level about 0.32 inch at elevation $812'5"$.
- c. When draining the fuel high-pressure system down to the level of the hole in the core after having operated the fuel circulating pump, the circulating pump and its nozzles will not be drained down to the level of the hole (at $\sim 812'5"$) and because the back of the pump cannot be vented except through Line 125, and then only if the dump tank pressure is slightly greater than the pressure back of the pump. This would result in more liquid being drained than would be required to fill the fuel high-pressure system to the level of the hole under the same conditions of the original volume calibration.
- d. There is an unknown error in the plot of the fuel high-pressure system volume calibration above the elevation of the orifice flange in Line 143, which is at $808'10"$, caused by the leakage of an estimated ~ 2 liters of water from Flange A-143 during the calibration. This error may have been greater than 2 liters. Comparing the fuel calibration curve with the blanket curve, at $\sim 808'8"$, which is just above the low point in Lines 103 and 203, the fuel high-pressure system contains 26 lb D_2O and the blanket high-pressure system contains 23 lb. These are probably accurate values. Between elevations $808'8"$ and $810'5"$, the volumes of fuel and blanket piping should be identical--yet the calibration curves show the fuel high-pressure system containing ~ 56 lb at $810'3"$ and the blanket high-pressure containing ~ 42 lb at the same level. This implies that the fuel high-pressure calibration is probably in error by ~ 11 lb above the level of Flange A-143 instead of the estimated 2 liters that had been noted in the original data.
2. Completeness of draining the high-pressure systems.--In draining either the fuel or the blanket high-pressure systems to the dump tank, the pressure in the high-pressure system must be greater than the dump tank pressure in order to drain below elevation $811'$.

In order to drain the fuel high-pressure system to the level of PCV-152, the fuel high pressure has to be greater than the fuel dump tank pressure by 3'6" of D₂O (1.66 psi); on the blanket side the required pressure difference to drain the blanket high-pressure system to the level of PCV-252 is 4'0-3/4" of D₂O (1.93 psi).

Normally, a sudden increase in dump tank pressure of 1 psi or greater has been interpreted to mean that gas is flowing into the dump tank. It is estimated that ~50 liters (STP) of gas injected into the low-pressure system, with both fuel and blanket cold traps and condensers open to the charcoal beds, would cause a 1 psi increase in dump tank pressure. Before gas will flow from the high-pressure system to the dump tanks (if the letdown valves and pressurizer bleed valves are closed and not leaking), the liquid level in the dump lines would have to be depressed to the lowest level to permit gas to bubble through the columns of liquid contained in the dump lines as they rise from the lowest point to the highest point prior to discharging into the dump tanks (see Fig. 1). The pressure differences between the high-pressure system and the dump tanks would have to be 2.74 psi in the fuel side and 3.2 psi on the blanket side for this to occur.

Normally, the high-pressure systems would not be completely drained at the first appearance of gas in the dump tank because the orifices in Lines 143 and 243 which drain Lines 102 and 202 throttle the flow to such an extent that Lines 103 and 203 would be empty several minutes sooner than Lines 102 and 202. It is estimated that for a one foot difference in head, the flow rate through Line 143 or 243 would be ~ 0.6 lb D₂O/min. Thus it can be seen that 10 or 15 lb D₂O could easily be left in Line 102 or 202 at the first appearance of gas in the dump tank. For this reason two and three blowdowns are required to completely drain the high-pressure systems. Flow rates of D₂O into the dump tanks during normal blowdowns were the order of 60 lb/min on the fuel side and 190 lb/min on the blanket side.

Lines 159 and 259, unless they are blocked with a freeze plug, would prevent complete draining of the high-pressure system to the dump tanks; however, freeze plugs were maintained in these lines during all of the draining tests.

3. Dump tank weighing errors.--The error in detecting changes in dump tank weight is estimated to be ± 10 lb on the blanket side and ± 4 lb on the fuel side.

B. Tests to locate elevation of hole.

1. The initial draining of the fuel high-pressure system, after having drained the blanket high-pressure system following system cool-down from Run 14 operation (Test No. 1):
 - a. The reported value was 112 lb D₂O, which presumably fills the fuel high-pressure system to the level of the crack.

This value is probably high for reasons discussed in Section II-A-c. The magnitude of the error is unknown, but could not be greater than the volume of the circulating pump and its pipe legs above the elevation of the hole in the core. This volume (above 812'-5") is estimated to be about 26 liters.

2. Pumping to the fuel high-pressure system, draining the blanket high-pressure system to make certain the fuel high-pressure system is full to elevation of hole, draining and weighing contents of the fuel high-pressure system:

Results of tests No. 2, 3, 5, and 7 show that 82, 66, 69, and 75 lb were drained from the fuel high-pressure system when filled to the level of the hole. The errors discussed in Section II-A make these results from 7 to 15 lb low. This suggests that the probable elevation of the hole indicated by this procedure could lie between 811'-9" and 812'-6.2", using the corrected calibration curve in Fig. 4.

It was postulated in the HRT Operations log book that if the hole were a peripheral horizontal crack, condensate could run down the inside walls of the core, hit the crack and part of it run through the crack into the blanket space without filling the core to the level of the crack. But in Steps 2-d and 2-f of Test No. 2, the transfer from the fuel to the blanket through the hole was quantitatively complete. The liquid level in the core was very likely up to the hole at the time of the final draining of the fuel high-pressure system in each of the above tests.

3. Pumping to the blanket high-pressure system, draining the fuel high-pressure system to make certain the blanket high-pressure system is full to elevation of hole, draining and weighing contents of the blanket high-pressure system:

a. Test No. 4

Except for the 10 lb blowdown from the fuel high-pressure system following the initial addition of 141 lb to the blanket high-pressure system, more than 392 lb were pumped to the blanket high-pressure system without any spill-over from the blanket to the core. This indicates that there is no hole below elevation 812'-2-3/4". The initial 10 lb drained from the fuel high-pressure system could have been left from the previous test.

Because of the poor material balance, in which an indicated 63 lb remained in the high-pressure system, the remainder of this test is inconclusive. In the blowdown of the fuel high-pressure system in Step 4-k, page 10, there appeared to be no gas blown to the fuel dump tank, as indicated by no pressure increase on PR-350.

b. Test No. 6

Again a poor material balance renders the data inconclusive, except that apparently no spill-over from blanket-to-core occurred until at least 478 lb of D_2O had been pumped to the blanket high-pressure system. This says that there is no hole below elevation 812'4". Finally, 532 lb were drained from the blanket high-pressure system after the fuel high-pressure system had been blown down 3 times.

c. Test No. 8

At least 234 lb were pumped to the blanket high-pressure system with no spill-over from blanket to fuel.

Again there was a poor material balance, although the final draining of the blanket high-pressure system after blowdown of the fuel high-pressure system indicated 525 lb of D_2O .

- d. The two results of b. and c., above (525 and 532 lb), could have errors that range from 15 lb high to 5 lb low, which says that the indicated elevation could be as low as 812'4-3/4" (505 lb), or as high as 812'5-1/4" (537 lb).

4. Visual observation.--Observations with the periscope appear to establish that the hole in the core is definitely below the intersection of the 30-90° cone, and it may be that the crack (identified in Section V-A-9b as a "gray crack line") is just above, possibly adjacent to, the top surface of the sixth screen from the top, at elevation $\sim 812'4-1/2"$.

It should not be surprising that water could flow through the crack without being seen because at the flows used, the order of 3 gpm, and the low head required, $\sim 1/8"$, the water would come through a crack, spill over the edge as a thin sheet and run down the outside surface without splashing. Such a flow of clear, colorless liquid could not be seen when viewed under the condition of the test.

The dripping at the very low flow reported in Section V-A-9-c cannot be discounted, since it placed the level of the hole well up in the neck, although it was inconclusive otherwise.

The fact that light could not be seen through the crack is surprising, although a curtain of oxide scale, or jagged crack might prevent straight-line transmission of light.

C. Tests to estimate size of hole.

The heads reported are accurate enough to estimate that the flow area is approximately 1.4 square inches, calculated as a sharp-edged submerged orifice. Greater accuracy could have been obtained, using an inclined manometer to measure the differential head, but it was not anticipated that these heads would be as small as observed.

The absolute elevation of liquid in the blanket side at the spill-over point could easily have been determined by lowering the probe about 8 inches, and measuring its length from a known elevation.

III. CONCLUSIONS

- A. There is at least one hole in the core vessel.
- B. The hole is a horizontal crack.
- C. Its location is above 812'4" and below 812'5-1/2" (i.e., at least one inch below the weld at the intersection of the 30-90° cone.)
- D. Its flow area is approximately 1.4 square inches.
- E. Draining the high-pressure systems must be carefully conducted to insure completeness of draining.

IV. SUGGESTIONS FOR FUTURE INVESTIGATIONS

- A. Determine the absolute elevation of the liquid in the blanket at the spill-over point, using a bubbler probe.
- B. Determine if the apparent crack goes completely around the circumference of the neck by lifting the core with enough force to deflect the core bellows a prescribed distance and carry the weight of the core also, while viewing the core neck at ~ 812'5" with a periscope in the blanket.

V. APPENDIX

A. Summary of test results for locating approximate elevation of hole in core vessel.

1. Test No. 1, 1250 to 1800, 4-5-58

The blanket high-pressure system (BHP) was dumped and blown down with oxygen pressure (introduced into the high-pressure system through Line 167). The fuel dump valve was kept closed, which should leave the liquid level in the fuel high-pressure system (FHP) at the same elevation as the hole in the core. The low-pressure system inventories were then recorded:

FDT	1028 lb	BDT	4475 lb
FCT	<u>416 lb</u>	BCT	<u>9.4 lb</u>
Total FLP	1444 lb	Total BLP	4484 lb

The fuel high-pressure system was then dumped and also blown down with O₂ pressure. New low-pressure system inventories were:

FDT	1153 lb	BDT	4460 lb
FCT	<u>403 lb</u>	BCT	<u>18.6 lb</u>
Total FHP	1556 lb	Total BHP	4478.6 lb

Net change on fuel side = 112 lb. BHP blown down again. BLP weight increased 31 lb.

2. <u>Test No. 2, 1814 - 1900, 4-5-58</u>	Indicated High-Pressure System Inventories		
	BHP	FHP	Total
a. FHP and BHP assumed to be empty.	0	0	0
b. Pumped 120 lb from FCT to FHP.	?	?	120
c. Blew down BHP; BDT wt. increased 56 lb.	0	64	64
d. Pumped 61.6 lb to FHP.	?	?	125.6
e. Blew down BHP; BDT wt. increased 60 lb.	0	65.6	65.6
f. Pumped 40 lb to FHP.	?	?	105.6
g. Blew down BHP; BDT wt. increased 42 lb.	0	63.6	63.6
h. Blew down FHP; FDT wt. increased 82 lb.	0	0	18.4

	Indicated High-Pressure System Inventories, lb		
	BHP	FHP	Total
3. <u>Test No. 3, 1909-2026, 4-5-58</u>			
a. FHP and BHP assumed to be empty.	0	0	0
b. Pumped 140 lb into FHP.	?	?	140
c. Blew down BHP; BDT increased 72 lb.	0	68	68
d. Blew down FHP; FDT increased 26 lb.	0	42	42
e. Blew down FHP; FDT increased 40 lb.	0	2	2
f. Blew down FHP and BHP; no increase. in either FDT or BDT.			
4. <u>Test No. 4, 2113, 4-5-58 to 0153, 4-6-58</u>			
a. Assumed BHP and FHP empty.	0	0	0
b. Pumped 141 lb into BHP.	?	?	141
c. Blew down FHP; FDT increased 10 lb.	131	0	131
d. Pumped 19 lb to BHP.	?	?	150
e. Blew down FHP; no increase in FDT.	150	0	150
f. Pumped 59 lb to BHP.	?	?	209
g. Blew down FHP; no increase in FDT.	209	0	209
h. Pumped 173 lb to BHP	?	?	382
i. Blew down FHP; no increase in FDT	382	0	382
j. Pumped 436 lb to BHP.	?	?	818
k. Blew down FHP; FDT increased 303 lb.	515	0?	515
l. Blew down BHP; BDT increased 452 lb.	0?	?	63

	Indicated High-Pressure System Inventories, lb		
	BHP	FHP	Total
5. <u>Test No. 5, 0229-0423, 4-6-58</u>			
a. BHP and FHP presumed empty (probably were not).	0	0	0
b. Pumped 212 lb to FHP.	?	?	212
c. Blew down BHP twice; BDT increased 204 lb.	0	8	8
d. Blew down FHP; FDT increased 69 lb.	0	-61	-61
e. Blew down FHP and BHP again. No data recorded on FDT or BDT weight change.	0	0	0
6. <u>Test No. 6, 0429-0530, 4-6-58</u>			
a. BHP and FHP presumed empty.	0	0	0
b. Pumped 498 lb to BHP.	?	?	498
c. Blew down 19.7 lb from FHP in 3 operations.	478	0	478
d. Blew down 532 lb from BHP.			-54
7. <u>Test No. 7, 0629-0735, 4-6-58</u>			
a. Assume BHP and FHP empty.	0	0	0
b. Pumped 411 lb to FHP.	?	?	411
c. Blew down 336 lb from BHP in 3 operations.	0	75	75
d. Blew down 75 lb from FHP.	0	0	0
8. <u>Test No. 8, 1430-2215, 4-9-58</u>			
a. Assumed BHP and FHP empty.	0	0	0
b. Pumped 233.8 lb to BHP.	?	?	234
c. Opened fuel dump valve; no increase in FDT wt; FDT pressure increased from 10.4 to 12.0 psia.	234	0	234
d. Pumped more D ₂ O to BHP until a total of 779 lb had been added.	?	?	779

8. Test No. 8, 1430-2215, 4-9-58 (Continued)	Indicated High-Pressure System Inventories, lb		
	BHP	FHP	Total
e. Blew down FHP; FDT wt. increased 425 lb.	354	0	354
f. Blew down BHP; BDT wt. increased 525 lb.	0	0	-171
g. Blew down FHP; FDT wt. increased 16 lb.	0	0	-187

9. Visual Observations

- a. 1400, 4-30-58 to 0230, 5-1-58--With the core and blanket open to atmosphere, D₂O was pumped to the BHP system until the blanket was filled to the level of the hole in the core as indicated by gain in weight in the fuel dump tank with the fuel dump valve open. Making certain that the core was empty of liquid by having the fuel dump valve open, the water level in the blanket was located by focusing the periscope on the core at the water level; the level was reported to be slightly lower than the intersection of the 30-90° cone: "The periscope had been focused on the core at the water level and the view showed the water level (as a black sector at the bottom); a gray area above that, apparently the wetted part; and a white sector at the top. The view was clear and water could be seen decreasing in level when the blanket dump valve was opened. At this point the light was lowered and this level on the outside of the core viewed again....A very clear picture was obtained while traversing across the neck of the core.

The fuel feed pump was turned on¹ and the east part of the neck viewed continuously with a well-focused view being obtained. 230 lb (D₂O) was pumped, blanket dump tanks increasing about 200 lb....No change in picture was observed. The focus did not change; no leakage was observed. Looked at the south end of neck and in between or all the way across the neck and no change from before pumping....Summary: Observed no leakage from (sic) blanket side at level of hole, while pumping into core."²

- b. 1530, 5-3-58, Core observation with extended mirror-- Using a calibrated (for length) periscope, the intersection of the 30-90° cones was observed to be 17'-6" below elevation 830' (floor level in the high-bay area)

¹This was an attempt to see water flowing through the hole by looking for either a change in focus (caused by water aberrations), or for a change in color from white to gray as the white film became wetted.

²Direct quotation from notes of D. F. Frech and J. E. Eve.

9. Visual Observations

13.

b. Core observation with extended mirror (Continued)

which places this level at 812'-6". A gray crack line (see sketch, Fig. 2) was noted at elevation 812'-4-1/2" to 812'-4-3/4".

"Focussed extended mirror on southeast of core. Vessel appears white with no cracks or lines apparent.

At 10 o'clock (north is 12 o'clock, east is 3 o'clock) on core, crack or mark noted that begins on 90° cone and continues across weld into 30° cone.

Four white horizontal bands noted around core vessel, third from top is on bottom side of gray crack band. White bands appear to be 1/4-3/8" wide with clear straight borders."³

- c. 0045, 4-10-58--"Started pumping condensate into core (with) FP³ (Fuel pressurizer purge pump) on lowest speed. Observed stream of D₂O flowing in blanket space as per sketch below:

Tried to follow stream up to origin but it is apparently coming from the far side of the core."⁴

- d. No light could be seen in the blanket space with the inside of the core illuminated with a 30-watt borescope light inserted down through some of the upper screens.

³Direct quotation from notes of J. R. Buchanan.

⁴Direct quotation from HRT Operations log book No. 83, page 6525.

APPENDIX (Continued)

B. Estimating size of hole in core vessel.

The following table summarizes the results of the head vs flow measurements that were obtained, using the bubbler probes and D₂O-filled manometers to determine the difference in levels.

TABLE 1
HEAD vs FLOW THROUGH HOLE IN CORE

Approx. D ₂ O Level in HP Sys. ft above sea level	Flow Rate Through Hole lb/min	Pressure Drop Across Hole in./D ₂ O	Method of Inducing Flow
<u>Flow from Core to Blanket</u>			
813.1	24(a)	1/8	Pumping to FHP.
813.2	19(a)	1/8	Pumping to FHP.
813.3	17(a)	~ 0	Pumping to FHP.
813.2	28(a)	~ 0	Pumping to FHP.
813.5	65(b)	5/8 - 3/4	Dumping the blanket.
<u>Flow from Blanket to Core</u>			
814.4	40(c)	3/8 - 1/2	Dumping the core.
814.5	26(c)	1/4	Dumping the core.

(a) Determined by change in fuel condensate tank weight.

(b) Determined by change in core liquid level.

(c) Determined by change in blanket liquid level.

Fig. 1. Arrangement of HRT High-Pressure Drain Lines.

FIG. 2

SURFACE FEATURES SEEN THROUGH PERISCOPE VIEWING NORTH SIDE OF HRT CORE VESSEL

ORNL-LR-DWG-31071

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