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SODIUM VAPOR DEPOSITS OBSERVED AT HEDL ON LARGE COMPONENTS

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INTRODUCTION

Testing of the Fast Flux Test Facility (FFTF) components in the High Temperature Sodium Facility (HTSF) has provided operating experience with sodium vapor deposits prior to reactor operation. Large component testing in liquid sodium at temperatures up to 1100°F (593°C) has simulated the thermal operating conditions of the FFTF including the evaporation rate of sodium from the surfaces of high temperature sodium.

Testing of several plant scale components with various reactor head plug gap configurations has made it possible to evaluate the influence of annuli gap clearance on sodium vapor deposits. The dimensions of the annuli are described, followed by details of the operating conditions of their exposure to sodium vapor and observations of the amount and character of vapor deposits.

COMPONENT CONFIGURATIONS

The several different configurations provided opportunities to better characterize sodium vapor deposits and their distribution. One plug configuration was modified to provide direct comparison of the deposit distribution in different sized annuli.

Three Dummy Control Rod Plugs (Figure 1.1) made it possible to compare the effectiveness of a convection restriction on vapor deposits. These assemblies were solid, 11 inch (279 mm) in diameter with the annuli gap in the vessel head hole for the plug ranging from 0.30 to 0.765 inch (76.2 to 194 mm).

A Core Restraint Plug (Figure 1.2) provided observations of deposits on thermal baffles. This assembly consisted of 2 inch (51 mm) diameter rods suspending twenty 0.35 inch (8.9 mm) thick baffle plates 9 inches (229 mm) above the level of the liquid sodium with an annuli gap of 0.063 inch (1.6 mm).

The Penetration Plug for the In-Vessel Handling Machine (IVHM) (Figure 1.3) provided a large diameter (68.6 inch / 1742 mm) surface for deposit formation. This assembly was a uniform diameter cylinder loaded into a stepped opening with annuli ranging from 0.248 to 1.39 inches (6.3 - 35.3 mm).

The IVHM Engineering Model (Figure 1.4) was examined after exposure to compare the deposits on 1) thermal baffles, 2) radiation shields, and 3) cylindrical plug. The average annuli gap of the prototype IVHM ranged from 0.248 to 0.545 inch (6.3 to 13.9 mm).

Average annuli gaps are listed in Table 1 with reference to their vertical location. However, the location of the local gaps relative to the height above the sodium (as shown in Figures 1.1, 1.2, 1.3, and 1.4) is needed to understand the influence of the gap on control of sodium vapor convection.

EXPOSURE CONDITIONS

All of these components were exposed to sodium vapor in the sodium vessel referred to as the Composite Reactor Components Test Activity (CRCTA). The vessel was filled with sodium at 400°F on September 11, 1974. The CRCTA was operated up to 1100°F (593°C) sodium pool temperature for 20 days during October and November of 1974. The sodium temperature was lowered to 350°F (177°C) on January 10, 1975 and increased to 1050°F (566°C) in early March for a fraction of a day. (See Table 2)

The Dummy Control Rod Plugs were exposed to 1100°F sodium for 20 days and 400°F (204°C) sodium for 95 days (1).

The Core Restraint Plug was exposed to 1100°F (593°C) sodium for 20 days and <350°F (117°C) for 101 days (2).

The IVHM Penetration Plug was exposed to 1100°F (593°C) sodium for 20 days and <350°F (177°C) for six months (3).

The exposure of the IVHM Engineering Prototype was six months in CRCTA, of which ten hours was over a sodium pool at 1050°F (566°C).

DEPOSIT OBSERVATIONS

The deposit found on the Dummy Control Rod Plug (DCRP) (1) was about 0.74 lb. (335 gm) on the plug having no convection constraint ring (S/N 3708). The deposit was distributed as unwetted draining droplets over the entire surface. Dimensions of the deposit ranging from 0.1 to 0.01 inch (25.4 to 2.54 mm) thick over a 4.5 inch (115 mm) band above the head shield. (See Figure 3.1.1) The eccentricity of this deposit band suggests a surface thermal gradient caused by location in the vessel head or eccentricity of annuli gap. The unwetted drips indicate refluxing of melted metallic sodium during the 20 days of 1100°F (593°C) exposure - and oxidation of the plug surface by cover gas impurities.

The deposits found on the DCRP fitted with convection restrictors were much the same in amount, but distributed differently. The unwetted draining drops of sodium were still found over the entire surface with short stalagtites at the bottom end surface of the plugs. However, the deposit band was restricted to below the convection restriction ring with the exception of one side. The band was also shortened to a length of 2.5 inches (64 mm). (See Figures 3.1.1 and 3.1.2)

The control of the deposit below the restrictor ring confirmed the expected effectiveness of such a device. Evidence of refluxing shows that post test measurement does not account for the accumulation of vapor deposits. It also demonstrates that the deposit will not accumulate indefinitely over this surface temperature providing cover gas purity can be maintained.

The metallic o-ring seal of the Core Restraint Plug (2) at the top of the plug was found to be free of any deposit. No deposits were found above the thermal baffles. The thermal baffles were found to have bright metallic sodium drips on the bottom surfaces about 0.8 inch (20 mm) in diameter and 0.4 inch (10 mm) in thickness. The top five baffles were found to have undrained deposits especially near the edge of the baffles. Although thermal records indicate 940°F (506°C) at the bottom baffle, during exposure over the 1100°F sodium pool the temperature of the top five baffles was <500°F (260°C).

The distribution of the sodium vapor deposits indicated that refluxing and draining occurred from horizontal surfaces of the lower plates at temperatures above 500°F (260°C), but deposits accumulate on upper plates below 500°F (260°C). The silver surface of the draining deposits suggest that cover gas impurities did not contribute to deposit buildup or delay draining. Prior cover gas oxidation of surfaces during removal may have contributed to this distribution.

The deposit on the IVHM Penetration Plug (3) was generally distributed over the entire exterior surface of the plug below the flange. (See Figure 3.2) Condensed sodium was even found to a depth of 0.5 inch (13 mm) in the dip seal. Draining drips were found on the bottom 10 inches of the plug surfaces and drained deposits ranged from 0.01 to 0.1 inch (0.254 to 2.54 mm) thick as a curtain of droplets over the second 10 inch (254 mm) from the bottom. A fine aerosol type deposit was found over the remaining exterior surface to a thickness of the 0.01 inch (0.25 mm).

The extensive volume of condensed deposits and their distribution over the full length of the annuli are explained by the wide gap (0.42 to 2.4 in/ 10.7 to 61 mm) of the annuli, which permitted unrestricted convection and transport of sodium vapor in the argon cover gas filled gap. The thick deposit 10 inches (254 mm) above the bottom of the plug also indicated that surface temperatures are critical to deposit accumulation below wetting temperature of 600°F (315°C) and above melting temperature of 208°F (98°C).

The unexpected amount of condensed metallic sodium in the drip seal indicates that poor drainage and low surface temperatures are critical conditions causing buildup of condensed deposits.

The Engineering Model IVHM was removed from the CRCTA after 300 hours exposure over 1050°F (566°C) sodium. Deposits found on the cylindrical plug with annuli ranging less than 0.05 inch (1.27 mm) deep. (See Figures 3.3.1 and 3.3.2) The density of this deposit was measured by a density to be 1.38 g/cc and found to contain 43 w/o Na. These results show that the argon cover gas (less than 0.5 ppm O_2 in cryogenic argon) was effective in preventing oxide buildup in the vapor deposits after 20 day operation at least over 1050°F (566°C) sodium. No trace of hydrogen, nitrogen or carbon could be found in these deposits.

The top surfaces (30 to 80%) of the thermal baffles of the IVHM were covered with massive puddles of condensed metallic sodium to a depth which varies from 0.3 to 0.06 inch (7.6 to 1.5 mm). The top plates drained at a rate of 1 drop/minute. Drips on the lower surfaces indicated refluxing. The inclination (0.5°) was not sufficient to completely drain horizontal surfaces at the lift-drain temperature of 290°F (143°C). The lower thermal baffles were also covered with sodium, but a lesser thickness of 0.05 inch (0.25 mm) depth on the top surface suggest high temperature operation.

The purity of CRCTA cover gas was measured and found to be 200 ppm N_2 and undetectable O_2 with 65 ppm O_2 in the inlet argon.

The inventory of sodium vapor deposits are summarized in Table 3.

CONCLUSIONS

Vapor deposit buildup is not linear with time of exposure to high temperature sodium surfaces because refluxing usually reduces the mass of the deposit. Convection restraints reduce annuli gaps and effectively reduce the amount of deposit in the annuli. These observations suggest that effective application of convection restriction gap to future FBR's need to be less than 0.75 inch (33.9 mm) and greater than 0.03 inch (0.8 mm).

Refluxing of melted sodium occurs on surfaces > 500°F (260°C). The degree of refluxing of vapor deposits depends on the deposit melting point, which is increased by the impurity (i.e. oxide) content. Therefore, it is apparent that the effectiveness of refluxing to prevent deposit buildup is proportional to the purity of the cover gas.

Distribution of sodium vapor deposits depends on the condensing surface temperature as well as the dimensional gap that allows convection.

Although no direct measurements of deposition rate from these observations are available, the major portion of the vapor deposits are formed by the higher evaporation rate of high temperature sodium (1050-1100°F/566-533°C).

Thermal baffles collect the major portion of the deposits because of their large available surface area at condensing temperatures. Near horizontal thermal baffles do not drain completely, so that such components should be inclined at least 5° from the horizontal and operate above 500°F (260°C).

Control of sodium generated vapor deposits from high temperature pools is best obtained by application of one or more of the following:

1) Promote refluxing by high surface temperature and an inclined drainage path.

2) Maintain good cover gas purity (< 1 ppm oxygen) to avoid increasing deposit melting point with impurities.

3) Minimize convection of cover gas by techniques such as convection restrictors at the lower end of head-plug annuli to reduce mass transport of sodium vapor.

REFERENCES

1. Danker, W. J., "Sodium Frost Observations on CRCTA Control Rod Dummy Plugs," HEDL-TME- 75-27, March 1975.

2. Danker, W. J., "Inspection of Core Restraint Plug in CRCTA," HEDL-TME 75-42, August 1975.

3. Currie, A. J., "Sodium Frost Observations in CRCTA, IVHM Penetration Plug," HEDL-TME 75-92, August 1975.

TABLE 1. SODIUM VAPOR DEPOSIT GAP ANNULI DIMENSIONS

Elevation (inch/mm)	Location	Gap Dimensions (inch/mm-Radial)				
		Dummy Control Rod Plug	Core Restrainer Plug	IVHM Penetration Plug	Engineer Model IVHM	FTFF IVHM
	Vapor Spacer Top					
137/3480	Gap 5	0.815/21	n/a	2.444/62	0.294/75	same as model
	Gap 4	0.256/6.5	n/a	2.441/62	0.248/6.3	" " "
	Offset	none	none	-----	-----	
	Gap 3	0.143/3.6	n/a	0.981/22	0.403/10	" " "
	S.F Down Ledge	none	none	-----	-----	-----
	Gap 2	0.130/3.3	n/a	0.391/8.8	0.513/13	same as model
	Gap 1	0.030/0.76	n/a	0.441/11	0.545/14	" " "
	Top Thermal Baffle	none	0.56/14	0.441/11	0.545/14	0.545/14
28/711	Bottom Thermal Baffle	none	0.56/14	0.423/11	0.545/14	0.810/20
	Plug Bottom Entering (9"/229mm Above Na)	0.598/15	n/a	0.423/11	0.555/14	0.810/20

Table 2. Exposure conditions of sodium vapor deposit components

	Dummy Control Rod Plugs	Core Restraint Plug	IVHM Penetration Plug	Engineering IVHM Prototype
(Days)				
In CRCTA over 400°F Na	95	101	180	300
(Hours)				
At 1100°F	480	480	480	None
At 1050°F	---	---	---	10

Table 3. Observed sodium inventory of vapor deposits

Dummy Control Plugs		Core Restraint Plug			IVHM Penetration Plug		IVHM Engineering Prototype		
Convection Restraint(in^3)		Location	Vol. Deposit On Surface (in^3)		Location	Vol. Deposit On Surface (in^3)	Location		Vol. Deposit On Surface (in^3)
With	None		Top	Bottom					
10	18	Plug	0		Upper	64	Rad.	4th	1000
					Mid	517	Shields	3rd	600
					Lower	4		2nd	600
								1st	13
		Thermal Baffles					Thermal Baffles	(7)	14
		23-27	0.1	0.2					
		8-22	0.01	0.07					
		1-7	0.007	0.03					
			0.117	0.30					
			0.417			588			2227

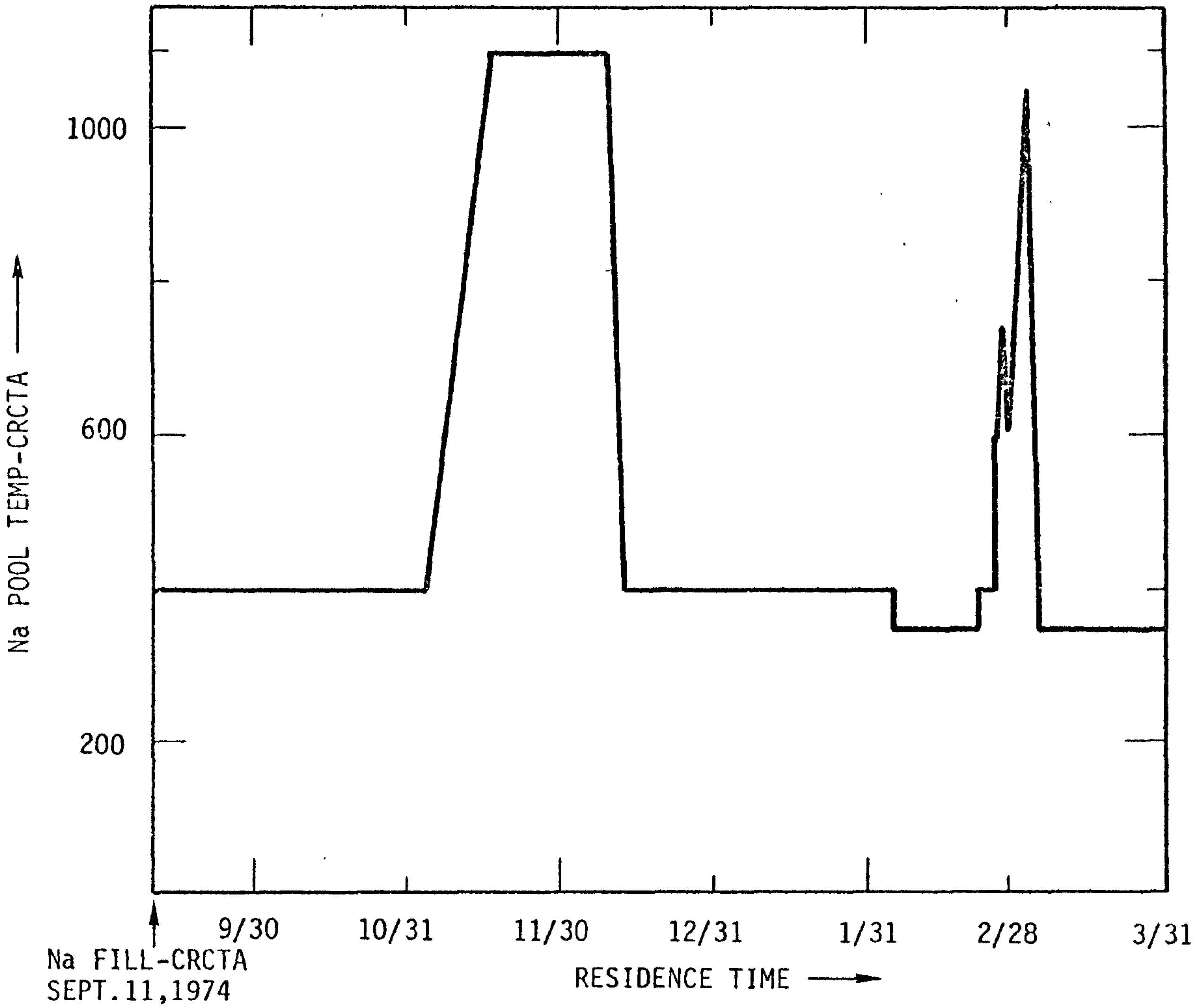

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FIGURE 2.1 Thermal History of CRCTA Sodium Pool Temperature

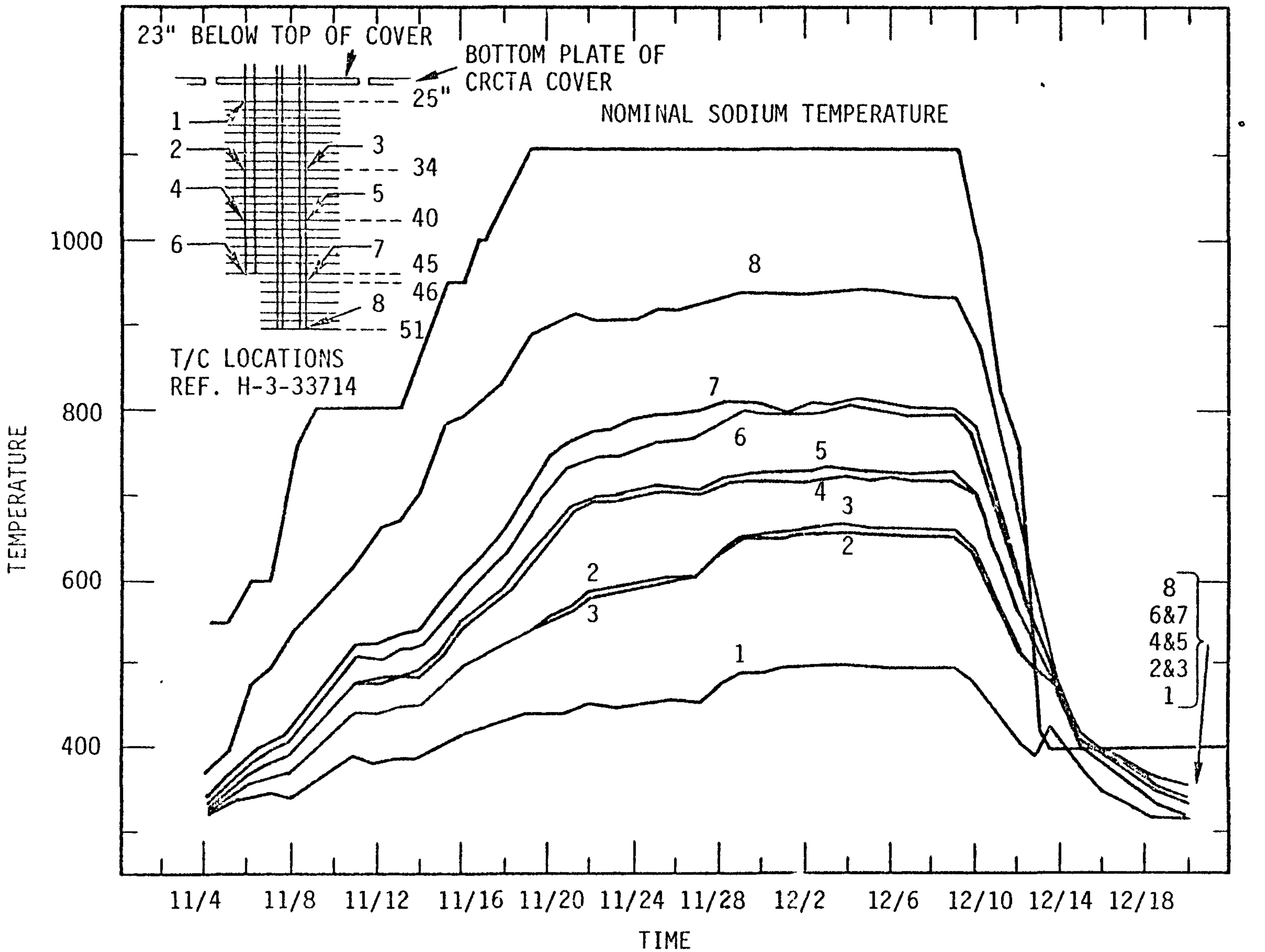

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FIGURE 2.2 Thermal History of Core Restraint Plug Thermal Baffles

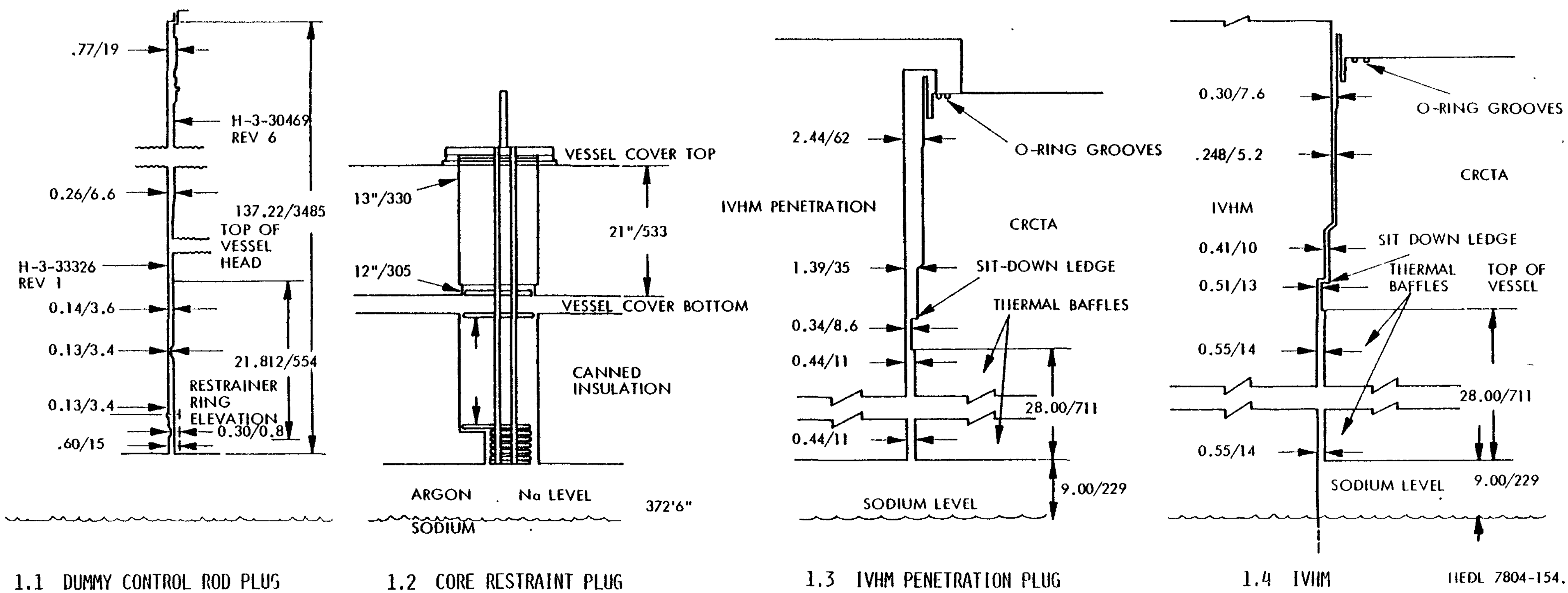

FIGURE 1. ANNULAR PROFILE OF CRCTA HARDWARE

Figure 3.1.1 Deposits on Control Rod Plug With Convection Restrictor

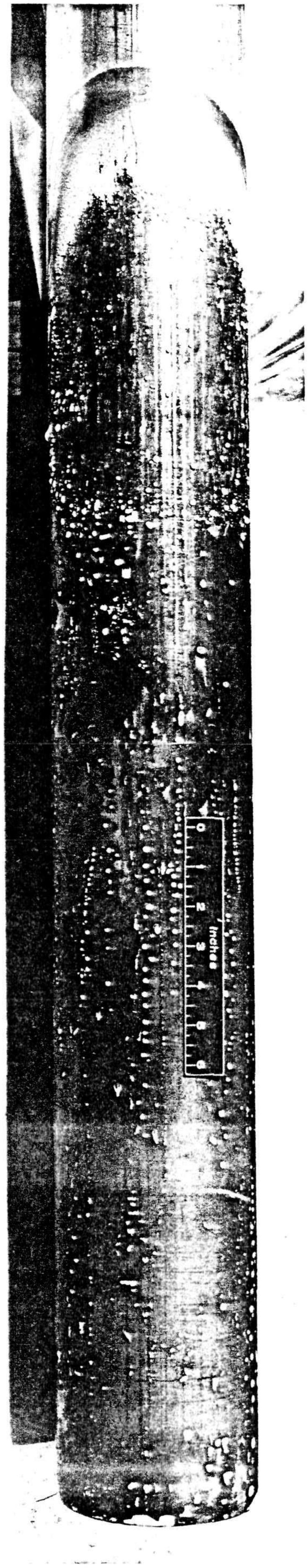

Figure 3.1.2 Deposits on Control Rod Plug Without Convection Restrictor

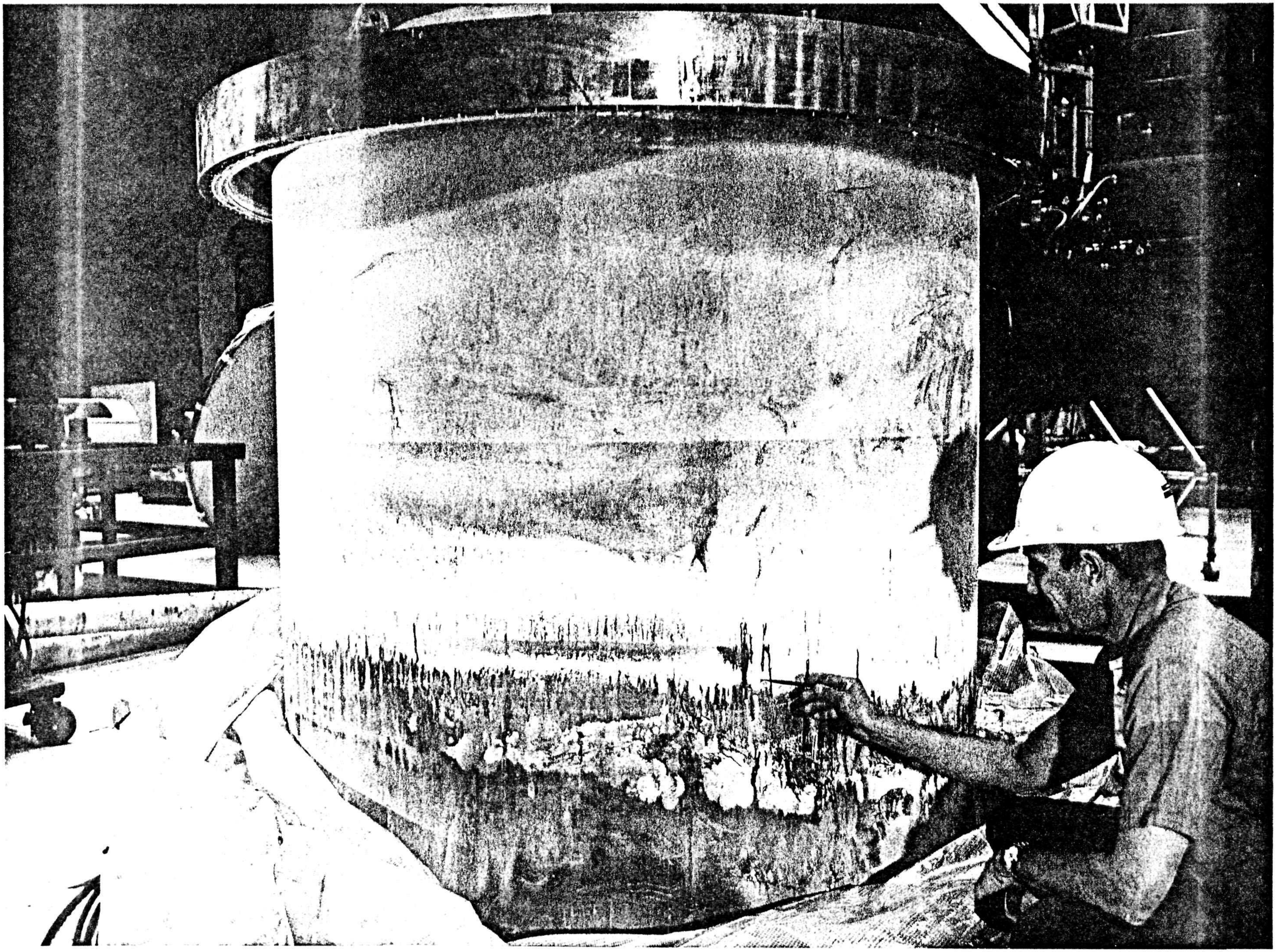

Figure 3.2 Deposits on IVHM Penetration Plug

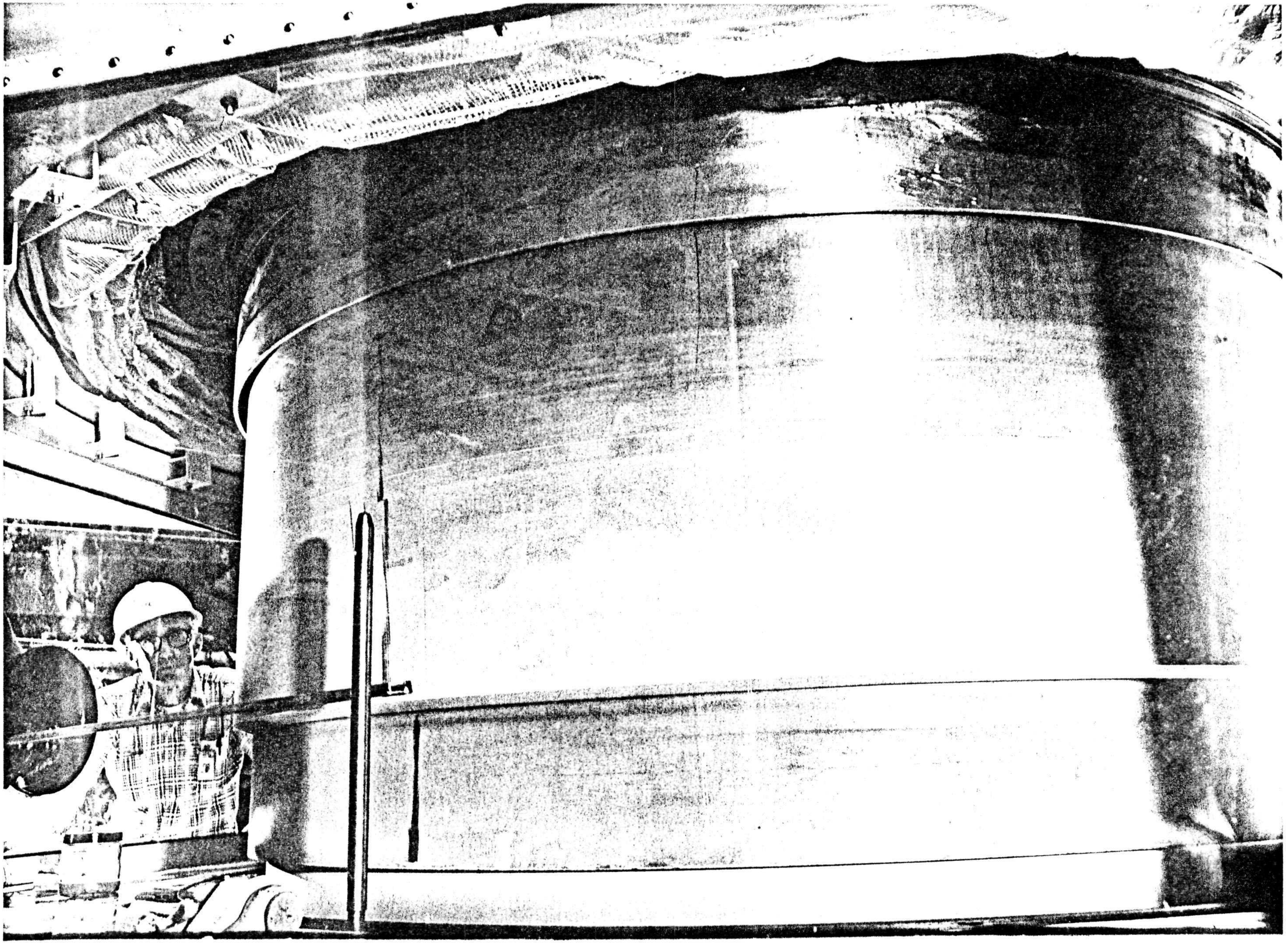

Figure 3.3.1 Gradiation of White Deposits on O.D. of Plug of IVHM

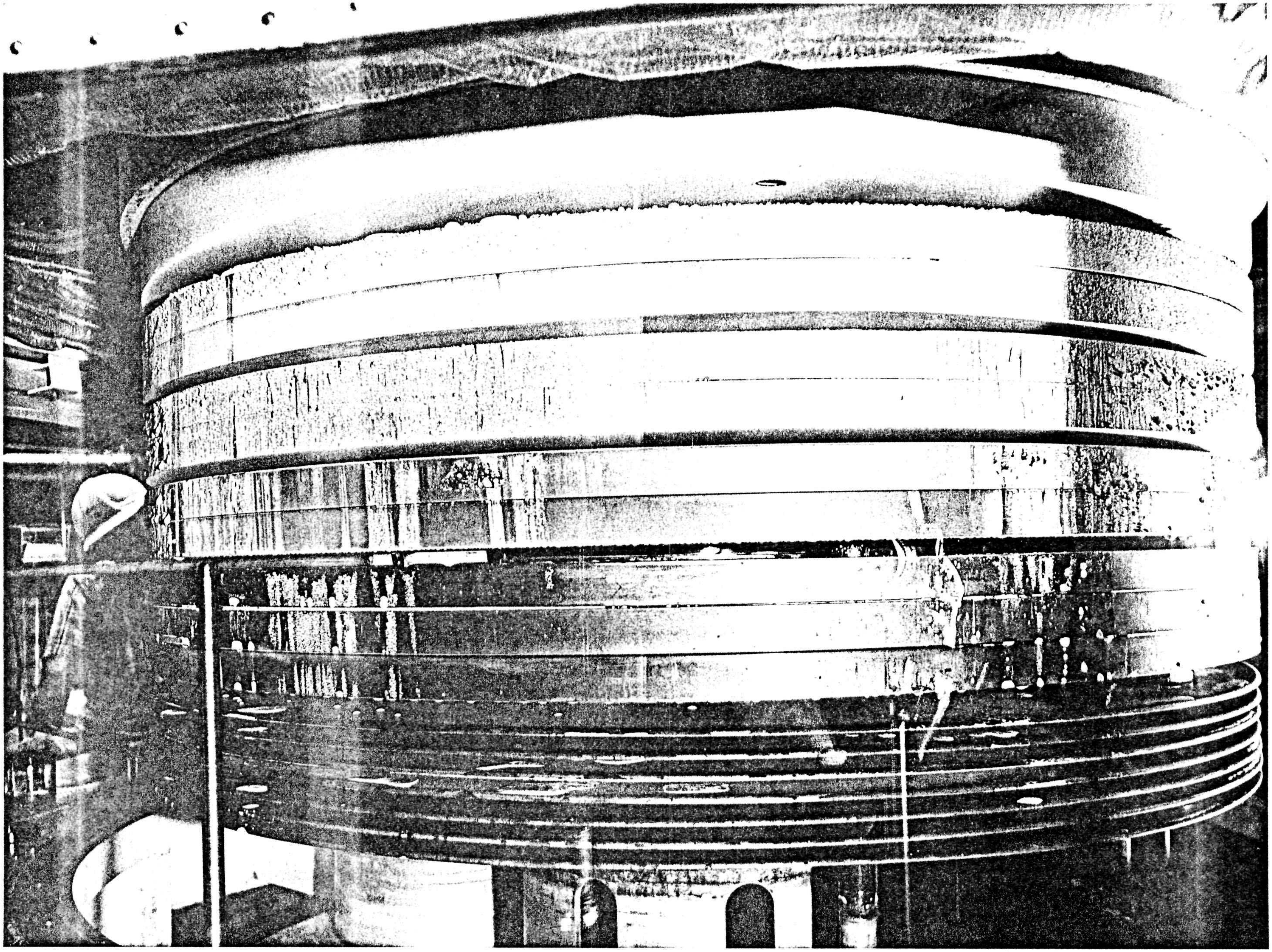

Figure 3.3.2 Solidified Metallic Sodium On Top Surfaces of Baffles and Shields