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Reactor Vessel Head Drop Analyses

Westinghouse Electric Company LLC

WCAP-9198

Reactor Vessel
Head Drop Analyses

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ABSTRACT

Various accident cases which involve dropping a reactor vessel head assembly in the refueling cavity were analyzed to determine the consequences. The analysis for each situation showed that the integrity of the fuel cladding and vessel nozzles and core cooling capability would be maintained.

1.0 INTRODUCTION

1.1 BACKGROUND

In March of 1977 the NRC requested Westinghouse to respond to a question pertaining to a RESAR-414 plant. It is stated as follows:

010.15 Provide analysis of the consequences of dropping the reactor (9.1.3) vessel head assembly during refueling operations, including:

1. The results of analyses which demonstrate that core cooling capability is maintained following the impact due to dropping of the reactor vessel head assembly over the vessel and for all critical points along its travel path to the storage stand.

2. The assumptions used in the above analysis.

3. A discussion and description of the resulting damage, including any damage to the core, as a result of the accident.

Similar questions have been asked on the W RESAR-41 and RESAR-3S dockets and have resulted in extensive research and analysis. The developed methods of evaluation have been applied in the RESAR-414 analysis and are incorporated into this report.

1.2 PURPOSE OF REPORT

The purpose of this report is to consider the consequences of the various accident cases which involve dropping a reactor vessel head assembly in the refueling cavity. The various accident cases described in this report were taken from the critical points along its travel path to or from the vessel head assembly storage stand.

2.0 ACCIDENT ASSUMPTIONS AND ANALYSES

2.1 INTRODUCTION

In a head assembly removal or reassembly (see Appendix A) it is postulated that the polar crane fails. If this unlikely event would occur, various consequences would prevail depending upon the position of the vessel head assembly in relation to the reactor vessel at the time of the polar crane failure. In order to maximize each accident, the weight of the falling vessel head assembly has been increased by 10% to take into account the weight of the polar crane's cable and load block.

2.2 ACCIDENT CASES

A listing of the design weights for the components involved in the accident cases analyzed are shown in Table I. Figures 1 and 2 show the suggested layout for a RESAR-414 plant. The reactor vessel head assembly is shown in Figure 3.

2.2.1 CASE I: HEAD ASSEMBLY FALLS APPROXIMATELY 14 FEET THROUGH AIR WHILE ENGAGED ON GUIDE STUDS AND IMPACTS THE VESSEL FLANGE

During reactor reassembly, the vessel head is positioned on the guide studs and the reactor cavity is drained to allow visual inspection of the Rod Cluster Control drive rod insertion into the head penetrations.

This postulated accident occurs while the head assembly is on the guide studs (approximately 14 feet above the mating surfaces), prior to being placed on the vessel. It is postulated that the polar crane's cable fails and the vessel head assembly falls directly back onto the reactor vessel. This situation is illustrated in Figure 4.

The package will impact on the reactor vessel flange at a velocity of

$$V = \sqrt{2gh}$$

V = impact velocity

g = acceleration of gravity

h = height

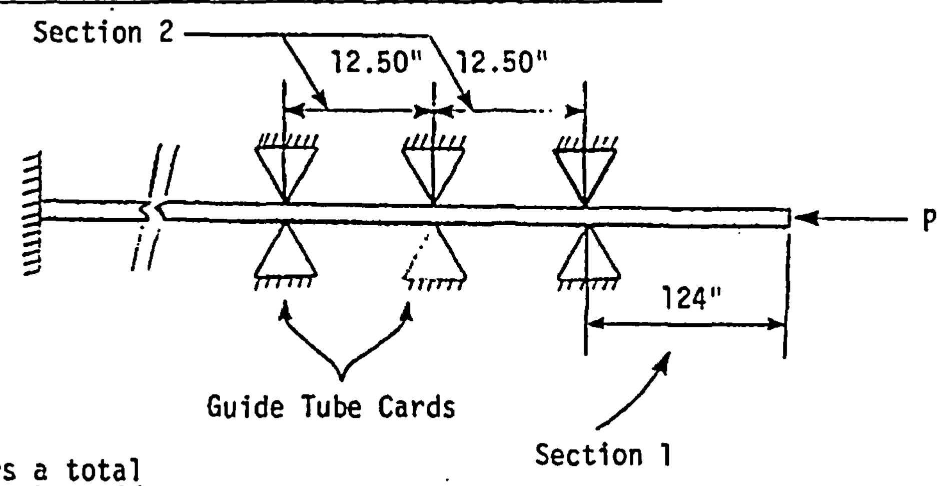
$V = \sqrt{2(32.2)(14)}$ = 30.03 ft/second = 360 inches/second

1. Consideration of Fuel Assemblies

The fuel assemblies, and specifically the fuel cladding, must retain their integrity in order to assure no release of fission-product gases. During this accident, the head assembly itself does not come in contact with the fuel assemblies.

The drive rods, which extend above the reactor vessel flange are carefully inserted into the head during normal refueling operations. However, during the accident, it cannot be assumed that all the drive rods enter the head penetrations. The drive rods will buckle under the weight of the falling head, but this buckling load must be able to be withstood by the fuel assembly that corresponds to each buckling drive rod.. This force is the only major one experienced by the fuel assemblies during this case and is calculated hereafter.

Model of Critical Buckling Load for the Drive Rod



Section 2 occurs a total of 6 times down the guide tube

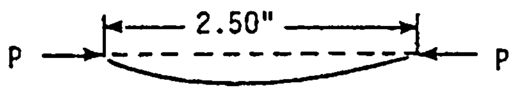
Radial clearance between drive rod and card = .325"

Largest diameter that can pass through guide tube card - 2.4"

a. Buckling Load of Section 1

Before the buckling load of Section 1 can be calculated, the end condition at its base must be defined. The end condition for Section 1 will be determined by the reaction and buckling load of Section 2. Section 2 will be considered to have 2 pinned ends because of the small radial clearance (.325").

b. Buckling Load for Section 2



$$P_{cr} = \frac{\pi^2 EI}{\ell^2}$$

P_{cr} = critical buckling load
E = modulus of elasticity
I = moment of inertia of an area
ℓ = length
R = outside (major) diameter of drive rod thread
r = inside (minor) diameter of drive rod thread

<u>Calculate I Average</u>

$$I_{min} = \frac{\pi(R^4 - r^4)}{64}$$

$$= \frac{\pi(1.475^4 - .875^4)}{64} = .2036 \text{ in}^4$$

$$I_{max} = \frac{\pi(1.75^4 - .875^4)}{64} = .4316 \text{ in}^4$$

$$I_{average} = .3176 \text{ in}^4$$

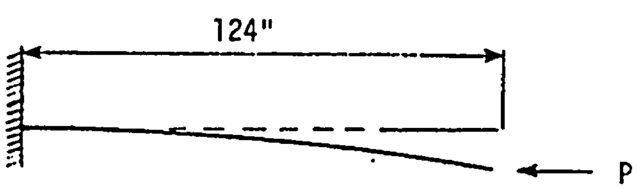
$$E = 28.3 \times 10^6 \text{ lb/in}^2$$

$$\ell = 12.50$$

$$P_{cr} = \frac{\pi^2 (28.3 \times 10^6)(.3176)}{(12.50)^2}$$

$$\underline{P_{cr} = 567{,}736 \text{ lbs}}$$

The buckling load for Section 2 is 567,736 lbs. A P_{cr} load for Section 1 of anything less than 567,736 lbs will indicate the two act independently of each other and Section 2 will not buckle, therefore Section 1 will be considered to have a clamped end and a free end.



$$P_{cr} = \frac{\pi^2 EI}{4\ell^2}$$

$$E = 28.3 \times 10^6 \text{ lb/in}^2$$

$$I_{avg} = .3176 \text{ in}^4$$

$$P_{cr} = \frac{\pi^2(28.3 \times 10^6)(.3176)}{4(124)^2}$$

$$\underline{P_{cr} = 1442 \text{ lbs}}$$

The maximum vertical force on the fuel assembly is the buckling load of Section 1. An impact force of this value will impart no damage to the fuel assembly, and fuel cladding integrity will be maintained.

2. Consideration of Reactor Vessel Nozzles

Description

The impact load of the head assembly on the vessel is transmitted through the vessel to the four supported vessel nozzles. The nozzles must be able to support this load without exceeding the allowable stress limits. The stresses in the nozzles are calculated below.

Assumptions

a. If it is assumed that the stresses due to the impact load are distributed throughout any elastic body exactly as in the case of static loading, then it can be shown that the vertical deformation δ_i and the stresses σ_i produced in any such body by the vertical impact of a body falling from a height (h) are greater than the deformation δ and stress σ produced by the weight of the same body applied as a static load in the ratio (Reference 1):

$$\frac{\delta_i}{\delta} = \frac{\sigma_i}{\sigma} = 1 + \sqrt{1 + 2\frac{h}{\delta}} \qquad (1)$$

If h=0, we have the case of sudden loading and $\frac{\delta_i}{\delta} = \frac{\sigma_i}{\sigma} = 2$ as usually assumed.

The above approximate formula is derived on the assumption that the impact load strains the elastic body in the same way (though not in the same degree) as static loading and that all the kinetic energy of the moving body is expended in producing this strain.

Actually in the impact some kinetic energy is dissipated and this loss, which can be found by equating the momentum of the entire system before and after impact, is more conveniently taken into account by multiplying the available energy by a factor K, the value of which is as follows (Reference 1):

Energy Dissipation Factor

$$K = \frac{1 + \frac{1}{3}\frac{M_1}{M}}{\left(1 + \frac{1}{2}\frac{M_1}{M}\right)^2} \qquad (2)$$

where

M - Mass of the moving body = $\frac{W}{g}$

M_1 - Mass of the body struck by the moving body = $\frac{W_1}{g}$

From (1) and (2), the impact load 'W_i' can be derived as follows:

$$W_i = W \left(1 + \sqrt{1 + \frac{2Kh}{\delta}}\right)$$

b. The rigidity of the vessel flange causes the impact loads to be distributed evenly to the four supporting nozzles.

c. The reactor vessel is supported by two inlet and two outlet nozzles.

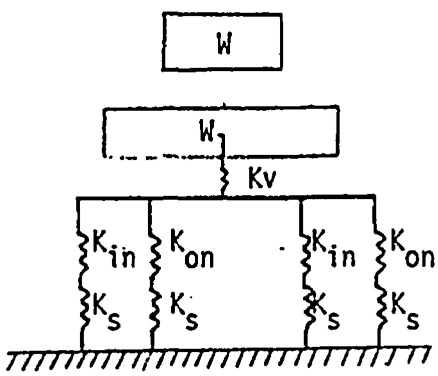
d. Deflection of the head at impact is neglected.

e. The area and moment of inertia for the inlet nozzle are larger than for the outlet nozzle at the nozzle to shell juncture region. Similar difference exists also for the cross section at the integral pad location. Hence, the outlet nozzle was evaluated for impact stresses.

Analysis

Determination of the Impact Load 'W_1'

The head upper package and reactor vessel can be idealized as a simple spring mass system as shown here.



W - weight of the upper package, head polar crane hooks, and cable

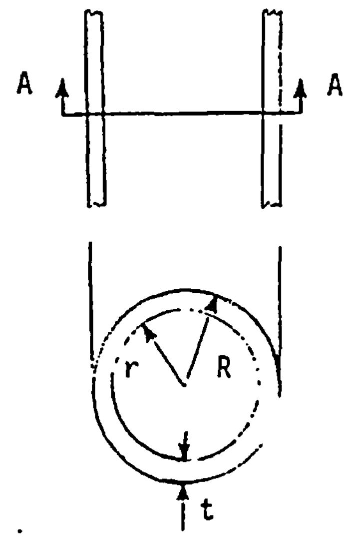
W_1 - weight of the vessel flange, nozzles, and region in between

k_{in} - spring constant of inlet nozzle region

k_{on} - spring constant of outlet nozzle region
k_s - spring constant of supports
k_v - spring constant of vessel and flange using equivalent cylinder analysis

Determination of Spring Constant "K_v":

The upper portion of the reactor vessel was idealized as spring "K_v". To simplify the analysis, the upper portion of the vessel was conservatively assumed to be a cylindrical member with the cross section and parameters as follows:



$$\delta = \frac{PL}{AE}$$

$$k_v = \frac{P}{\delta} = \frac{AE}{L}$$

where

R = outside radius
r = inside radius
t = thickness
A = area
L = length
E = modulus of elasticity for carbon molysteel at 70°F
A $= \pi(R^2 - r^2)$
$= \pi(97.5^2 - 85^2) = 7166.8$ sq. in.

$$k_v = \frac{(7166.8)(29.9 \times 10^6)}{91} = 2.36 \times 10^9 \text{ lb/in}$$

Spring constants for the inlet (k_{in}) and outlet (k_{on}) regions were determined from a 3D finite element analysis of the reactor vessel.

Determination of equivalent spring constant "k" of the system shown in previous figure :

$$k_{in} = 79.8 \times 10^6 \text{ lbs/in}$$
$$k_{on} = 71.7 \times 10^6 \text{ lbs/in}$$
$$K_S = 58.0 \times 10^6 \text{ lbs/in}$$
$$K_V = 2.355 \times 10^9 \text{ lbs/in}$$

For the nozzles and supports in series:

$$k_{inlet\text{-}support} = \frac{1}{1/k_{in} + 1/k_s} = k_{ins}$$

$$k_{inlet\text{-}support} = 3.36 \times 10^7 \text{ lbs/in} = k_{ins}$$

$$k_{outlet\text{-}support} = \frac{1}{\frac{1}{k_{on}} + \frac{1}{k_s}}$$

$$k_{outlet\text{-}support} = 3.21 \times 10^7 \text{ lbs/in} = k_{ons}$$

For springs in parallel:

$$k_p = 2\ k_{ons} + 2\ k_{ins}$$

$$k_p = 1.314 \times 10^8 \text{ lbs/in}$$

For the springs in series:

$$k_e = \frac{1}{1/k_v + 1/k_p} = 1.244 \times 10^8$$

The weight of the upper package, head assembly, and crane block (W) is 318,673 lbs.

The weight of the vessel flange and nozzle shell (W_1) is 290,000 lbs.

$$k = \frac{1 + 1/3 \frac{M1}{M}}{(1 + 1/2 \frac{M1}{M})^2} = \frac{1 + 1/3 \left(\frac{290,000}{318,673}\right)}{1 + 1/2 \left[\left(\frac{290,000}{318,673}\right)\right]^2} = .616$$

Energy dissipation factor (K) is .616.

$$\delta = \frac{W}{K_e} = 0.00256 \text{ in}$$

Static deflection (δ) is .00256 inches.

<u>Impact Load</u>

Equation $W_1 = W(1 + \quad 1 + \frac{2kh}{\delta})$ becomes

$$W_1 = W \times IF$$

Where IF = Impact Factor = 285.34

Impact Load = 90.93×10^6 lbs.

Assuming a perfect drop and four supported nozzles equally share the impact load

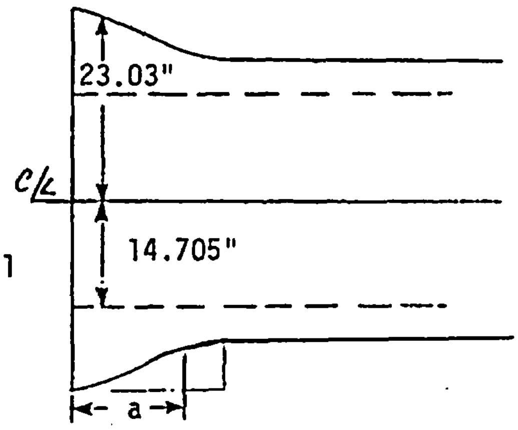
Impact force/nozzle = 22.7×10^6 lbs.

Determine the stress developed in the outlet nozzle due to impact load.

$R = 23.03''$

$r = 14.705''$

Moment $(I) = \frac{\pi}{4}(R^4 - r^4)$
$= 1.842 \times 10^5$



Maximum Bending Stress

$\sigma_B = \frac{MR}{I} = 40{,}869$ psi.

M = Impact Force/Nozzle x a
$M = 22.7 \times 10^6 \times 14.4''$

Shear Stress

Maximum load at the nozzle cross section = Impact Force/nozzle = 22.7×10^6 lbs

$$\tau_{avg} = \frac{\text{Impact Force/nozzle}}{\pi(R^2 - r^2)} = \frac{22.7 \times 10^6}{\pi(23.03^2 - 14.705^2)} = 23{,}001$$

Maximum Principal Stress

$$\sigma_{max} = \frac{1}{2}\sigma_B + \sqrt{\frac{1}{4}\sigma_B^2 + \tau_{avg}^2} = 51{,}202 \text{ psi}$$

Therefore, σ_{max} is less than the allowable limit of 84,000 psi (Lesser of 3.6 S_m or 1.05 S_u).

The results of the analysis show the bending and shear stresses are less than the allowable limits, therefore there will be no consequential damage to the structural integrity of the vessel nozzles and core cooling capability will be maintained.

3. Consideration of Core Barrel (Figure 5)

In a normal reassembly of the reactor vessel, the head assembly first contacts the upper internals flange applying pressure against the core barrel holddown spring. The upper internals depresses the holddown spring until the head assembly contacts the vessel flange (Figure 6). During this accident case the above reassembly description occurs compressing the holddown spring. Any amplified effects could cause some yielding on the outer portion of the core barrel and upper internals flanges.

The bottom of the core barrel is designed with supports (Figure 5) for a hypothetical accident in which the core barrel support, the flange, might fail and allow the core barrel to fall. These supports will limit its travel to approximately 1 1/4" in a cold condition without any failure to the fuel. Therefore, in an unlikely event of this accident case causing failure of the core barrel the lower internals supports would limit the core barrel travel as in the hypothetical accident to approximately 1 1/4" and still maintain the integrity of the core.

4. Conclusion

In the event of a Case I accident, core cooling capability and the integrity of the fuel cladding will be maintained.

2.2.2 CASE II: HEAD ASSEMBLY FALLS 4 FEET THROUGH AIR, 24.5 FEET THROUGH WATER, AND IMPACTS THE VESSEL FLANGE

During reactor disassembly or reassembly, the vessel head is positioned 28.5 feet above the vessel flange, while the water depth is 24.5 feet. When the head assembly is directly above the reactor vessel and at the maximum lift height, the polar crane cable is postulated to fail. The head assembly falls, engages on the guide studs and lands directly on the reactor vessel flange. Figure 7 illustrates the situation.

1. Head assembly impact velocity calculation.

Assumptions

a. Final velocity is assumed to be equivalent to that of a 28.5 foot drop through water.

b. Only half the buoyant force is taken into account since none of the head assembly is in the water at the beginning of the drop.

c. Drag coefficient is that of a flat-surfaced hemisphere.

d. The head does not bind with the guide studs.

Analysis

The general equation for acceleration through a liquid is (Reference 2):

$$(W-B) - C_D \rho w (A/2)(dy/dt)^2 = md^2y/dt^2$$

W = weight of water
B = weight of displaced water
ρ_W = density of water
C_D = drag coefficient
A = projected area of object
m = mass of object
v = velocity of object

Integrating results in the equation for velocity:

$$v = \sqrt{\frac{C_1}{C_2}} \quad \frac{e^{t/c_3} - 1}{e^{t/C_3} + 1}$$

C_1 = W-B
C_2 = $C_D \rho_W A/2$
C_3 = $m/(2\sqrt{C_1 C_2})$

Integrating results in the equation for distance:

$$y = \sqrt{\frac{C_1}{C_2}} \quad [2\ C_3 \ln (\frac{e^{t/C_3} + 1}{2}) - t]$$

The parameter values for this problem are:

W = 318,673 lbs
B = $\frac{\rho_W}{2\rho s} W$ = 20,325 lbs.
ρ_W = .0361 lbs/in^3 = 1.937 $slugs/ft^3$
ρ_{steel} = .283 lbs/in^3
C_D = 1.17 (reference 3)
A = 219 ft^2
m = 9897 slugs

C_1 = 294,348 lbs
C_2 = 248.2 $lbs \cdot sec^2/ft^2$
C_3 = .58 seconds

For y = 28.5 feet, collision occurs after 1.546 seconds.

At that time, the velocity is 363.1 inches/second.

The final velocity would actually be less than 363.1 inches/second, since flow around the head assembly is hindered as the head approaches the vessel flange; this flow hindrance increases the resistant force on the head assembly.

Due to this increased resistance, the final velocity would be less than the Case I final velocity (360 in/sec) so the kinetic energy of the drop in Case II is less than that of Case I.

2. Consideration of Fuel Assemblies

The description, assumptions, methods of analysis and conclusions are all the same as in Case I.

3. Consideration of Nozzles

Since Case I involves more impact energy than Case II, the stresses developed in the Case I accident will be an upper limit for the Case II accident. There will be no consequential damage to the structural integrity of the vessel nozzles and core cooling capability will be maintained.

CONCLUSIONS

In the event of a Case II accident, core cooling capability and the integrity of the fuel cladding will be maintained.

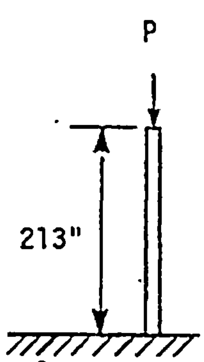
2.2.3 CASE III: HEAD ASSEMBLY FALLS 4 FEET THROUGH AIR, 6.5 FEET THROUGH WATER, STRIKES THE GUIDE STUDS, FALLS 18 FEET THROUGH WATER AND IMPACTS THE VESSEL FLANGE AT AN ANGLE OF 2.83°

During disassembly or reassembly, the vessel head is positioned at a maximum height of 28.5 feet above the vessel flange, while the water depth is 24.5 feet. The postulated crane cable failure could result in the vessel head assembly falling through 4 feet of air and 6.5 feet of water. At that point the head assembly could strike the guides studs. If this occurred the head assembly would buckle the guide studs and fall the remaining 18 feet impacting the reactor vessel flange. The assumption has been made that the vessel head assembly impacts the vessel flange while rotated at an angle of 2.83°. This assumption is detailed in the following analyses.

1. Impact velocity-consideration of guide studs:

   Energy Absorbed by Guide Studs Before Buckling

   P_{cr} - Critical Buckling Load/Guide Stud



$$P_{cr} = \frac{\pi^2 EI}{4\ell^2}$$

$E = 30 \times 10^6 \text{ lb/in}^2$

$\ell = 213 \text{ in}$

$$I = \frac{\pi(D^4 - d^4)}{64} = 92.86 \text{ in}^4$$

D = Outside Diameter of guide stud = 7.13"

d = Inside Diameter of guide stud = 5.13"

$$P_{cr} = \frac{\pi^2 \ (30 \times 10^6) \ (92.86)^4}{4(213)^2}$$

P_{cr} = 151,506 lbs/column

Axial Stiffness of Guide Studs:

$$K = \frac{AE}{\ell}$$

$$A = \pi \ (R^2 - \gamma^2) = \pi \ [(\frac{7.13}{2})^2 - (\frac{5.13}{2})^2] = 19.26$$

$$K = \frac{19.26 \ (30 \times 10^6)}{213} = 2.71 \times 10^6 \text{ lb/in}$$

Energy (u) Absorbed By Each Guide Stud Before Buckling:

$$u = \frac{1}{2} P_{cr}^2 / k$$
$$u = \frac{1}{2} (151{,}506 \ \frac{\text{lbs}}{\text{col}})^2 / 2.71 \times 10^6 \text{ lb/in}$$
$$u \doteq 4235 \ \frac{\text{in-lbs}}{\text{col}}$$

The energy absorbed by the 3 guide studs before they buckle (12705 in-lb) is negligible, compared to the total energy of the head before impact. When the buckling load for the 3 guide studs is exceeded, they will give way and essentially be unable to absorb any more energy. The head will impact on the vessel with approximately the same velocity as it did for Case II.

2. Consideration of Rotational Effects of Guide Studs

Description

If one guide stud engages and two do not, the forces acting on the head will be uneven and the head will rotate as a result. The angle of rotation at impact is calculated as follows:

Assumptions

a. Moment of inertia of head assembly is conservatively assumed to be that of a solid sphere. ($I = 2/5\ mr^2$)

b. All of the energy involved during buckling compression of the studs is converted into rotational energy.

Analysis

Moment of Inertia = $I = 2/5\ mr^2$

$m = \frac{w}{g}$

w = weight of drop head assembly

g = acceleration of gravity

r = vessel head radius

$I = 2/5\ (\frac{w}{g})\ r^2$

$= 2/5\ (\frac{318,673}{32.2})\ (8.54)^2$

$= 2.887 \times 10^5$ slug-ft^2

Rotational Energy: $U = \frac{1}{2} I\omega^2$ = energy of 2 guide studs

$U = 2 \times \frac{4235}{12} = 706$ ft-lb

Angular Velocity: $\omega = \sqrt{2U/I} = \sqrt{2(706)/2.887 \times 10^5}$

$= 0.07$ rad/sec

Time to drop 18 ft. to vessel flange: .705 sec

Angle of Rotation at Impact: $\theta = \omega t = (.0683)(.705)$

$\theta = .078$ radians $= 2.76°$

Conclusion

The guide studs rotate the head assembly by a negligible amount, and therefore the head will impact the vessel similar to Case II.

3. Consideration of Fuel Assemblies

The description, assumptions, analysis and conclusions are all the same as in Case I.

4. Consideration of Nozzles

The conclusion is the same as in Case II.

CONCLUSIONS

In the event of a Case III accident, core cooling capability and the integrity of the fuel cladding will be maintained.

2.2.4 CASE IV: HEAD ASSEMBLY FALLS 4 FEET THROUGH AIR, 24.5 FEET THROUGH WATER, AND LANDS PARTIALLY ON THE REACTOR VESSEL FLANGE AND PARTIALLY ON THE CONCRETE

During disassembly or reassembly, the vessel head is positioned at a height of 28.5 feet above the vessel flange, but it is not directly centered above the reactor vessel. The postulated crane cable failure would result in the head assembly falling and landing partially on the reactor vessel flange and partially on the concrete floor of the refueling cavity. Figures 8 and 9 illustrate the situation.

1. Impact Velocity Calculation

   The final velocity will be the same as the velocity in Case II, or less than 360 inches/second.

2. Consideration of Fuel Assemblies and Nozzles

   Since Case IV involves the same energy as Case II and only part of the energy is imparted on the reactor vessel, the stresses developed in the Case II accident will be an upper limit for the Case IV accident. The assumptions and conclusions are the same as in Case II.

   Conclusion

   The conclusions are the same as in Case II, core cooling capability and the integrity of the fuel will be maintained.

2.2.5 CASE V: HEAD ASSEMBLY FALLS 4 FEET THROUGH AIR, 24.5 FEET THROUGH WATER, AND STRIKES THE CAVITY FLOOR

During disassembly or reassembly, the head assembly is positioned at its height of 28.5 feet above the cavity floor. As the head is being carried to the storage stand the polar crane cable is postulated to fail. This would result in the head assembly falling through 4 feet of air and 24.5 feet of water thus striking the primary shield wall and the upper internal storage stand. This situation is illustrated in Figures 10 and 11.

1. Impact Velocity Calculation

   The final velocity of the head assembly will be less than that of Case II or less than 360 inches/second. The upper internals storage stand is designed to collapse when acted upon with excessive forces.

2. Consideration of Fuel Assemblies

   Since the head assembly does not strike the reactor vessel the fuel assemblies will not be damaged.

3. Consideration of reactor coolant loop piping and reactor vessel nozzles

   The Reactor Coolant Loop piping and the vessel nozzles do not experience impact loads since the head assembly strikes the primary shield wall which prevents it from impacting the piping and nozzles located below the cavity floor. Refer to Figure 1 for the location of the primary shield wall.

Conclusion

In the event of a Case V accident, core cooling capability and the integrity of the fuel cladding will be maintained.

2.2.6 CASE VI: HEAD ASSEMBLY HITS REFUELING CAVITY WALL, ROTATES INTO THE REFUELING CAVITY AND FALLS 24.5 FEET THROUGH WATER; VESSEL HEAD CLOSURE FLANGE STRIKES THE CONCRETE

During disassembly or reassembly, the vessel head assembly is positioned at a height of 28.5 feet above cavity floor as it is being carried over the refueling cavity wall which is located between the vessel head storage stand and the reactor vessel cavity. It is postulated the polar crane cable fails and the head assembly falls and strikes the top of the refueling cavity wall. This causes the assembly to rotate and fall into the refueling cavity which results in the vessel head closure flange landing on the concrete of the cavity floor. See Figure 13 for illustrations.

1. Impact Velocity Calculation

   The refueling cavity wall absorbs some of the energy of the fall. The final velocity of the head assembly will be less than that of Case II, or less than 360 inches/second.

2. Consideration of Fuel Assemblies

   Since the head assembly does not strike the reactor vessel, the fuel assemblies will not be damaged.

3. Consideration of reactor coolant leg piping and reactor vessel nozzles

In this case it is very unlikely that the head assembly would strike the area above the reactor vessel nozzles. It is, however, reasonable to assume that it could strike the concrete area above the RCL piping. Although, if either event occurred, the head assembly would impact upon the primary shield wall and, therefore, would not effect the integrity of the RCL piping or the R.C. nozzles.

If the falling head assembly breached the cavity floor, canal water may leak out, however, borated water would still be contained within the vessel because the RCL piping would still be structurally in tact. The unborated water that may leak out of the canal would flow to the containment sump. This water would then be available to be pumped back to the reactor vessel via the low head safety injection recirculation loop.

4. Consideration of Piping Underneath Cavity Floor

The architect-engineer should determine whether any auxiliary piping beneath the cavity floor could be damaged.

Conclusion

In the event of a Case VI accident, core cooling capability and the integrity of the fuel cladding will be maintained.

3.0 CONCLUSIONS

The six cases in this report present the consequences of dropping the reactor vessel head assembly at all critical points along its travel path to the vessel head storage stand. In all six cases, there will be no consequential damage to the structural integrity of the vessel nozzles and core cooling capability and the integrity of the fuel cladding will be maintained.

TABLE 1

COMPONENT DESIGN WEIGHTS

Head	165150 lbs
Part Length CRDM	0
Full Length CRDM	74100
Rod Position Indicator Coil Stack	14895
Cooling Shroud	5250
Seismic Platform	11100
Stud Tensioner Hoist	900
Dummy Cans	848
Lifting Rig	15100
Sling Block Platform	570
Head Insulation	1700
	289703
+ 10% additional	28970
for load block	318673 lbs

APPENDIX A

HEAD REMOVAL PROCEDURE

The refueling operation follows a detailed procedure which provides a safe, efficient refueling operation. Prior to initiating refueling operations, the Reactor Coolant System is borated and cooled down to refueling shutdown conditions as specified in the technical specifications. Criticality protection for refueling operations, including a requirement for daily checks of boron concentration, is specified in the technical specifications. The following significant points are assured by the refueling procedure:

1. The refueling water and the reactor coolant contains approximately 2000 ppm boron. This concentration, together with the negative reactivity of control rods, is sufficient to keep the core approximately 10 percent $\delta k/k$ subcritical during the refueling operations. It is also sufficient to maintain the core subcritical in the unlikely event that all of the rod cluster control assemblies were removed from the core.

2. The water level in the refueling cavity is high enough to keep the radiation levels within acceptable limits when the fuel assemblies are being removed from the core.

The refueling operation is divided into four major phases: 1) preparation, 2) reactor disassembly, 3) fuel handling, and 4) reactor assembly. A general description of a typical refueling operation through the four phases is given below:

1. Phase I - Preparation

The reactor is shutdown and cooled to cold shutdown conditions with a final K_{eff} <0.9 (all rods in). Following a radiation survey, the containment is entered. At this time, the coolant level in the reactor vessel is lowered to a point slightly below the vessel flange. Then the fuel transfer equipment and refueling machine are checked for proper operation.

2. Phase II - Reactor Disassembly

The general reactor disassembly sequence is:

a. All cables, air ducts, and insulation are removed from the vessel head.

b. The RV studs are detensioned and removed. The stud hole plugs and guide studs are installed.

c. The refueling canal drain holes are closed.

d. The bolts holding the blind flange are removed.

e. The Davit arm holding the blind flange is raised and then swung to one side.

f. The seals are removed from the blind flange face and brass plugs are installed in the leak test ports.

g. The vessel head assembly is unseated and raised approximately one foot above the vessel flange.

h. Water from the refueling water storage tank is pumped into the Reactor Coolant System by the residual heat removal pumps causing the water to overflow into the refueling cavity.

i. The vessel head and the water level in the refueling cavity are raised simultaneously, keeping the water level just below the head.

j. The head assembly is taken to its storage pedestal when the water reaches a safe shielding depth (see Section 9.1.3.3.4).

3. Phase III - Fuel Handling

4. Phase IV - Reactor Assembly

Reactor assembly, following refueling, is essentially achieved by reversing the operations given in Phase II - Reactor Disassembly, except in step i. When the vessel head engages the guide studs, the refueling cavity is drained to allow visual inspection of the RCC drive rod insertion into the head.

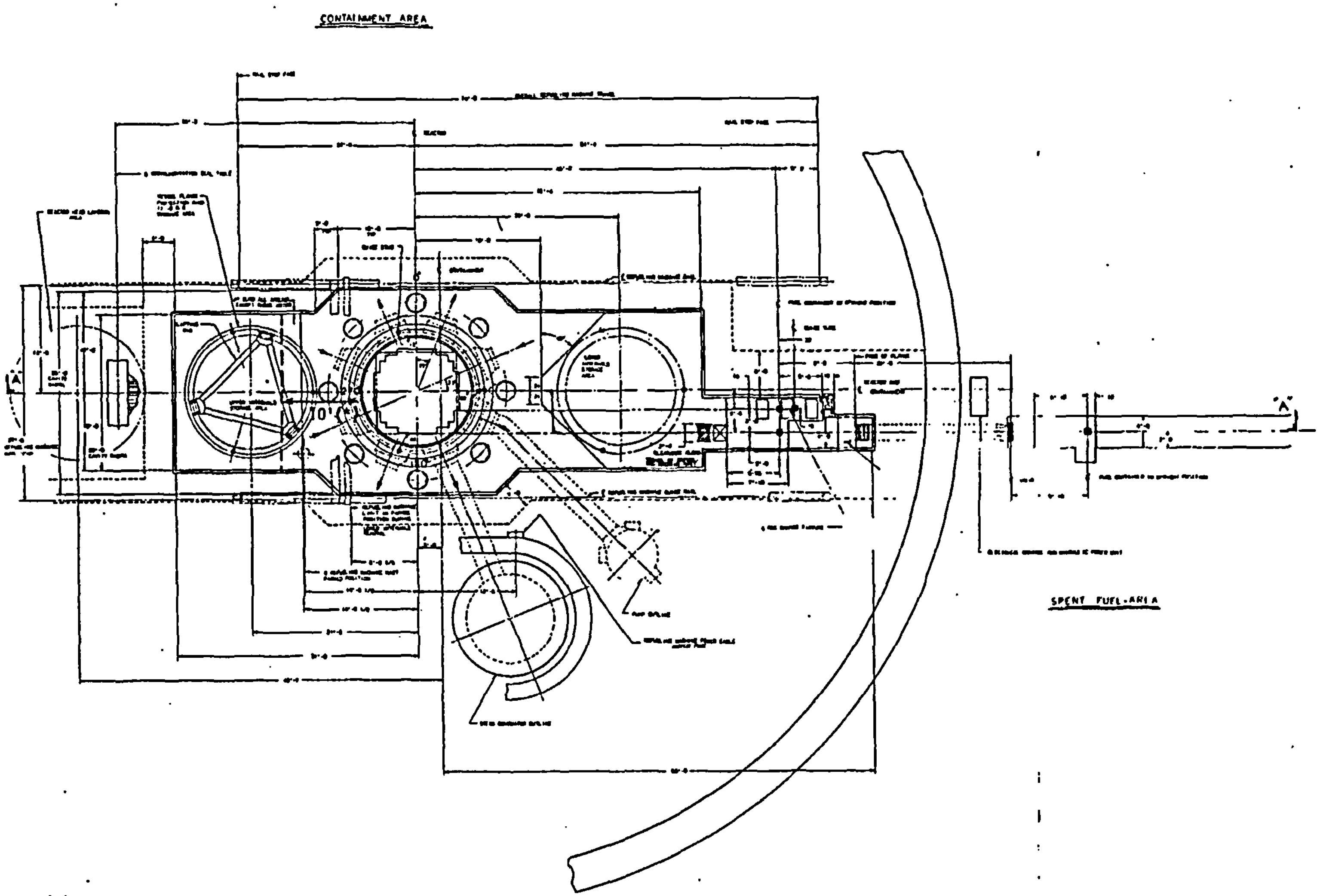
APPENDIX B

REFERENCES

1. Roark, R. J. "Formulas For Stress and Strain Fourth Edition", page 340, 370 and 371, respectively.

2. Hunsaker, J. C. and B. G. Rightnire, "Engineering Applications of Fluid Mechanics", page 183.

3. Hoemer, J. F., "Fluid-Dynamic Drag", page 317.



(*) Primary Shield Wall

Figure 1 Sheet 1 Suggested Elevations and Arrangement Drawing

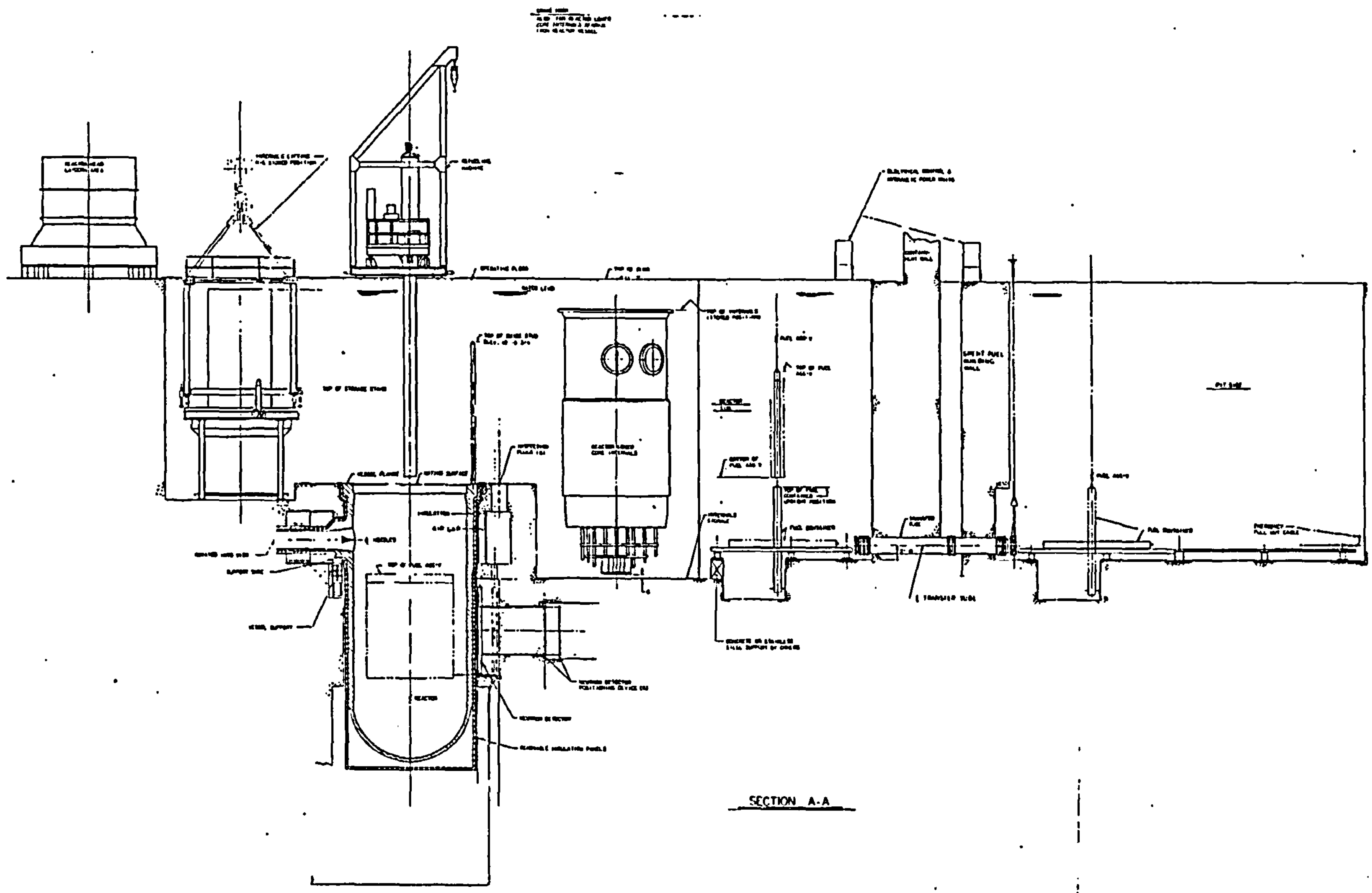


Figure 2 Sheet 2 Suggested Elevations and Arrangement Drawing

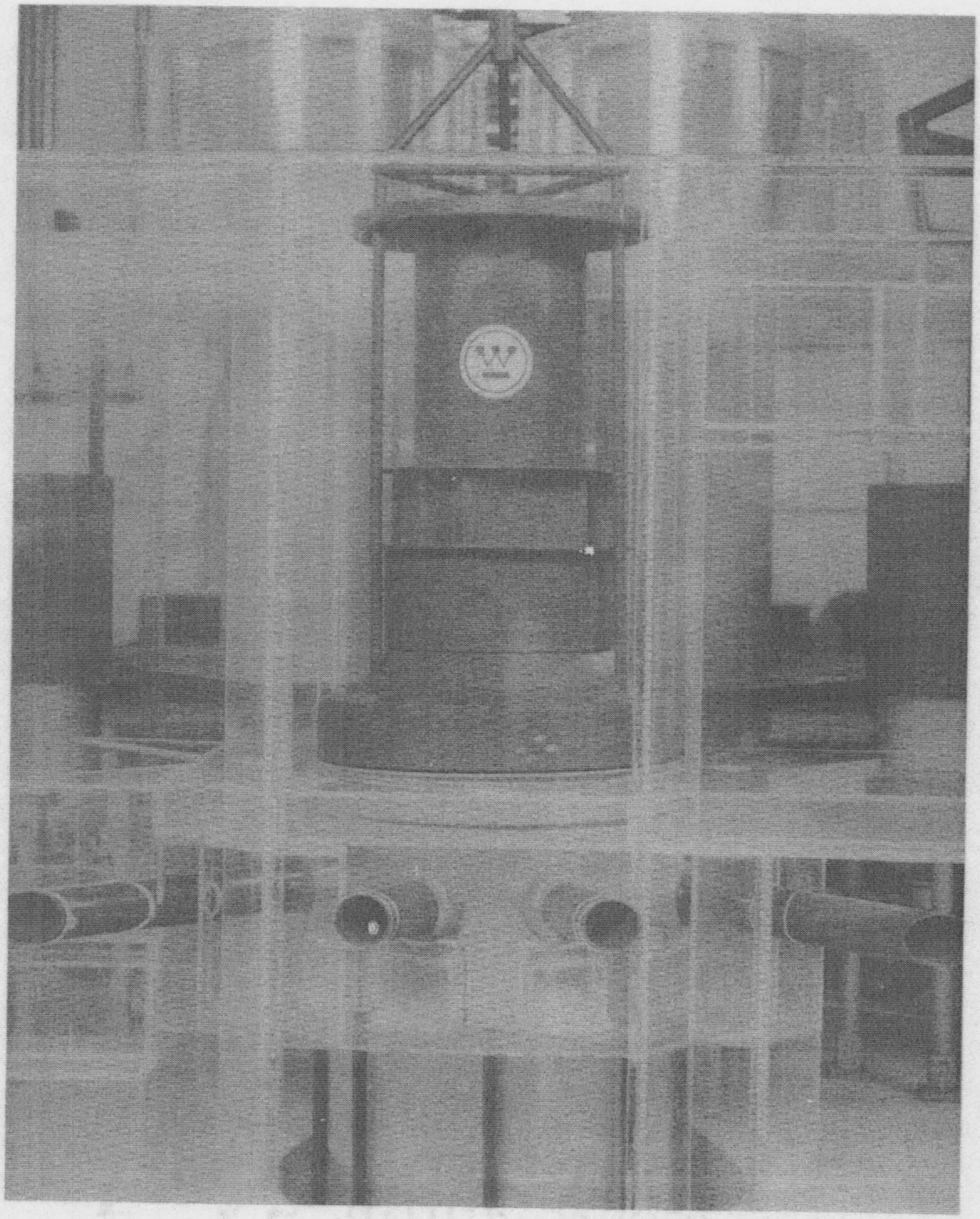


Figure 3 Simulated Reactor Vessel Head Assembly

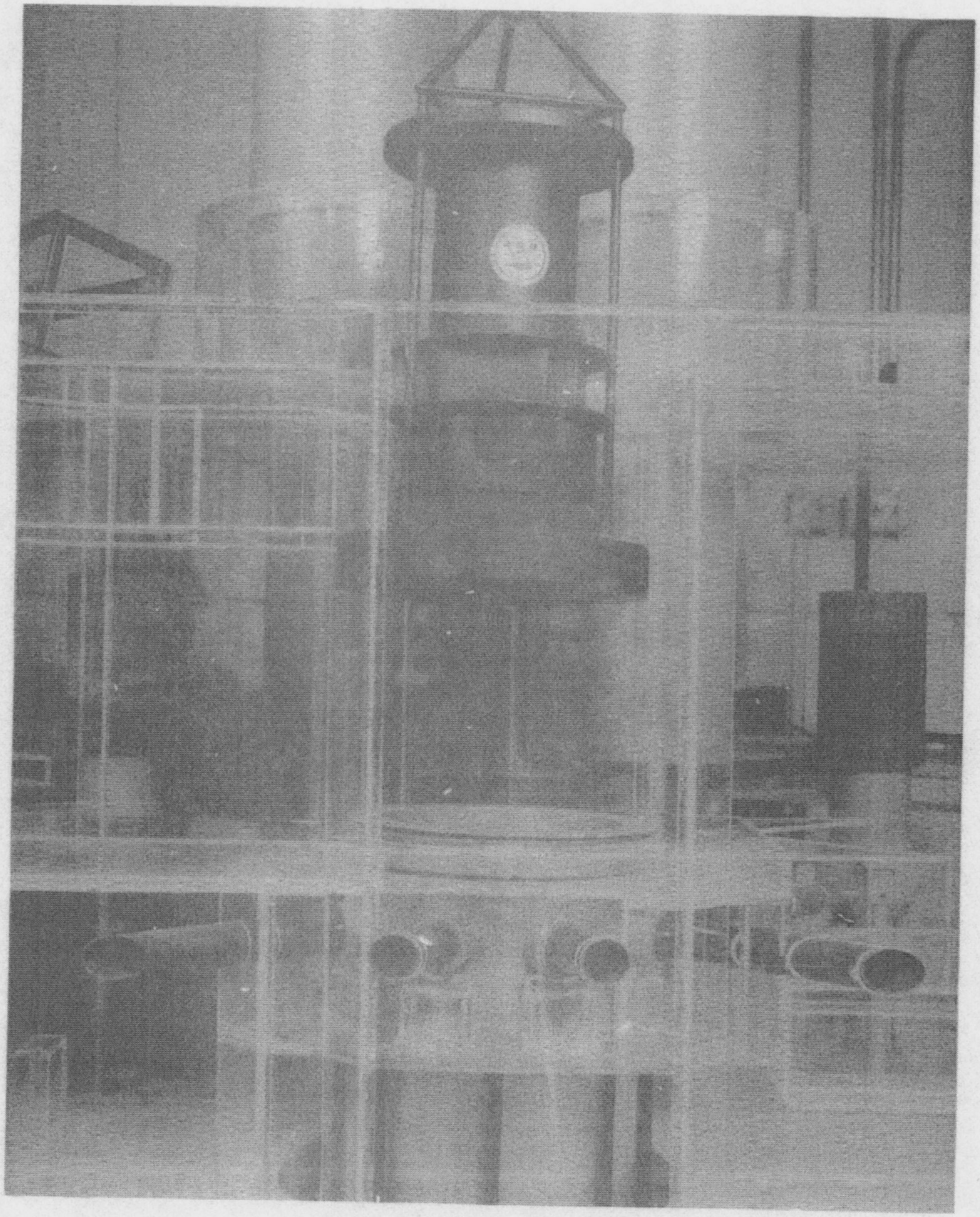


Figure 4 Simulation of Case I

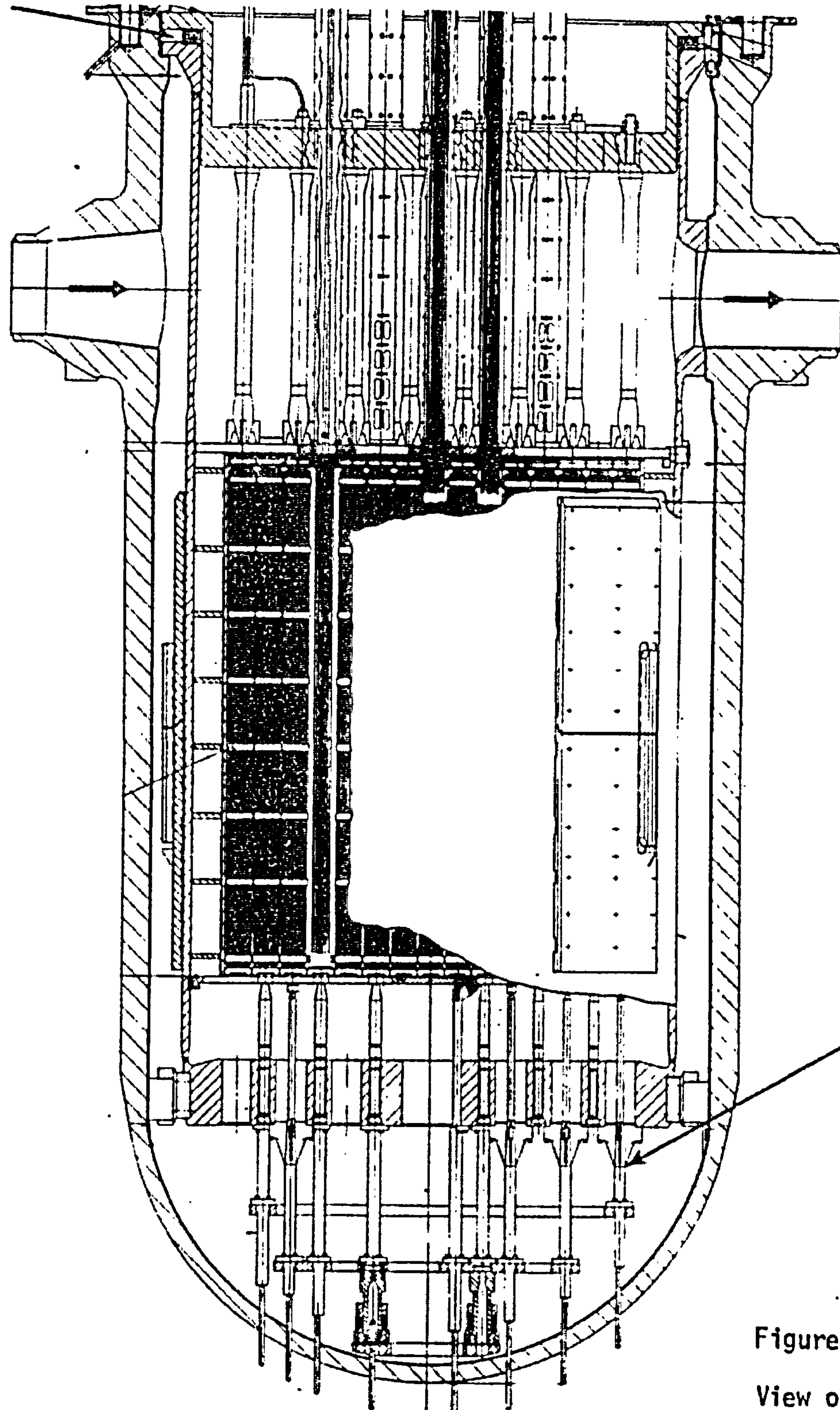


Figure 5

View of Lower Internals and Supports in Reactor Vessel

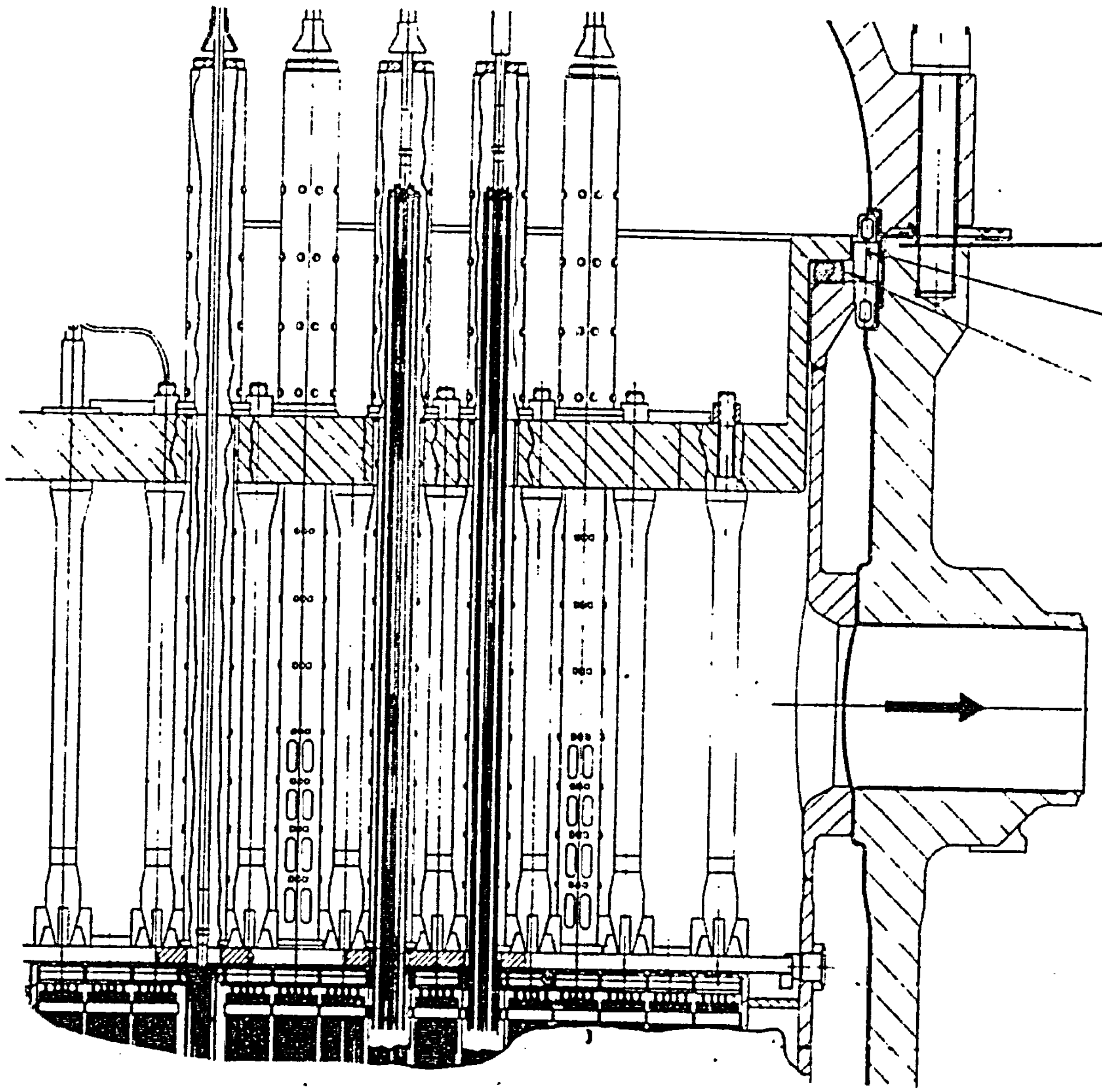


Figure 6

Closeup View of Upper Internals and Core Barrel Supports

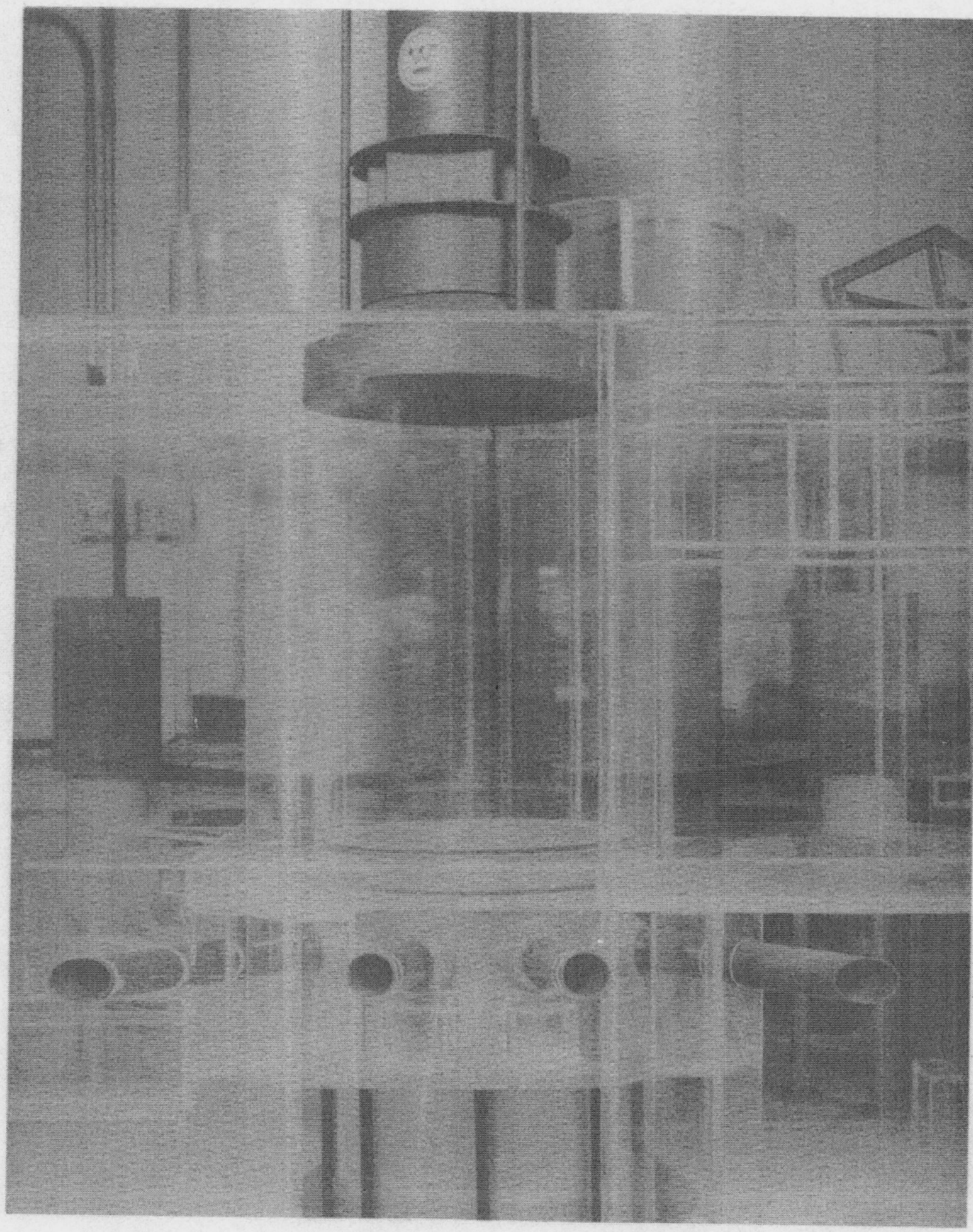


Figure 7 Simulation of Case II

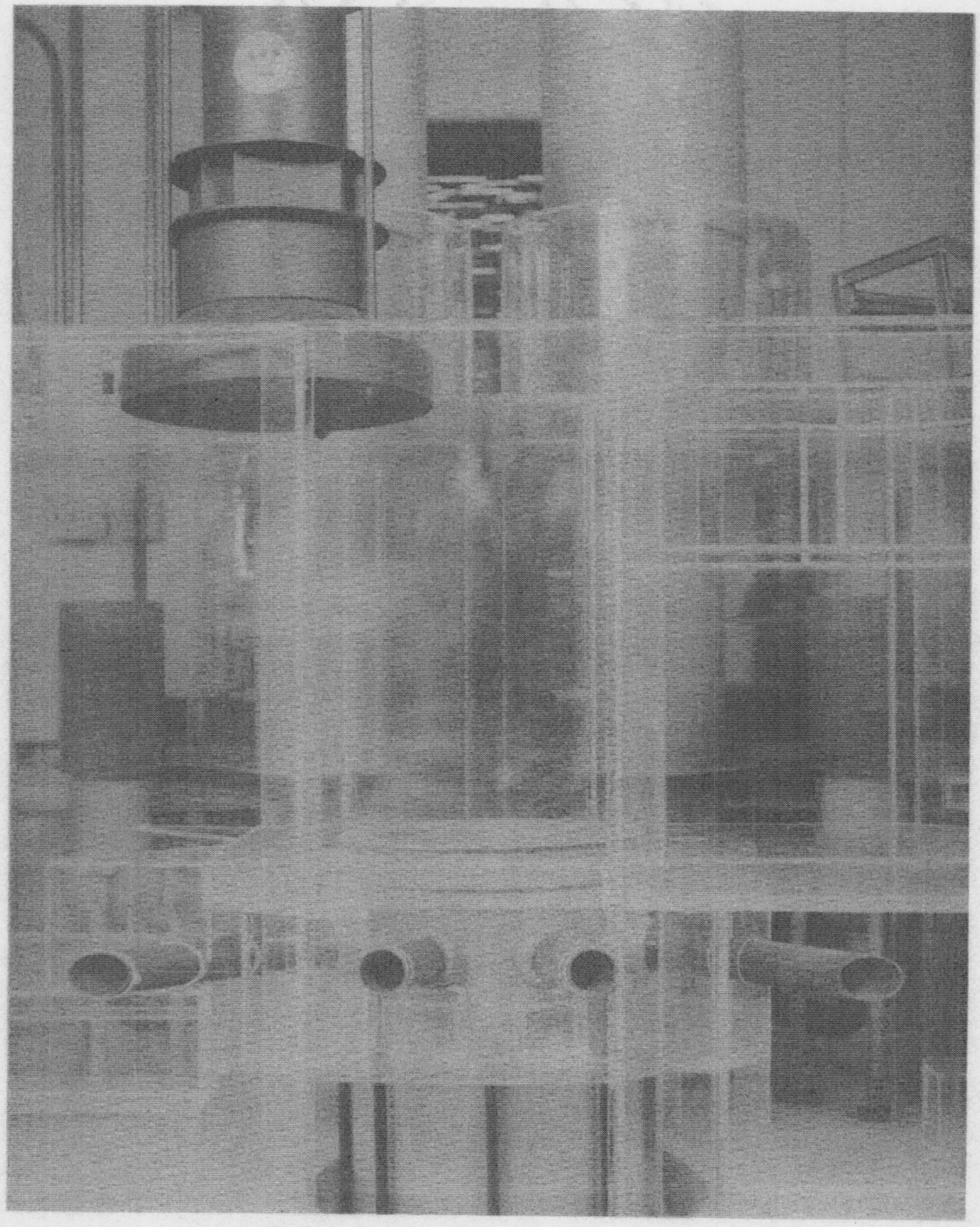


Figure 8 Simulation of Case IV prior to Polar Crane Failure

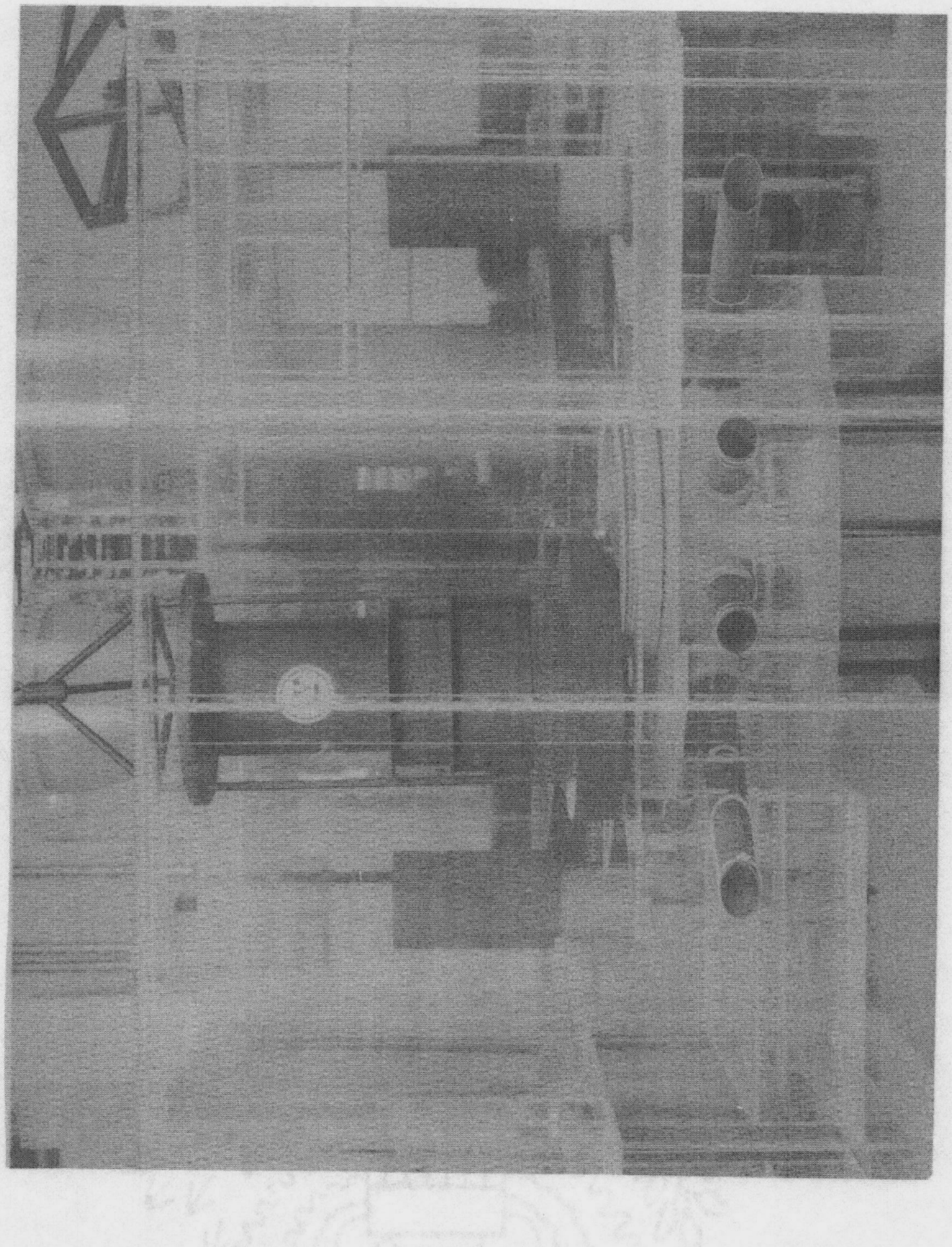


Figure 9 Simulation of Case IV after Reactor Vessel Head Assembly Falls

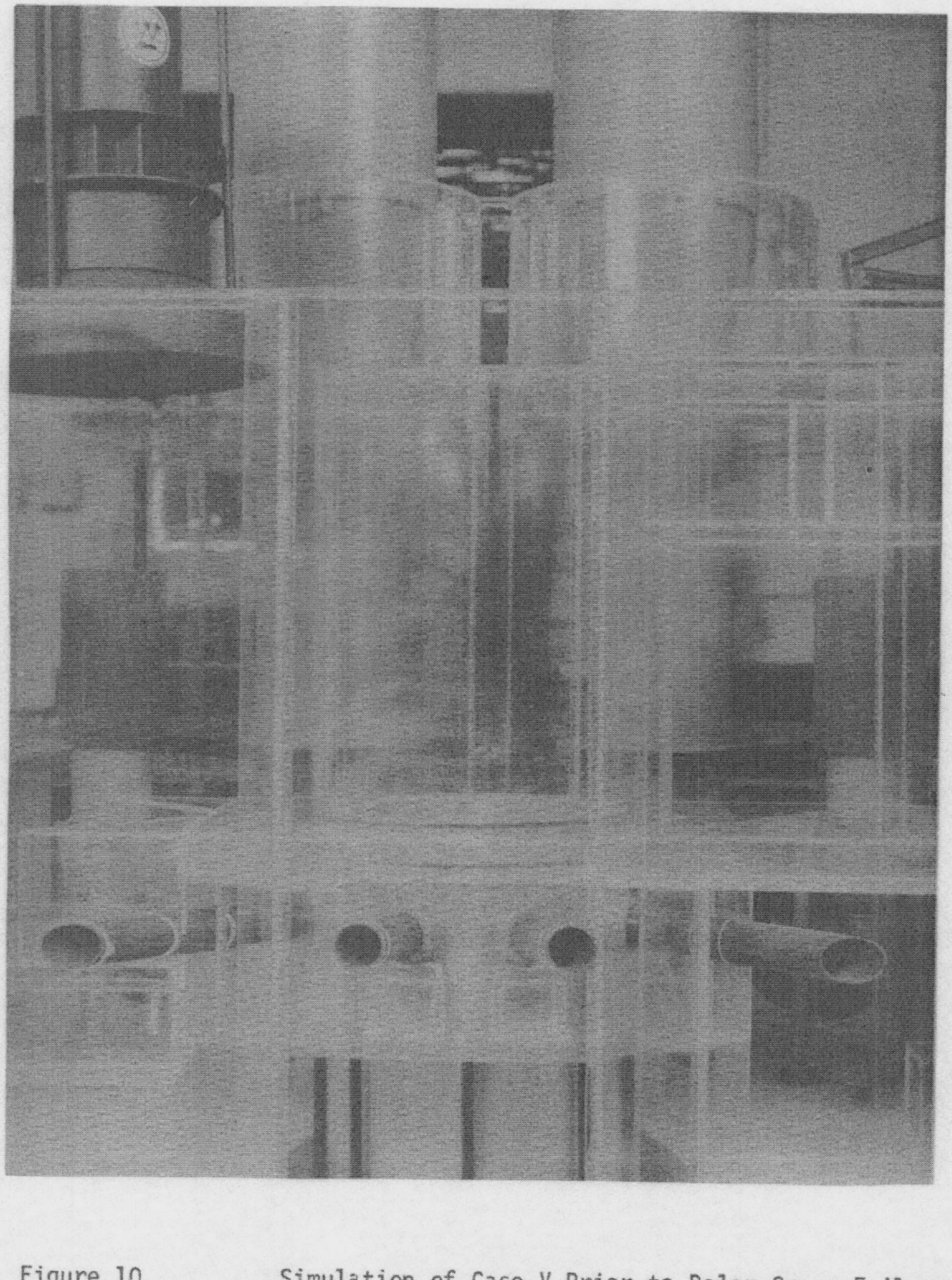


Figure 10 Simulation of Case V Prior to Polar Crane Failure

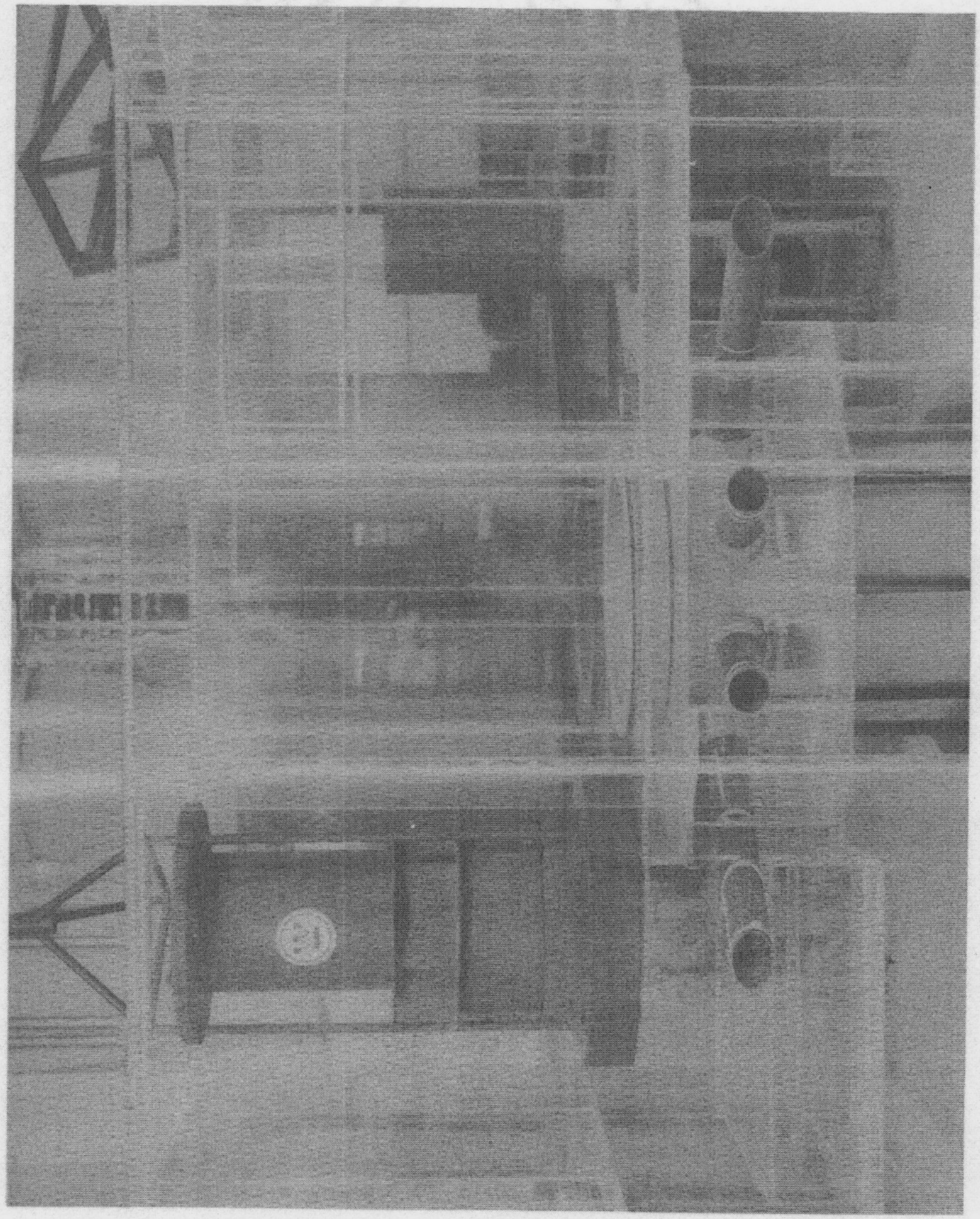


Figure 11 Simulation of Case V after Reactor Vessel Head Falls

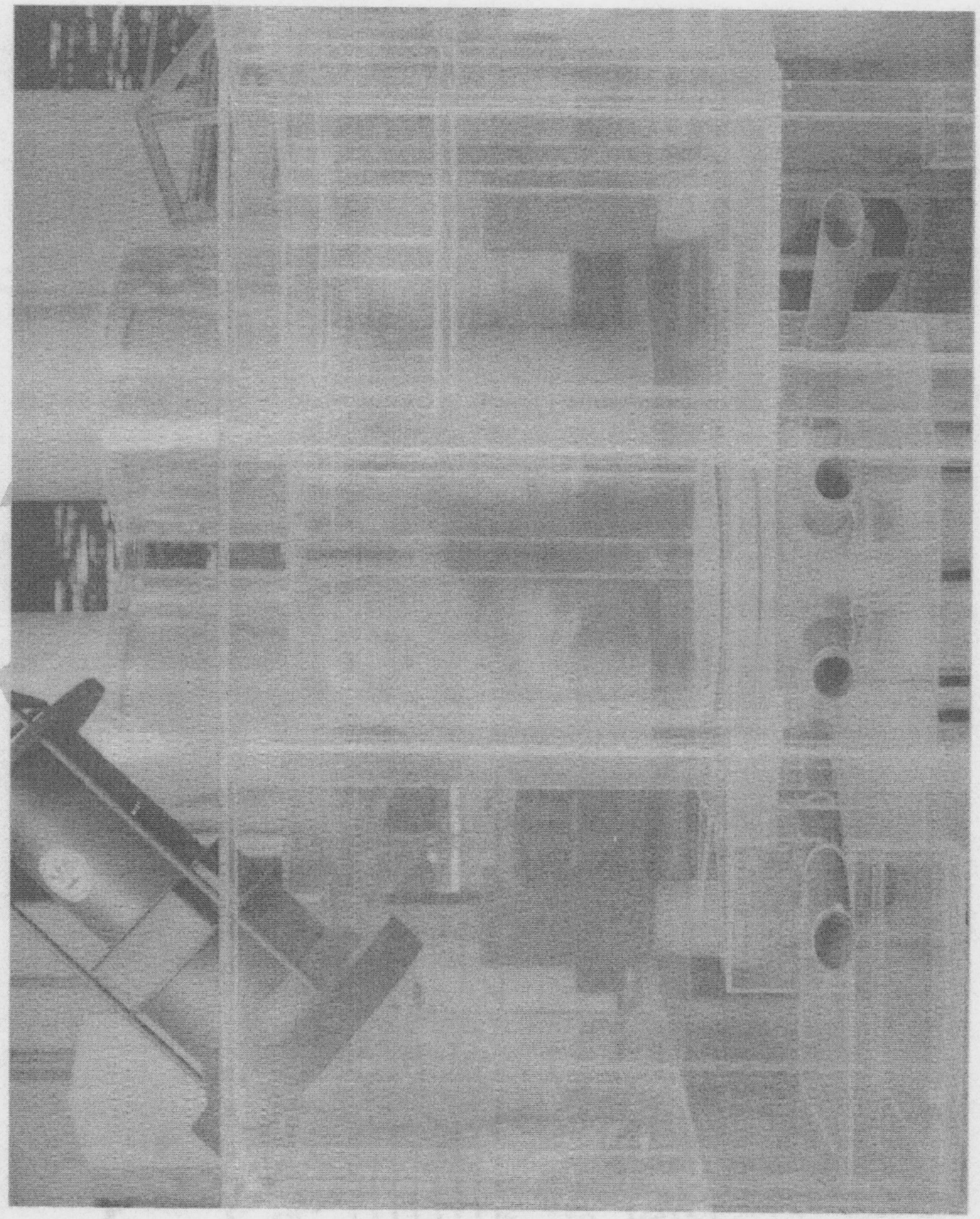


Figure 12 Simulation of Case VI