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Task Scope REVIEW OF NATURAL CIRCULATION CRITERIA UPON INADVERTENT COOLANT PUMP TRIP

To: M. Levenson
S. Levy
E. Zebroski

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Reason felt task is complete:

Determined that additional criteria were needed to prevent loosing the pressurizer during the attempt to initiate natural circulation. The concept and related criteria were reviewed with the TMI management committee. The specific criteria/procedure will be drafted as the next task.

Members of Committee

DAVE TUCKER

DENNIS KELLY

JIM THIESING

JOHN HENCH

WOODY STROMBERG

[signature]
Signed
Committee Leader

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4/25/79

J. HENCH
D. KELLY
W. STROUFE
D. TOOKER

ASSIGNMENT

Review Emergency Procedure EP-32, "Loss of RCP's Successful Natural Circulation"

SUMMARY

The above plan was reviewed to determine if the current criteria for establishment natural circulation provide adequate indication of natural circulation (or lack of natural circulation) and provide sufficient protection for the primary system in the event a natural circulation attempt had to be aborted. One measure of sufficient protection is maintaining water coverage of the pressurizer heaters maintaining pressure controllability.

This study concluded that an additional criterion should be added to those already listed in EP-32. The limits set in this criterion should not be exceeded until at least five hours after the reactor coolant pump trip. Specific recommendations are included at the end of this report.

DISCUSSION

Calculations completed by all groups involved to date indicate that natural circulation will be established with a very small rise, less than 25°F, in core outlet temperature. Conservatively assuming a 15°F rise of the average temperature of the total primary system water, approximately 11,000 ft^3 the volume will increase 72 ft^3 and the pressurizer level will increase 22 inches (See Attachment I) assuming a constant mass system. It is expected that the actual pressurizer level rise will be less than 10" for successful natural circulation

However, assuming that natural circulation is not established, the current criteria of EP-32 would allow the water in the core to reach saturation at about 900 psig.

As shown on Attachment II, the system expansion for the vessel water volume during this heatup is 1100 ft^3 (1). Clearly this volume increase is an order of that magnitude greater than that expected for successful natural circulation and would clearly indicate that the process occurring in the primary system is not understood or under control and that the natural circulation attempt should be aborted. Thus, another criterion to confirm the achievement of natural circulation must be considered. However, first consider the alternate means of handling this increase in the volume of the primary system if natural circulation is unsuccessful. This expansion can be handled by either allowing the water level to rise in the pressurizer or by system letdown.

If the expansion volume is letdown, the mass of the water in the RCS will be reduced by about 30%. When the natural circulation attempt is aborted by the criteria currently in EP-32, a coolant pump could be started when the entire vessel is at saturation temperature, 532°F. The secondary side of the "A" OTSG would be about 230°F. Attachment III indicates that the volume would be reduced

(1) Note for these calculations: It is assumed that the temperatures of the hot and cold leg remains unchanged.

DISCUSSION (cont)

by 800 ft^3 in about five minutes. This will definitely uncover the heaters and likely be a severe transient terminated by the operation of HPI. This result is considered unacceptable since it effectively relinquishes pressure control.

The total volume of the pressurizer is approximately 1500 ft^3. If the water level is at 270" and the pressurizer goes solid at 400" the expansion volume is (400-270) (3 ft^3/incl) 400 ft^3.

As an example of a case where natural circulation is not established, we choose to confine all core heat to the vessel region. The following analysis proceeds from that assumption.

To reach saturation temperature in the entire vessel the expansion volume is about 1000 ft^3 and the pressurizer will therefore go solid before saturation is reached in the vessel.

The pressurizer will go solid about 4 hour after the pump trip since the water level will rise at 40"/hr if no steam voids are accumulated in the vessel and no natural circulation occurs. To provide more time for natural circulation to occur without going solid the pressurizer level should be reduced to the minimum "comfortable" (e.g. 110" ± 10") immediately after the event. To provide margin to "going solid" an upper limit of 350" is proposed for the pressurizer level. This allows a minimum of 6 hours -- (350-110)/40"/hr -- before the natural circulation attempt would be aborted per this criterion.

Additional time would be provided by giving natural circulation a "nudge" by energizing a coolant pump first for 5 seconds and later for 10 seconds as pressurizer levels of 300" and 350" are reached. If the "nudging" attempts were unsuccessful and the level reaches 350" a second time, the proposed criterion calls for an abort.* At this time the average temperature of the water in the reactor vessel would have risen from about 230°F to about 485°F (Attachment IV).

There are several indications that if natural circulation has not yet been achieved it is proper to abort the attempt. These indications are:

1. At least 6 hours have elapsed to establish flow and no natural circulation flow is established.

2. Two attempts to "nudge" the system to natural circulation flow will have been made with no success in inducing natural circulation.

3. The vessel water average temperature has risen over 200°F -- more than sufficient heat will have been generated to cause natural circulation. Something is definitely wrong if natural circulation does not occur.

*Footnote: The abort criteria based on the rising water level in the pressurizer could be replaced with equivalent criteria based on levels in the makeup tank, by holding the pressurizer level constant. This has the advantage of allowing maintenance of higher levels in the pressurizer.

RECOMMENDATIONS (Shown schematically on Attachment VI):

It is recommended that EP-32 be amended as follows for the loss of forced circulation.

1. Take the necessary measures to make the primary system a constant mass system.

2. Reduce the pressurizer level to 100" ± 10.

3. Check pzr. level every 15 minutes. Sustained--for 5 hrs. level rise of ~10"/15 minutes expected if natural circulation not achieved. If natural circulation is achieved, the level rise is expected to be less than 25".

4. When (if) the pzr. level reaches 300"(*) energize pump 2A for 5 seconds (not to full pump speed). If pump fails to start, go to pump 1A for a 5 second jog. Expect to see:

   a) T_h ↑

   b) pzr. level drop

   If neither 2A or 1A jog, go to 5.2.3 of EP-32.

5. Measure pzr. level every 15 minutes.

6. When (if) pzr. level reaches the 350" level, energize pump 2A for 10 seconds. If pump fails to start, go to pump 1A for a 10 second jog. If neither jog, go to 5.2.3.

7. Measure level. If the level stays at or reattains 350", abort the natural circulation criteria, i.e. go to 5.2 of EP32.

* Expected to take about 5 hours after the pump trip.

Attachment ~~B~~ I

Natural Circulation Criteria

The following provides an upper bound on expected change in RCS volume and associated pzr. level increase assumming that natural circulation is achieved.

Assumptions:

1) Initial RCS temperature, $T_1 = 220°F$
2) RCS pressure held constant @ 900 psi
3) Mixing achieved throughout the RCS inventory ($11{,}000\ ft^3$)
4) Upper bound on system average temperature increase of ~~20~~ 15°F (ie. final inventory average temperature $T_2 \leq 235°F$)
5) A system volume change of 24 gallons coorresponds to a 1" change in pzr level.

$$v_{f_2} \ @T_2 = 0.01688$$
$$v_{f_1} \ @T_1 = 0.01677$$
$$\Delta v_{f(T_2 - T_1)} \simeq 0.00011$$

Change in RCS volume $\Delta V_{RCS} = \left(\frac{Volume}{v_{f_1}}\right) \Delta v_{f(T_2-T_1)}$

$$\Delta V_{RCS} = \left(\frac{11000}{0.01677}\right) 0.00011 \ ft^3$$

$$\Delta V_{RCS} \simeq 72.15 \ ft^3$$

or

$$\Delta V_{RCS} \simeq 540 \text{ gal.}$$

$\therefore$ ΔV_{RCS} corresponds to a pzr. level change $= \frac{540 \text{ gal}}{24 \text{ gal/in.}}$

= 22.5" rise in pressurizer level

Please note that this calculation represents an upper bound and anticipate pzr. rise should be less than or ~ 1 ft in"

Attachment II

NATURAL CIRCULATION CRITERIA

Inadventant Pump 2A Trip

Current temp ~ ~~180°F~~ 220°F corresponding v_{f_2} = ~~0.01651~~ 0.01677

Assume a pressure of 900 psi (Ref. EP-32, Rev. 1)

$T_{sat} \simeq 532^0F$ corresponding v_{f_1} = 0.0212

Exercise performed to determine the volume change in going to T_{sat} (Reactor Vessel)

R.V. volume $\simeq$ 4041 ft^3 = V

Change in specific volume $\Delta v_f = v_{f_1} - v_{f_2}$

= 0.0212 - ~~0.01651~~ 0.01677

$\Delta v_f \simeq$ ~~0.0047~~ 0.00443

\# of water in RV = V/v_{f_1}

$\simeq$ 4041/~~0.01651~~ 0.01677

$\simeq$ ~~244760~~ 240900 Lb_f

∴ Change in RCS volume associated with the RV inventory going to $T_{sat} \simeq 532^0F$ is:

$\Delta V \simeq$ (~~244760~~ 241,000 Lb_f H_2O) Δv_f

$\simeq$ (~~244760~~ 241,000) (~~0.0047~~ 0.00443)

$\Delta V \simeq$ ~~1150~~ 1068 ft^3

Total pzr volume $\simeq$ 1500 ft^3

Presently @ pzr. level 267" we have substantially less than 700 ft^3 before the system goes solid.

Conclusion

In addition to the criteria outlined in EP-32, Rev. 1, Paragraph 5.1.5 for temperature indication which will abort the natural circ. attempt, a criteria for pzr. level is required.

ATTACHMENT III

ROUGH ANALYSIS OF THE TIME REQUIRED TO REDUCE THE RCS AVERAGE TEMPERATURE AFTER STARTUP OF A-LOOP RC PUMP, ASSUMING FAILURE TO ACHIEVE NATURAL CIRCULATION.

I. TRANSIT TIME FOR HOT VESSEL WATER TO BE FLUSHED THROUGH OTSG.

HOT LEG FLOW TEMP = 500 F

HOT LEG FLOW = 14,449 lb/sec

HOT LEG FLOW AREA = 10 ft^2

$$V = \frac{14{,}449}{10\ ft^2}\ \frac{lb}{sec}\ .0204\ \frac{ft^3}{lb} = 30\ ft/sec$$

ASSUME HOT LEG LENGTH OF 100 ft:

$$t_1 = \frac{100}{30} = 3.3 \text{ SECONDS}$$

THUS, IT TAKES ABOUT 3 SECONDS FOR THE LEADING EDGE OF THE HOT SLUG TO REACH THE OTSG. ASSUME THE ENTIRE VESSEL IS HEATED TO 500 F, FIND THE TIME TO GET THE TRAILING EDGE OF THE HOT SLUG INTO THE OTSG.

$$t_2 = \frac{W}{\dot{w}} = \frac{4000\ ft^3}{.0204\ \frac{ft^3}{lb}\ 14{,}449\ \frac{lb}{sec}} = 13.5$$

$$t_2 = 13.5 \text{ sec}$$

RPV VOLUME = 4000 ft^3

THUS, IF THE TRANSIT TIME IS LIMITING, IT WOULD ONLY

II Time To Cool The Hot Slug In The OTSG

Assume:

Tube Side HTC Of 25 Btu/hr ft² °F

Hot Slug Temp Of 500°F

Cold Shell Side Temp Of 230°F

Heat Transfer Area Of 120,000 ft²

Then The Heat Transferred Would Be

$$q = hA\Delta T = (25)\frac{Btu}{hr\,ft^2\,{}^\circ F}(120{,}000)\,ft^2\,(500-230)\,{}^\circ F$$

$$q = 8.1 \times 10^8 \ Btu/hr$$

The Instantaneous Temperature Drop Rate Of The Hot Slug, If Heat Were Being Transferred At A Rate Of 8.1×10^8 Btu/hr Would Be:

$$\frac{\partial T}{\partial t} = \frac{q}{\omega C} = \frac{(8.1\times10^8)}{(4000)\,ft^3}\,\frac{Btu\,(.0204)\,ft^3}{hr\,(\ \ )\,lb}\,\frac{lb\,{}^\circ F}{(1)\,Btu} = 4131\ {}^\circ F/hr$$

$$\frac{\partial T}{\partial t} = 1.14\ {}^\circ F/sec$$

The Time To Cool The Hot Slug 270°F At This Rate Would Be (1.14×270) 310 Seconds., Or Approximately 5 min.

Therefore, The Time To Cool Down A Hot Slug Of Water From The RPV At 500°F Is About 5 To 10 Minutes

ATTACHMENT III - CALCULATION OF RCS SHRINKAGE

THE VOLUME OF THE REACTOR VESSEL (4000 ft^3) IS ASSUMED TO DROP FROM 533°F TO 230°F. THE SHRINKAGE OF THIS WATER WILL BE

$$\text{MASS} = \frac{V_1}{v_1} = \frac{V_2}{v_2}$$

$$V_2 = \frac{v_2}{v_1} V_1$$

$v_2 = v_f$ AT 230°F = .01684

$v_1 = v_f$ AT 532°F = .02121

$V_1 = 4000$ ft^3

$$V_2 = \left(\frac{.01684}{.02121}\right)(4000) = 3176$$

$$\Delta V = V_1 - V_2 = 824 \; ft^3 = 6164 \text{ gallons}$$

Natural Circulation Criteria

The following determines the RCS average temperature, Tave assuming that natural circulation is not achieve and that the attempt is aborted when pzr. level reaches the 350" mark.

Assumptions:

1) Initial pzr. level is $L_1 = 100''$ (see Attachment 1 recommendation)
2) Initial RCS ave temp is 220°F $= T_1$
3) Pressure is held constant @ 900 psi
4) Mixing is achieved in the volume of water in the reactor vessel. $V \approx 4041\ ft^3$
5) A 24 gal. change in RCS inventory coorespnds to a 1" change in pzr. level.
6) Final pzr. level at time of abort is $L_2 = 350''$

Additional volume of water in the pzr.

$$\Delta V_{RCS} = \left(24 \frac{gal}{in}\right)(L_2 - L_1)$$

$$= 24(350-100)\ gal.$$

$$\therefore \Delta V_{RCS} = 6000\ gal.$$

or

$$\Delta V_{RCS} \simeq 802\ ft^3$$

v_{f_1} @ $T_1 = 220° = 0.01677$

$$\Delta V_{RCS} = \frac{\text{Reactor Volume, } V}{v_{f_1}} \Delta(v_{f_2} - v_{f_1})$$

where v_{f_2} is the specific volume associated with the Reactor vessel inventory

$$\therefore v_{f_2} = \frac{V v_{f_1} + (\Delta V_{RCS})(v_{f_1})}{\text{Reactor Volume, } V}$$

$$\therefore \quad v_{f_2} = \frac{v_{f_1} \, V + \Delta V_{RCS}}{V}$$

$$= \frac{0.01677\,(4041 + 802)}{4041}$$

$$v_{f_2} \cong 0.02010$$

According to the steam tables, this value of v_{f_2} coorresponds to a temperature of ~ 455°F

Conclusion: This calculation verifies that the proposed level criteria for abortion of the natural circulation attempt is not overally restrictive and should not cause the operator to prematurely abort the attempt.

CONSTANT MASS PRIMARY CONTROL

This attachment indicates methods for achieving a constant primary system mass. The extension of the primary system, consisting of:

1. the primary system
2. the seal flow system and seal return system
3. the letdown system
4. the makeup tank

represents a constant mass system with the exception of some small system outleakage (2.5 gal/min) which has been constant and fairly accurately known. Maintaining the level in the makeup tank at a constant value via letdown or seal flow will assure that the primary system is at a constant mass. The system can be made more accurate by adding water to the makeup tank at a rate equal to the estimated rate of outleakage. Moreover, the pressurizer level adjustment desired at the beginning of the transient can be accomplished on a constant mass basis by reflecting the initial difference onto the initial makeup tank level to determine a makeup tank control level.

Inadvertent Pump 2A Trip