ENCLOSURE 2

KEWAUNEE HATCH CLOSURE TASK ASSESSMENT

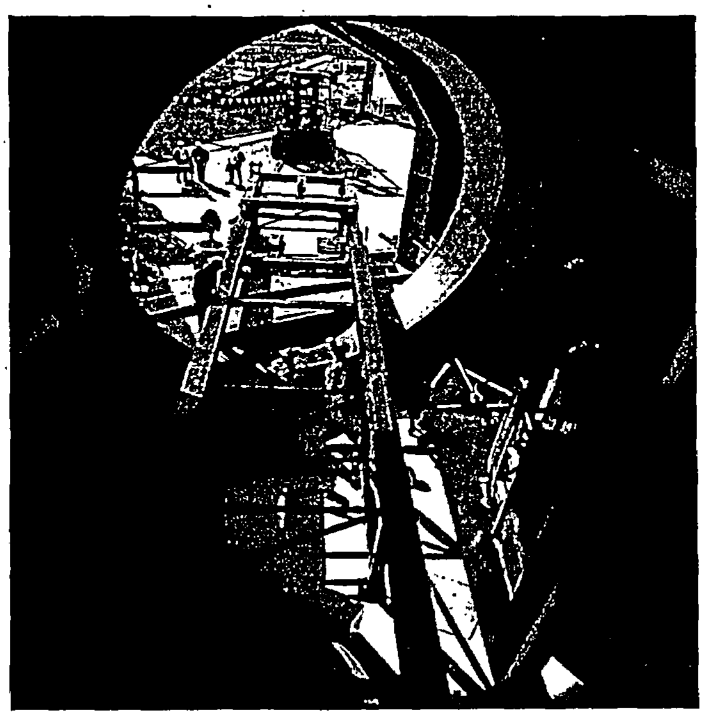
35 pages follow

ENERCON SERVICES, INC.

REPORT PREPARED FOR:

KEWAUNEE NUCLEAR POWER PLANT

KEWAUNEE HATCH CLOSURE TASK ASSESSMENT



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1.0 BACKGROUND

Kewaunee Nuclear Power Plant (KNPP) identified a condition (Reference 1) which would have prevented the closure of the Containment Equipment Hatch using normally applied means. This problem was the result of an interference between the interior runway beam and the equipment hatch that prevented initial closing of the containment equipment hatch. In order to close the containment equipment hatch, the interior runway was modified by cutting a portion of the interior runway with an acetylene torch. KNPP was able to restore the containment hatch to a closed position in a timely manner resolving the as found condition. As part of the overall assessment KNPP performed an evaluation of their ability to restore the containment boundary in the event an emergency condition occurred with the equipment hatch blocked open. ENERCON was requested to perform a third party review of this evaluation. This report documents that review and its findings. It is ENERCON's judgement that the overall conclusions of the KNPP review are valid.

2.0 PURPOSE

The purpose of this effort is to perform a review of the KNPP assessment of their ability to perform the necessary tasks to close the equipment hatch under emergency conditions. The emergency condition identified by the KNPP staff is the loss of all AC power to the station. This assumed event results in the loss of decay heat removal from the reactor. This produces a condition where steam will exit the reactor, via openings in the reactor coolant system, into the containment where the necessary work to close the containment equipment hatch must be performed. ENERCON has been tasked to evaluate the ability to perform the tasks necessary to close the hatch under these environmental conditions.

Specifically, the steam exhausting into the containment will produce elevated noise, temperature, humidity, radiation and pressure conditions. The ability of the response team to perform the necessary tasks to close the equipment hatch in the required time has been evaluated by ENERCON and is documented in this report.

3.0 REFERENCES

1. "Kewaunee Nuclear Power Plant Runway Interference Prevented Timely Closure of Containment Equipment Hatch" Event Date: 10/14/04 RCE000668 CAP023950
2. "Heat Stress Control Guidelines" FP-IH-SAF-01 Revision 0.
3. CMP-89A-02 Rev. D "BLD – Containment Building Inner Equipment Door Opening and Closing Instructions"
4. "Containment Building Equipment Hatch Temporary Closure Plan" Revision 0 Dated 10/05/04
5. Wisconsin Public Service Kewaunee Nuclear Power Plant Calculation/Evaluation: "Evaluation in support of closure time for the Containment Equipment Hatch."
6. KNPP Equipment Hatch Closure Issue Report, undated
7. Engineering Handbook by safety valve manufacturer Crosby Valves (relevant pages provided in Attachment 2)
8. American Petroleum Institute publication API RP521
9. "Kewaunee Response to a Potential Loss of RHR at Reduced Inventory Conditions" by R. Ofstun, Westinghouse Electric Company; March, 2005
10. OSHA Regulation (Standards – 29 CFR) Occupational Noise Exposure – 1910.95 1910.95(b)(2) (Relevant Pages Provided in Attachment 2)
11. 10 CFR 20, Standards for Protection Against Radiation

4.0 ASSUMPTIONS

1. The precautions and limitations documented in Section 2.2 of Reference 3 are appropriate and applicable at the time when the hatch would need to be closed.
2. All requirements outlined in Reference 4 are reasonably assumed to be in place and can be credited as part of the overall assessment of the scenario.
3. The containment pressure, temperature, steaming rates are as established by the Westinghouse calculation (Reference 9).
4. The closing time of the containment hatch, which is assumed in the Reference 9 analysis at 84 minutes, is the central event that results in the degraded containment environmental conditions. For this evaluation, 156 minutes will be used as the time to close the equipment hatch. This time includes the bolting actions but does not include the team egress time.

5. Egress time has been conservatively assumed to be 34 minutes. It is reasonable to assume that egress will be achieved in less time but this conservative value will be used in this evaluation.
6. Sufficient emergency and/or portable lighting is provided to illuminate the work area for safe and effective completion of the tasks.
7. The event condition under consideration is a loss of all AC power to the station. It is assumed that the working time line to clear the obstruction and close the hatch will not be substantially impacted by other operator burdens associated with restoring AC power.

5.0 EVALUATIONS

The evaluation of the ability of workers to safely close the containment equipment hatch and egress containment considers the tasks associated with the effort. It evaluates these tasks against the environmental conditions that are reasonably expected. Given the task difficulty and the conditions that are expected to exist during the task, an assessment of whether the task can be achieved will be developed. These assessments will be focused primarily on the pressure, temperature and humidity levels. As such, this is primarily a heat stress evaluation of each task. The evaluation of radiation exposure and noise levels will be evaluated based on the total time associated with the hatch closure. For example, the noise levels and radiation exposure must remain sufficiently low to allow the workers to stay for the duration of the task without adverse impact on their general health as defined by the appropriate regulations. Given a duration for hatch closure, the expected radiation exposure would be developed.

5.1 Time Line Assessment

The time line evaluation is provided in Attachment 1 of this Report and summarized in Table 1. The assessment and documentation of the time line is an important task to allow for a comparison of the task with the working conditions.

Table 1

Time	Event/Task	Activity Exertion Level for Task
0	Station Blackout condition occurs. RHR is lost and Reactor begins to Heatup.	NA
30 minutes	Control Room requests Equipment Hatch Closure.	NA
45 minutes	Response team activated	NA
60 minutes	Instructions conveyed to response team	NA
80 minutes	Reactor Building Entry (or transit to hatch area for those already in RB)	Low Exertion Level Activity Walking
95 minutes	Team sets up in Hatch area and verifies tools required are available.	Low Exertion Level Activity Walking
110 minutes	Team removes cables, cords and other equipment from the hatch area.	Medium Exertion Level Activity light lifting and carrying.
120 minutes	Attempt to close Hatch and identify interference.	High Exertion Level Activity chain pulling to maneuver the hatch into position
135 minutes	Notify Control Room of interference and obtain additional equipment from outside the Reactor Building.	NA
150 minutes	Remove Interference from the area.	High Exertion Level Activity Lifting, moving and carrying heavy objects.
156 minutes	Close Equipment Hatch and tighten four bolts	High Exertion Level Activity chain pulling to maneuver the hatch into position, climbing a ladder and tightening bolts
190 minutes	Exit the Reactor Building	Low Exertion Level Activity Walking.

5.2 Heat Stress Conditions

To evaluate the heat stress conditions that the response team will be exposed to, an estimate of the environmental conditions must be established. This environmental evaluation will produce a time line of conditions that can then be compared with the tasks outlined previously to ensure the hatch will be closed. Analyses were performed by Westinghouse for KNPP in support of this effort. The analyses results considered for this evaluation as most appropriate are documented in Figures 1 and 2. Figure 1 shows the building's temperature response while Figure 2 shows the building's pressure response.

The analysis associated with these results assumes that the hatch is closed at 5040 seconds, or approximately 84 minutes, from the loss of RHR. The assessment of the time line (Table 1) indicates that the hatch is not fully closed until 156 minutes. The results shown in Figures 1 and 2 indicate that the building pressure is clearly held constant until the hatch is closed, but the temperature is creeping upward even prior to closure of the hatch. Based on these results it is reasonable to assume that the containment conditions would be approaching 112°F at the time of the hatch closure and nearly 120°F at the time of egress as identified in Table 2. (Note: Figures 1 and 2 depict containment pressure and temperature responses predicted by the GOTHIC analysis as a result of the identified plant event. The GOTHIC analysis assumes the start time for the event, as presented on the Figures, to be 900 seconds. For the purpose of this report, the time of 0 seconds corresponds with the 900 second start provided in the Figures.)

There are two things that need to be considered when applying these analytical results to the Table 2 assessment. The first is that with the hatch open the local conditions (work area) would be greatly influenced by the outside air conditions. The second is that the results of this analysis do not consider stratification of the temperature within the building. With regards to the first, it is reasonable to assume that the working conditions in containment in the vicinity of the hatch, prior to successful closure of the hatch, would be approximately equal to the outside temperature of 70°F (Reference 6). The containment response analysis used an initial temperature of 80°F, which is a more conservative value from the perspective of heat stress on the workers. An 80°F temperature will be used to remain consistent with the analysis conditions.

Once the hatch is closed the temperature conditions within the building will reflect those predicted directly by the time line supported by Figure 1. This is assumed despite the delayed closure of the hatch predicted by the time line (Table 1) assessment relative to the analysis. The analysis assumption of hatch closure time (84 minutes) could be used to argue that the temperature rise following the hatch closure should be essentially equal to the post hatch closure temperature rise to be applied in this assessment. This is not, however, a valid assumption since it is clearly evident from Figure 1 that the temperature in the building is rising fairly steeply prior to the hatch closure. Based on this argument the temperature within the building rises from 108°F at the time of the assumed hatch closure to approximately 120°F at the time the response team exits the building. Once the hatch is closed the stratification would provide the basis for lower temperature working conditions. However, without specific supporting analysis of the stratification condition the benefit of this phenomenon only represents conservatism in this assessment. No credit can be taken for the lower work area temperatures that would be expected.

Applying these arguments, a comparison of the tasks versus the expected containment conditions at the time of the task can be developed. Such a comparison is provided in Table 2.

Table 2

Time	Event/Task	Activity Exertion Level for Task	Work Area Conditions
80 minutes	Reactor Building Entry (or transit to hatch area)	Low Exertion Level Activity Walking	14.7 psia, 80°F
95 minutes	Team sets up in Hatch area and verifies tools required are available.	Low Exertion Level Activity Walking	14.7 psia, 80°F

Time	Event/Task	Activity Exertion Level for Task	Work Area Conditions
110 minutes	Team removes cables, cords and other equipment from the hatch area.	Medium Exertion Level Activity light lifting and carrying.	14.7 psia, 80°F
120 minutes	Attempt to Close Hatch and identify interference.	High Exertion Level Activity chain pulling to maneuver the hatch into position	14.7 psia, 80°F
150 minutes	Remove Interference from the area.	High Exertion Level Activity Lifting and carrying heavy objects.	14.7 psia, 80°F
156 minutes	Close Equipment Hatch and tighten four bolts	High Exertion Level Activity chain pulling to maneuver the hatch into position, climbing ladder and tightening bolts	14.7 psia, 108°F, 100% RH
190 minutes	Exit the Reactor Building	Low Exertion Level Activity Walking	15.2 psia, 120°F, 100% RH

Based on the evaluation documented in Table 2, the final tasks performed with the hatch closed would not require that ice vests be used (per Reference 2) to ensure successful completion of the tasks to secure the hatch and exit the containment. However, it is recommended that hatch team personnel be pre-hydrated.

ENERCON also reviewed heat stress guidelines to ensure that the KNPP guideline (Reference 2) presented reasonable guidance. Our conclusion is that the KNPP guidelines are in alignment with other industry guidance.

Another consideration that is related to containment environment is associated with the increase in containment pressure following closure of the hatch. As shown in Figure 2, the containment will reach approximately 15.2 psia at the time the team will egress the containment. Equalizing valves are provided on the airlock to enable opening of the airlock doors when a differential pressure exists. Hatch team personnel should be familiar with the operation of the equalizing valves and air lock.

Attachment 1 provides the detailed evaluation results.

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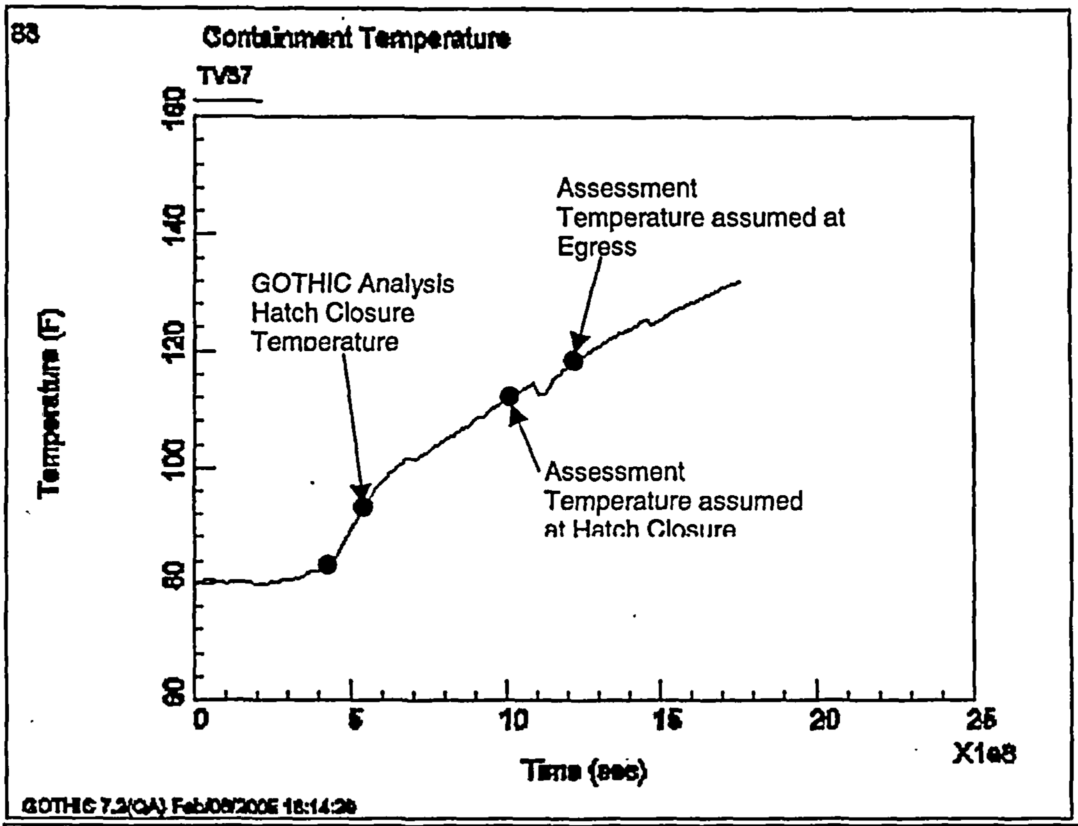

Figure 1 – Reactor Building Temperature Response

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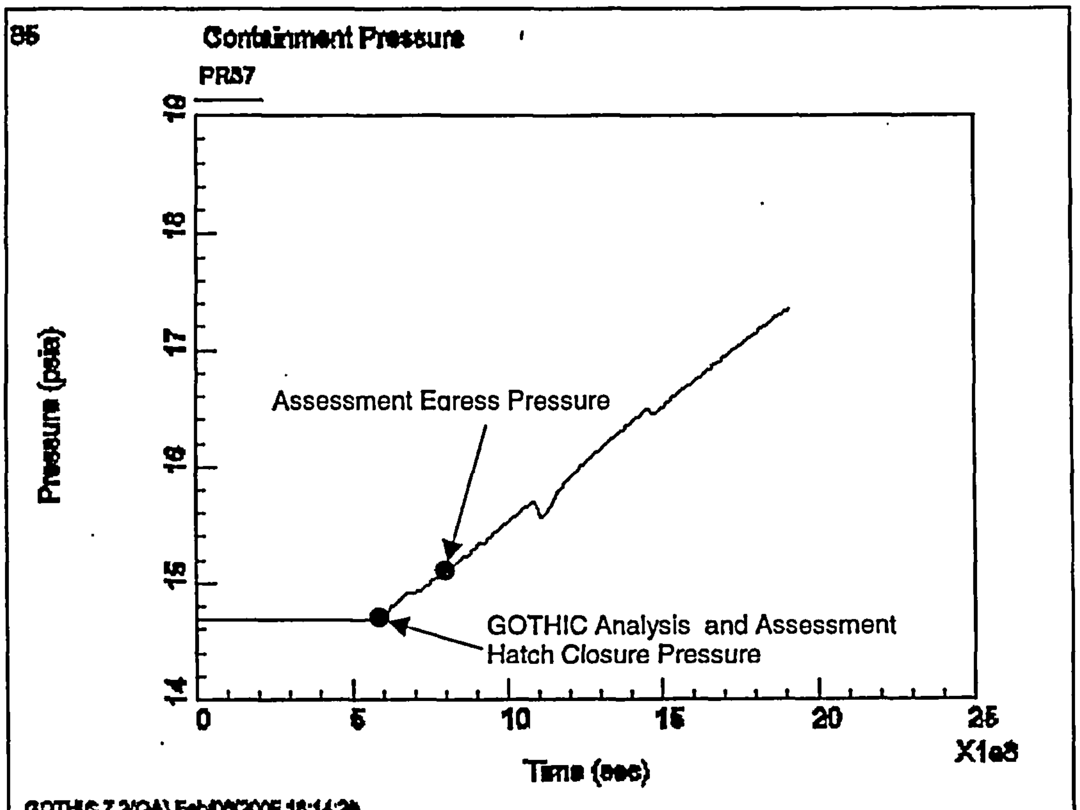


Figure 2 – Reactor Building Pressure Response

5.3 Noise Evaluation

To ensure that the response team can successfully close the equipment hatch, sound levels must be demonstrated to be sufficiently low that they will not hinder this effort. The noise level as a result of steam flow from the open six-inch safety valve pipe flange was evaluated using the methodology provided in the Engineering Handbook by safety valve manufacturer Crosby Valves (Reference 7). This methodology is based on American Petroleum Institute publication API RP521 (Reference 8). The details and supporting reference material are provided as Attachment 2 of this report.

The method is based on calculating the sound level at 100 feet from the source. These levels are then corrected to account for the actual distance from the source to the work location. The distance from the Safety Valve location to the hatch area is approximately 70 feet.

$$L100 = L + 10\text{Log}_{10}(0.29354WkT/M)$$
$$Lp = L100 - 20\text{Log}_{10}(r/100)$$

where:

L100 = Sound level at 100 ft (dB)
Lp = Sound level at work location
W is the mass flow rate in lb/hr.
k is the ratio of steam specific heat.
T is the Temperature of the steam at the inlet (R).
M is the Molecular weight of steam.
r is the distance between the source of the sound and the work location.

The steam flow from the reactor head flange gap was not considered. The condition evaluated provides for a conservative estimate of noise level as all steam flow would exit from one reactor coolant system opening. The steam mass flow rate and reactor pressure that were used as input were obtained from the report "Kewaunee Response to a Potential Loss of RHR at Reduced

Inventory Conditions" by R. Ofstun, Westinghouse Electric Company (Reference 9). For this analysis, Case 1 will be the controlling case, for which Figure 4.2-2 provides reactor pressure and Figure 4.2-3 provides steam flow rate. The worst case scenario for this analysis assumed reactor pressure at 30 psia at saturation temperature and a steam flow rate of approximately 4 pounds per second.

The calculation shows that the noise level from the steam flow, Lp, will be approximately 97.5 decibels. Per Reference 10 (OSHA 1910.95(b)(2)), this noise level is acceptable for a duration of approximately three hours per day. For the case with steam flow also passing through the reactor head flange gap, the noise level will be lower as the total flow will be split between two reactor coolant system openings. Hearing protection, which is required for personnel entering the containment, would reduce the noise level further and allow additional stay time if necessary.

The results of our analysis support the conclusions documented in the KNPP report that noise levels in containment will not hinder hatch closure operation nor will the personnel be exposed to occupationally unacceptable noise levels.

5.4 Radiation Level Evaluation

The radiation exposure of the workers that will be closing the hatch is evaluated as part of the overall effort to ensure that, if required, the hatch could have been successfully secured following a loss of RHR event. The details of the calculation of radiation exposure are found in Attachment 3 of this report.

Two postulated loss of RHR cooling cases, Case 1 and Case 2 were evaluated for KNPP in Reference 9. The radiological impacts of Case 1 and 2 were considered, however; Case 2 was found to be clearly bounding. The time period of exposure of the hatch team and the level of activity in containment for Case 2 far exceeded that of Case 1. Case 2 was selected for evaluation of the occupational dose for this hypothetical event.

Case 2 considers steam releases through the Pressurizer safety valve piping and reactor head gap using a Gothic analysis of the KNPP RCS and containment response to a loss of AC power and RHR cooling at 4 days, 9 hours and 50 minutes after shutdown. Occupational doses for Case 2 were determined based on three assumptions regarding containment mixing and the level of activity of the hatch team.

- Case 2a - dilution in the containment limited to 50%, doses based on a reference man working under conditions of light work,
- Case 2b - dilution in the containment assumed to be 100%, doses based on a reference man working under conditions of light work, and
- Case 2c - dilution in the containment limited to 50%, doses based on a reference man working under conditions of increased activity.

The TEDE dose is defined as the sum of the deep dose equivalent for external exposures and the committed dose equivalent for internal exposures. The deep dose equivalent and the committed dose equivalent calculated for the postulated event are given in Table 3. The dose to the skin of the whole body was also calculated. The skin dose is taken as an estimation of the dose to the lens of the eye. Doses are provided for releases assuming dilution is 50% (Case 2a and 2c) and 100% (Case 2b) of the containment volume. Generally, even in instances where good mixing can be demonstrated, dilution is limited to 50% of the release volume.

Table 3

Dose Summary

	Case 2a	Case 2b	Case 2c
Skin Dose	0.001 rem	0.001 rem	0.001 rem
Dose to Lens of the Eye	0.001 rem	0.001 rem	0.001 rem
Deep Dose Equivalent	0.001 rem	0.001 rem	0.001 rem
Committed Dose Equivalent	0.564 rem	0.282 rem	0.862 rem
TEDE	0.565 rem	0.283 rem	0.863 rem

The annual limit for the total effective dose equivalent (TEDE) is 5 rem. The annual limits to the lens of the eye, to the skin of the whole body, and to the skin of the extremities are:

a. A lens dose equivalent of 15 rems, and
b. A shallow-dose equivalent of 50 rem to the skin of the whole body or to the skin of any extremity.

Doses received in excess of the annual limits, including doses received during accidents, emergencies, and planned special exposures, must be subtracted from the limits for planned special exposures that the individual may receive during the current year and during the individual's lifetime.

The results show that the occupational dose to a member of the hatch closure team during the postulated event scenario occurring while the equipment hatch was open is within the annual dose limits defined in 10 CFR 20 Subpart C, Paragraph 20.1201 (Reference 11).

Review of the KNPP-provided documentation detailing radiological conditions within the containment during the postulated event generated the following comments.

1. The KNPP evaluation used 100% of containment volume for dilution. As good mixing in the containment can not be demonstrated, dilution should be limited to 50%.
2. Releases from both the RPV flange and the pressurizer safety vent path should be considered in the evaluation of the occupational dose.
3. The occupational dose limits defined in 10 CFR 20 apply to the sum of the dose received from internally deposited radioactive material (inhaled in this case) as well as dose received from external exposure. KNPP did not evaluate external exposure; however, this analysis shows that the immersion doses are small in comparison to the inhalation dose.

6.0 CONCLUSION

Based on a review of the anticipated tasks, procedures and predicted environmental conditions, ENERCON concludes that the hatch could have been closed prior to core uncovery and with acceptable environmental conditions for this type of work. The working conditions for the final portion of the task would have been performed under conditions that are less than desirable, but could have been performed successfully without the use of ice vests. While it is concluded that hearing protection would not be required for the specific conditions present, members of the response team entering containment would be wearing hearing protection. Radiation exposure to the response team would have remained within the regulatory limits.

Attachment 1: Kewaunee Time Line Development and Heat Stress Evaluation

PURPOSE

The purpose of this investigation is to determine the ability of KNPP personnel to close the containment equipment hatch in a timely manner given that a reactor head replacement rail was installed and resulted in a hatch closure interference. The timely closure would be required upon loss of off-site and on-site power resulting in a loss of RHR cooling. Closure must be accomplished prior to core uncovery and with acceptable environmental conditions for this type of work.

ASSUMPTIONS

The evaluation of task times assumes that the personnel involved are full time employees, physically fit, available when called out and are familiar with the reactor building layout. This assessment also assumes that the responding personnel are knowledgeable of the location of necessary tools, procedural requirements, and will have a means of communicating with the control room with a loss of all AC power. Further, it is assumed that during emergency conditions, the most expeditious method of clearing the hatch obstruction would be employed.

METHODOLOGY

The methodology used in this evaluation is as follows:

- Review of plant related investigations, CAP(s), studies, etc.
- Review of plant general arrangements and equipment hatch drawings
- Review of plant procedures related for hatch closure during normal and emergency modes
- Plant mode vs. most conservative configuration
- Review of environmental conditions as a function of time at required work locations(s) as well as ingress/egress to work area
- Location of equipment and supplies required for hatch closure
- Location of other items that may be required that are not specified in the hatch closure procedure
- Location of safety equipment
- Availability of required personnel
- Location and availability of emergency lighting including flashlights
- Interviews with plant personnel responsible for hatch closure during normal and emergency hatch closure modes
- Interviews with other plant personnel with similar experiences
- Review of regulations regarding heat stress
- Review of heat stress procedures/guidance from other sources

EVALUATION

The evaluated scenario is as follows based on information provided by References 1 and 2:

- Equipment is in transit inside the equipment hatch
- Cables and hoses are run through the equipment hatch
- Off-site power is lost
- On-site power is unavailable
- RHR system becomes inoperable
- Temporary lighting located outside the hatch is available using portable equipment. Once the hatch is closed, flashlights are available to provide necessary lighting.
- Containment isolation is required and Equipment Hatch closure is required
- Person in charge of Containment Hatch Closure is contacted by CR personnel
- Person in charge of Containment Hatch closure summons dedicated crew to assemble
- Dedicated personnel enter containment (if not already in) and commence execution of maintenance procedure
- Tools and supplies are available inside containment
- Hatch is in process of closure when personnel identify interference of rail with hatch
- Task supervisor is notified
- Task supervisor notifies Control Room
- Proposed resolution is developed
- Additional tooling is required
- Containment environment is changing. Temperature and humidity begin to increase.
- Personnel commences interference removal
- Interference removal is completed
- Containment hatch is over closure position
- Swing bolts are engaged and tightened as per procedure requirement. Temperature and humidity continue to increase due to isolation from the outside environment. Work is done with back-up lighting only.
- Bolts are tightened. NOTE: Only four bolts out of 12 are required for this evolution.
- Personnel exit the containment

Reviews of the general arrangement drawings indicate that the equipment hatch is at elevation 606' and the top of the shield wall where the steam path would exit to the reactor building environment is at 623' 7". Since the steam will be generated and released in the proximity of the reactor vessel and/or pressurizer, there will be a time delay before the atmospheric conditions by the equipment hatch will start to deteriorate, particularly with the equipment hatch open.

Based on our review we consider the following scenario to be "worst case":

- The plant has entered the applicable emergency condition. All non-essential personnel are considered no longer available
- At 34.5 minutes into the event, the Control Room requests Equipment Hatch closure to minimize exposure to the public and contacts person responsible for hatch closure as per Hatch Closure Point of Contact list

- Person responsible activates the response team
- Minimal clothing requirements are needed (coveralls and no respirators).
- Dress-up and reactor building entry, if required
- Backup lights (flashlights) are available in the reactor building
- Emergency lights are available outside the hatch
- Travel to Equipment Hatch area and verify all tooling required is available
- Remove cables, cords etc. from hatch
- Hatch is in process of being closed when rail interference is identified. No documentation is required due to emergency.
- Task supervisor notifies Control Room and recommends course of action
- Additional tools/equipment are required from outside the reactor building and additional personnel are required
- Remove interference
- Close Equipment Hatch
- Four swing bolts 90 degrees apart are engaged and tightened.
- Personnel exit the reactor building.

ENVIRONMENTAL ASSESSMENT

Temperature

The temperature profiles presented in Reference 17 were developed for determining the reactor building conditions using a particular vent path and assumed the hatch is closed at 84 minutes after loss of RHR. Hatch closure results in an increase in temperature, as well as pressure and humidity due to loss of venting capacity through the equipment hatch. As long as the hatch is open, the conditions in the vicinity of the hatch are not significantly changing from the initial conditions. Only after the hatch is closed will the environmental parameters start to increase.

The temperature based on best judgement is expected to be close to ambient for the entire evolution until the hatch is closed. Once the hatch is closed, the temperature is assumed to linearly rise to 120° F while the crew completes work in containment (to tighten the four swing bolts and to exit the building).

Pressure

Similarly, as indicated in the Temperature section above, the pressure will not increase as long as the hatch is open. Once the hatch is closed and the personnel are tightening the swing bolts, the pressure will start to linearly increase, but only by less than 0.5 psi over the next 30-40 minutes. Based on our judgement, this is considered tolerable by the workers. The air lock is provided with equalizing valves to enable opening of the air lock doors when a differential pressure exists. Hatch team personnel should be familiar with the operation of the air lock and equalizing valves.

Humidity

The relative humidity for the reactor building in general will start to increase prior to hatch closure and could reach 100% prior to hatch closure. But given the temperature and humidity conditions during the work period, it is judged to be acceptable. 100% humidity and 90-100° F temperature are acceptable working conditions for short durations. See Heat Stress section below.

Heat Stress

In order to assess the heat stress to workers, the tasks were evaluated as being light, moderate or heavy work. Walking to and from the area is considered light work, moving hoses and cables is considered moderate (medium) and movement, closing the equipment hatch, climbing ladders and bolt tightening is considered heavy work.

For temperatures between 100-120°F, the site specific Heat Stress procedure (Reference 4) requires ice vests for medium and high exertion levels and work time limits of 75 and 60 minutes, respectively. However, for short entries into hot environments (<15 minutes), ice vests are not required. Given the conditions under which the final efforts are taken, ice vests are not required as the work time at the higher exertion levels is expected to be within this time limit. Review of other heat stress procedures and guidelines indicates that work is permitted in areas with temperatures between 100 and 110° F for two hours with plain coveralls, and one hour between 110 and 120° F. The stay time at the worst temperatures expected (108 to 120° F) was 34 minutes, which is the time after which all heavy work has been completed.

The reactor building temperature will vary between 70° to 80° F (at the start of event) with 70°F (Reference 2) in the near vicinity of the hatch and 95-120° (at the end of event). The humidity is assumed to be 100% during the hatch closure evolution.

RESULTS

The containment Equipment Hatch can be closed in 190 minutes or less after a need for closure is identified and a hatch closure obstruction is identified. No significant heat stress is expected for personnel involved in the hatch closure since temperatures will be at acceptable working levels for the duration of the majority of the task steps. Once the hatch is closed, the local area temperature is expected to increase for the remaining steps of engagement and tightening of the four swing bolts and personnel egress. These steps will take about 40 minutes, which is well within the ability of the personnel to work at the specified conditions.

CONCLUSIONS AND RECOMMENDATIONS:

1. Containment Equipment Hatch closure can be accomplished safely within approximately 190 minutes after initiation.
2. Personnel heat stress is not considered an issue.

3. It is recommended that KNPP consider dry runs on future evolutions for similar tasks that could prevent Equipment Hatch closure.
4. Consider establishing Equipment Hatch maximum closure times.
5. Personnel on the hatch team should be encouraged to pre-hydrate prior to containment entry.

REFERENCES

1. NMC RCE 000668 Runway Interference Prevented Timely Closure of Containment Hatch Event date 10/14/04
2. KNPP Equipment Hatch Closure Issue Report 10 pages undated
3. ENERCON Proposal to KNPP DJM-N05-006/NMCK-N05-3001 dated February 14, 2005
4. NMC Corporate Procedure FP-IH-SAF-01 Rev. 0 Heat Stress Control Guidelines
5. WPSC Corrective Maintenance Procedure CMP-89A-02 Rev. D BLD- Containment Building Inner Equipment Hatch Opening and Closing Instructions
6. Containment Building Equipment Hatch Temporary Closure Plan dated 10-5-2004
7. KNPP Hatch Closure Points of Contact dated January 26, 2005
8. NRC GL 87-12 Loss of Residual Heat Removal (RHR) While the Reactor Coolant System (RCS) is Partially Filled
9. NRC GL 88-17 Loss of Decay Heat Removal
10. NIOSH DHHS Publication 86-113 Criteria for a Recommended Standard: Occupational Exposure to Hot Environments Chapters V and IX
11. NIOSH DHHS Publication 85-115 Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities
12. OSHA Technical Manual Section III Chapter 4 Heat Stress
13. EPRI TR-109445 Heat Stress Management Program for Power Plants: Clothing Update of EPRI NP-4453-L—1991 Report
14. Idaho NEEL PRD-2107 Rev. 3 Heat and Cold Stress
15. US Coast Guard Coast Guard Cutter Heat Stress Program
16. Various utilities Heat Stress and/or Control Programs
17. "Kewaunee Response to a Potential Loss of RHR at Reduced Inventory Conditions" by R. Ofstun, Westinghouse Electric Company; March, 2005

Attachment 2: Kewaunee Noise Level Evaluation

Noise Level:

Ref: Crosby Valve Engineering Handbook and API RP521 Noise Evaluation Methodology (see attached pages)

The noise level at 100 ft from the point of steam discharge is:

$L_{100}=$ $L+10LOG_{10}(0.29354*WkT/M)$

Where:

Mass flow, W = 14400 lbs/hr — Ref Fig. 4.2-13
Ratio of Sp heat of steam, k = 1.32 — Ref Crane Tech Paper 410
Molecular weight of steam, M = 18
Temperature of steam, T = 710.34 R at pressure of 30 psia
Pressure ratio, PR = Pinlet/Poutlet = 30/14.7 = 2.04 — Ref Fig. 4.2-12

$X = 10LOG_{10}(0.29354*WkT/M) = 53.43$

From Figure F7-7, at PR = 2.04, ordinate, L = 41

Noise level at 100 ft from the venting point = X+L

$L_{100} = 94.43$ decibels

Distance Correction:

The safety valve opening (Noise source) location is about 70 ft from the hatch location.

$Lp = L100 - 20LOG_{10}(r/100)$

Lp = Sound level at distance r, from the point of discharge in decibels
r = Distance from point of discharge, ft.
r = 70 ft
$L_{100}=$ 94.43

Lp = 97.53 decibels

This noise level is acceptable. Per OSHA 1910.95(b)(2), this noise level is acceptable for approximately three hours per day.

For a case with additional flow through flange gap, noise level will be lower.

Noise Level Calculations

The following formulae are used for calculating noise level of gases, vapors and steam as a result of the discharge of a pressure relief valve. The expressed formulae are derived from API Recommended Practice 521. Table T7-4 on page 7-11 lists relative noise levels.

$$L_{100} = L + 10\ LOG_{10}\ (0.29354\ \ W\ \ k\ \ T/M)$$

Where:

- L_{100} = Sound level at 100 feet from the point of discharge in decibels.
- L = Noise intensity measured as the sound pressure level at 100 feet from the discharge. Reference Figure F7-7 on page 7-11.
- W = Maximum relieving capacity, pounds per hour.
- k = Ratio of specific heats of the fluid. Reference Table T7-7 on page 7-26. (For steam, k = 1.3 if unknown.)
- T = Absolute temperature of the fluid at the valve inlet, degrees Rankine (°F + 460).
- M = Molecular weight of the gas or vapor obtained from standard tables or Table T7-7 on page 7-26. (For steam, M = 18)

When the noise level is required at a distance of other than 100 feet, the following equation shall be used:

$$L_p = L_{100} - 20\ LOG_{10}\ (r/100)$$

Where:

- L_p = Sound level at a distance, r, from the point of discharge in decibels.
- r = Distance from the point of discharge, feet.

Example #1

Gas/Vapor Mass Flow (lb/hr)

Fluid:	Natural Gas
Set Pressure:	210 psig
Overpressure:	10%
Back Pressure:	50 psig
Inlet Relieving Temperature:	120F
Molecular Weight:	19.0 (page 7-26)
Compressibility:	1
Selected Area:	0.503 square inches
Noise to be calculated at:	500 feet

Although the required capacity has been given, the noise level of the valve should be calculated on the total flow through the selected valve at the specified overpressure. Therefore the rated flow must first be calculated. The following formula is a rearrangement of the area calculation formula for gas and vapor in mass flow units (lb/hr). Reference page 5-3.

P_1 = Absolute relieving pressure
210 + 21 + 14.7 = 245.7 psia

K_b = 1.0

C = 344 from Table T7-7 on page 7-26.

K = 0.975

$$W = A\ P_1 C\ K\ K_b \sqrt{M} / \sqrt{TZ}$$

$$W = (0.503)(245.7)(344)(0.975)(1)(\sqrt{19}) / \sqrt{(580)(1)}$$

W = 7502 lb/hr

T = 120F + 46F = 580R

P_b = 50 psig

Continuing with the noise level calculation:

$$L_{100} = L + 10\ LOG_{10}\ (0.29354\ \ W\ \ k\ \ T/M)$$

Where:

- PR = Absolute relieving pressure/absolute back pressure
  = $P_1 / (P_b + 14.7)$ = 245.7/(50 + 14.7) = 3.8
- L = 54.5 (Figure F7-7, page 7-11.)
- k = 1.27 (Table T7-7, page 7-26.)
- W = 7502 lb/hr
- M = 19
- T = 120F + 460F = 580R

L_{100}=54.5+ 10 LOG_{10} [(0.29354)(7502)(1.27)(580)/(19)]

L_{100}=103.8 decibels

At a distance of 500 feet:

$$L_p = L_{100} - 20\ LOG_{10}\ (r/100)$$

Where:

r = 500 feet

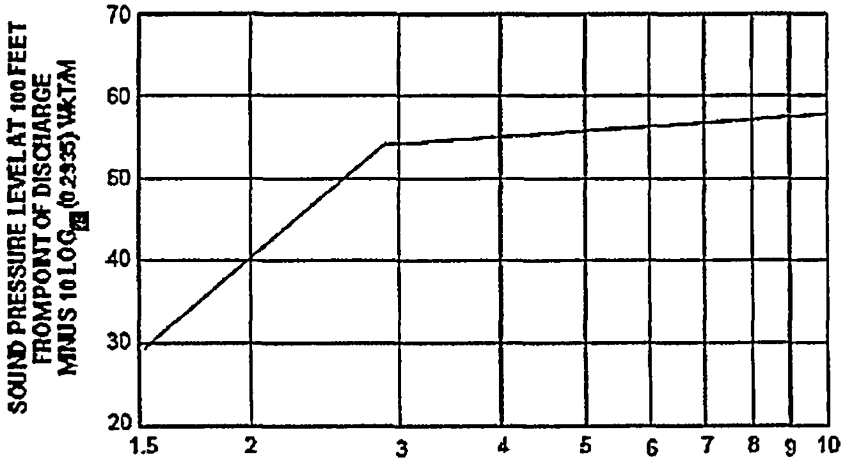
L_p = 103.8 - 20 LOG_{10} (500/100)

L_p = 89.9 decibels

Noise Intensity

(At 100 feet from the Discharge)

Figure F7-7



Absolute Relieving Pressure / Absolute Back Pressure

Table T7-4

Relative Noise Levels			
130	Decibels	-	Jet Aircraft on Takeoff
120	Decibels	-	Threshold of Feeling
110	Decibels	-	Elevated Train
100	Decibels	-	Loud Highway
90	Decibels	-	Loud Truck
80	Decibels	-	Plant Site
70	Decibels	-	Vacuum cleaner
60	Decibels	-	Conversation
50	Decibels	-	Offices

Regulations (Standards - 29 CFR)

Occupational noise exposure. - 1910.95

1910.95(a)
Protection against the effects of noise exposure shall be provided when the sound levels exceed those shown in Table G-16 when measured on the A scale of a standard sound level meter at slow response. When noise levels are determined by octave band analysis, the equivalent A-weighted sound level may be determined as follows:

FIGURE G-9 - Equivalent A-Weighted Sound Level

Equivalent sound level contours. Octave band sound pressure levels may be converted to the equivalent A-weighted sound level by plotting them on this graph and noting the A-weighted sound level corresponding to the point of highest penetration into the sound level contours. This equivalent A-weighted sound level, which may differ from the actual A-weighted sound level of the noise, is used to determine exposure limits from Table 1.G-16.

1910.95(b)
1910.95(b)(1)
When employees are subjected to sound exceeding those listed in Table G-16, feasible administrative or engineering controls shall be utilized. If such controls fail to reduce sound levels within the levels of Table G-16, personal protective equipment shall be provided and used to reduce sound levels within the levels of the table.

1910.95(b)(2)
If the variations in noise level involve maxima at intervals of 1 second or less, it is to be considered continuous.

TABLE G-16 - PERMISSIBLE NOISE EXPOSURES (1)

Duration per day, hours	Sound level dBA slow response
8	90
6	92
4	95
3	97
2	100
1 1/2	102
1	105
1/2	110
1/4 or less	115

Footnote (1): When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. If the sum of the following fractions: C(1)/T(1) + C(2)/T(2) C(n)/T(n) exceeds unity, then, the mixed exposure should be considered to exceed the limit value. Cn indicates the total time of exposure at a specified noise level, and Tn indicates the total time of exposure permitted at that level. Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level.

Attachment 3: Kewaunee Equipment Hatch Closure Event Radiological Evaluation

Purpose

Review the KNPP-provided documentation detailing radiological conditions within the containment during a postulated event scenario that could occur while the equipment hatch was open and obstructed. Estimate the expected exposure to the hatch closure team during this evolution.

Background

During the KNPP 2004 refueling outage, the equipment hatch was opened to facilitate ingress/egress of materials and equipment. In order to facilitate movement of the reactor head, a runway system was installed which extended from the reactor head stand area inside containment to approximately twenty feet outside containment. The runway system was designed with a splice such that a portion of the runway system could be removed to allow for equipment hatch closure during refueling operations.

On 10/14/04, day 6 of the outage, in preparation for the reactor vessel head lift, an attempt to close the equipment hatch was made. It was revealed that the remaining rail system interfered and prevented putting the hatch in position for closure. It was determined that the procedural requirements and approved plan for reinstalling the hatch in the event there was an emergent need would have been delayed.

The plant was in the following configuration during the event. The Pressurizer Safety valve was removed, Diesel Generator A was out of service, the RCS was drained to six inches below the reactor vessel flange, the Steam Generators were in wet lay-up, the Containment Hatch was open, and for a portion of the time the reactor head studs were de-tensioned. If RHR cooling were lost under these conditions, the RCS would begin to heat up and eventually boil. Steam would be released to containment through the flange gap and the pressurizer safety valve piping.

Summary of Results

A duration of 190 minutes (11,400 seconds) was used in evaluation of doses to workers closing the equipment hatch. Two event scenarios designed to represent realistic conditions were considered. Case 1 considered steam releases through the Pressurizer safety valve piping determined from a Gothic analysis of the KNPP RCS and containment response to a loss of AC power and RHR cooling at 3 days after shutdown. Case 2 considered steam releases through the Pressurizer safety valve piping and reactor head gap using a Gothic analysis of the KNPP RCS and containment response to a loss of AC power and RHR cooling at 4 days, 9 hours and 50 minutes after shutdown.

The release path to containment for Case 1 was through the pressurizer safety valve piping. For Case 1, the Gothic analysis showed that releases to the containment begin approximately 11,100 seconds after the loss of RHR cooling and the beginning of the hatch closure evolution. Workers would therefore only be exposed to elevated activity for approximately 5 minutes (300 seconds). A total of 1.24E+03 lbm of reactor coolant was released late in the period where the hatch closure team is in the containment.

The release path to containment for Case 2 was through the RPV head gap as well as the pressurizer safety valve piping. For Case 2, the Gothic analysis showed that releases to the containment began much sooner with boiling in the RPV occurring approximately 35 minutes after the loss of RHR. Workers tasked with removing the obstruction and closing the hatch would be exposed to elevated activity levels for approximately 155 minutes (9300 seconds). A total of 1.20E+04 lbm of reactor coolant was released during the period where the hatch closure team was in the containment. Case 2 is clearly bounding with regard to radiological conditions and is selected for evaluation of the occupational dose for this hypothetical event.

The TEDE dose is defined as the sum of the deep dose equivalent for external exposures and the committed dose equivalent for internal exposures. The deep dose equivalent and the committed dose equivalent calculated for the postulated event are given in Table 1. The dose to the skin of the whole body was also calculated. The skin dose is taken as an estimation of the dose to the lens of the eye. Doses are provided for releases assuming dilution in 50% (Case 2a) and 100% (Case 2b) of the containment volume. Generally, even in instances where good mixing can be demonstrated, dilution is limited to 50% of the release volume.

The Derived Air Concentration (DAC) inhalation dose calculation methodology applied herein is based on a reference man working under conditions of light work (inhalation rate 1.2 cubic meters of air per hour). If the work activity level is light from start to 95 minutes, moderate to high from 95 to 156 minutes and light from 156 to 190 minutes, the *inhalation* doses would be increased by a factor of 1.28. Case 2c provides occupational doses adjusted for an increased work activity level assuming dilution of the releases in 50% of the containment volume.

Table 1
DOSE SUMMARY

	Case 2a	Case 2b	Case 2c
Skin Dose	0.001 rem	0.001 rem	0.001 rem
Dose to Lens of the Eye	0.001 rem	0.001 rem	0.001 rem
Deep Dose Equivalent	0.001 rem	0.001 rem	0.001 rem
Committed Dose Equivalent	0.564 rem	0.282 rem	0.862 rem
TEDE	0.565 rem	0.283 rem	0.863 rem

The annual limit for the total effective dose equivalent (TEDE) is 5 rem. The annual limits to the lens of the eye, to the skin of the whole body, and to the skin of the extremities are:

a) A lens dose equivalent of 15 rems, and
b) A shallow-dose equivalent of 50 rem to the skin of the whole body or to the skin of any extremity.

Doses received in excess of the annual limits, including doses received during accidents, emergencies, and planned special exposures, must be subtracted from the limits for planned special exposures that the individual may receive during the current year and during the individual's lifetime.

Conclusions

As given in the results section above, this evaluation shows that the occupational dose to a member of the hatch closure team during the postulated event scenario occurring while the equipment hatch was open is within the annual dose limits defined in 10 CFR 20 Subpart C, paragraph 20.1201. Review of the KNPP-provided documentation detailing radiological conditions within the containment during the postulated event generated the following comments.

1. The KNPP evaluation used 100% of containment volume for dilution. As good mixing in the containment can not be demonstrated, dilution should be limited to 50%.
2. Releases from both the RPV flange and the pressurizer safety vent path should be considered in the evaluation of the occupational dose.
3. The occupational dose limits defined in 10 CFR 20 apply to the sum of the dose received from internally deposited radioactive material (inhaled in this case) as well as dose received from external exposure. KNPP did not evaluate external exposure, however; this analysis shows that the immersion doses are small in comparison to the inhalation dose.

References

1. 10 CFR 20, Standards for Protection Against Radiation
2. Regulatory Guide 8.34, "Monitoring Criteria and Methods to Calculate Occupational Radiation Doses", July 1992
3. NUREG 1736, "Consolidated Guidance: 10 CFR Part 20 – Standards for Protection Against Radiation", October 2001
4. "Kewaunee Response to a Potential Loss of RHR at Reduced Inventory Conditions" by R. Ofstun, Westinghouse Electric Company; March 2005.
5. FGR 12, Federal Guidance Report No. 12, "External Exposure To Radionuclides In Air, Water, And Soil", Keith F. Eckerman And Jeffrey C. Ryman, September 1993
6. Kewaunee RHR sample results dated 10/12/04 04:49, attached.
7. Exposure Factors Handbook, Environmental Protection Agency, August 1997

Acceptance Criteria

Occupational dose limits for adults are given in 10 CFR 20 Subpart C, Paragraph 20.1201. [Reference 1] The licensee shall control the occupational dose to individual adults, except for planned special exposures under § 20.1206, to the following dose limits:

1. An annual limit, which is the more limiting of:
   a. The total effective dose equivalent being equal to 5 rems; or
   b. The sum of the deep-dose (immersion) equivalent and the committed dose equivalent to any individual organ or tissue other than the lens of the eye being equal to 50 rems (0.5 Sv).

2. The annual limits to the lens of the eye, to the skin of the whole body, and to the skin of the extremities, which are:
   a. A lens dose equivalent of 15 rems (0.15 Sv), and
   b. A shallow-dose equivalent of 50 rem (0.5 Sv) to the skin of the whole body or to the skin of any extremity.

Doses received in excess of the annual limits, including doses received during accidents, emergencies, and planned special exposures, must be subtracted from the limits for planned special exposures that the individual may receive during the current year and during the individual's lifetime. The assigned deep-dose equivalent must be for the part of the body receiving the highest exposure. The assigned shallow-dose equivalent must be the dose averaged over the contiguous 10 square centimeters of skin receiving the highest exposure.

Assumptions

1. Steaming rates utilized in this computation were calculated using the results of Gothic analyses of the postulated event scenario. Two release cases were considered. The first case corresponds to KNPP Case 1. Initial conditions were specified for this analysis to provide a conservative estimate of the containment conditions at three days after shutdown. Initial conditions were as follows: decay heat at 8 MW, RCS level at –0.5 ft, RCS average temperature of 118° F and the RCS vented through pressurizer safety valve piping. The KNPP containment model was initialized to a temperature of 80 F and vented to atmosphere. The second case corresponds to KNPP Case 2. Initial conditions were specified for this analysis to provide a realistic estimate of the containment conditions at 4 days, 9 hours and 50 minutes after shutdown. Initial conditions were as follows: decay heat at 6.82 MW, RCS level at –0.5ft, RCS average temperature of 114 F, RCS vented through a pressurizer safety valve, RPV studs de-tensioned and the flange gap open with an area of 0.1226 sq. ft. The KNPP containment model was initialized to a temperature of 80 F and vented to atmosphere.

   The release path to containment for Case 1 was through the pressurizer safety valve piping. For Case 1, the Gothic analysis showed that releases to the containment began approximately 11,100 seconds after the loss of RHR cooling and the beginning of the hatch closure evolution. Workers would therefore only be exposed to elevated activity for approximately 5 minutes (300 seconds). A total of 1.24E+03 lbm of reactor coolant was released late in the period where the hatch closure team was in the containment.

The release path to containment for Case 2 was through the RPV head gap as well as the pressurizer safety valve piping. For Case 2, the Gothic analysis showed that releases to the containment began much sooner with boiling in the RPV occurring approximately 35 minutes after the loss of RHR. Workers tasked with removing the obstruction and closing the hatch would be exposed to elevated activity levels for approximately 155 minutes (9300 seconds). A total of 1.20E+04 lbm of reactor coolant was released during the period where the hatch closure team was in the containment. Case 2 is clearly bounding with regard to radiological conditions and is selected for evaluation of the occupational dose for this hypothetical event.

2. Steaming rates (lbm/sec) were provided by KNPP for the RPV flange gap and the Pressurizer safety vent path. The total steaming rate is taken as the sum of the two except where the flow is negative in which case the negative flow is neglected.
3. The event scenario evaluated has an assumed duration of 190 minutes (3.167 hours).
4. The activity levels in the RHR sample dated 10/12/04 04:49 is used for the Reactor Coolant System (RCS) activity. This sample provided the highest activity levels during the time period where the containment hatch was obstructed. This activity will provide conservative RCS steaming releases.
5. 100% of the activity in the coolant released is conservatively assumed to be released to the containment. No partition factor is applied. No removal mechanisms such as filtration, plate-out, or ventilation exhaust are assumed. Additionally, no protection factors associated with equipment such as respirators or eye protection are applied.
6. Credit for mixing of the steaming releases in the primary containment is conservatively limited to 50% for Cases 2a and 2c since good mixing can not be demonstrated. Given that the equipment hatch is open for much of the event scenario, there would be some natural circulation.
7. For most geometries, the lens of the eye dose coefficients for photons are comparable to the skin coefficients. Also since the lens of the eye is deeper than the 7 mg/cm^2 depth assumed for the skin, it is assumed that the skin dose coefficient for electrons is a conservative estimator of the lens of the eye absorbed dose. Therefore, the skin dose is taken as an estimation of the dose to the lens of the eye.
8. The DAC method for calculation of the CEDE for inhalation is based on a breathing rate associated with "light" labor. Although the conditions surrounding closure of the containment hatch would be considered stressful, the DAC method is considered acceptable since the breathing rate for light labor is comparable to that assumed for the operator in the control room under accident conditions.

   If the activity level is light from start to 95 minutes, moderate to high from 95 to 156 minutes and light from 156 to 190 minutes, the *inhalation* doses would be increased by a factor of 1.28. This is based on the use of an effective ventilation rate of 1.83 m3/hr in determination of the DAC as compared to a value of 1.2 m3/hr previously assumed. The external doses would not be changed.

Methodology

In accordance with 10 CFR 20 Subpart C, paragraph 20.1201 [Reference 1], DAC and Annual Limit on Intake (ALI) values are presented in table 1 of Appendix B to part 20 and may be used to determine an individual's occupational dose and to demonstrate compliance with the occupational dose limits. NUREG 1736 [Reference 3] provides program specific guidance regarding 10 CFR 20. It consolidates references to radiation protection guidance from

Regulatory Guides, NUREG reports and Information Notices. Regulatory Guide 8.034 [Reference 2] provides specific methods acceptable to the NRC for calculation of occupational doses. The guidance and requirements of 10 CFR 20, NUREG 1736 and Regulatory Guide 8.034 will be applied herein.

Two dose cases were considered. The first case, Case 2a, corresponds to KNPP Case 2. Initial conditions were specified for this analysis to provide a realistic estimate of the containment conditions at 4 days, 9 hours and 50 minutes after shutdown. The dilution of the release in containment is limited to 50%. The second case, Case 2b, corresponds to KNPP Case 2 also. However, 100% of the containment volume is used for dilution of the release. This is non conservative as good mixing in the containment can not be demonstrated.

The DAC inhalation dose calculation methodology applied herein is based on a reference man working under conditions of light work (inhalation rate 1.2 cubic meters of air per hour). If the activity level is light from start to 95 minutes, moderate to high from 95 to 156 minutes and light from 156 to 190 minutes, the inhalation doses would be increased by a factor of 1.28. Case 2c provides occupational doses adjusted for an increased activity level assuming dilution of the releases in 50% of the containment volume.

Calculations

The activity postulated to be released to containment is based on a sample of the RHR system taken on 10/12/04 at 04:49 and steaming rates determined from Gothic models of the event scenario. KNPP provided this data. The "total effective dose equivalent" identified in the acceptance criteria given above is defined as the sum of the "deep dose (immersion) equivalent" for external exposures and the committed dose equivalent" for internal exposures.

The internal dose component needed for evaluation of the total effective dose equivalent is the committed effective dose equivalent. The committed effective dose equivalent is the 50-year effective dose equivalent that results when radioactive material is taken into the body, whether through inhalation, ingestion, absorption through the skin, accidental injection or introduction through a wound. The contribution from all occupational intakes is added for these modes over a year. For this evaluation the appropriate mode of material intake for consideration is inhalation. Absorption through the skin is neglected since personnel permitted access to the KNPP containment must wear protective clothing (coveralls). There are several methods of calculating the committed dose equivalent from inhaled radioactive materials. In this analysis, the DAC method described in RG 8.034, Section 3.3 will be used.

The stochastic DAC is calculated from the stochastic ALI by the following equation:

$$DAC_{stoc,i} = \frac{ALI_{stoc,i}}{2.4\,x\,10^9}$$

Where:

$DAC_{stoc,i}$ = The stochastic DAC for radionuclide i (µCi/ml)
$ALI_{stoc,i}$ = the stochastic ALI for radionuclide i (µCi)
2.4×10^9 = the volume of air inhaled by a worker in a work year.

DAC and ALI values are presented in Table 1 of Appendix B to 10 CFR Part 20.

$$H_{i,E} = \frac{5C_i t}{2000\,DAC_{stoc,i}}$$

Where:

$H_{i,E}$ = Committed effective dose equivalent for radionuclide i (rems)
C_i = the airborne concentration of radionuclide i to which the worker is exposed (µCi/ml)
t = the duration of the exposure (hours)

The external dose component needed for evaluation of the total effective dose equivalent is the deep dose (immersion) equivalent. External dose is typically determined by the use of individual monitoring devices such as film badges and dosimeters. For postulated radiological conditions such as this, air immersion dose to the whole body or skin of an individual can be determined using the following equation:

$$D_{c,n} = \int C_n(t)\,dt\,(DCF_{c,n} / G_F)$$

Where:

C_n = the instantaneous concentration of the radionuclide n in the compartment.
$DCF_{c,n}$ = the immersion (cloud) dose conversion factor for nuclide *n*.

The Murphy-Campe geometric factor, G_F, relates the dose from an infinite cloud to the dose from a cloud of volume V as:

$$G_F = \frac{1173}{V^{0.338}}$$

Immersion dose conversion factors are provided in Federal Guidance Report 12 [Reference 5].