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SUBJECT: Radiological Hazards from Rupture of the Secondary Coolant System of the 10 Mw ESCR

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I STATEMENT OF PROBLEM

1. To investigate the radiological hazards associated with rupture of the secondary loop of ESCR type reactors.
2. To determine the permissible radiation level from the secondary sodium lines of the 10 Mw ESCR and to evaluate the corresponding radioactive concentration in the secondary loop and the maximum permissible effective activation flux in the intermediate heat exchanger.

II SUMMARY OF RESULTS AND RECOMMENDATIONS

A. Results

1. Radiation Levels and Radioactive Concentration in Secondary Loop

The radiation levels from the 10 Mw ESCR secondary system coolant lines, during normal operation, are shown in Fig. I as a function of line diameter and Na²⁴ concentration in the sodium.

The 10 Mw ESCR has 4" and 6" diameter secondary coolant lines. In order to limit the radiation level to 7.5 mr/hr at one foot from the surface of the 6" diameter line, the Na²⁴ concentration in the sodium must not exceed 0.06 uc/gm.

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2. Permissible Activation Flux Level

The effective thermal neutron activation flux level in the intermediate heat exchanger is shown in Fig. II as a function of C_0 , the Na^{24} concentration in the secondary loop and R, the ratio of the time spent in the flux field to the time spent in making one cycle.

In order to limit the Na^{24} concentration in the secondary loop of the 10 Mw ESCR to less than 0.06 $\mu\text{c/gm}$ (7.5 mr/hr at 1 foot from a 6" line), the equivalent thermal flux level at the intermediate heat exchanger must be less than 3.5×10^6 n/cm²/sec.

3. Radiological Hazards from Accidents Involving the Release of Sodium

The average concentration of Na^{24} in the reactor room atmosphere can be determined from Fig. III if it is assumed that all the sodium in the secondary system is released to the room and burns and the ventilation system is inoperative. The corresponding Na^{24} concentration in the reactor room with the ventilation system on can be obtained from Fig. IV. Fig. V shows the downwind concentration of Na^{24} resulting from the release and burning of all the secondary sodium on an open pad area exterior to the reactor building.

Using the above curves and known parameters for the 10 Mw ESCR, it can be shown that the radiological hazards resulting from the release and burning of sodium are not of a serious nature. The maximum concentration attained in the room atmosphere is less than 4 times the Maximum Permissible Concentration (MPC) for Na^{24} if all the secondary sodium is released to the reactor room and burns ($\text{MPC} = 5 \times 10^{-6} \mu\text{c/cc}$)⁽¹⁾. If ventilation is continued, the air concentration would be below the MPC in less than one hour. On the other hand, if the sodium is released and burns on the open pad area, the maximum downwind concentration would be less than MPC at all distances beyond 14 meters from the pad area.

4. Toxicological Hazards from Release of Sodium

Because of the low Na^{24} specific activity permitted in the secondary loop, the toxicological hazards from the release of secondary sodium are more serious than the radiological hazards. If all the secondary sodium in the 10 Mw ESCR is released to the room and burns, the sodium concentration in the room atmosphere would approach 1.4×10^5 times the Maximum Acceptable Concentration (MAC) for sodium in air ($\text{MAC} = 2 \text{ mg/m}^3$)⁽²⁾. This concentration could not be tolerated unless adequate respiratory protection were employed. With a ventilation rate of 2 air

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changes per hour, the concentration in the room would be below the MAC in 6 hours.

If all the secondary sodium is released and burns in an open pad area (2000 sq ft)⁽³⁾, the maximum sodium concentration in the center of the cloud and for average meteorological conditions would be 4.2×10^4 times the MAC at 14 meters (the corresponding Na^{24} concentration would be equal to the MPC). However, such a cloud would have the desirable advantage of being visible and could be avoided by personnel in its path. If no fallout occurred, the maximum sodium concentration in the center of the cloud would be below the MAC at 6,000 meters.

The downwind concentration could be reduced if the burning time can be increased or the area covered by the spill decreased. This can be accomplished by limiting the pad area or placing the secondary coolant lines in a trench (a covered trench would be preferable).

B. Recommendations

1. The radiation level one foot from the surface of the secondary system lines must be less than 0.75 mr/hr if they are located in areas normally occupied by personnel and not more than 7.5 mr/hr* if they are located in areas not normally occupied by personnel. As a result, it is recommended that the latter criteria be used for the ESCR reactors.
2. The permissible Na^{24} concentration in the secondary loop of the 10 Mw ESCR must be less than 0.06 $\mu\text{c/gm}$ to limit the radiation level from an unshielded 6" secondary line to 7.5 mr/hr at a distance of 1 foot. The corresponding equivalent thermal neutron activation flux level in the intermediate heat exchanger must be less than 3.5×10^6 n/cm²-sec.
3. From the results of the analysis which has been performed, it can be seen that, in the event of an accident, the toxicological hazards are more severe than the radiological hazards. Therefore, appropriate design factors should be incorporated in the ESCR to minimize the toxicological hazard. The amount of sodium in the secondary loop should be kept to a minimum. The secondary loop

* Radiation levels above 7.5 mr/hr may be permissible (or at least economically justifiable) if the secondary system lines could be located in remote areas not normally accessible to personnel. This scheme for locating the secondary coolant lines could permit a corresponding decrease in the amount or type of (neutron) shielding required between the reactor and intermediate heat exchanger. If the need for such a relaxation in radiation levels is necessary, further analysis of the proposed design layout would be required to determine the permissible levels of radiation from the system and in adjacent areas.

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should be placed in a trench (or some other confining medium) to confine sodium leakage to a minimum area. The trench should be covered or enclosed to reduce the burning rate, and thus the resultant air concentrations and the amount of sodium which could become airborne.

4. In the analysis which has been performed, no account was taken of the effects of sodium fallout from the cloud which is formed as a result of the fire. It is conceivable that if most of the sodium particulates formed in the burning process are of relatively large size, fallout effects could reduce the off-site cloud concentrations by several orders of magnitude. Also, since the time for the sodium to burn and for the cloud to pass ~~are~~ are relatively short, a short term exposure to a cloud containing levels considerably above the MAC may be permissible.

However, very meager information is readily available concerning particle sizes or permissible short term exposures to sodium smokes. If redesign of the secondary loop, to minimize the burning rate or to reduce the airborne sodium to acceptable levels, is impractical or uneconomical, a program to investigate these factors should be initiated at AI. Some work to determine particle sizes formed from burning sodium is presently underway at AI.

III METHOD USED, DESCRIPTION OF EQUIPMENT AND CALCULATIONS

A. Description of System and Assumptions

The particular system under consideration in this analysis is the secondary sodium system. The sodium in this system is pumped through a circuit which passes through a low flux area in the reactor and consequently becomes activated. The complete system is described in NAA-SR-Memo 4633⁽³⁾. A block diagram of the portions of the system which are of interest in this analysis is shown in the following sketch.

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The most serious radiological hazard associated with the secondary loop is due to the Na^{24} activity which it contains. During normal operation, the gamma radiation from the Na^{24} will cause radiation fields in the vicinity of the lines carrying the secondary sodium. In the event of an accident, the danger lies in the release of the sodium from the secondary system to either the reactor building or the open pad area. If such a release occurred, the sodium could burn and create an inhalation hazard to on-site or off-site personnel.

All the calculations which follow were made using the assumptions noted below:

- 1) The reactor has operated for a sufficient length of time at full power to cause an equilibrium concentration of Na^{24} in the secondary loop (at least one week).
- 2) Radiation hazards from the system are based on the radiation level one foot from the surface of the pipes carrying the sodium. Personnel exposure at closer distances is unlikely, particularly since the pipes will be covered with insulation. The permissible radiation levels from lines located in routinely occupied areas is 0.75 mr/hr whereas it is 7.5 mr/hr if the lines are located in areas accessible to, but not normally occupied by, personnel.
- 3) An accident is postulated which considers the complete rupture of a secondary sodium line with the loss of all the coolant to an area below the system. For completeness, it is assumed that the event could occur either in the building or out in the open. In either case, the spill would be confined to a maximum area defined by the perimeter of the building or pad. Complete burning of the sodium is then assumed.

B. Unit Basis for Calculations

Because several of the nuclear and physical parameters have not been firmly established for the ESCR, the analysis is made and presented on the basis of a unit value for several of the parameters (diameter of secondary piping, quantity of sodium in secondary loop, area of building or pad, building volume, etc.). In this way the information is made less specific and will be more useful if any of these parameters change or larger reactors are planned. All that need be done for a specific reactor is to multiply the general solution by the known parameters.

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C. Radiation Level from Secondary System Lines

The radiation level one foot from the surface of a secondary system line is shown in Figure I in the appendix. The curve shows the radiation level in mr/hr as a function of coolant line diameter in inches and Na²⁴ concentration in the sodium in $\mu\text{c/gm}$. The method of calculating the radiation level is shown in the appendix.

The radiation levels and permissible Na²⁴ concentration in the secondary system lines, for the 10 Mw ESCR described in NAA-SR-Memo 4633(3), can be obtained from the curve in Figure I. The present ESCR secondary coolant system consists of both 4" and 6" diameter lines. In order to limit the radiation level to 7.5 mr/hr at one foot from the 6" diameter lines, the Na²⁴ concentration in the sodium must not exceed 0.06 $\mu\text{c/gm}$.

D. Permissible Flux Level at Intermediate Heat Exchanger

The relationship giving the concentration of Na²⁴ in the secondary sodium as it circulates through the secondary loop and is irradiated by neutrons during its passage through the intermediate heat exchanger is,

$$C_o = \frac{\phi_{th} \Sigma_a R}{3.7 \times 10^4} \quad (1)$$

where:

C_o = Na²⁴ concentration (at equilibrium) in $\mu\text{c/gm}$

ϕ_{th} = neutrons/cm²-sec (average activation flux level in the heat exchanger assuming that the flux is all thermal neutrons)

Σ_a = macroscopic activation cross section in cm⁻¹

$$= \frac{\rho A \sigma_a}{W}$$

= density of sodium = 0.9 gm/cc (assumed)

A = Avogadro's number = 0.602×10^{24} atoms/mole

σ_a = microscopic activation cross section for sodium at 650°F(3), 0.324×10^{-24} cm²/atom

W = atomic weight of sodium = 23

R = ratio of time spent in the flux field to the time spent making one cycle.

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Solving for ϕ_{th} ,

$$\phi_{th} = \frac{C_0 \times 3.7 \times 10^4}{0.9 \times 0.602 \times 0.324 \times R} \quad (2)$$
$$= 4.85 \times 10^6 \frac{C_0}{R} \text{ n/cm}^2/\text{sec}$$

This relation is plotted in Figure II with the flux as a function of C_0 and R . For the 10 Mw ESCR:

$$C_0 = 0.06 \text{ uc/cc}$$

$$R = \frac{\text{average tube length of heat exchanger}}{\text{sodium velocity through exchanger}} \div \frac{\text{volume of Na in loop}}{\text{flow rate in loop}} \quad (3)$$
$$= \frac{40 \text{ ft}}{3.95 \text{ ft/sec} \times 60 \frac{\text{sec}}{\text{min}}} \div \frac{600 \text{ gal}}{500 \text{ gpm}}$$
$$= 0.0835$$

Substituting in Equation 2 yields $\phi_{th} = 3.5 \times 10^6 \text{ n/cm}^2\text{-sec}$ as the permissible activation flux level.

E. Release of Activity in Building During an Accident

1. System and parameters

The basic system was shown in the sketch in section III, A above. The parameters and constants necessary for analysis of the hazards are:

Loop Characteristics

M = mass of sodium in loop, lbs

Q_0 = total amount of radioactive material in loop during operation (equilibrium conditions), μc

C_0 = Na^{24} concentration in loop during operation (equilibrium conditions), $\mu\text{c/gram of Na}$

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Building Characteristics

- A = building area or area covered by spill, ft^2
B = burning rate of the sodium which is released, lbs/hr-ft^2
T = time during which the sodium burns, hours
F = fraction of activity which becomes airborne
V = building volume, ft^3
P = building ventilation or leakage rate, air changes/hr
 $C_2 = \text{Na}^{24}$ concentration in room air, $\mu\text{c/cc}$

2. Rate and duration of incident

The accident which is assumed consists of a break in the secondary coolant line which subsequently releases all the sodium in the loop to the reactor room or building housing the loop. Complete combustion of the released sodium is assumed. The burning time is then related to the mass of sodium in the loop and the area of the spill by the following expression:

$$ABT = M \quad (4)$$

where $B = 4 \text{ lbs/hr-ft}^2$ (4)

Hence,

$$T = \frac{M}{AB} = \frac{M}{4A} \text{ hours} \quad (5)$$

A plot of this expression is shown on Figure III, curve A, where the burning time in hours (T) is plotted as a function of the pounds of sodium in the loop (M) and the area covered by the spill (A).

For the 10 Mw ESCR, the amount of sodium in the secondary loop has been estimated at approximately 5000 lbs⁽⁵⁾ and the reactor building floor area at 3000 sq. ft⁽³⁾. Therefore, from curve A of Figure III, the time for a spill in the reactor building to completely burn out would be not less than 0.42 hours.* An

* Complete combustion or sustained combustion at a rate of 4 lbs/hr-ft² is unlikely if the ventilation system is inoperative. The assumption of complete burning is useful however since it represents the upper limit for the worst case.

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obvious way of increasing the burning time would be to limit the area which the spill could cover. Increasing the time by at least a factor of 10 should be feasible by appropriate design (e.g., locating the secondary coolant pipes in a trench).

3. Concentration of radioactivity in building atmosphere

a. General case

It is assumed that the burning sodium releases radioactivity to the room atmosphere at a constant rate until the fire goes out. (The decay of the source is neglected because the burning time is relatively short compared to the Na^{24} half life.) The concentration of radioactivity in the room air (C_2) as a function of time during burning (T) and time after burning has stopped (t) is then described by the following relations (fallout neglected).

$$C_2(T) = \frac{A B C_0 F}{V(\lambda + P)} \left[1 - e^{-(\lambda + P)T} \right] \times \frac{454 \text{ grams/lb}}{28.3 \times 10^3 \text{ cc/ft}^3}$$

$$= \frac{A B C_0 F \times 1.6 \times 10^{-2}}{V(\lambda + P)} \left[1 - e^{-(\lambda + P)T} \right] \quad (6)$$

$$C_2(t) = \frac{A B C_0 F \times 1.6 \times 10^{-2} \left[1 - e^{-(\lambda + P)T} \right] \left[e^{-(\lambda + P)t} \right]}{V(\lambda + P)} \quad (7)$$

For the case with no ventilation or leakage out of the building, $P = 0$; $\lambda = 0.693/15 \text{ hrs} = 0.046 \text{ hrs}^{-1}$; $B = 4 \text{ lbs/hr-ft}^2$

$$C_2(T) = \frac{A C_0 F}{V} \times 1.38 (1 - e^{-0.046T}) \quad (8)$$

$$C_2(t) = \frac{A C_0 F}{V} \times 1.38 (1 - e^{-0.046T}) (e^{-0.046t}) \quad (9)$$

For the case with a ventilation or leakage rate of 2 air changes per hour,

$$C_2(T) = \frac{A C_0 F}{V} \times 0.0312 (1 - e^{-2.046T}) \quad (10)$$

$$C_2(t) = \frac{A C_0 F}{V} \times 0.0312 (1 - e^{-2.046T}) (e^{-2.046t}) \quad (11)$$

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Equations (8) and (9), for the case in which the building ventilation system is inoperative, are plotted in Figure III, curve B, with the quantity AC_0F/V set equal to 1. Equations (8) and (9) represent a maximum theoretical concentration since, in actual practice, it is unlikely that combustion could be sustained if there were no building ventilation.

In order to find the Na^{24} concentration in the room atmosphere for a given reactor system of the ESCR type, the following steps must be followed.

- (a) Given the pounds of sodium in the loop (M) and the area of the room or spill in ft^2 (A), find the burning time (T) from curve A of Figure III.
- (b) Knowing T, the value of C_2/K can be found from curve B for any desired time after the incident.
- (c) Evaluate the quantity AC_0F/V from the given values of the spill area in sq. ft (A), the room volume in cu. ft (V), the fraction of the sodium which becomes airborne (F), and the initial concentration of Na^{24} in the sodium (C_0) which can be obtained from Figure I.
- (d) The Na^{24} concentration in the room atmosphere at the selected time can then be determined by multiplying the value of C_2/K by the numerical value of AC_0F/V .

Equations (10) and (11), for the case in which the building ventilation system is in operation, are plotted in Figure IV, curve B. These curves may be used in the same way that curves (8) and (9) are used.

b. Application to 10 Mw ESCR

The concentration of radioactivity in the room atmosphere of the 10 Mw ESCR, as described in NAA-SR-Memo 4633, can now be determined using the known parameters and Figure I, III and IV as follows.

$$M = 5000 \text{ lbs (sodium in secondary loop)}^{(5)}$$

$$A = 3000 \text{ sq. ft (reactor room area)}^{(3)}$$

$$T = 0.42 \text{ hours (from curve A, Fig. III or IV)}$$

$$C_0 = 0.06 \text{ } \mu\text{c/gm of sodium for 7.5 mr/hr (from Fig. I)}$$

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$F = 0.5$ (author's estimate)

$V = 1.4 \times 10^5 \text{ ft}^3$ (volume of reactor room)(3)

$K = \frac{3000 \times 0.06 \times 0.5}{1.4 \times 10^5} = 6.43 \times 10^{-4}$

$P = 0$ (ventilation system inoperative)

$P = 2$ (ventilation system in operation)

Values of C_2/K and C_2 are shown in the following Table as a function of time after the incident.

Time after Incident, hours	Activity in Room Air Assuming No Ventilation or Leakage		Activity in Room Air with a Ventilation or Leakage Rate of 2 Air Changes Per Hour	
	C_2/K	$C_2, \mu\text{c/cc}$	C_2/K	$C_2, \mu\text{c/cc}$
0.01	6.4×10^{-4}	4.1×10^{-7}	6.4×10^{-4}	4.1×10^{-7}
.1	6.4×10^{-3}	4.1×10^{-6}	6×10^{-3}	3.85×10^{-6}
.42	2.6×10^{-2}	$1.7 \times 10^{-5} \text{ (max)}$	1.8×10^{-2}	$1.16 \times 10^{-5} \text{ (max)}$
1.	2.5×10^{-2}	1.6×10^{-5}	5.5×10^{-3}	Less than MPC
10.	1.7×10^{-2}	1.1×10^{-5}	----	Less than MPC
30.	5.0×10^{-3}	Less than MPC		Less than MPC

From the above table it can be seen that the maximum concentration of Na^{24} in the room atmosphere occurs at 0.42 hours after initiation of the incident and is $1.7 \times 10^{-5} \mu\text{c/cc}$ or approximately 4 times the MPC for Na^{24} . Considering the serious accident that was postulated, the radiological hazards from Na^{24} are therefore quite nominal. Evacuation of the building would not be necessary because of radioactivity since the average concentration over a period of a one week exposure would be less than the MPC.

However, it should be noted that the sodium concentration in the room would be exceptionally high. For the case with no ventilation, and neglecting fallout, the maximum concentration would occur at 0.42 hours and would be:

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$$\text{Sodium concentration} = \frac{\text{sodium released to atmosphere}}{\text{room volume}} = \frac{MF}{V} \quad (12)$$

$$= \frac{5000 \text{ lbs} \times 454 \times 10^3 \text{ mg/lb} \times 0.5}{1.4 \times 10^5 \text{ ft}^3 \times 0.0283 \text{ m}^3/\text{ft}^3}$$
$$= 2.8 \times 10^5 \text{ mg/m}^3$$

and,

$$\text{Multiple of MAC} = \frac{2.8 \times 10^5 \text{ mg/m}^3}{2 \text{ mg/m}^3} = 1.4 \times 10^5 \quad (13)$$

A sodium vapor concentration in air of 1.4×10^5 times the MAC could not be tolerated (unless adequate respiratory protection were employed). If the building ventilation system was operative, the concentration would be reduced to tolerable levels in a short period of time (i.e., less than MAC in 6 hours for a ventilation rate of 2 air changes per hour).

F. Release of Activity from Open Pad Area During Accident

1. General Treatment

The diffusion equation developed by Sutton was used to determine the downwind concentration due to the release of radioactive sodium from an open pad area situated in a locality similar to SRE. The equation for a continuous point source is:⁽⁶⁾

$$\chi_{(x,y)} = \frac{2 Q_r \times 10^{-6} \text{ m}^3/\text{cc}}{\pi C^2 \bar{u} x^{2-n}} \exp\left(-\frac{y^2 + h^2}{C^2 x^{2-n}}\right) \quad (14)$$

where

χ = ground concentration at point (x,y), (mc/cc)

Q_r = release rate (mc/sec)

C = diffusion coefficient for isotropic turbulence

$\bar{u}$ = mean wind speed (meters/sec)

x = distance downwind (meters)

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n = stability parameter (dimensionless)

y = distance crosswind (meters)

h = height of source (meters)

The following average meteorological data as reported for the SRE⁽⁷⁾ site, were used in determining the downwind concentration in the center of the plume ($y = 0$).

$$C = 0.2$$

$$\bar{u} = 2 \text{ meters/sec}$$

$$n = 0.25$$

In the calculations, a ground level release of activity ($h = 0$) was assumed and no radioactive decay or fallout was considered. By substituting the above meteorological data and the value of Q_r in terms of A , B and C_0 , as previously described, Sutton's equation becomes:

$$\begin{aligned} X_{(x)} &= \frac{2 \times 10^{-6} C_0 \times B \times A \times 454 \text{ grams/lb}}{\pi \times 0.04 \times 2 (x)^2 - 0.25 \times 3600 \text{ sec/hr}} \\ &= \frac{10^{-6} C_0 \times B \times A}{(x)^{1.75}} \end{aligned} \quad (15)$$

and, when $B = 4 \text{ lbs/hr-ft}^2$,

$$X_{(x)} = \frac{4 \times 10^{-6} C_0 \times A}{(x)^{1.75}}$$

The above equation is plotted in Figure V. The concentration is plotted as a function of the downwind distance in meters (x) and the area of the spill in sq. ft (A), with C_0 equal to $1 \mu\text{c/gram}$. To obtain the actual airborne concentration, the value obtained from the ordinate must be multiplied by the actual value of C_0 in $\mu\text{c/gm}$.

2. Application to 10 Mw ESCR

For the 10 Mw ESCR, the area of the pad is 2000 sq. ft.⁽³⁾, and C_0 , the permissible Na^{24} concentration in the secondary loop, is $0.06 \mu\text{c/gm}$. From Figure V, the following values can be obtained.

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Downwind Distance Meters	$\frac{\chi}{C_0} \left(\frac{\mu\text{c/cc}}{\mu\text{c/gm released}} \right)$	χ ($\mu\text{c/cc}$)
10	1.4×10^{-4}	8.4×10^{-6}
14	8.3×10^{-5}	5×10^{-6} (MPC)
100	2.6×10^{-6}	1.6×10^{-7}

Therefore, for the 10 Mw ESCR and average meteorological conditions, the downwind concentration of Na^{24} would be less than MPC at distances beyond 14 meters from the incident. The off-site radiological hazards from Na^{24} are therefore insignificant.

The corresponding sodium concentration in the atmosphere for the average meteorological conditions specified above can be calculated as follows:

$$\text{mg of sodium/m}^3 \text{ air} = \frac{\chi(x) \times 10^3 \text{ mg/gram}}{C_0 \times 10^{-6} \text{ m}^3/\text{cc}} \quad (16)$$

For the 10 Mw ESCR where $C_0 = 0.06 \mu\text{c/gm}$ of sodium:

$$\text{mg of sodium/m}^3 \text{ air} = 1.67 \times 10^{10} \chi(x) \quad (17)$$

From Figure 5, the following values can be obtained:

Downwind Distance, meters	Sodium Concentration, mg Sodium/m ³ Air
10	1.4×10^5
14	8.4×10^4
100	2.7×10^3
1000	47
5000	3
6000	Less than MAC

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It should be noted that contact of sodium oxide smoke or hydroxide mist with the throat and lungs is very irritating due to the stinging and coughing caused by the smoke. There is no recognized local or systemic form of acute or chronic toxicity resulting from sodium or sodium oxide smoke. Therefore, injury to the throat or lungs resulting from contact with sodium or sodium oxide would be due to thermal or alkalie burns and not to any toxicity of the fumes or smoke.

Review of the literature gives no insite into the possible extent by which the MAC can be increased for short exposures (i.e., no short exposure tolerance is given). It can be reasoned, however, that the 2 mg/m^3 value for the MAC is probably relatively remote from the concentration which will cause irritation. Therefore, there would undoubtedly be some higher sodium concentration which could be tolerated in this situation. However, no numbers can be given at this time.

The concentrations in the table on the bottom of page 14 would actually be significantly lower than indicated because of fall-out. The concentrations could also be significantly reduced by decreasing the area of the spill. Placing the secondary coolant lines in a narrow covered trench could probably reduce the concentrations by a factor of 10 or more. This decrease in concentration would not reduce the total inhaled dose if one remained in the cloud; however, it would allow more time to evacuate an area or avoid exposure from the cloud. A highly concentrated sodium vapor cloud can not be tolerated but it would have the desirable advantage of being visible and could be avoided by personnel.

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IV REFERENCES

1. Code of Federal Regulations, Title 10, Part 20, Filed January 25, 1957.
2. Dangerous Properties of Industrial Materials, N. Irvine Sax, 1957.
3. NAA-SR-Memo 4633, "An Experimental Sodium Cooled Reactor", D. H. Johnson, November 14, 1959.
4. NAA-SR-Memo 4067, "Additional Safeguards Evaluation for the U-Mo Fueled Core at the Hallam Nuclear Power Facility", the Staff of Atomics International, July 7, 1959.
5. Personal Communication, C. P. Craig, Dept. 785, Atomics International, December 11, 1959.
6. "Meteorology and Atomic Energy", AECU 3066, July 1955.
7. NAA-SR-3175 Revised, "Hazard Summary for Thorium-Uranium Fuel in the Sodium Reactor Experiment", Prepared by the AI Staff, July 1, 1959.

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Figure I

Radiation Level one foot from
surface of Pipe filled with
Sodium vs Na^{24} Concen-
tration in Sodium in uc/gm

Figure II

K&E 10 X 10 TO THE 1/2 INCH 359-11
KEUFFEL & ESSER CO. MADE IN U.S.A.

$N/cm^2 \cdot sec$

Effective Thermal
Activation Flux ($N/cm^2 \cdot sec$) in Heat Exchanger
VS
Na²⁺ Concentration (μm) Sodium and R
[R = Ratio of time Spent
in flux field to time
Spent making one cycle]

$\frac{C_2}{K}$ multiply $\frac{C_2}{K}$ by K to get C_2 in building atmosphere

$T+t = \text{Hours After Incident}$

Figure V

Distance - meters 145 022

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Dose rate from line full of Sodium

Parameters

$\mu/\text{cc} = \text{variable}$

$v/\text{hr} = \text{variable}$

$a = 12" = 30.5\text{cm}$

$l = \text{infinity}$

$R_0 = \text{variable}$

$t_{\text{Fe equiv}} = 0.5" = 1.27\text{cm}$

$\theta_1 = \theta_2 = \theta = \frac{\pi}{2}$

$$r/\text{hr}(\text{at point } P) = \frac{BSvR_0^2 F(\theta, l, a)}{2K(a+z)} = \frac{SvR_0^2 F(\theta, l, a)}{2K(a+z)} \quad \text{For } \theta_1 = \theta_2 = \theta \quad (B=1 \text{ for no shielding and } \mu \text{ used})$$

$$Sv = 1\mu\text{c/cc} (3.7 \times 10^4 \delta_{1.4} / \text{sec} - \mu\text{c} + 3.7 \times 10^4 \delta_{2.76} / \text{sec} - \mu\text{c})$$

$$= (3.7 \times 10^4 \delta_{1.4} / \text{sec} - \mu\text{c} + 3.7 \times 10^4 \delta_{2.76} / \text{sec} - \mu\text{c})$$

$$K = \begin{cases} 4 \times 10^5 \delta_{1.4} / \text{cm}^2 - \text{sec} - v/\text{hr} & \text{for } 1.4 \text{ mev } \gamma \\ 2.4 \times 10^5 \delta_{2.76} / \text{cm}^2 - \text{sec} - v/\text{hr} & \text{for } 2.76 \text{ mev } \gamma \end{cases}$$

$$m/\text{hr}/\mu\text{c/cc} = \left[\frac{3.7 \times 10^4 R_0^2 F(\theta, l, a)}{2 \times 4 \times 10^5 \times (a+z)} + \frac{3.7 \times 10^4 R_0^2 F(\theta, l, a)}{2 \times 2.4 \times 10^5 (a+z)} \right] \times 10^3 \frac{m}{\text{hr}}$$

$$m/\text{hr}/\mu\text{c/cc} = \frac{46.2 R_0^2 F(\theta, l, a)_{1.4}}{(a+z)_{1.4}} + \frac{77.2 R_0^2 F(\theta, l, a)_{2.76}}{(a+z)_{2.76}}$$

Pipe DIA Inches	R_0 cm	R_0^2 cm ²	a cm	a/R_0	$a+R_0$	$\mu_{1.4}$	$\mu_{2.76}$	γ	μ_1	μ_2	$\frac{\mu_1 + \mu_2}{2}$	$\mu_1 \pm \mu_2$	$\mu_1 \mp \mu_2$	$\mu_1 + \mu_2$	$F(\theta, l, a)$	$m/\text{hr}/\mu\text{c/cc}$	
4	5.08	25.9	30.5	6	35.6	.0333	1.19	0.2	.29	.37	.78	.156	4.68	.526	.6	20.4	65.2
						.0252	.898	0.15	.218	.28	.78	.117	2.95	.397	.75	44.8	
6	7.62	58	30.5	4	38.1	.0333	1.27	0.25	.29	.37	.93	.232	7.0	.602	.56	40	124.5
						.0252	.962	0.18	.218	.28	.93	.167	6.65	.444	.7	24.5	
8	10.16	103	30.5	3	40.7	.0333	1.36	0.28	.29	.37	1.04	.291	8.75	.661	.5	60.7	190.
						.0252	1.03	0.2	.218	.28	1.04	.208	8.25	.488	.64	130.	
12	15.24	232	30.5	2	45.7	.0333	1.52	0.35	.29	.37	1.2	.42	12.6	.79	.43	107	341
						.0252	1.15	0.26	.218	.28	1.2	.312	12.4	.592	.56	234	
16	20.32	413	30.5	1.5	50.8	.0333	1.7	0.38	.29	.37	1.3	.495	14.9	.865	.38	160	507
						.0252	1.28	0.3	.218	.28	1.3	.39	15.5	.67	.5	347	

$$\mu_{1.4} = (.05 \text{ to } .025) = 0.037 \text{ At.} \times 0.9 \text{ gm/cm}^3 = .0333 \text{ cm}^{-1}$$

$$\mu_{2.76} = (.036 \text{ to } .02) = 0.028 \text{ At.} \times 0.9 \text{ gm/cm}^3 = .0252 \text{ cm}^{-1}$$

$$\mu_{1.4} = (\text{same}) = 0.037 \times 7.8 \text{ gm/cm}^3 = .29 \text{ cm}^{-1}$$

$$\mu_{2.76} = (\text{same}) = 0.028 \times 7.8 \text{ gm/cm}^3 = .218 \text{ cm}^{-1}$$

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