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RESPONSE TO NRC STAFF QUESTION 240.03 CONCERNING CONSEQUENCES OF LIQUID PATHWAY RELEASES FROM A CORE MELT ACCIDENT

PERRY NUCLEAR POWER PLANT

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1.0 QUESTION

240.03
(7.1)

Calculate the radiological consequences in terms of population dose for a liquid pathway release from a postulated core melt accident. The analysis should assume, unless otherwise justified, that there has been a penetration of the reactor basemat by the molton core mass, and that a substantial quantity of radioactivity-contaminated suppression pool water has been released to the ground. The possibility of rapid movement of contamination to Lake Erie through the underdrain system should be taken into account in the analysis.

Doses should be compared to those calculated for the Liquid Pathway Generic Study (NUREG-0440, 1978) land-based Great Lakes site. Provide a summary of your analysis procedures and the values of parameters used (e.g., permeabilities, retardation factors, gradients, populations affected, water use). It is suggested that meetings with the staff of the Hydrologic Engineering section be arranged so that we may share with you the body of information necessary to perform this analysis.

2.0 RESPONSE

The "Liquid Pathway Generic Study" (NUREG-0440, 1978)[(1)] and the recent report "The Consequences from Liquid Pathways After a Reactor Meltdown Accident" (NUREG-1596, 1981)[(2)] have assembled a comprehensive set of methodologies for calculating the radiological consequences in terms of population dose for liquid path releases from a postulated core melt accident. It is believed that these two reports and their major referenced studies represent a reasonable state-of-the art approach to the requested analysis. Accordingly, this analysis will follow and make use of the methodologies and calculations presented in them.

While NUREG-0440 and -1596 use the same or similar release, transport and dose calculation models, generic parameter selection is quite different in many cases. Since it has been requested to compare the doses calculated for the Perry Nuclear Power Plant (PNPP) to those calculated in NUREG-0440, the NUREG-0440 doses and associated parameters will be used as a scaling basis for the calculations of Perry doses. However, information and data contained in the NUREG-1596 report have been used where applicable to supplement information in NUREG-0440 in order to develop scaling factors.

The PNPP design contains a foundation underdrain system which provides a de-watering capability. This system normally maintains the groundwater level below the basemat elevations. The presence of this system and how it would be operated in the years following a melt down accident significantly affects the pathway analysis of liquid releases. Accordingly, this analysis treats three potential underdrain system operational modes to bound the potential liquid pathway population dose resulting from a melt down accident. These modes are:

Mode 1 Underdrain system operational in the passive mode only; i.e., gravity discharge system operational and system pumps turned off. This mode is essentially the "do nothing" scenario and represents the worst case analysis.

Mode 2 Underdrain system operational in the passive mode only, and basemat penetrations opened. Stand pipes extending from the underdrain system to inside safety buildings and flow pathways to non-safety buildings would have to be manually opened by removing pipe caps or seals sometime before flow through the gravity discharge pipe is started (before 6.57 years). This mode would use the storage volume of the buildings to further delay the release of activity to the gravity discharge system.

Mode 3 Underdrain system totally inoperable. This mode would require an overt decision to close the gravity discharge system. Closing after the accident could be by either filling two discharge man holes with concrete (the simplest method) or by installing control devices such as valves or removable plugs in the gravity discharge piping.

Modes 2 and 3, while interdictive measures, have been included because they represent actions that have an extremely high benefit-cost ratio i.e., large decrease in population doses for relatively small financial cost and no social costs.

A fourth mode, not considered here, is use of the underdrain system as part of an interdictive system. The underdrain system, either with pumping or gravity discharge, would effectively collect contaminated groundwater which could be treated to remove radioactivity. In essence, the underdrain system represents an inplace interdictive system which could be used or not used, dependent on the evaluation of actual conditions following a melt down accident.

The results of the liquid pathway analysis of a melt down accident for PNPP are as follows:

Underdrain Operation Mode	PNPP Population Dose man-rems**	NUREG-0440 Population Dose* man-rems	Ratio of PNPP Dose to NUREG-0440 Dose
1	1.6×10^7	1.7×10^7	0.96
2	2.4×10^6	1.7×10^7	0.14
3	0.00	1.7×10^7	0.00

*Mean of range
**Based on Cs-137 and Sr-90 scaling.

As can be seen, the population doses for PNPP are in all cases, less than to the doses calculated for a generic site and reference plant in NUREG-0440.

The following sections present the basic scaling methods used, the calculation of each scaling factor, the calculation of doses and their comparison to NUREG-0440 doses.

2.1 Scaling Method

The basic method used in this analysis for calculating population doses is to scale the population doses presented in NUREG-0440, Tables 6.2-18 and 19[4] by factors relating to population exposed, quantity of activity being transported, intake rate to the population and transport time specific to the PNPP site.

The parameters and/or assumptions used in NUREG-0440 for the generic site have been carefully examined and those parameters which are plant/site dependent have been evaluated for the PNPP site. Linear scaling factors have been developed for each process or parameter which is different for the PNPP site and plant and which will significantly affect the calculated population dose.

All processes not treated specifically in this analysis are assumed to have a scaling factor of 1. NUREG-1596 was used extensively to determine the sensitivity of models to specific parameters.

In the following sections, scaling factors have been developed and calculated for the following plant, site and environmental characteristics.

Scaling Factor	Description	Parameters Involved
S_I	Core inventory	Power level
S_{TL}	Transport to lake	Aquifer characteristics
S_{LT}	Lake transport	Lake hydrologic characteristics
S_{PDW}	Population obtaining drinking water from lakes	Drinking water withdrawals
S_{PAF}	Population obtaining aquatic foods from lakes	Fish harvests
S_{PSH}	Population using shoreline	Recreational uses
S_{PSW}	Population swimming in lakes	Recreational uses

The basic scaling equation is given on the following page. This equation is applicable for all pathways (i.e., drinking water, aquatic foods, shoreline and swimming) and for prompt (immediate release) and delayed (released by core leaching) source terms. It should be noted that the scaling accounts for the population doses from both Lake Erie and Lake Ontario. For exposure situations where the nuclide transport times range from approximately 2.7 to 27 years for strontium and 27 to 270 years for cesium, both NUREG-0440 and -1596 indicate that only Sr-90 and Cs-137 are significant contributors.[5,6] For the PNPP, the mean nuclide discharge time to the lake is 16.0 years for mode 1 and 95.2 years for Mode 2 (see Section 2.5). Accordingly all scaling factors are based on the properties of these radionuclides.

The fractions of total dose originating from the near field (close to entrance point in lake) and far field (entire lake) pathways and from strontium and cesium have been developed from information given in NUREG-0440 and -1596.[1,2] The values used are presented in Table 1.

2.2 Accident Conditions

The most probable release category analyzed in NUREG-0440 is PWR 7.[3] This accident scenario also results in the largest population doses for both prompt and delayed release sources.[4] Only PWR's (pressurized water reactors) are considered in NUREG-0440. NUREG-1596 also considers boiling water reactors (BWR's) accident scenarios from which release category BWR 3 has been selected for this population dose analysis for the PNPP. BWR 3 is the most probable BWR release category[10] and has the same delayed release source term as the PWR 7 category.[11] Thus use of BWR 3 allows a direct comparison between the generic site presented in NUREG-0440 to the Perry site.

BASIC SCALING EQUATION

$$
\begin{aligned}
\mathrm{Dose}_{i,j} = D_{i,j} S_I \Bigg\{ & F^N S_P^N S_{LT}^N \left(f_{SR}^N S_{TL,SR} + f_{CS}^N S_{TL,CS} \right) \\
& + \Bigg[F^F f_{SR}^F S_{TL,SR} \left(S_{LT,SR}^O S_P^{O,F} + S_{LT,SR}^E S_P^{E,F} \right) \\
& + f_{CS}^F S_{TL,CS} \left(S_{LT,CS}^O S_P^{O,F} + S_{LT,CS}^E S_P^{E,F} \right) \Bigg] \Bigg\}
\end{aligned}
$$

Where:

Dose	=	Population dose from PNPP
D	=	Population dose for NUREG-0440 generic site
F	=	Fractions of D attributed to lake regions (N = near field, F = far field)
f	=	fraction of D x F attributed to nuclides (Cs or Sr)
S	=	Scaling factors

superscripts:	N=	New field lake region
	F=	Far field lake region
	O=	Lake Ontario
	E=	Lake Erie
subscripts:	P=	Population
	TL=	Transport to lake
	LT=	Lake transport
	I=	Inventory
	i=	source type
	j=	pathway

TABLE 1A

FRACTION OF TOTAL DOSE ATTRIBUTED TO NEAR AND FAR FIELD LAKE REGIONS*

Source Type	Pathway***	Region: Far	Region: Near
Prompt	DW, AF	0.89	0.11
Prompt	SH, SW	0.67	0.33
Delayed	DW, AF	0.90	0.10
Delayed	SH, SW	0.67	0.33

TABLE 1B

FRACTION OF DOSE ATTRIBUTED TO CESIUM-137 AND STRONTIUM-90**

Source Type	Lake Region	Pathway	Nuclide: Cs-137	Nuclide: Sr-90
Prompt	Near	DW, AF	0.44	0.56
	Far	DW, AF	0.37	0.63
Delayed	Near	DW, AF	0.0	1.00
	Far	DW, AF	0.0	1.00
Prompt	Near	SH, SW	1.00	0.0
	Far	SH, SW	1.00	0.0
Delayed	Near	SH, SW	0.0	1.00
	Far	SH, SW	0.0	1.00

*Values for "F" in basic scaling equation
**Values for "f" in basic scaling equation
***DW = drinking water
AF = aquatic foods
SH = shoreline
SW = swimming

At the time of the melt down accident, the initial core inventory of PNPP is assumed to contain the quantities of radionuclides listed in NUREG-0440, Table A-7[12] corrected by the ratio (S_I) of the PNPP rated power level to that of the reference plant. The inventories of both BWR and PWR plants are similar for both short and long time periods and can be scaled according to rated power level.[13]

$$\text{Inventory Scaling Factor} = \frac{\text{Rated Power level} \quad \text{PNPP}}{\text{Rated Power level} \quad \text{0440}}$$

$$S_I = \frac{3579 \text{ MWT}^{(14)}}{3425 \text{ MWT}^{(15)}} = 1.045$$

Upon core melt down and melt through of the reactor vessel, the core inventory will be partitioned between the melted core and the containment atmosphere. The fractions of initial inventory remaining with the melted core are given in NUREG-0440, Table A-8[16] for PWR 7 and NUREG-1596, Table A-14[17] for BWR 3. These values are identical and are used for the PNPP.

The PNPP has a foundation underdrain system which under normal operation lowers the groundwater table at least to the 568-foot elevation.[18] It is assumed that at the start of the melt down accident this system has maintained this groundwater elevation. The underdrain system has been analyzed to determine its influence on the amount of radioactivity transported to Lake Erie (see section 2.5) and on the leached (delayed) source term. Its effects are fully considered in the calculated PNPP doses. NUREG-0440 does not consider such a system in its reference plant.

2.3 Releases to the Hydrosphere

NUREG-0440 and -1596 identify three PWR release mechanisms for radioactivity transport to the hydrosphere.[19, 20]

These are:

- o Leaching from solidified melted core inventory by contact with groundwater.

- o Release of contaminated water from within the containment structure.

- o Release of the contaminated gases through a breach in the plant basemat.

NUREG-1596 states [(21)] that for the reference BWR design used (Design type 5), the last two mechanisms would not be possible. This is based on the lack of a system to transfer significant quantities of the atmospheric content to the suppression pool water (i.e., a radionuclide removal spray system) and the lack of sufficient containment strength to overcome soil pore pressure. The PNPP BWR is a different design than considered in NUREG-1596. It has a secondary containment structure (design pressure 15 psig[(22)] as compared to approximately 50 psig for a PWR) and a containment spray system. The spray system is designed solely for pressure suppression rather than radionuclide removal; however, it would be fairly effective for cesium removal.

For a water release to occur, the Perry BWR design requires that more barriers would have to be breached than have been considered in the NUREG-0440 PWR analysis. However, a preliminary analysis of the potential pathways for suppression pool water releases has not totally ruled out the possibility of such a release. Accordingly, this analysis assumed a prompt release source term (depressurization or water release) identical to that used in NUREG-0440. This assumption is considered highly conservative.

The underdrain system will affect the release of activity to the hydrosphere in two ways.

- o The system provides a delay time before leachate from the melted core starts transport either with the groundwater or through the gravity discharge system.

- o The system provides a direct pathway to Lake Erie through the gravity discharge system.

The population dose is evaluated with the gravity discharge system operational after the accident, with building penetrations open, and with the discharge system being closed sometime before groundwater flow starts discharging through it (within 6.57 years of the accident as discussed in Section 2.5).

The gravity discharge system does not have controls or valves for stopping flow through it. However, disabling the system either temporarily or permanently at either the inspection or pumping manholes outside the plant, the emergency service water pump house or along the discharge pipe could be readily accomplished.

It should be noted that the underdrain systems provide an installed, ready to use interdictive measure. A decision would not need to be made whether to employ the system for at least 6.57 years after the accident (see Section 2.5).

2.4 Groundwater Aquifer Characterization

The site region between the Unit 1 reactor building and Lake Erie is underlain by Lacustrine deposits and glacial tills that rest on shale bedrock. The Lacustrine soil deposits, the main source of groundwater, consist of low permeability, fine silty sands and silty clay with an average thickness in this site region of 25 feet. The glacial tills underlying the Lacustrine soil are essentially impervious and contain little groundwater. The upper till is approximately 10 feet thick over a 20-foot thick lower till. Bedrock is impervious except along joints and within the thin weathered and fractured zone near the till-shale contact.(23) The permeability of the fractured zone is expected to be similar to the lower till and in no case as high as the Lacustrine, which is the limiting stratum.

The permeabilities of the various strata used in this analysis are given below.(24)

Stratum	Thickness (ft)	Range of Reliable Field Test Values (cm/sec)	Estimated Mean of Field Test Data (cm/sec)
Lacustrine	25	4.2×10^{-7} to 1.2×10^{-4}	1.0×10^{-5}
Upper till	10	5.0×10^{-8} to 3.0×10^{-6}	1.5×10^{-7}
Lower till	20	3.8×10^{-8} to 3.1×10^{-6}	2.0×10^{-7}
Shale	-	1.3×10^{-8} to 8.4×10^{-7}	8.0×10^{-8}

The natural groundwater level (prior to construction) sloped northerly toward Lake Erie from an elevation of 617 feet at the reactor building to an elevation of 610 feet near the lake bluff.[25] The distance from the reactor core location to the bluff is 1,110 feet: thus the groundwater gradient is 0.0063 ft/ft. This is essentially the same as the slope of the shale bedrock surface.[26] This gradient is used for all equilibrium groundwater transport calculations.

Groundwater travel velocities for the four strata are calculated as

$$V = \frac{P \times S}{n}$$

Where: V = true pore velocity (ft/yr)

P = permeability (ft/yr)

S = slope (ft/ft)

n = effective porosity

The calculated velocities using a porosity of 0.2 are:

Stratum	Velocity ft/yr
Lacustrine	3.25×10^{-1}
Upper till	4.89×10^{-3}
Lower till	6.52×10^{-3}
Shale	2.61×10^{-3}

Considering the relative thicknesses of the strata, and the calculated velocities, the Lacustrine soil will transmit over 97 percent of the horizontal water flow in the soil column. Accordingly, the upper till will be considered impervious in transport analysis.

The potential for bluff erosion has been considered. A value of 200 feet[27] for shortening of groundwater travel distance has been assumed. Accordingly, a distance from he reactor building to discharge into the lake of 910 feet (1,110-200) has been sed in the PNPP accident evaluation.

NUREG-0440 uses distribution coefficients (K_d) in soil of 2 ml/gm for Sr-90 and 20 ml/gm for Cs-137. NUREG-1596 has selected values 10 times higher (2[illegible] and 200) as representative of th[illegible] Great Lakes region. Values used for the PNPP site are 20 and 200 based on the pH of the groundwater, 8.1,[28] and on the high clay-silt content, 79 percent. These values are still considered very conservative.

2.5 Underdrain System Operation

A pressure relief underdrain system is installed beneath the primary plant structure to maintain the groundwater level below elevation 568 feet in order to reduce the buoyancy effect and to increase the dynamic stability of the structures.[24] This level is maintained by pumping water from the horizontal underdrain system. The perimeter of the collection system is approximately 2700 feet and covers an area of about 32,000 square feet. The projected width of the system perpendicular to the groundwater slope is 530 feet.

The system also includes a gravity discharge that will maintain the groundwater below elevation at 582.6 feet (invert elevation of discharge pipes) if the pumps are turned off. The gravity drain discharges into the emergency service water pump house pool at 4 feet above mean high lake level.

In the event of a melt down accident, the underdrain system pumps are assumed to shutdown, either manually or automatically, upon detection of radioactivity in the underdrain system.

At the start of the melt down, the groundwater level is assumed to be at elevation 568 feet. The groundwater depression (drawdown) has been observed to extend approximately 650 feet from the system in the south direction and 300 feet in the east-west directions.[30] Seepage into the system during construction was estimated to be approximately 4 gpm[31] and originated in the Lacustrine soil. This flow value is higher than could be sustained over a long period of time as it exceeds the flow into the region of the plant.

Using a cross sectional area equal to the perimeter of the total zone of influence times the thickness of the aquifer, the total flow passing the reactor building is estimated to be 0.1 gpm as follows.

$$Q = V \times n \times A$$

Where: V = pore velocity (ft/yr)

n = effective porosity

A = area of vertical section (ft^2)

$V = 3.25 \times 10^{-1}$

$n = 0.2$

$A = 4330 \times 25 = 1.08 \times 10^5 \text{ ft}^2$

$Q = 7.04 \times 10^3 \text{ ft}^3/\text{yr}$

$= 0.10$ gpm

An additional calculation of seepage rate based on observed stabilized groundwater drawdown curves taken during construction, indicates a flow of 0.28 gpm. This value includes local infiltration through the class A fill, which was not yet sealed with class B fill when the drawdown observations were made. Thus, the value is conservative in this respect.

Based on these two calculated values (0.10 and 0.28 gpm), a conservative value of 0.5 gpm has been used in this analysis to account for possible variations in permeability. Since the source of seepage water is the Lacustrine soil which is located above the gravity discharge invert elevation, this inflow rate is assumed to be constant whenever the gravity drain is open.

The time required for the inflow to establish a groundwater elevation of 582.6 feet (elevation of the gravity discharge invert) will determine the time at which leached radioactivity could be transported to Lake Erie by way of the underdrain system. The free storage volume, up to elevation 582.6 feet, within the underdrain system (including class A fill) and within the buildings are approximately 1.72 and 10.2 million gallons. The time for discharge to start through the gravity system is thus:

$$\text{Time} = \frac{\text{Storage volume}}{\text{inflow rate}}$$

For Mode 1

$$= \frac{1.72 \times 10^6 \text{ gal} \times 1.91 \times 10^{-6} \text{ yr/min}}{0.5 \text{ gpm}}$$

$$= 6.57 \text{ years}$$

For Mode 2

$$= \frac{1.02 \times 10^7 \text{ gal} \times 1.91 \times 10^{-6} \text{ yr/min}}{0.5 \text{ gpm}}$$

$$= 39.0 \text{ years}$$

If the gravity discharge system is closed by modifying the system after the accident, water will continue to rise until it reaches the natural groundwater level of 617 feet. It is conservatively estimated that it will take an additional 16 years and 95 years for Modes 1 and 2 based on the elevation changes necessary to fill the depression.

2.6 Transport to Lake Erie

The amount of material transported from leaching of the melted core or from contaminated containment water is dependent on the time period to complete the transport. For this analysis, it is assumed that the melted core solidifies before the groundwater level reaches either the gravity drain system or the Lacustrine aquifer (i.e., 6.57 years). NUREG-0440 uses a value of one year. If the time to solidification is longer than 6.57 years, the consequences will be lessened due to a longer decay time before water contacts with the core. It is also assumed that material is instantaneously leached from the solidified core even with the small amount of groundwater flow beneath the reactor area. NUREG-0440 indicates total leach times from months to several years but does not select a time period for the generic site. Population dose results are presented for instantaneous leaching to up to several years. As a base case, this analysis uses the instantaneous release. Finally, it is assumed that the leachate is instantly mixed with the groundwater contained within the underdrain system. Even though the melted core maybe located 100 to 200 feet below the aquifer, it is assumed that groundwater flows down the porous melt and then rises due to the bouyancy effect of a still heated core.

NUREG-0440 has used a groundwater travel time of 0.613 years. This results in nuclide transport times ranging from 0.613 to 50.9 years for potentially significant nuclides.

2.6.1 Gravity Discharge System Operational (Mode 1 and Mode 2)

If the underdrain gravity discharge system is left operable, the groundwater transport by way of a natural pathway would have to be through the upper and lower till. For the most permeable till layer, the groundwater travel time is:

$$T = \frac{\text{Distance}}{\text{pore velocity}}$$

$$= \frac{910 \text{ ft}}{6.52 \times 10^{-3} \text{ ft/yr}}$$

$$= 1.40 \times 10^{5} \text{ years}$$

Even without accounting for nuclide retardation, this pathway clearly does not transport a significant amount of activity because of the long decay times (greater than 1000 half lives for cesium and strontium). With nuclide retardation, the transport time is

$$T' = T \left[1 + \frac{\rho}{E} K_d\right]$$

where:

ρ = bulk density - gm/cm^3 (1)

E = total porosity (0.2)

K_d = distribution coefficient - ml/gm

$$T'_{Sr-90} = 1.40 \times 10^{5} \ (1 + (5 \times 20\ ))$$

$$= 1.41 \times 10^{7} \text{ years}$$

$$T'_{Cs-137} = 1.40 \times 10^5 (1 + (5 \times 200))$$

$$= 1.40 \times 10^8 \text{ years}$$

Accordingly, transport through the till or shale is not considered further.

However, after 6.57 years, contaminated groundwater will start discharging to Lake Erie by way of the underdrain gravity discharge system. The activity will continue to be discharged at smaller and smaller concentrations (due to dilution of incoming water) until all the material is flushed out of the system. It is estimated that 10 replacement volumes would be necessary for complete flushing. Thus 66 years of discharge would be necessary to transport all the material to the lake. For population dose analysis, a mean time to discharge of 1.44 (1/ln 0.5) times the replacement time is used. Thus the total mean transport time for Mode 1 is

$$T = 1.44 \times 6.57 + 6.57 = 16.0 \text{ years}$$

and for Mode 2 is

$$T = 1.44 \times 39.0 + 39.0 = 95.2 \text{ years}$$

The scaling factor for transport time (S_{TL}) is:

$$S_{TL} = \frac{\exp(-0.693/t_{½} \times \text{transport time}) \quad \text{PNPP}}{\exp(-0.693/t_{½} \times \text{transport time}) \quad 0440}$$

A value must be calculated for each significant nuclide. These are as follows:

		Fraction Reaching Lake		S_{TL}
Mode	Nuclide	NUREG0440	PNPP	Scaling Factor
1	Sr-90	0.87	0.67	0.77
1	Cs-137	0.31	0.69	2.23
2	Sr-90	0.87	0.095	0.11
2	Cs-137	0.31	0.11	0.35

2.6.2 Underdrain System Closed (Mode 3)

If the underdrain gravity discharge system is closed, the groundwater level will continue to rise. At elevation 595 feet, the Lacustrine stratum will be reached and horizontal transport through the soil will start. Neglecting the time necessary to resaturate the Lacustrine soil, the groundwater travel time to Lake Erie is:

$$T = \frac{\text{Distance}}{\text{pore velocity}}$$

$$= \frac{910 \text{ ft}}{0.325 \text{ ft/yr}}$$

$$= 2800 \text{ years}$$

The radionuclide transport times (T') are then

$$T'_{Sr-90} = 2800\,(1 + (5 \times 20)) = 2.8\text{x}10^5 \text{ years}$$

$$T'_{Cs-137} = 2800\,(1 + (5 \times 200)) = 2.8\text{x}10^6 \text{ years}$$

The scaling factors as defined in Section 2.6.1 are as follows:

	Fraction Reaching Lake		S_{TL}
Nuclide	NUREG0440	PNPP	Scaling Factor
Sr-90	0.87	$<10^{-99}$	0
Cs-137	0.31	$<10^{-99}$	0

2.7 Lake Erie Transport

NUREG-0440 considers a generic site located adjacent to Lake Ontario. The PNPP is located adjacent to Lake Erie which flows into Lake Ontario. Accordingly, both lakes must be considered in the transport of radioactivity. For long half-life radionuclides, the population dose is directly proportional to time and space integrated concentration in the lake. NUREG-1596 presents the results of integration for Lake Ontario (single) and Lakes Erie and Ontario in series using the same model as NUREG-0440.[33] These integrated concentrations (I) are used as the basis for the lake transport scaling factors (S_{LT}).

$$S_{LT(far)} = \frac{I_{Lake\ (series)}}{I_{Ontario(single)}}$$

		Far Field Integrated Concentration (yr/m^3)		S_{LT}	
Lake	System	Sr90	Cs137	Sr90	Cs137
Ontario	Single	3.4×10^{-12}	2.6×10^{-12}	-	-
Erie	Series	3.1×10^{-12}	6.0×10^{-13}	0.91	0.23
Ontario	Series	1.6×10^{-12}	1.0×10^{-13}	0.47	0.038

These calculations use the same sedimentation parameters employed in the NUREG-0440 study.

The NUREG-0440 near shore model assumes a lake which has a mean current velocity of 0.33 feet per second and a current direction equally distributed between the two along shore directions with a direction persistence of at least 3 days. Lake Erie in the vicinity of the PNPP has a net current transport in the ENE along shore direction with frequent current reversals.[41] Observation of currents indicate that over a 16 month period only 6 periods of currents persisting in one direction for 3 days or more occurred.

Since the net transport current is in an easterly direction, all material entering the lake will eventually pass drinking water intakes located to the east of the plant.[39] However intakes located to the west of the plant[39] will only be affected when a current persists in a westerly direction with a velocity sufficient to reach the intakes. Lake current data has been reviewed to determine the fraction of time that this occurs.[34] Using the maximum current velocity observed during persistent westerly current periods, a total of 417 hours (out of 6700 hours of observation) where identified when material was being transported toward the westerly intakes <u>and</u> would reach the intakes at 7.0, 7.5 and 10 miles. The actual time that material remains in the area of the intake would be less.

The fraction of time that the westerly water intakes would be effected is thus estimated conservatively as 0.062 (417 hrs/6700 hrs). The easterly intake at 4.2 miles is assumed to be effected for the remainder of the time.

The scaling factor necessary to treat the above characterization can be either associated with the population being exposed to an integrated near field lake concentration or associated with the concentration exposing the population. To be consistent with the approach used in NUREG-0440, the scaling factor chosen was based on the integrated concentration.

$$S_{LT(near)} = \frac{F_W \cdot POP_W + F_E \cdot POP_E}{F\,(POP_W + POP_E)}$$

where:

F_W	=	fraction of time westerly intakes are effected
F_E	=	fraction of time easterly intakes are effected
F	=	fraction of time toward intake, NUREG-0440
POP_W	=	population served by westerly intakes
POP_E	=	population served by easterly intakes

$$S_{LT(near)} = \frac{0.062 \times 94885 + 0.94 \times 9128}{0.5 \times 104{,}013} = 0.28$$

This factor is only applicable to the drinking water doses. A factor of 1 is used for all other pathways.

2.8 Drinking Water Populations

NUREG-0440 uses a far field drinking water population of two million persons and near field drinking water population of 50,700.[35] The PNPP liquid pathway release will first enter Lake Erie, flow to Lake Ontario by way of the Niagara River and then into the St. Lawrence River. Because two major water bodies are involved, two scaling factors are used; one for Lake Erie and the Niagara River and one for Lake Ontario and the St. Lawrence River. The populations served where calculated from reference 36 data taking into account populations within the Lake Erie and Lake Ontario basin which do not obtain their water from the lakes.

The drinking water population scaling factors (S_{PDW}) are defined as:

$$S_{PDW(Lake)} = \frac{\text{Population obtaining drinking water from lake}}{\text{Population used in NUREG-0440}}$$

	Population Served		
Water Body	NUREG0440	PNPP	S_{PDW}
Erie	2.0×10^6	3.3×10^6 (40)	1.65
Ontario	2.0×10^6	8.1×10^5 (36)	0.41
Near Field	5.0×10^4	1.04×10^5 (39)	2.09

2.9 Aquatic Food Populations

NUREG-0440 uses an annual fish harvest of 1.2×10^7 kg/year(37) for the generic site. In developing this value, fish harvests from Lake Erie of 1.5×10^7 kg/yr and from Lake Ontario of 3×10^6 kg/yr were identified. This analysis uses these values for calculating the scaling factors to account for fish being affected in the two lakes. Accordingly,

$$S_{P\text{-}AF}(\text{Ontario}) = \frac{3.0 \times 10^6}{1.2 \times 10^7} = 0.25$$

$$S_{P\text{-}AF}(\text{Erie}) = \frac{1.5 \times 10^7}{1.2 \times 10^7} = 1.25$$

2.10 Lake Shore and Swimming Populations

NUREG-0440 uses lake-wide annual participation values of 4.4×10^8 and 1.2×10^8 user-hours for shoreline and swimming pathways for the generic Great Lakes site.[38] Participation values specifically for Lake Erie and Lake Ontario were derived from data given in the Great Lakes Basin Framework Study[42, 43, 44]. Exposure time per activity day factors used were:[45]

- swimming - 2.5
- boating - 1.0
- fishing - 3.0
- other - 2.5

The scaling factors, defined as: $\frac{\text{Participation time (PNPP)}}{\text{Participation time (NUREG-0440)}}$ are as follows.

Lake	Pathway	Participation time (hrs/year) NUREG-0440	PNPP	S_p Scaling Factor
Erie	Swimming	1.2×10^{8}	2.7×10^{7}	0.22
Erie	Shoreline	4.4×10^{8}	1.4×10^{8}	0.32
Ontario	Swimming	1.2×10^{8}	5.2×10^{6}	0.04
Ontario	Shoreline	4.4×10^{8}	3.1×10^{7}	0.07

The Lake Ontario factors were used for the near-field exposure under the assumption that usage density for the near and far field are the same.

2.11 Population Dose Calculation and Comparison to NUREG-0440

Population doses have been calculated according to the scaling equation presented in Section 2.1. The base doses, $D_{i,j}$ were obtained from NUREG-0440, Tables 6.2-18 and 19[4] for release category PWR 7. The means of the ranges where used as representative of the generic site. The fractional contributions for lake region and nuclides are presented in Section 2.1, Table 1. The scaling factors, developed in the previous sections, are summarized in Table 2. The population doses for each pathway, source type and underdrain operational mode and presented in Tables 3 and 4 for Modes 1 and 2.

With the underdrain gravity discharge system operational (Mode 1), the total PNPP estimated population dose is essentially the same as that of the generic site analyzed in NUREG-0440. In general, the size of the population exposed at the

PNPP is larger, the average nuclide transport to the lake is approximately the same and the dilution and removal in the lake are greater. If the building penetrations are used to allow building storage (Mode 2), the population dose is approximately 14 percent of the NUREG-0440 doses because of long transport time to the lake.

If the underdrain system is made non-operational (Mode 3), the PNPP population dose becomes a very small fraction ($<10^{-99}$) of the NUREG-0440 dose. This is due to the much longer groundwater transport time to the lake. All other factors remain the same as in Mode 1.

TABLE 2

SUMMARY OF SCALING FACTORS FOR PNPP SITE

Scaling Factor	Applicable Pathways* DW	AF	SH	SW	Underdrain Mode	Both Lake Regions and Nuclides	Both Regions Cs	Sr	Near Field	Far Field by Lake** All Nuclides E	O	Cs E	O	Sr E	O
S_I	X	X	X	X	1 & 2	1.045	-	-	-	-	-	-	-	-	-
S_{TL}	X	X	X	X	1	-	2.23	0.77	-	-	-	-	-	-	-
S_{TL}	X	X	X	X	2	-	0.35	0.11	-	-	-	-	-	-	-
S_{TL}	X	X	X	X	3	-	0	0	-	-	-	-	-	-	-
S_{LT}	X				1 & 2	-	-	-	0.28	-	-	0.23	0.038	0.91	0.47
S_{LT}		X	X	X	1 & 2	-	-	-	1.00	-	-	0.23	0.038	0.91	0.47
S_P	X				1 & 2	-	-	-	2.09	1.65	0.41	-	-	-	-
S_P		X			1 & 2	-	-	-	1.0	1.25	0.25	-	-	-	-
S_P			X		1 & 2	-	-	-	0.32	0.32	0.07	-	-	-	-
S_P				X	1 & 2	-	-	-	0.22	0.22	0.04	-	-	-	-

*DW = drinking water
AF = aquatic food
SH = shore line
SW = swimming

**E = Erie
O = Ontario

TABLE 3

MODE I
Estimated Population Doses (Total Body man-rem)
From A Core Melt Down Accident - Perry Nuclear Power Plant

Underdrain Mode	Source Type	Pathway**	PNPP Population Dose (man-rem)	NUREG-0440 Population Dose (man-rem)*	Ratio PNPP to NUREG-0440
1	Prompt	DW	2.9×10^6	2.5×10^6	1.16
		AF	7.7×10^4	8.0×10^4	0.96
		SH	1.6×10^6	4.5×10^6	0.36
		SW	2.8×10^2	1.1×10^3	0.25
		Total	4.6×10^6	7.1×10^6	0.62
1	Delayed	DW	1.1×10^7	8.9×10^6	1.26
		AF	1.6×10^5	1.6×10^5	0.99
		SH	3.9×10^5	1.5×10^6	0.26
		SW	4.5×10^1	2.7×10^2	0.17
		Total	1.2×10^7	1.0×10^7	1.20
1	Total	DW	1.4×10^7	1.1×10^7	1.27
		AF	2.4×10^5	2.4×10^5	1.00
		SH	2.0×10^6	6.0×10^6	0.33
		SW	3.2×10^2	1.4×10^3	0.23
		Total	1.6×10^7	1.7×10^7	0.96

*Mean of range.

**DW = drinking water
AF = aquatic food
SH = shore line
SW = swimming

TABLE 4

MODE 2
Estimated Population Doses (Total Body man-rem)
From A Core Melt Down Accident - Perry Nuclear Power Plant

Underdrain Mode	Source Type	Pathway**	PNPP Population Dose (man-rem)	NUREG-0440 Population Dose (man-rem)*	Ratio PNPP to NUREG-0440
2	Prompt	DW	4.3×10^5	2.5×10^6	0.171
		AF	1.1×10^4	8.0×10^4	0.142
		SH	2.6×10^5	4.5×10^6	0.057
		SW	4.3×10^1	1.1×10^3	0.039
		Total	7.0×10^5	7.1×10^6	0.099
2	Delayed	DW	1.6×10^6	8.9×10^6	0.181
		AF	2.3×10^4	1.6×10^5	0.142
		SH	5.6×10^4	1.5×10^6	0.037
		SW	6.8×10^6	2.7×10^2	0.025
		Total	1.7×10^6	1.0×10^7	0.170
2	Total	DW	2.0×10^6	1.1×10^7	0.182
		AF	3.4×10^4	2.4×10^5	0.142
		SH	3.2×10^5	6.0×10^6	0.053
		SW	5.0×10^1	1.4×10^3	0.036
		Total	2.3×10^6	2.4×10^7	0.141

*Mean of range.

**DW = drinking water
AF = aquatic food
SH = shore line
SW = swimming

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