ATTACHMENT (1)

EVALUATION OF ACID PRODUCTION BY BETA DOSE

Calvert Cliffs Nuclear Power Plant, Inc.
December 11, 2008

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NRC Question:

In the Calvert Cliffs application dated August 27, 2008, the calculation to determine the amount of nitric acid generated from radiation appears to only account for the gamma dose. Please discuss whether the beta dose was also considered in the calculation. If not, please explain why your method provides for a conservative amount of sodium tetraborate to maintain the pool pH>7 following a LOCA.

CCNPP Response:

One year total integrated post-accident beta and gamma doses in Containment are summarized on page F-2 of Reference 3. Both beta and gamma airborne doses were used in the calculation of HCl from cable insulation. However, only the 1-year integrated TID airborne gamma dose of 16.84 MRad was utilized for the calculation of nitric acid from sump water, which was consistent with the methodology employed for the previously approved calculation for trisodium phosphate (TSP). This response will consider the impact from other potential sources of post-accident dose for the sump water.

Airborne Beta Source

Table 1 below summarizes the dominant contributors to the airborne component of the total integrated beta dose (138.28 MRad at 1-year) and their associated mean beta energy. The maximum range in water is calculated using the relationship $R_{max}\rho=0.412E^{(1.265 - 0.0954 \ln E)}$ from Reference 1 (p. 93), where R_{max} is maximum range in cm, ρ is density (1 g/cc), and E is mean beta energy. As can be seen, the maximum penetration of any airborne beta into the sump water is ~1 cm, with a majority being absorbed in the first 1 mm of the surface of the sump (half in the first 100 microns using the apparent beta mass attenuation coefficient of $17/E^{1.14}$ from Reference 1, p. 92). Further, per Updated Final Safety Analysis Report Table 6-6 the mean spray drop diameter is 700 microns, so even the sprayed water will not see significant airborne beta dose.

Table 1 – Penetration Distance of Airborne Beta into Sump Water

Isotope	Percentage of total integrated beta dose 30-days	1-year	Beta Energy (Mev)	Max Range (cm)	50% Attenuated (cm)
Kr-85	2.79%	24.84%	0.2505	0.060	0.0084
Kr-87	1.85%	1.40%	1.3237	0.583	0.0561
Kr-88	1.67%	1.26%	0.3643	0.104	0.0129
Rb-88	8.59%	6.50%	2.0664	0.981	0.0933
I-131	3.00%	2.47%	0.1917	0.039	0.0062
I-133	1.65%	1.24%	0.4106	0.124	0.0148
Xe-133	72.54%	56.20%	0.1357	0.023	0.0042
Xe-135	3.52%	2.66%	0.3172	0.085	0.0110
			1-year weighted penetration	0.105	0.0121

Thus, nitric acid production from airborne beta exposure of water will be negligible.

Sump Beta and Gamma Sources

Dose for a point inside the sump water in Containment has not been calculated for previous analyses, but can be determined using information from EQ calculations of dose to Auxiliary Building components during the recirculation phase. These calculations utilize the standard Regulatory Guide 1.89/TID-14484 assumption that the sump at t=0 contains 50% of the core inventory of halogens, and 1% of the core inventory of fission products.

Table 2 provides the sump water integrated photon source as a function of time. A simple MCNP5 model of an infinite sump source was then run to obtain the integrated MeV/g per history for each time step spectrum (see sample for 11 days below Table 2). This result is then divided by 6.24E7 MeV/g per Rad, and multiplied by the total photons from Table 2 to determine the integrated dose in Rads. The results are plotted in Figure 1 below.

Table 3 provides the sump water specific activity for halogen and fission product isotopes as a function of time. The infinite beta dose rate in water in rad/hr for an isotope at a given time step is determined by multiplying the isotope specific activity (μCi/cc) by 2.1346*E Rad/hr per μCi/cc, where E is the mean beta energy in MeV. Mean beta energies were obtained from References 2 and 4. The time dependent dose rate for each sump isotope, and the total integrated beta dose from all isotopes as a function of time (using trapezoidal integration) is provided in Table 4. The latter is also plotted in Figure 1 below.

As can be seen in Figure 1, the beta+gamma integrated doses in the sump water due to isotopes in the water exceed the 1-year airborne integrated gamma dose at ~20 days, and reach 42 MRad in one year. Note it is not appropriate to sum the airborne and water gamma doses as both doses assume that all of the released halogen is present in each location (i.e., would double count dose from these isotopes).

Conclusion

It was determined above that the dose rate applied to the sump water for nitric acid should have been 2.51 times greater than what was used in Reference 3. Applying this change alone would increase the sodium tetraborate (STB) amount required to maintain a pH of 7.0 by ~226 lbm to 13674 lbm. This is still below the proposed Technical Specification 3.5.5 required STB amount of 13750 lbm. However, additional conservatism is also present in the dose utilized to calculate the amount of hydrochloric acid produced from cable insulation. Reference 3 applies one of the highest 1-year integrated doses possible for any cable (567.6 MRad beta+gamma at the outside surface of the iodine removal unit housing) to the entire mass of cable insulation in Containment. However, the 1-year integrated gamma dose at the containment electrical penetrations (which are relatively close to the iodine removal units) ranges from 18-42 MRad. Even when combined with the 1-year integrated airborne+plateout beta dose of 227 MRad, the resulting 250-270 MRad suggests that most cables in Containment would see half the dose, and that a reduction in HCl amount on par with the increase in nitric acid above could be achieved from an explicit accounting of dose to cables.

Table 2 – Integrated Photon Source (photons-hr/cc-sec); Reference 4

Time (days)	11	27	47	365
Mean E (MeV)				
0.015	1.82E+10	2.74E+10	3.51E+10	9.06E+10
0.025	1.89E+10	2.75E+10	3.29E+10	6.42E+10
0.045	2.58E+10	3.73E+10	4.45E+10	9.53E+10
0.080	2.23E+10	3.20E+10	3.67E+10	6.59E+10
0.150	9.48E+09	1.40E+10	1.81E+10	5.28E+10
0.300	1.46E+11	2.09E+11	2.29E+11	2.49E+11
0.500	5.90E+10	7.01E+10	7.92E+10	1.17E+11
0.650	2.01E+10	2.78E+10	3.29E+10	7.94E+10
0.750	2.29E+10	4.31E+10	6.43E+10	1.78E+11
0.900	1.19E+10	1.38E+10	1.48E+10	1.77E+10
1.250	1.46E+10	1.50E+10	1.54E+10	1.90E+10
1.750	8.92E+09	1.28E+10	1.46E+10	1.61E+10
2.500	7.45E+08	1.00E+09	1.16E+09	1.95E+09
3.500	2.79E+07	2.92E+07	2.99E+07	3.18E+07
4.500	2.02E+06	2.02E+06	2.02E+06	2.02E+06
5.500	1.90E+05	1.90E+05	1.90E+05	1.90E+05
6.500	5.75E+02	5.75E+02	5.75E+02	5.75E+02
7.500	1.60E+01	1.60E+01	1.60E+01	1.60E+01
9.000	1.06E-01	1.06E-01	1.06E-01	1.06E-01
12.000	1.65E-22	9.76E-22	2.89E-21	1.40E-19
Total	3.79E+11	5.31E+11	6.18E+11	1.05E+12
Total Photons*	5.71E+21	8.01E+21	9.32E+21	1.58E+22

* photons-hr/cc-sec x 3600 sec/hr x 4.19E6 cc model volume

```
11d integrated photon dose in water
1     1 -1.0 2 -1 imp:p=1 $water
2     1 -1.0 -2   imp:p=1 $water tally cell
3     0  1   imp:p=0 $outside world

*1   SO 100
2    SO 5

m1    1000  2  $ water
      8000  1
MODE P
SDEF  POS=0 0 0 RAD=d1 ERG=d2
si1 100
sp1 -21
si2 l 0.015 0.025 0.045 0.080 0.150 0.300 0.500 0.650
      0.750 0.900 1.250 1.750 2.500 3.500 4.500 5.500
      6.500 7.500 9.000 12.000
sp2 d 1.82E+10 1.89E+10 2.58E+10 2.23E+10 9.48E+09 1.46E+11
      5.90E+10 2.01E+10 2.29E+10 1.19E+10 1.46E+10 8.92E+09
      7.45E+08 2.79E+07 2.02E+06 1.90E+05 5.75E+02 1.60E+01
      1.06E-01 1.65E-22
F16:P 2  $MeV/g
ctme 10
print   -85
```

Table 3 - Sump Water Specific Activity as a Function of Time (µCi/cc) using 50% halogens and 1% Fission Products per Regulatory Guide 1.89 (TID-14484 methodology)

	initial	0.1 hr	1.0 hr	4.0 hr	8.0 hr	13.0 hr	24.0 hr	72.0 hr	144.0 hr	264.0 hr	648.0 hr	1848.0 hr	3288.0 hr	4968.0 hr	6792.0 hr	8760.0 hr
ba137m	6.15E+01	6.11E+01	6.10E+01	6.10E+01	6.10E+01	6.10E+01	6.10E+01	6.10E+01	6.10E+01	6.10E+01	6.09E+01	6.07E+01	6.05E+01	6.02E+01	5.99E+01	5.96E+01
ba140	7.24E+02	7.24E+02	7.22E+02	7.17E+02	7.11E+02	7.03E+02	6.86E+02	6.15E+02	5.23E+02	3.98E+02	1.67E+02	1.10E+01	4.23E-01	9.42E-03	1.52E-04	1.76E-06
br 84	5.45E+03	4.78E+03	1.47E+03	2.91E+01	1.56E-01	2.25E-04	1.27E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
br 85	6.51E+03	1.53E+03	3.31E-03	4.37E-22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
br 87	1.10E+04	1.25E+02	3.82E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
br 88	1.24E+04	3.35E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ce143	6.62E+02	6.62E+02	6.53E+02	6.13E+02	5.64E+02	5.07E+02	4.03E+02	1.47E+02	3.24E+01	2.60E+00	8.18E-04	9.25E-15	6.77E-28	0.00E+00	0.00E+00	0.00E+00
ce144	5.17E+02	5.17E+02	5.17E+02	5.17E+02	5.17E+02	5.16E+02	5.16E+02	5.13E+02	5.10E+02	5.03E+02	4.84E+02	4.29E+02	3.70E+02	3.12E+02	2.60E+02	2.13E+02
cs134	9.82E+01	9.82E+01	9.82E+01	9.82E+01	9.82E+01	9.82E+01	9.81E+01	9.79E+01	9.77E+01	9.72E+01	9.58E+01	9.15E+01	8.66E+01	8.12E+01	7.57E+01	7.02E+01
cs136	2.39E+01	2.39E+01	2.38E+01	2.37E+01	2.35E+01	2.32E+01	2.27E+01	2.04E+01	1.74E+01	1.34E+01	5.76E+00	4.14E-01	1.76E-02	4.40E-04	8.03E-06	1.07E-07
cs137	6.46E+01	6.46E+01	6.46E+01	6.46E+01	6.46E+01	6.46E+01	6.46E+01	6.46E+01	6.46E+01	6.46E+01	6.45E+01	6.43E+01	6.40E+01	6.38E+01	6.35E+01	6.31E+01
cs138	7.75E+02	6.88E+02	2.25E+02	4.74E+00	2.70E-02	4.24E-05	2.86E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
i131	1.93E+04	1.93E+04	1.92E+04	1.90E+04	1.88E+04	1.84E+04	1.77E+04	1.49E+04	1.15E+04	7.48E+03	1.88E+03	2.53E+01	1.43E-01	3.44E-04	4.90E-07	4.17E-10
i132	2.79E+04	2.71E+04	2.07E+04	8.66E+03	2.94E+03	1.03E+03	4.75E+02	2.98E+02	1.58E+02	5.44E+01	1.81E+00	4.34E-05	1.24E-10	4.23E-17	4.02E-24	1.07E-31
i133	4.03E+04	4.02E+04	3.90E+04	3.53E+04	3.09E+04	2.61E+04	1.81E+04	3.66E+03	3.32E+02	6.09E+00	1.69E-05	7.25E-23	0.00E+00	0.00E+00	0.00E+00	0.00E+00
i134	4.52E+04	4.18E+04	2.07E+04	1.98E+03	8.52E+01	1.65E+00	2.76E-04	9.11E-21	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
i135	3.75E+04	3.71E+04	3.37E+04	2.46E+04	1.61E+04	9.51E+03	2.98E+03	1.88E+01	9.45E-03	3.00E-08	7.60E-26	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
i137	1.93E+04	7.28E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
i138	9.66E+03	1.94E-13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
la140	7.29E+02	7.29E+02	7.29E+02	7.28E+02	7.27E+02	7.26E+02	7.20E+02	6.78E+02	5.93E+02	4.57E+02	1.92E+02	1.27E+01	4.87E-01	1.09E-02	1.74E-04	2.02E-06
la143	6.62E+02	4.93E+02	3.50E+01	5.15E-03	4.00E-08	1.64E-14	1.46E-28	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
mo 99	7.24E+02	7.23E+02	7.16E+02	6.94E+02	6.66E+02	6.32E+02	5.63E+02	3.40E+02	1.59E+02	4.51E+01	7.97E-01	2.65E-06	7.08E-13	1.52E-20	7.16E-29	6.66E-38
nb 95	6.77E+02	6.77E+02	6.77E+02	6.77E+02	6.77E+02	6.77E+02	6.77E+02	6.77E+02	6.75E+02	6.70E+02	6.38E+02	4.73E+02	2.86E+02	1.46E+02	6.71E+01	2.83E+01
nb 95m	7.55E+00	7.55E+00	7.55E+00	7.55E+00	7.55E+00	7.55E+00	7.55E+00	7.50E+00	7.37E+00	7.07E+00	5.99E+00	3.49E+00	1.82E+00	8.53E-01	3.75E-01	1.54E-01
pr143	6.51E+02	6.51E+02	6.51E+02	6.51E+02	6.50E+02	6.49E+02	6.45E+02	6.06E+02	5.31E+02	4.14E+02	1.83E+02	1.42E+01	6.62E-01	1.85E-02	3.81E-04	5.77E-06
pr144	5.22E+02	5.20E+02	5.17E+02	5.16E+02	5.16E+02	5.17E+02	5.16E+02	5.13E+02	5.10E+02	5.03E+02	4.84E+02	4.29E+02	3.70E+02	3.12E+02	2.60E+02	2.13E+02
rb 88	3.74E+02	3.00E+02	5.05E+01	7.92E+00	2.97E+00	8.79E-01	5.98E-02	4.86E-07	1.13E-14	2.12E-27	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
rb 89	4.85E+02	3.69E+02	3.14E+01	8.56E-03	1.51E-07	1.73E-13	1.47E-26	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
rb 90	4.77E+02	9.34E+01	3.94E-05	2.22E-26	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ru103	6.62E+02	6.62E+02	6.62E+02	6.60E+02	6.58E+02	6.56E+02	6.50E+02	6.28E+02	5.95E+02	5.45E+02	4.11E+02	1.70E+02	5.89E+01	1.71E+01	4.48E+00	1.05E+00
ru106	3.00E+02	3.00E+02	3.00E+02	3.00E+02	3.00E+02	3.00E+02	2.99E+02	2.98E+02	2.97E+02	2.94E+02	2.85E+02	2.60E+02	2.32E+02	2.04E+02	1.77E+02	1.52E+02
sr 89	4.56E+02	4.56E+02	4.56E+02	4.55E+02	4.54E+02	4.53E+02	4.50E+02	4.38E+02	4.20E+02	3.92E+02	3.15E+02	1.59E+02	6.97E+01	2.67E+01	9.42E+00	3.06E+00
sr 90	4.64E+01	4.64E+01	4.64E+01	4.64E+01	4.64E+01	4.64E+01	4.64E+01	4.64E+01	4.64E+01	4.64E+01	4.63E+01	4.62E+01	4.60E+01	4.58E+01	4.55E+01	4.53E+01
sr 91	6.10E+02	6.06E+02	5.67E+02	4.56E+02	3.41E+02	2.37E+02	1.06E+02	3.22E+00	1.70E-02	2.73E-06	1.97E-18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
sr 95	5.94E+02	2.86E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
tc 99m	6.46E+02	6.46E+02	6.45E+02	6.37E+02	6.23E+02	5.99E+02	5.41E+02	3.29E+02	1.54E+02	4.37E+01	7.72E-01	2.57E-06	6.86E-13	1.47E-20	6.93E-29	0.00E+00
te129	1.23E+02	1.17E+02	7.48E+01	2.57E+01	1.67E+01	1.58E+01	1.56E+01	1.50E+01	1.41E+01	1.27E+01	9.14E+00	3.26E+00	9.45E-01	2.23E-01	4.65E-02	8.57E-03
te129m	2.49E+01	2.49E+01	2.49E+01	2.48E+01	2.47E+01	2.46E+01	2.44E+01	2.34E+01	2.20E+01	1.98E+01	1.43E+01	5.09E+00	1.47E+00	3.48E-01	7.26E-02	1.34E-02
te131	3.33E+02	2.85E+02	7.66E+01	1.60E+01	1.42E+01	1.27E+01	9.83E+00	3.24E+00	6.14E-01	3.84E-02	5.38E-06	4.89E-18	1.74E-32	0.00E+00	0.00E+00	0.00E+00
te131m	7.60E+01	7.58E+01	7.43E+01	6.93E+01	6.32E+01	5.63E+01	4.37E+01	1.44E+01	2.73E+00	1.71E-01	2.39E-05	2.17E-17	7.72E-32	0.00E+00	0.00E+00	0.00E+00
te132	5.48E+02	5.48E+02	5.43E+02	5.29E+02	5.10E+02	4.88E+02	4.43E+02	2.89E+02	1.53E+02	5.28E+01	1.75E+00	4.21E-05	1.20E-10	4.10E-17	3.90E-24	1.03E-31
te133	4.73E+02	3.57E+02	5.34E+01	4.15E+00	2.06E-01	4.83E-03	1.25E-06	2.81E-22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
te133m	3.70E+02	3.43E+02	1.75E+02	1.84E+01	9.12E-01	2.14E-02	5.54E-06	1.24E-21	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
te134	7.70E+02	6.97E+02	2.85E+02	1.44E+01	2.69E-01	1.86E-03	3.28E-08	5.96E-29	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
y 89m	4.19E-01	4.24E-02	4.24E-02	4.23E-02	4.22E-02	4.21E-02	4.18E-02	4.07E-02	3.91E-02	3.65E-02	2.93E-02	1.48E-02	6.48E-03	2.48E-03	8.76E-04	2.85E-04

Table 3 - Sump Water Specific Activity as a Function of Time (µCi/cc) using 50% halogens and 1% Fission Products per Regulatory Guide 1.89 (TID-14484 methodology)

	initial	0.1 hr	1.0 hr	4.0 hr	8.0 hr	13.0 hr	24.0 hr	72.0 hr	144.0 hr	264.0 hr	648.0 hr	1848.0 hr	3288.0 hr	4968.0 hr	6792.0 hr	8760.0 hr
y 90	4.93E+01	4.93E+01	4.93E+01	4.92E+01	4.91E+01	4.89E+01	4.86E+01	4.77E+01	4.70E+01	4.65E+01	4.63E+01	4.62E+01	4.60E+01	4.58E+01	4.55E+01	4.53E+01
y 91	5.63E+02	5.63E+02	5.63E+02	5.63E+02	5.63E+02	5.62E+02	5.60E+02	5.48E+02	5.28E+02	4.98E+02	4.12E+02	2.28E+02	1.12E+02	4.88E+01	1.99E+01	7.51E+00
y 91m	3.53E+02	3.53E+02	3.45E+02	2.88E+02	2.16E+02	1.50E+02	6.75E+01	2.05E+00	1.08E-02	1.74E-06	1.25E-18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
y 95	7.24E+02	5.04E+02	1.43E+01	9.85E-05	1.30E-11	3.25E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
zr 95	6.82E+02	6.82E+02	6.82E+02	6.81E+02	6.80E+02	6.78E+02	6.75E+02	6.60E+02	6.39E+02	6.05E+02	5.09E+02	2.96E+02	1.55E+02	7.25E+01	3.18E+01	1.31E+01

Table 4 - Beta Dose Rates (rad/hr) and Total Integrated Dose (MRad) for a Point in an Infinite Sump

Isotope	(MeV)	initial	0.1 hr	1.0 hr	4.0 hr	8.0 hr	13.0 hr	24.0 hr	72.0 hr	144.0 hr	264.0 hr	648.0 hr	1848.0 hr	3288.0 hr	4968.0 hr	6792.0 hr	8760.0 hr
ba137m	0.0651	8.55E+00	8.49E+00	8.48E+00	8.48E+00	8.48E+00	8.48E+00	8.48E+00	8.48E+00	8.48E+00	8.48E+00	8.46E+00	8.44E+00	8.41E+00	8.37E+00	8.32E+00	8.28E+00
ba140	0.3128	4.83E+02	4.83E+02	4.82E+02	4.79E+02	4.75E+02	4.69E+02	4.58E+02	4.11E+02	3.49E+02	2.66E+02	1.12E+02	7.34E+00	2.82E-01	6.29E-03	1.01E-04	1.18E-06
br84	1.2291	1.43E+04	1.25E+04	3.86E+03	7.63E+01	4.09E-01	5.90E-04	3.33E-10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
br85	1.04	1.45E+04	3.40E+03	7.35E-03	9.70E-22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
br87	1.62	3.80E+04	4.32E+02	1.32E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
br88	2.5	6.62E+04	1.79E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ce143	0.4325	6.11E+02	6.11E+02	6.03E+02	5.66E+02	5.21E+02	4.68E+02	3.72E+02	1.36E+02	2.99E+01	2.40E+00	7.55E-04	8.54E-15	6.25E-28	0.00E+00	0.00E+00	0.00E+00
ce144	0.0922	1.02E+02	1.02E+02	1.02E+02	1.02E+02	1.02E+02	1.02E+02	1.02E+02	1.01E+02	1.00E+02	9.90E+01	9.53E+01	8.44E+01	7.28E+01	6.14E+01	5.12E+01	4.19E+01
cs134	0.1636	3.43E+01	3.43E+01	3.43E+01	3.43E+01	3.43E+01	3.43E+01	3.43E+01	3.42E+01	3.41E+01	3.39E+01	3.35E+01	3.20E+01	3.02E+01	2.84E+01	2.64E+01	2.45E+01
cs136	0.1389	7.09E+00	7.09E+00	7.06E+00	7.03E+00	6.97E+00	6.88E+00	6.73E+00	6.05E+00	5.16E+00	3.97E+00	1.71E+00	1.23E-01	5.22E-03	1.30E-04	2.38E-06	3.17E-08
cs137	0.187	2.58E+01	2.58E+01	2.58E+01	2.58E+01	2.58E+01	2.58E+01	2.58E+01	2.58E+01	2.58E+01	2.58E+01	2.57E+01	2.57E+01	2.55E+01	2.55E+01	2.53E+01	2.52E+01
cs138	1.2067	2.00E+03	1.77E+03	5.80E+02	1.22E+01	6.95E-02	1.09E-04	7.37E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
i131	0.1917	7.90E+03	7.90E+03	7.86E+03	7.77E+03	7.69E+03	7.53E+03	7.24E+03	6.10E+03	4.71E+03	3.06E+03	7.69E+02	1.04E+01	5.85E-02	1.41E-04	2.01E-07	1.71E-10
i132	0.4953	2.95E+04	2.87E+04	2.19E+04	9.16E+03	3.11E+03	1.09E+03	5.02E+02	3.15E+02	1.67E+02	5.75E+01	1.91E+00	4.59E-05	1.31E-10	4.47E-17	4.25E-24	1.13E-31
i133	0.4106	3.53E+04	3.52E+04	3.42E+04	3.09E+04	2.71E+04	2.29E+04	1.59E+04	3.21E+03	2.91E+02	5.34E+00	1.48E-05	6.35E-23	0.00E+00	0.00E+00	0.00E+00	0.00E+00
i134	0.6223	6.00E+04	5.55E+04	2.75E+04	2.63E+03	1.13E+02	2.19E+00	3.67E-04	1.21E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
i135	0.367	2.94E+04	2.91E+04	2.64E+04	1.93E+04	1.26E+04	7.45E+03	2.33E+03	1.47E+01	7.40E-03	2.35E-08	5.95E-26	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
i137	1.965	8.10E+04	3.05E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
i138	2.9	5.98E+04	1.20E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
la140	0.537	8.36E+02	8.36E+02	8.36E+02	8.34E+02	8.33E+02	8.32E+02	8.25E+02	7.77E+02	6.80E+02	5.24E+02	2.20E+02	1.46E+01	5.58E-01	1.25E-02	1.99E-04	2.32E-06
la143	1.3238	1.87E+03	1.39E+03	9.89E+01	1.46E-02	1.13E-07	4.63E-14	4.13E-28	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
mo99	0.3922	6.06E+02	6.05E+02	5.99E+02	5.81E+02	5.58E+02	5.29E+02	4.71E+02	2.85E+02	1.33E+02	3.78E+01	6.67E-01	2.22E-06	5.93E-13	1.27E-20	5.99E-29	5.58E-38
nb95	0.0444	6.42E+01	6.42E+01	6.42E+01	6.42E+01	6.42E+01	6.42E+01	6.42E+01	6.42E+01	6.40E+01	6.35E+01	6.05E+01	4.48E+01	2.71E+01	1.38E+01	6.36E+00	2.68E+00
nb95m	0.1663	2.68E+00	2.68E+00	2.68E+00	2.68E+00	2.68E+00	2.68E+00	2.68E+00	2.66E+00	2.62E+00	2.51E+00	2.13E+00	1.24E+00	6.46E-01	3.03E-01	1.33E-01	5.47E-02
pr143	0.3142	4.37E+02	4.37E+02	4.37E+02	4.37E+02	4.36E+02	4.35E+02	4.33E+02	4.06E+02	3.56E+02	2.78E+02	1.23E+02	9.52E+00	4.44E-01	1.24E-02	2.56E-04	3.87E-06
pr144	1.2075	1.35E+03	1.34E+03	1.33E+03	1.33E+03	1.33E+03	1.33E+03	1.33E+03	1.32E+03	1.31E+03	1.30E+03	1.25E+03	1.11E+03	9.54E+02	8.04E+02	6.70E+02	5.49E+02
rb88	2.0664	1.65E+03	1.32E+03	2.23E+02	3.49E+01	1.31E+01	3.88E+00	2.64E-01	2.14E-06	4.98E-14	9.35E-27	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
rb89	1.0131	1.05E+03	7.98E+02	6.79E+01	1.85E-02	3.27E-07	3.74E-13	3.18E-26	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
rb90	1.75	1.78E+03	3.49E+02	1.47E-04	8.29E-26	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
ru103	0.0748	1.06E+02	1.06E+02	1.06E+02	1.05E+02	1.05E+02	1.05E+02	1.04E+02	1.00E+02	9.50E+01	8.70E+01	6.56E+01	2.71E+01	9.40E+00	2.73E+00	7.15E-01	1.68E-01
ru106	0.01	6.40E+00	6.40E+00	6.40E+00	6.40E+00	6.40E+00	6.40E+00	6.38E+00	6.36E+00	6.34E+00	6.28E+00	6.08E+00	5.55E+00	4.95E+00	4.35E+00	3.78E+00	3.24E+00
sr89	0.5832	5.68E+02	5.68E+02	5.68E+02	5.66E+02	5.65E+02	5.64E+02	5.60E+02	5.45E+02	5.23E+02	4.88E+02	3.92E+02	1.98E+02	8.68E+01	3.32E+01	1.17E+01	3.81E+00
sr90	0.1957	1.94E+01	1.94E+01	1.94E+01	1.94E+01	1.94E+01	1.94E+01	1.94E+01	1.94E+01	1.94E+01	1.94E+01	1.93E+01	1.93E+01	1.92E+01	1.91E+01	1.90E+01	1.89E+01
sr91	0.6555	8.54E+02	8.48E+02	7.93E+02	6.38E+02	4.77E+02	3.32E+02	1.48E+02	4.51E+00	2.38E-02	3.82E-06	2.76E-18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
sr95	2.21	2.80E+03	1.35E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
tc99m	0.0162	2.23E+01	2.23E+01	2.23E+01	2.20E+01	2.15E+01	2.07E+01	1.87E+01	1.14E+01	5.33E+00	1.51E+00	2.67E-02	8.89E-08	2.37E-14	5.08E-22	2.40E-30	0.00E+00
te129	0.5443	1.43E+02	1.36E+02	8.69E+01	2.99E+01	1.94E+01	1.84E+01	1.81E+01	1.74E+01	1.64E+01	1.48E+01	1.06E+01	3.79E+00	1.10E+00	2.59E-01	5.40E-02	9.96E-03
te129m	0.2601	1.38E+01	1.38E+01	1.38E+01	1.38E+01	1.37E+01	1.37E+01	1.35E+01	1.30E+01	1.22E+01	1.10E+01	7.94E+00	2.83E+00	8.16E-01	1.93E-01	4.03E-02	7.44E-03
te131	0.7192	5.11E+02	4.38E+02	1.18E+02	2.46E+01	2.18E+01	1.95E+01	1.51E+01	4.97E+00	9.43E-01	5.90E-02	8.26E-06	7.51E-18	2.67E-32	0.00E+00	0.00E+00	0.00E+00
te131m	0.2024	3.28E+01	3.27E+01	3.21E+01	2.99E+01	2.73E+01	2.43E+01	1.89E+01	6.22E+00	1.18E+00	7.39E-02	1.03E-05	9.38E-18	3.34E-32	0.00E+00	0.00E+00	0.00E+00
te132	0.1021	1.19E+02	1.19E+02	1.18E+02	1.15E+02	1.11E+02	1.06E+02	9.65E+01	6.30E+01	3.33E+01	1.15E+01	3.81E-01	9.18E-06	2.62E-11	8.94E-18	8.50E-25	2.24E-32
te133	0.8189	8.27E+02	6.24E+02	9.33E+01	7.25E+00	3.60E-01	8.44E-03	2.19E-06	4.91E-22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
te133m	0.7047	5.57E+02	5.16E+02	2.63E+02	2.77E+01	1.37E+00	3.22E-02	8.33E-06	1.87E-21	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
te134	0.2995	4.92E+02	4.46E+02	1.82E+02	9.21E+00	1.72E-01	1.19E-03	2.10E-08	3.81E-29	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
y89m	0.4	3.58E-01	3.62E-02	3.62E-02	3.61E-02	3.60E-02	3.59E-02	3.57E-02	3.48E-02	3.34E-02	3.12E-02	2.50E-02	1.26E-02	5.53E-03	2.12E-03	7.48E-04	2.43E-04
y90	0.9349	9.84E+01	9.84E+01	9.84E+01	9.82E+01	9.80E+01	9.76E+01	9.70E+01	9.52E+01	9.38E+01	9.28E+01	9.24E+01	9.22E+01	9.18E+01	9.14E+01	9.08E+01	9.04E+01
y91	0.6022	7.24E+02	7.24E+02	7.24E+02	7.24E+02	7.24E+02	7.22E+02	7.20E+02	7.04E+02	6.79E+02	6.40E+02	5.30E+02	2.93E+02	1.44E+02	6.27E+01	2.56E+01	9.65E+00

Table 4 - Beta Dose Rates (rad/hr) and Total Integrated Dose (MRad) for a Point in an Infinite Sump

Isotope	(MeV)	initial	0.1 hr	1.0 hr	4.0 hr	8.0 hr	13.0 hr	24.0 hr	72.0 hr	144.0 hr	264.0 hr	648.0 hr	1848.0 hr	3288.0 hr	4968.0 hr	6792.0 hr	8760.0 hr
y91m	0.0273	2.06E+01	2.06E+01	2.01E+01	1.68E+01	1.26E+01	8.74E+00	3.93E+00	1.19E-01	6.29E-04	1.01E-07	7.28E-20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
y95	1.5277	2.36E+03	1.64E+03	4.66E+01	3.21E-04	4.24E-11	1.06E-19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
zr95	0.1163	1.69E+02	1.69E+02	1.69E+02	1.69E+02	1.69E+02	1.68E+02	1.68E+02	1.64E+02	1.59E+02	1.50E+02	1.26E+02	7.35E+01	3.85E+01	1.80E+01	7.89E+00	3.25E+00
Dose Rate (rad/hr)		4.59E+05	1.89E+05	1.31E+05	7.70E+04	5.74E+04	4.55E+04	3.21E+04	1.50E+04	9.91E+03	7.29E+03	3.95E+03	2.06E+03	1.52E+03	1.17E+03	9.48E+02	7.81E+02
Int. Dose (MRad)		0	0.03	0.18	0.49	0.76	1.01	1.44	2.57	3.47	4.50	6.66	10.26	12.84	15.10	17.03	18.73

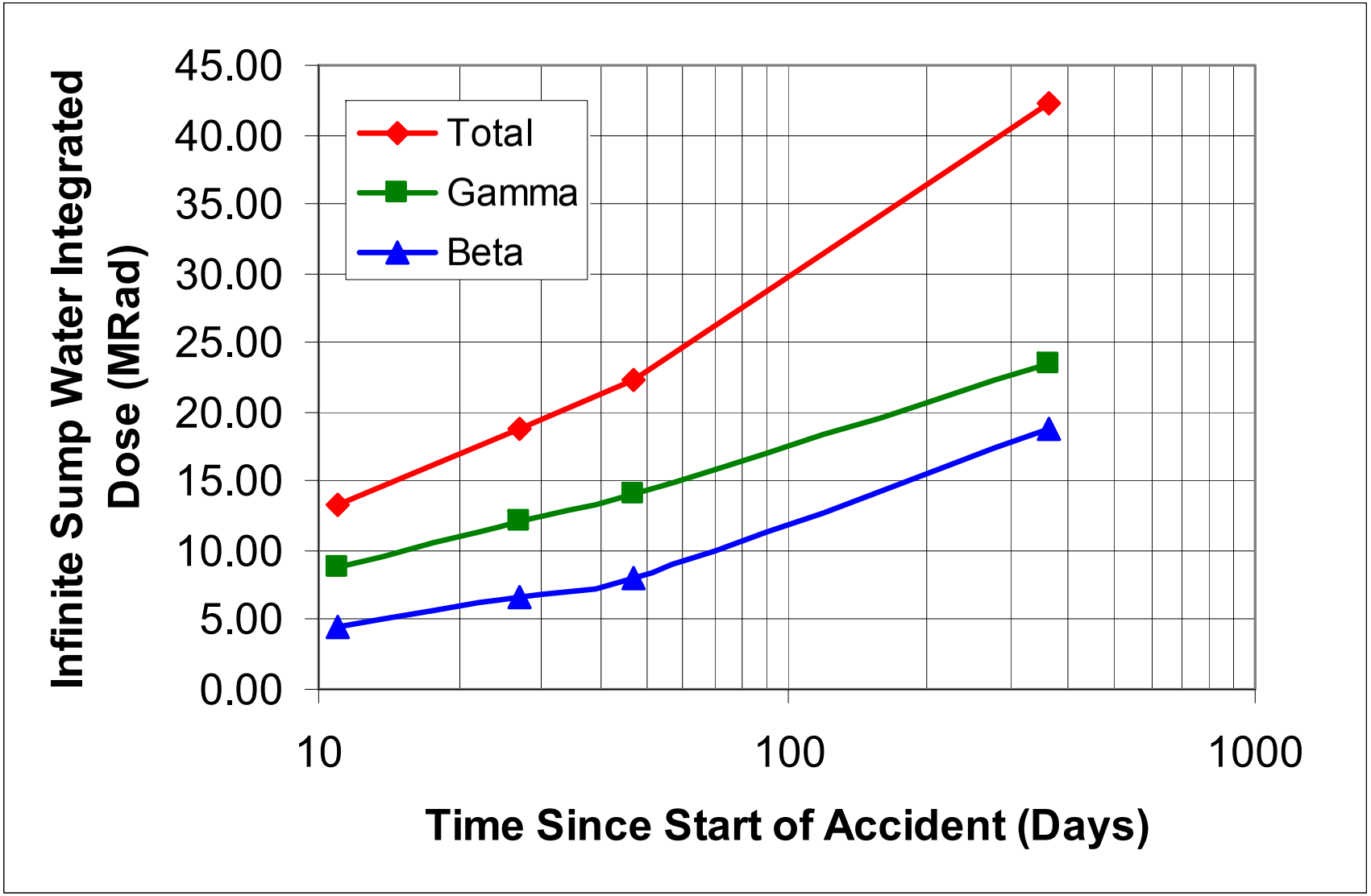

Figure 1 – Total Integrated Dose to a Point inside an Infinite Sump Water Source

REFERENCES:

1. Lamarsh, J. R., Introduction to Nuclear Engineering, 2nd Edition, 1983
2. ICRP Publication 38, Radionuclide Transformations: Energy and Intensity of Emissions, 1983
3. Calculation 0090-0148-01, Mass of Sodium Tetraborate Decahydrate Buffer Required for Post-LOCA, Containment Building Sump pH Control, August 25, 2008
4. Brookhaven National Laboratory Chart of Nuclides *http://www.nndc.bnl.gov/chart/)*