Validation of the Public Radiation Exposure Calculation for the Incident at the National Institute of Standards and Technology Center for Neutron Research on February 3, 2021

Performed by Subject Matter Experts of Department of Energy/National Nuclear Security Administration Nuclear Emergency Support Team

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National Nuclear Security Administration

NEST NUCLEAR EMERGENCY SUPPORT TEAM

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Executive Summary

The Department of Energy/National Nuclear Security Administration Consequence Management Program was contacted by the Health Physics Chief of the National Institute of Standards and Technology Center for Neutron Research (NCNR) to review public radiation exposure calculations for an event that occurred on its Gaithersburg, Maryland, campus on February 3, 2021. Subject matter experts from the Nuclear Emergency Support Team (NEST) assets, specifically the Consequence Management Home Team (CMHT) and the National Atmospheric Release Advisory Center (NARAC), were selected to provide support.

CMHT used three separate modeling codes to validate the results the scientists at NCNR calculated using the HotSpot model. The analyses were performed using NARAC's in-house Lagrangian dispersion codes known as LODI and Aeolus, as well as the Turbo FRMAC software from Sandia National Laboratories. The team used parameters provided by the NCNR scientists regarding the site, applicable observable meteorological data, and environmental survey and sampling data to estimate public exposure. Each model estimated public dose at much less than 0.5 mrem. CMHT concurs with the NCNR public radiation exposure calculations which state that members of the public at the 400-meter boundary would have received a radiological dose of less than 0.5 mrem.

Background

The Department of Energy/National Nuclear Security Administration's Consequence Management Home Team (CMHT) was requested by the Health Physics Chief of the National Institute of Standards and Technology Center for Neutron Research (NCNR) to review public radiation exposure calculations for an event that occurred on its Gaithersburg, Maryland, campus on February 3, 2021. More information on the event can be found on the NCNR website: https://www.nist.gov/ncnr.

NCNR staff collected radiological sampling and monitoring data during the event. NCNR staff then used the HotSpot Health Physics code, developed by National Atmospheric Release Advisory Center (NARAC) located at Lawrence Livermore National Laboratory (LLNL), to estimate the exposure to the general public as a result of the plume release. HotSpot is a fast-running, local-scale, steady-state Gaussian plume model for radiological releases that provides predictions of time-integrated effects such as dose received by an individual if exposed to a plume. HotSpot was created to provide emergency response personnel and emergency planners with a fast, field-portable set of software tools for evaluating incidents involving radioactive material. The conservative assumptions used in the model also make it suitable for safety and hazard analyses (https://narac.llnl.gov/tools/hotspot-epicode).

NCNR staff shared their radiological sampling and monitoring data and HotSpot calculation results with CMHT staff. CMHT asked for some clarifying information and all requests were fulfilled by NCNR staff on March 21, 2021. CMHT staff (which includes scientists from NARAC) then began the process of validating the public exposure estimate.

Using the NCNR model inputs and radiological data, NARAC implemented its primary dispersion model to estimate public exposure. NARAC's primary dispersion model, the Lagrangian Operational Dispersion Integrator (LODI), uses wind, turbulence, and other gridded meteorological fields generated by NARAC's meteorological data assimilation model to predict 2-D and 3-D gridded concentrations of hazardous material released into the atmosphere. In some release scenarios, buildings and infrastructures may impact dispersion. In these circumstances, NARAC also employs Aeolus, a computational fluid dynamics code. Aeolus, like LODI, simulates Lagrangian contaminant transport and dispersion, but integrates the impacts of buildings on the wind flow, unlike LODI which accounts only for terrain. Both models output time series of instantaneous and time-integrated air concentrations and ground deposition. The results of these models are further processed to create NARAC visualization products, spatially displaying areas where airborne or ground contamination may be found. Model results can also be converted to specific levels of concern, such as Environmental Protection Agency/Department of Homeland Security protective action guide levels for radiological releases (https://narac.llnl.gov/tools/operational-modeling/dispersion-model-lodi).

Data

NCNR provided all pertinent radiological data and HotSpot modeling inputs to CMHT in order to validate the public dose calculation. Via email communication, NCNR also provided clarifications to questions posed by CMHT during the data review process.

The HotSpot model used by NCNR was shared with CMHT. The following model inputs and supporting information for each parameter were included:

- Radiological mixture and release activity

- Stack height, flow rates, and cross-sectional area of the stack
- Distances from the stack to the NCNR fence line
- Meteorological data

Radiological data from the environment was provided to CMHT and included the following:

- 400-meter boundary air sample results and locations
- 400-meter boundary exposure rate surveys and locations
- NCNR fence line GammaTRACER data and locations
- Stack monitor count rates

NARAC Plume Model

NARAC simulated the dispersion of nuclides from NCNR using LODI with the source term provided by NCNR that included 14 nuclides for a total of 29.65 Ci (see Table 1 below). The meteorology used for dispersion models included many publicly available weather observations from weather stations in the region as well as the wind observations from the meteorological tower at NCNR. In the simulation, the release began at 0913 EST on 3 Feb 2021 and ended at 1000 EST on 6 Feb 2021. The release was simulated from a 30 m stack that has a radius of 0.65 m. Given that LODI assumes a circular stack and the NCNR stack is square, a correction factor was applied. A circle with a radius of 0.65 m has the same surface area as the actual stack which is 1.39 m x 0.91 m or 4.57 ft x 3 ft. The flow rate from the stack was 0.05 m/s (150 cfm). In NARAC simulations, radiological decay is applied when materials are released to the atmosphere.

Table 1: List of total activity per nuclide included in the NARAC model.

Nuclide	Release Activity (Curies)
Kr-83m	1.53E+00
Kr-85m	5.16E-02
Kr-87	9.03E-02
Kr-88	1.14E-01
Rb-88	9.35E-02
Xe-137	4.91E-01
Xe-138	5.10E-01
Xe-131m	4.88E+00
Xe-133	1.80E+01
Xe-133m	9.70E-02
Xe-135	1.30E+00
Kr-85	2.49E+00
Co-60	9.01E-13
Cs-138	1.32E-12

Two release scenarios were simulated using LODI, with both totaling 29.65 Ci over the entire release period. In the first scenario, the ratio of the nuclides to the total source is held constant and the rate of release is also constant throughout the entire release period. See Figure 1 for a dose projection map for the constant release scenario. It should be noted that the dose projections are well below any health effect guidelines.

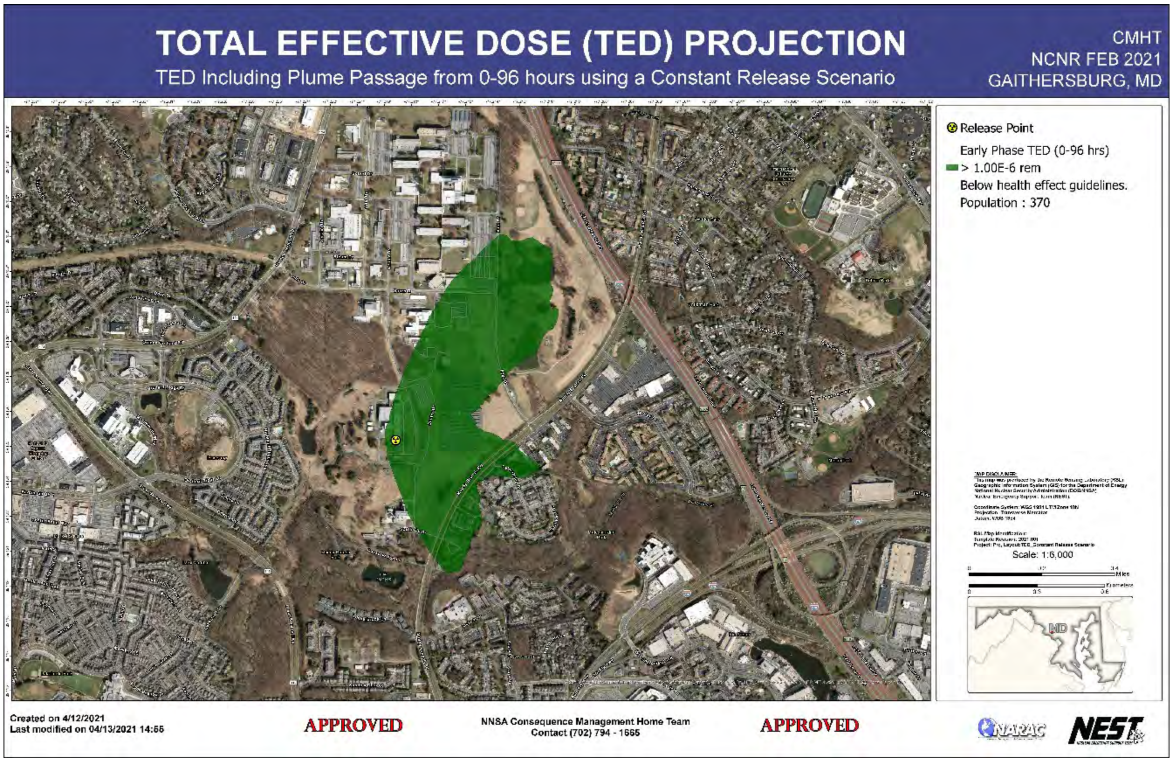


Figure 1: Dose projection for the constant release scenario.

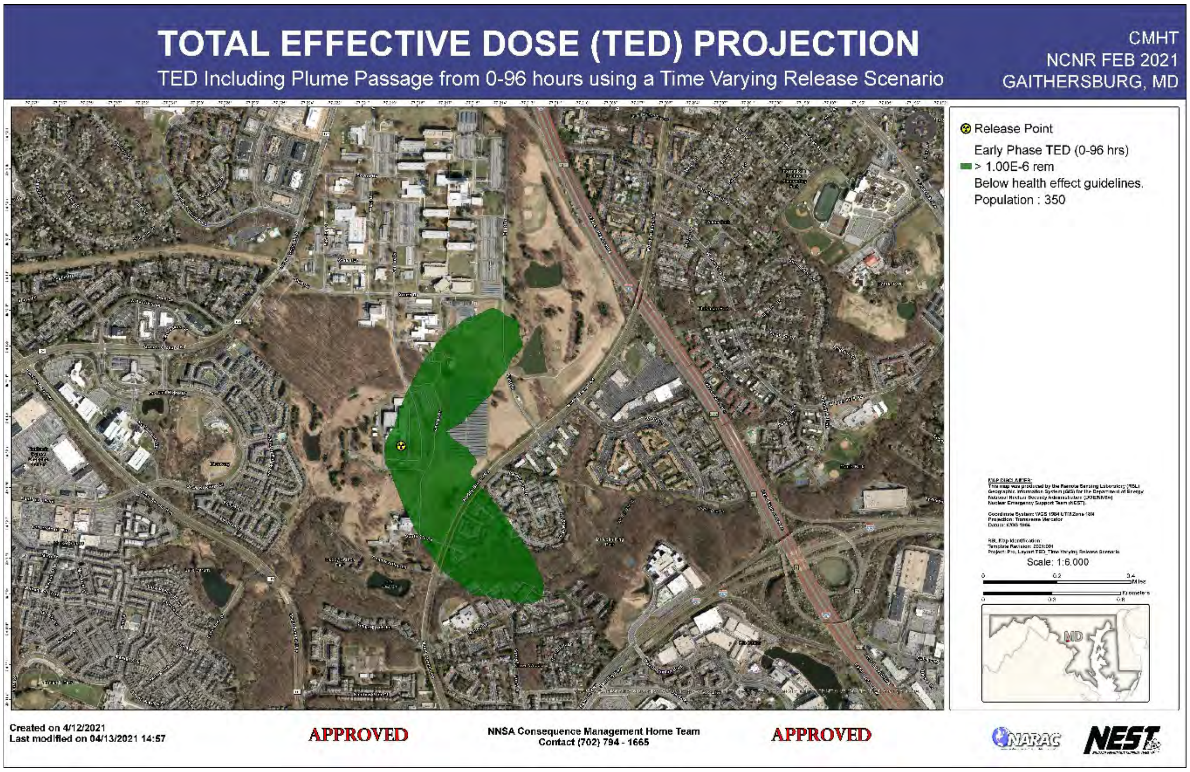
In the second release scenario, the release period was separated into 4 phases based on the data from the count rate monitor from the stack. All of the Co-60 and Cs-138 from the source term were released in Phase 1 based on the data from the stack charcoal/filter samples. The remaining nuclides maintained a constant ratio, though the rate of total material released in each phase varied. The second release scenario is described in Table 2.

Table 2: Characterization of the time-varying release simulated by NARAC using LODI.

Note: The percentage of the total activity is applicable for all nuclides except Co-60 and Cs-138, 100% of which was released in Phase 1.		
Phase	**Start Time**	**Percent of Activity**
1	09:13 EST 3 February 2021	50
2	20:15 EST 3 February 2021	10
3	16:00 EST 4 February 2021	30
4	16:00 EST 5 February 2021	10

The wind direction shifted throughout the duration of the release, and thus the plume was dispersed over a broad region from 0^{o} (north) to 180^{o} (south), clockwise. This reduced the concentration of contamination in any single direction. See Figure 2 for a dose projection map for the time-varying release scenario. It should be noted that the dose projections are well below any health effect guidelines.

Figure 2: Dose projection for the time-varying release scenario.



As a result of the wind shifts, the total effective dose during both release scenarios was well below 0.5 mrem. In the constant release rate scenario, the maximum dose was on the order of 8.0×10^{-3} mrem (see Table 3) and occurred within the 400-meter boundary. In the time-varying release rate scenario, the maximum dose was 1.1×10^{-2} mrem (see Table 4) and occurred within the 400-meter boundary.

Table 3: Constant release rate centerline results

Radial Distance	Path Length	Location	Concentration (mrem)	Arrival Time	Departure Time
10.0 m	10 m	39.126245 N, 77.218763 W	4.00E-03	Feb 3, 2021 14:20:13 UTC	Feb 6, 2021 05:43:43 UTC
20.0 m	20.094896 m	39.126175 N, 77.218690 W	7.00E-03	Feb 3, 2021 14:13:16 UTC	Feb 6, 2021 05:53:14 UTC
30.0 m	30.176698 m	39.126092 N, 77.218641 W	8.00E-03	Feb 3, 2021 14:13:16 UTC	Feb 6, 2021 06:09:40 UTC
40.0 m	41.389096 m	39.126044 N, 77.218527 W	7.00E-03	Feb 3, 2021 14:13:42 UTC	Feb 6, 2021 06:02:03 UTC
50.0 m	53.427561 m	39.125936 N, 77.218526 W	6.00E-03	Feb 3, 2021 14:13:16 UTC	Feb 6, 2021 04:59:55 UTC
60.0 m	66.245309 m	39.125903 N, 77.218384 W	6.00E-03	Feb 3, 2021 14:14:06 UTC	Feb 6, 2021 04:48:37 UTC
70.0 m	79.425129 m	39.125785 N, 77.218400 W	6.00E-03	Feb 3, 2021 14:13:28 UTC	Feb 6, 2021 05:38:38 UTC
80.0 m	89.509966 m	39.125701 N, 77.218354 W	5.00E-03	Feb 3, 2021 14:13:27 UTC	Feb 6, 2021 05:32:12 UTC

Radial Distance	Path Length	Location	Concentration (mrem)	Arrival Time	Departure Time
90.0 m	110.638505 m	39.125729 N, 77.218112 W	5.00E-03	Feb 3, 2021 14:13:30 UTC	Feb 6, 2021 06:12:07 UTC
100.0 m	123.829359 m	39.125610 N, 77.218114 W	5.00E-03	Feb 3, 2021 14:13:47 UTC	Feb 6, 2021 05:53:28 UTC
200.0 m	359.768924 m	39.127612 N, 77.217198 W	3.00E-03	Feb 4, 2021 18:12:06 UTC	Feb 6, 2021 14:59:47 UTC
300.0 m	460.818348 m	39.128363 N, 77.216540 W	3.00E-03	Feb 4, 2021 18:12:11 UTC	Feb 6, 2021 15:02:38 UTC
400.0 m	560.935122 m	39.129010 N, 77.215732 W	2.00E-03	Feb 4, 2021 18:13:21 UTC	Feb 6, 2021 15:04:09 UTC
500.0 m	662.396967 m	39.129794 N, 77.215129 W	2.00E-03	Feb 4, 2021 18:35:21 UTC	Feb 6, 2021 15:01:30 UTC
600.0 m	765.435662 m	39.130327 N, 77.214154 W	2.00E-03	Feb 4, 2021 18:07:53 UTC	Feb 6, 2021 15:03:32 UTC
700.0 m	867.484812 m	39.130858 N, 77.213191 W	1.00E-03	Feb 4, 2021 18:33:52 UTC	Feb 6, 2021 15:08:24 UTC
800.0 m	970.836234 m	39.131678 N, 77.212623 W	1.00E-03	Feb 4, 2021 18:30:56 UTC	Feb 6, 2021 15:05:47 UTC
900.0 m	1.071011E3 m	39.132384 N, 77.211903 W	1.00E-03	Feb 4, 2021 19:32:31 UTC	Feb 6, 2021 15:12:05 UTC
1000.0 m	1.172371E3 m	39.133161 N, 77.211287 W	1.00E-03	Feb 4, 2021 18:32:18 UTC	Feb 6, 2021 15:09:15 UTC
2500.0 m	2.78505E3 m	39.136819 N, 77.193237 W	3.89E-04	Feb 4, 2021 19:52:43 UTC	Feb 6, 2021 15:31:31 UTC
5000.0 m	8.36546E3 m	39.086571 N, 77.191656 W	1.49E-04	Feb 3, 2021 14:41:07 UTC	Feb 4, 2021 18:29:17 UTC
7500.0 m	1.336264E4 m	39.102542 N, 77.137653 W	5.15E-05	Feb 4, 2021 01:00:00 UTC	Feb 6, 2021 08:02:32 UTC
10000.0 m	1.586556E4 m	39.093428 N, 77.111190 W	2.30E-05	Feb 4, 2021 00:54:51 UTC	Feb 6, 2021 09:40:03 UTC

Table 4: Time-varying release rate centerline results

Radial Distance	Path Length	Location	Concentration (mrem)	Arrival Time	Departure Time
10.0 m	10 m	39.126244 N, 77.218766 W	7.00E-03	Feb 3, 2021 14:13:53 UTC	Feb 6, 2021 05:49:15 UTC
20.0 m	20.000487 m	39.126163 N, 77.218717 W	1.00E-02	Feb 3, 2021 14:13:35 UTC	Feb 4, 2021 23:02:53 UTC
30.0 m	30.061995 m	39.126087 N, 77.218653 W	1.10E-02	Feb 3, 2021 14:13:52 UTC	Feb 4, 2021 23:02:52 UTC
40.0 m	40.872363 m	39.126030 N, 77.218551 W	1.10E-02	Feb 3, 2021 14:13:18 UTC	Feb 6, 2021 05:41:12 UTC
50.0 m	51.496401 m	39.125937 N, 77.218524 W	1.00E-02	Feb 3, 2021 14:13:35 UTC	Feb 4, 2021 23:07:56 UTC
60.0 m	61.541938 m	39.125854 N, 77.218476 W	1.00E-02	Feb 3, 2021 14:13:21 UTC	Feb 5, 2021 18:18:23 UTC
70.0 m	75.800387 m	39.125831 N, 77.218314 W	9.00E-03	Feb 3, 2021 14:13:26 UTC	Feb 6, 2021 05:08:07 UTC

Radial Distance	Path Length	Location	Concentration (mrem)	Arrival Time	Departure Time
80.0 m	86.016153 m	39.125748 N, 77.218262 W	9.00E-03	Feb 3, 2021 14:13:26 UTC	Feb 6, 2021 05:38:12 UTC
90.0 m	96.532912 m	39.125695 N, 77.218162 W	8.00E-03	Feb 3, 2021 14:13:33 UTC	Feb 6, 2021 05:38:16 UTC
100.0 m	108.006705 m	39.125593 N, 77.218143 W	8.00E-03	Feb 3, 2021 14:13:33 UTC	Feb 6, 2021 05:35:00 UTC
200.0 m	208.066323 m	39.124887 N, 77.217424 W	5.00E-03	Feb 3, 2021 14:13:52 UTC	Feb 6, 2021 05:14:35 UTC
300.0 m	309.24206 m	39.124274 N, 77.216558 W	4.00E-03	Feb 3, 2021 14:14:24 UTC	Feb 6, 2021 06:10:19 UTC
400.0 m	409.271267 m	39.123607 N, 77.215781 W	3.00E-03	Feb 3, 2021 14:14:52 UTC	Feb 6, 2021 05:33:55 UTC
500.0 m	509.465813 m	39.122969 N, 77.214961 W	2.00E-03	Feb 3, 2021 14:15:07 UTC	Feb 6, 2021 05:47:40 UTC
600.0 m	611.274939 m	39.122175 N, 77.214373 W	2.00E-03	Feb 3, 2021 14:16:02 UTC	Feb 6, 2021 05:08:39 UTC
700.0 m	711.68305 m	39.121540 N, 77.213546 W	2.00E-03	Feb 3, 2021 14:16:44 UTC	Feb 6, 2021 02:50:30 UTC
800.0 m	811.819274 m	39.120889 N, 77.212745 W	1.00E-03	Feb 3, 2021 14:17:36 UTC	Feb 6, 2021 02:12:07 UTC
900.0 m	916.986865 m	39.120418 N, 77.211690 W	1.00E-03	Feb 3, 2021 14:18:35 UTC	Feb 6, 2021 02:39:48 UTC
1000.0 m	1.018347E3 m	39.119655 N, 77.211046 W	9.85E-04	Feb 3, 2021 14:18:50 UTC	Feb 6, 2021 02:20:35 UTC
2500.0 m	2.518712E3 m	39.109336 N, 77.199844 W	2.77E-04	Feb 3, 2021 14:24:22 UTC	Feb 4, 2021 22:33:25 UTC
5000.0 m	5.132626E3 m	39.086794 N, 77.191124 W	1.00E-04	Feb 3, 2021 14:38:09 UTC	Feb 4, 2021 18:38:47 UTC
7500.0 m	7.842459E3 m	39.073392 N, 77.164951 W	4.34E-05	Feb 3, 2021 15:05:30 UTC	Feb 4, 2021 18:54:09 UTC
10000.0 m	1.070208E4 m	39.065585 N, 77.133463 W	2.18E-05	Feb 3, 2021 15:20:37 UTC	Feb 4, 2021 19:52:58 UTC

Because the variable release scenario resulted in a slightly higher dose, this release scenario was also used to estimate dose with Aeolus. This would allow the scientists to simulate the impact of buildings near the release location on the calculated maximum dose value and distance. The buildings on the NCNR campus increased turbulent mixing in the lower atmosphere, resulting in a higher concentration of nuclides near the surface. Still, the maximum estimated dose was 7.5×10^{-3} mrem, and therefore still in agreement with the HotSpot estimate of a maximum dose less than 0.5 mrem.

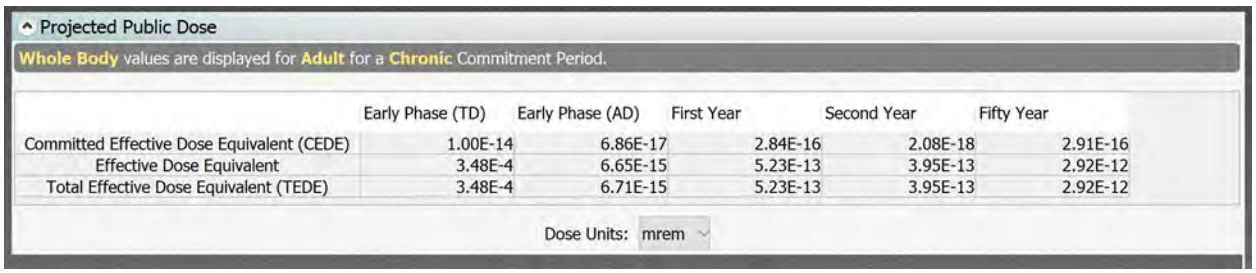
Turbo FRMAC

Turbo FRMAC is another tool used by CMHT to validate the NCNR calculation of public dose. The Turbo FRMAC analysis tool performs complex calculations to quickly evaluate radiological hazards during an emergency response by assessing impacts to the public, workers, and the food supply. Turbo FRMAC can be used to evaluate the hazard from a wide variety of radiological incidents, including nuclear power plant emergencies. Turbo FRMAC calculations are based on methods established by the Federal

Radiological Monitoring and Assessment Center (FRMAC). These interagency consensus methods are specified in the FRMAC Assessment Manual. FRMAC is a multi-agency group comprised of radiological experts from U.S. Federal and State stakeholders. Turbo FRMAC is pre-populated with default settings for many of the required calculation inputs. However, settings can be customized based on specific situations or regulations (https://nirp.sandia.gov/Software/TurboFRMAC/TurboFRMAC.aspx#Overview).

A projected public dose calculation was performed in Turbo FRMAC. This code differs with NARAC codes because it assumes an instantaneous release of the source term and an instantaneous exposure by an individual. The analysis in Turbo FRMAC, using default settings and the source term provided by NCNR, resulted in a projected public dose of 3.5×10^{-4} mrem mainly due to the inhalation of noble gases (see Figure 3). The Turbo FRMAC public dose calculations agree with the HotSpot estimate of a maximum dose less than 0.5 mrem.

Figure 3: Turbo FRMAC results table


Projected Public Dose

Whole Body values are displayed for Adult for a Chronic Commitment Period.

	Early Phase (TD)	Early Phase (AD)	First Year	Second Year	Fifty Year
Committed Effective Dose Equivalent (CEDE)	1.00E-14	6.86E-17	2.84E-16	2.08E-18	2.91E-16
Effective Dose Equivalent	3.48E-4	6.65E-15	5.23E-13	3.95E-13	2.92E-12
Total Effective Dose Equivalent (TEDE)	3.48E-4	6.71E-15	5.23E-13	3.95E-13	2.92E-12

Dose Units: mrem

Bias

It should be noted that CMHT subject matter experts involved with reviewing the public exposure calculations are not, nor have they ever been employed by the NCNR. The calculations performed by CMHT were done independently from NCNR staff. NCNR staff shared data and information with CMHT in a timely manner and without compulsion. CMHT should be considered an independent, third party reviewer.

Conclusion

CMHT concurs with the NCNR public radiation exposure calculations which state that members of the public at the 400-meter boundary would have received a radiological dose of less than 0.5 mrem. CMHT used three separate modeling codes to validate the results NCNR calculated when using the HotSpot model. Each model estimated public dose at much less than 0.5 mrem.