Estimation of Dose from Potential Radionuclide Emissions from the Sample Preparation Laboratory at the Materials and Fuels Complex

A Jeffrey Sondrup

September 2018

INL
Idaho National Laboratory

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6. Site Area	Materials and Fuels Complex		

7. Objective/Purpose:

The Sample Preparation Laboratory (SPL) at the Materials and Fuels Complex will perform sample preparation, examination, and mechanical-property testing of highly irradiated materials. The purpose of this report is to document calculation of the estimated dose at public receptor locations from potential radionuclide releases to the atmosphere from SPL.

Atmospheric dispersion and dose calculations were performed with the computer model CAP88-PC Version 4 in accordance with the requirements of Code of Federal Regulations (CFR), Title 40, "Protection of the Environment," Part 61, "National Emission Standards for Hazardous Air Pollutants (NESHAPs)," Subpart H, "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities" (40 CFR 61, Subpart H 2010). Emission potentials were calculated based on the methodology in 40 CFR Part 61, Appendix D and additional guidance/approval by EPA Region 10 [see letter from Donald Dossett (EPA Region 10) to Tim Safford (DOE-ID), Oct 19, 2017 (CCN 241475)] for solid materials that undergo heating. Estimates of total effective dose are based on low-level chronic exposure.

8. If revision, please state the reason and list sections and/or pages being affected:

NA.

9. Conclusions/Recommendations

The potential maximum dose to a member of the public was calculated to be 0.02 mrem/year based on an estimated 16 g of the 30 kg source term (0.053%) being exposed to very high temperatures associated with electrical-discharge machining (EDM) and the remaining material heated to 100°C. Calculations show the maximum dose could be as high as 0.05 mrem/year if the remaining material were heated to 1400°C (i.e., the melting point of stainless steel).

The potential maximum dose to a public receptor from emissions at SPL is not expected to exceed 0.1 mrem/year (1% of the standard) so long as the material impacted by EDM does not exceed

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56 g (3.5 times the expected mass of 16 g and less than 0.2% of the total source term), and the remaining material is not heated to temperatures greater than 1400°C.

It should be noted that credit for HEPA filtration does not impact the dose results because the dose is dominated by radionuclides that have exceeded their boiling point; thus, no credit for HEPA filtration may be applied to the emission factor.

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PROJECT ROLES AND RESPONSIBILITIES

Project Role	Name (Typed)	Organization	Pages covered (if applicable)
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Nuclear Safety[e]	N/A	N/A	
Document Owner[e]	A. Jeffrey Sondrup	B360	

Responsibilities:

a. Confirmation of completeness, mathematical accuracy, and correctness of data and appropriateness of assumptions.

b. Concurrence of method or approach. See definition, LWP-10106.

c. Concurrence with the document's markings in accordance with LWP-11202.

d. Concurrence of procedure compliance. Concurrence with method/approach and conclusion.

e. Concurrence with the document's assumptions and input information. See definition of Acceptance, LWP-10200.

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SCOPE AND BRIEF DESCRIPTION

The Sample Preparation Laboratory (SPL) at the Materials and Fuels Complex will perform sample preparation, examination and mechanical property testing of highly irradiated materials. Specifically, SPL provides:

1.   Receipt and preparation of micro- and nano-scale examination and mechanical-properties-testing samples that involve sizing, grinding, and polishing activities (beta-gamma materials only)

2.   Micro- and nano-scale examination of prepared samples (beta-gamma and some alpha materials that would have been prepared elsewhere) in instruments like the scanning electron microscope, a focused ion beam, an X-ray photoelectron spectroscopy

3.   Mechanical-properties testing, including tensile testing, high-temperature fatigue testing, and Charpy V-notch testing.

The purpose of this report is to document calculation of the estimated dose at public receptor locations from potential radionuclide releases to the atmosphere from SPL. Atmospheric dispersion calculations were performed in accordance with the requirements of Code of Federal Regulations (CFR), Title 40, "Protection of the Environment," Part 61, "National Emission Standards for Hazardous Air Pollutants (NESHAPs)," Subpart H, "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities" (40 CFR 61, Subpart H 2010). Emission potentials were calculated based on the methodology in 40 CFR Part 61, Appendix D and additional guidance/approval by EPA Region 10 [see letter from Donald Dossett (EPA Region 10) to Tim Safford (DOE-ID), Oct 19, 2017 (CCN 241475)] for solid materials that undergo heating.

DESIGN OR TECHNICAL PARAMETER INPUT AND SOURCES

The following are sources for the primary data used in the assessment:

1. The radionuclide source term was taken from ECAR-4023, "Evaluation of the Inhalation Dose Consequences for the Sample Preparation Laboratory" (2018).

2.   Melting points and boiling points of the radionuclides were taken from the *CRC Handbook of Chemistry and Physics* http://hbcponline.com/faces/contents/InteractiveTable.xhtml?tableId=15.

3.   Meteorological data from the EBR MESONET station were provided by the Idaho Falls National Ocean Atmospheric Administration (NOAA) Air Resources Laboratory.

Other data sources and references are provided in the Discussion/Analysis section.

RESULTS OF LITERATURE SEARCHES AND OTHER BACKGROUND DATA

See Discussion/Analysis Section and References Section.

ASSUMPTIONS

See Discussion/Analysis Section.

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COMPUTER CODE VALIDATION

All computer code modeling and calculations were performed on a Dell Optiplex 7020 computer (Intel Core i7-4790 CPU @ 3.60 GHz, property tag 604112) running Microsoft Windows 7 Enterprise, Service Pack 1. Atmospheric transport modeling of radionuclide emissions was performed using the CAP88-PC Version 4 (EPA 2013a) computer model. CAP88-PC is a set of computer programs, databases, and associated utility programs for estimation of dose and risk from radionuclide emissions to the air. CAP88-PC is both a mature and the EPA-recommended model for demonstration of compliance with the applicable performance objective (40 CFR 61, Subpart H). Testing and validation of CAP88-PC is performed by EPA and documented in EPA (2013b). Verification of proper installation and operation of CAP88-PC is performed annually at INL by simulating the example problem (Modtest) provided in the CAP88-PC download zip file. Additional information about CAP88-PC can be found at http://www.epa.gov/radiation/assessment/CAP88/aboutcap88.html.

Microsoft Excel 2013 (15.0.5041.1000) MSO (15.0.5031.1000) 32 bit, part of Microsoft Office Professional Plus 2013, was used for supporting calculations and creating graphs of results. Cell formulas were checked for accuracy, and a sample of the calculations was checked by hand. All formula cells have been locked for editing and password protected.

All electronic files, including computer code input, output, and spreadsheet files are contained in a zip file that can be accessed by selecting "Additional Information" (select Native File) in the INL Electronic Document Management System.

DISCUSSION/ANALYSIS

Source Term and Emissions Potential

ECAR-4023 identifies the SPL source term, or annual possession quantity, as radionuclide activities in 30 kg of Type 316 stainless steel (SS) irradiated to a fluence of 5×10^{21} neutrons/cm^2 with a decay time of 30 days. This source term has been identified as a reasonable amount of mass and activity that would bound the large majority of the materials handled in the laboratory in one year. The radionuclide distribution in the 30 kg sample of SS is shown in Table 1.

To determine the emission potential from the source term, radionuclide activities in Table 1 were multiplied by appropriate emission factors based on the physical state of the material. Because the material could undergo heating, an alternative to the method in 40 CFR 61 Appendix D, approved for use at INL by EPA Region 10)see letter from Donald Dossett [EPA Region 10] to Tim Safford [DOE-ID] Oct 19, 2017 [CCN 241475]) was used to determine the emission factors for radioactive solid materials with high melting and boiling points. These emission factors are:

- 1 for radioactive solid materials heated to temperatures greater than or equal to 90% of the boiling or subliming point;

- 10^{-3} for radioactive solid materials heated to temperatures greater than or equal to their melting point but less than 90% of their boiling or subliming point; and

- 10^{-6} for radioactive solid materials heated to temperatures above ambient temperature but less than their melting point.

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Melting points and boiling points were taken from the *CRC Handbook of Chemistry and Physics*, 99th Edition (2018). Melting points and 90% of boiling points are shown in Table 1. Emission factors were determined for each radionuclide over a temperature range between 20 and 4300°C which is greater than the 90% boiling point for all radionuclides. These emission factors are provided in Appendix A.

Table 1. Radionuclide activities and physical properties for determining emissions potential.

Radionuclide	Activity in 30kg Type 316 SS Sample After 30 Days Decay (Ci)	Melting Point (C)	90% of Boiling Point (C)
Al-28	5.44E-19	660	2267
C-14	1.01E+00	-999[a]	-999[a]
Co-58	2.63E+03	1495	2634
Co-60	2.02E+02	1495	2634
Cr-51	4.04E+04	1907	2404
Cu-64	3.93E-17	1085	2304
Cu-66	3.30E-06	1085	2304
Fe-55	2.02E+04	1538	2575
Fe-59	1.23E+03	1538	2575
H-3	4.42E-04	-259[b]	-227[b]
Mn-54	3.82E+03	1246	1855
Mo-93	1.01E-01	2622	4175
Mo-93m	2.51E-31	2622	4175
Mo-99	4.00E+00	2622	4175
Nb-92	4.88E+00	2477	4267
Nb-94	1.51E-04	2477	4267
Nb-95	1.30E+00	2477	4267
Nb-95m	3.54E-03	2477	4267
Nb-96	7.75E-10	2477	4267
Nb-97	2.41E-15	2477	4267
Nb-97m	2.12E-15	2477	4267
Ni-59	2.98E+00	1455	2622
Ni-63	4.39E+02	1455	2622
Ni-66	3.29E-06	1455	2622
P-32	4.32E+01	44	252
P-33	3.05E-03	44	252
Ru-103	7.33E-01	1963	3326
S-35	2.92E+00	115	400
Sc-47	6.81E-06	1541	2552
Sc-48	4.18E-08	1541	2552
Tc-99	3.93E-03	2157	3836
Y-89m	3.28E-04	1522	3011
Y-90	4.60E-07	1522	3011
Zn-65	6.49E-04	420	816
Zr-89	3.28E-04	1854	3965
Zr-95	4.77E-01	1854	3965
Zr-97	2.24E-15	1854	3965

a. C-14 modeled as CO_2, therefore low melting and boiling points assigned to be considered gas at any temperature.
b. H-3 assigned melting and boiling points for tritium gas (HT or T_2).

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For this analysis, doses were calculated for unmitigated and mitigated emissions. Credit for HEPA filtration (mitigated) was accounted for by applying an additional emission factor of 0.01 to the source term activity if the temperature to which the material is heated is less than the melting point. This adjustment is allowed for particulates per Appendix D of 40 CFR 61, "Methods for Estimating Radionuclide Emissions."

Atmospheric Dispersion Modeling

Air-dispersion modeling of radionuclide emissions from SPL to potential public receptor locations was conducted according to guidance for performing environmental compliance-driven air modeling of emissions from INL facilities (Staley et al. 2004). The modeling entailed calculating annual doses (in mrem/year) for unit emission rates (1 Ci/year) for each of the radionuclides listed in Table 1 using the computer model CAP88-PC Version 4 (EPA 2013a). Unit dose factors (mrem/Ci) were calculated for each of the sixty-two INL Site NESHAP receptor locations that encircle the INL Site boundary (see Figure 1). Radionuclides were assumed to be released from a single ground-level point source with no momentum or buoyant plume rise.

Unit dose factors are used because the CAP88-PC simulations only have to be done once for each radionuclide. The unit dose factors are multiplied by radionuclide emission rates to get the dose for each radionuclide without having to run CAP88-PC for each temperature-dependent emission rate. The total dose is, then, the sum of the individual radionuclide doses.

The unit dose factor is the annual effective dose equivalent at a specific location for a unit (1 Ci/year) release and is given by:

$$UDF_{i,j} = \frac{D_{i,j}}{Q_i}$$

where:

$UDF_{i,j}$ = unit dose factor for radionuclide i (including progeny), at receptor j (mrem/Ci)

$D_{i,j}$ = CAP88-PC total pathway parent/progeny annual effective dose equivalent for radionuclide i, at receptor j (mrem/year)

Q_i = unit release rate for radionuclide i, (1 Ci/year).

The unit dose factors include the effects of ingestion, inhalation, air immersion, and radiation from ground surface. Doses were calculated using the local food-production option in CAP88-PC to simulate a rural subsistence-farming scenario for the public receptors. This is conservative because it assumes most of the food products consumed are grown in the assessment area, which is unlikely. The CAP88-PC Version 4.0 default parameters for this exposure scenario are shown in Table 2.

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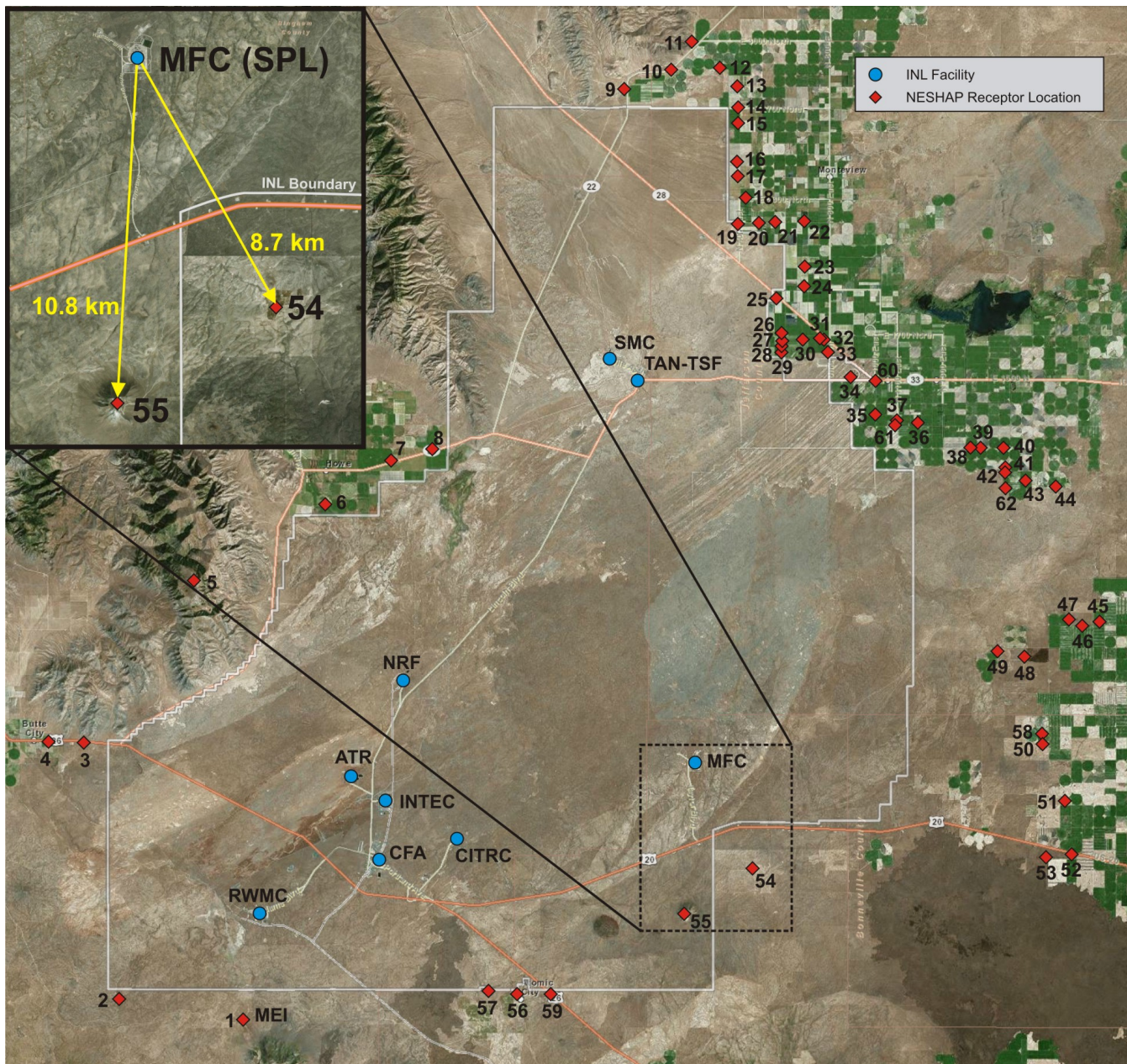

Figure 1. INL NESHAP public receptor locations. Locations 54 and 55 are the locations nearest (see inset).

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A meteorological data file provided by the Idaho Falls Office of the National Oceanic and Atmospheric Administration (NOAA) was used as input to CAP88-PC. Meteorological monitoring stations are located near each of the major INL facilities. The meteorological data file represents average wind conditions over a 10-year (2006-2015) period from the lower (10 m) measurement height of the EBR station located immediately east of MFC. A stability array (*.str) file provided by NOAA was converted to a wind (*.wnd) file using the computer program WINDGET. The wind file is presented in Appendix B. Other meteorological data used in the modeling is provided in Table 3.

For most of the radionuclides modeled, there is only one chemical form option in CAP88-PC, and that is particulate. All radionuclides were simulated as their default chemical form in CAP88-PC, with the exception of C-14, which was modeled as gaseous CO_2. The default chemical form for C-14 is particulate, but the gas forms CO and CO_2 produce equal, but slightly higher doses than the particulate form. The default form for H-3 is HTO vapor which, for the conditions modeled, results in a higher dose than the particulate or gaseous form. For other radionuclides for which a chemical form other than particulate is an option (S, Ni, Ru), the particulate form produces a higher dose than any other forms, so it was used.

Development of CAP88-PC input files and execution of code were performed using three Perl Scripts. The first script (*mkFiles.pl*) creates the CAP88-PC input files using a facility-specific template file and radionuclide-specific template files for radionuclides listed in the file *NucList.inp*. The MFC-facility template file contains the file path and name of the wind file, receptor distances, model options, release parameters, and other meteorological data (see Table 3). The radionuclide template files were created with the graphical-user-interface version of CAP88-PC, one at a time, using generic facility data. After creating each file, the generic facility-specific information was removed so the file could be combined with the MFC-facility template file using the *mkFiles.pl* script. Each radionuclide template file contains radionuclide-specific data, including half-life and decay chain information, deposition velocity and scavenging coefficient, food transfer factors, radionuclide solubility class, and particle size. CAP88-PC default parameter values were used in all radionuclide template files with one exception. C-14 was modeled as CO_2 gas because the dose for CO_2 is greater than particulate default form.

The second script (*runFiles.pl*) makes each CAP88-PC run for all files in the *NucFiles.inp* file. After each simulation, *runFiles.pl* copies the summary output file (*.SUM) for each radionuclide to the appropriate directory. The third script (*getCAP88dose2.pl*) post-processes all the *.SUM files listed in *OutputFiles.inp*. The script extracts the total dose result from the CAP88 *.SUM files and writes the output to a text file (*tempdoses.txt*) containing facility name, radionuclide, receptor distance and direction, and unit dose factor. Copies of the three Perl scripts and required input files are included in Appendix C. It should be noted that the Perl scripts are not necessary, but are used for convenience due to the number of model runs. The veracity of the scripts can easily be checked, and several random checks were performed.

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Table 2. CAP88-PC Version 4.0 radionuclide-independent parameters for the rural receptor scenario.

Parameter Description	Value	Units
Inhalation rate	5.263E+03[a]	m^3/year
Effective surface density of soil, dry weight (assumes 15 cm plow depth)	215	kg/m^2
Build-up time for radionuclides in soil	100	year
Build-up time radionuclides deposited on ground/water	3.65E+04	day
Delay time, ingestion of pasture grass by animals	0	hr
Delay time, ingestion of stored feed by animals	2160	hr
Delay time, ingestion of leafy vegetables by man	336	hr
Delay time, ingestion of produce by man	336	hr
Delay time, transport time from animal feed-milk-man	2	day
Delay time, time from animal slaughter to consumption	20	day
Removal rate constant for physical loss by weathering	2.90E-03	1/hr
Crop exposure duration, pasture grass	720	hr
Crop exposure duration, crops or leafy vegetables	1440	hr
Agricultural productivity, grass-cow-milk-man pathway	0.28	kg/m^2
Agricultural productivity, produce/leafy vegetables for human consumption	0.716	kg/m^2
Fallout interception fraction, vegetables	0.2	---
Fallout interception fraction, pasture	0.57	---
Fraction of year animals graze on pasture	0.4	---
Fraction of daily feed that is pasture grass (when animal on pasture)	0.43	---
Animal consumption rate of contaminated feed/forage (dry weight)	15.6	kg/day
Milk production of cow	11	L/day
Muscle mass of animal at slaughter	200	kg
Fraction of animal herd slaughtered per day	3.81E-03	---
Fraction of radioactivity retained after washing (leafy veg & produce)	0.5	---
Fraction of produce ingested grown in garden of interest	1	---
Fraction of leafy vegetables ingested grown in garden of interest	1	---
Human produce ingestion rate	76.2[a]	kg/year
Human milk ingestion rate	53[a]	L/year
Human meat ingestion rate	84[a]	kg/year
Human leafy vegetable ingestion rate	7.79[a]	kg/year
Fraction of time spent swimming	0	---
Depth of water for dilution for water immersion doses	1	cm
Fraction vegetables home produced	0.7[b]	---
Fraction milk home produced	0.4[b]	---
Fraction meat home produced	0.44[b]	---
Fraction vegetables from assessment area	0.3[b]	---
Fraction meat from assessment area	0.60[b]	---
Fraction meat from assessment area	0.56[b]	---
Minimum ingestion fractions from outside area, vegetables	0[a]	---
Minimum ingestion fractions from outside area, meat	0[a]	---
Minimum ingestion fractions from outside area, milk	0[a]	---
Default beef cattle density	7.19E-02[c]	#/ha
Milk cattle density	8.56E-03[c]	#/ha
Land fraction cultivated for vegetables	7.15E-02[c]	---

a.   Value is changed from CAP88-PC Version 3.0
b.   Value for a rural food source option. Options are Urban, Rural, Local, Regional, or Imported.
c.   Values specific to the State of Idaho.

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Table 3. Other meteorological parameters used for the CAP88-PC modeling.

Variable	Value[a]	Units
Lid height	800	meters
Mean temperature	280.2	Kelvin
Annual Precipitation	20.8	cm/year
Absolute humidity	3.54	g/m^3

a.   Values represent a 10-year average at the INL (Clawson et al. 1989).

RESULTS

Unit Dose Factors

As might be expected, the maximum dose occurs at the receptor locations nearest the source (locations 54 and 55, see Figure 1). Although receptor location 54 is closer to MFC (~8.7 km SSE), wind conditions produce equal or slightly higher doses for most radionuclides at receptor location 55 located ~10.8 km south of MFC at the top of East Butte (see Table 4). Although location 55 is located on the INL Site and there are no permanent residents there, it has been considered as a public receptor site for the annual NESHAP evaluation because of the potential for consistent public or worker presence. For conservatism, the maximum unit dose factor from either location 54 or 55 was used for this assessment although the differences between each location were small. These maximum unit dose factors are provided in the last column of Table 4. These were multiplied by the annual emission estimates (Ci/year) to calculate the estimated doses (mrem/year) as a function of temperature.

Maximum Annual Dose Estimate

Figure 2 shows the maximum annual dose to a public receptor as a function of temperature if the total mass of material is heated to that temperature. This is not a realistic scenario, but is shown for informational purposes only. This represents both the unmitigated and mitigated cases. They are essentially the same because at any given temperature, the dose is driven by one or a few radionuclides, the boiling points of which have been exceeded; thus, any adjustments to the emission factor for HEPA filtration may not be applied.

The results indicate that if the material is not exposed to temperatures above 1850°C (greater than the melting point of Type 316 SS of 1400°C), the dose will be less than 0.05 mrem/year which is significantly less than the 10 mrem/year standard allowed by 40 CFR 61, Subpart H, and less than the 0.1 mrem/year limit above which an application to construct or modify is required. At a temperature over 1850°C, the dose increases to 15.3 mrem/year. This dose is due almost entirely to Mn-54 because at this temperature manganese must be considered a gas (emission factor = 1).The maximum potential dose is 39.2 mrem/year, which occurs at temperatures above 4270°C (greater than 90% of the boiling point of all radionuclides) at which all radionuclides must be considered a gas and released. This can be thought of as the dose if the entire inventory in Table 1 is released each year.

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Table 4. Radionuclide activities and unit dose factors from CAP88-PC modeling.

Radionuclide	Activity in 30kg Type 316 SS Sample After 30 Days Decay (Ci)	Location 54 Unit Dose Factor (mrem/Ci)	Location 55 Unit Dose Factor (mrem/Ci)	Maximum Unit Dose Factor from Location 54 or 55 (mrem/Ci)
Al-28	5.44E-19	3.50E-12	3.0E-13	3.50E-12
C-14[a]	1.01E+00	4.60E-04	4.7E-04	4.70E-04
Co-58	2.63E+03	1.20E-03	1.3E-03	1.30E-03
Co-60	2.02E+02	6.40E-02	6.5E-02	6.50E-02
Cr-51	4.04E+04	1.80E-05	1.8E-05	1.80E-05
Cu-64	3.93E-17	3.70E-06	3.7E-06	3.70E-06
Cu-66	3.30E-06	4.00E-10	1.5E-10	4.00E-10
Fe-55	2.02E+04	1.90E-04	1.9E-04	1.90E-04
Fe-59	1.23E+03	1.10E-03	1.2E-03	1.20E-03
H-3[b]	4.42E-04	9.30E-06	9.5E-06	9.50E-06
Mn-54	3.82E+03	3.90E-03	4.0E-03	4.00E-03
Mo-93	1.01E-01	2.40E-03	2.4E-03	2.40E-03
Mo-93m	2.51E-31	2.00E-05	2.0E-05	2.00E-05
Mo-99	4.00E+00	2.70E-05	2.8E-05	2.80E-05
Nb-92	4.88E+00	2.40E-01	2.5E-01	2.50E-01
Nb-94	1.51E-04	2.50E-01	2.6E-01	2.60E-01
Nb-95	1.30E+00	4.60E-04	4.7E-04	4.70E-04
Nb-95m	3.54E-03	5.50E-05	5.6E-05	5.60E-05
Nb-96	7.75E-10	5.50E-05	5.6E-05	5.60E-05
Nb-97	2.41E-15	1.70E-06	1.5E-06	1.70E-06
Nb-97m[c]	2.12E-15	NA	NA	NA
Ni-59[d]	2.98E+00	8.80E-05	8.9E-05	8.90E-05
Ni-63[d]	4.39E+02	1.80E-04	1.8E-04	1.80E-04
Ni-66[d]	3.29E-06	4.60E-05	4.7E-05	4.70E-05
P-32	4.32E+01	2.90E-04	2.9E-04	2.90E-04
P-33	3.05E-03	6.50E-05	6.6E-05	6.60E-05
Ru-103[d]	7.33E-01	3.80E-04	3.9E-04	3.90E-04
S-35[e]	2.92E+00	2.50E-04	2.5E-04	2.50E-04
Sc-47	6.81E-06	1.60E-05	1.6E-05	1.60E-05
Sc-48	4.18E-08	1.20E-04	1.2E-04	1.20E-04
Tc-99	3.93E-03	1.20E-02	1.2E-02	1.20E-02
Y-89m	3.28E-04	7.10E-20	3.1E-20	7.10E-20
Y-90	4.60E-07	2.90E-05	2.9E-05	2.90E-05
Zn-65	6.49E-04	7.70E-03	7.9E-03	7.90E-03
Zr-89	3.28E-04	7.10E-05	7.2E-05	7.20E-05
Zr-95	4.77E-01	1.60E-03	1.6E-03	1.60E-03
Zr-97	2.24E-15	3.70E-05	3.8E-05	3.80E-05

a.   C-14 modeled as CO_2 gas. Dose for CO_2 is greater than particulate default form.
b.   H-3 modeled as HTO vapor (default) which produces greater dose than particulate or gas form.
c.   Nb-97m is not included in the CAP88-PC database likely due to short half-life (52.7 seconds).
d.   Vapor chemical form is an option in CAP88-PC, but modeled as default particulate form which results in greater dose.
e.   Sulfur dioxide (SO_2) and carbon disulfide (CS_2) chemical forms are options in CAP88-PC, but modeled as default particulate form which results in greater dose.

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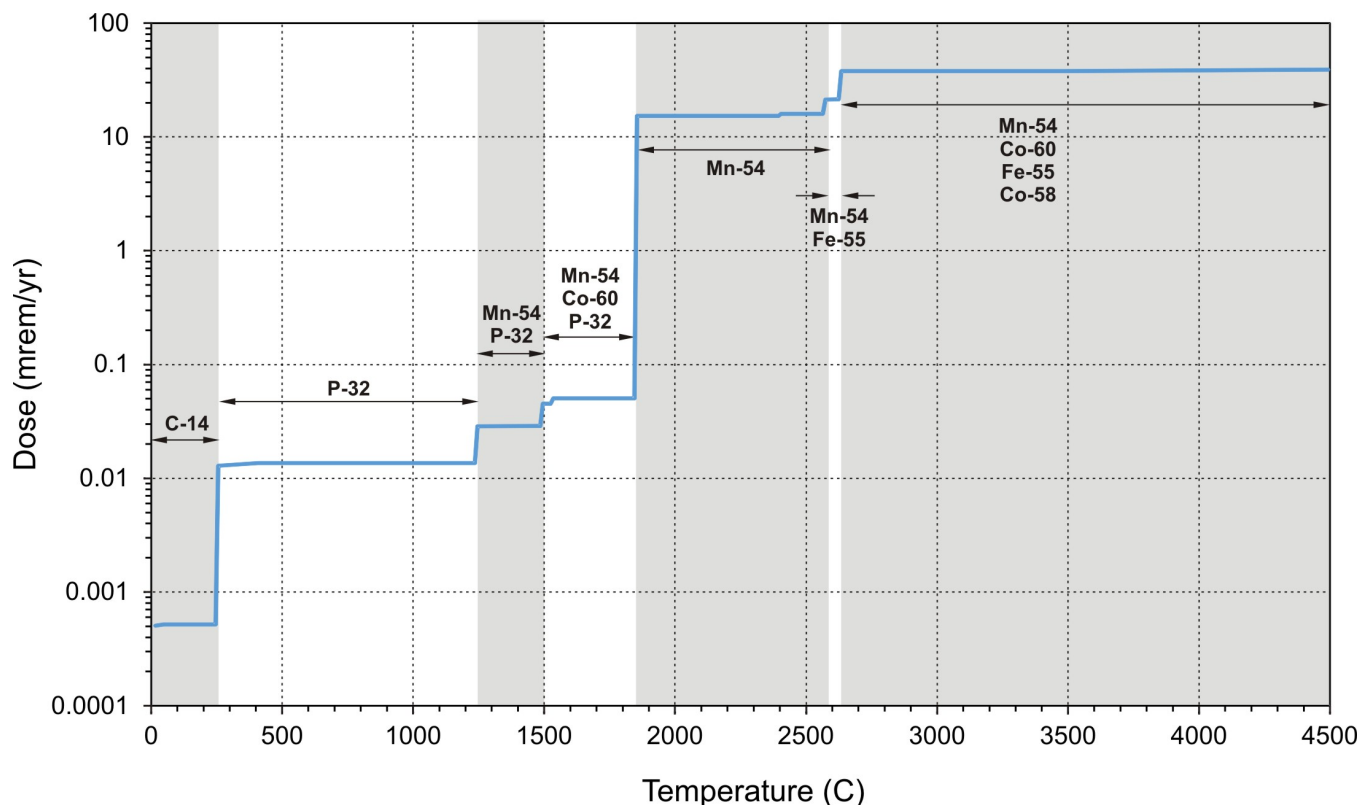ECAR No.: 4239   Rev. No.: 0   Project No.:   N/A   Date: 09/19/2018

Figure 2. Annual dose (mrem/year) as a function of the temperature to which the material is heated. The radionuclides that dominate the dose for each temperature interval are shown on the figure.

As stated previously, the results in Figure 2 are unrealistic because they assume the entire source term is heated to that temperature when, in reality, only a very small percentage of the source term will be exposed to temperatures above room temperature. Activities such as cutting (with a low-speed saw), grinding, and mechanical-properties testing of samples may cause elevated local temperatures, but the temperatures are expected to be less than 100°C, and far less than the melting point of the steel (~1400°C). The only process that would cause local temperatures to exceed 1400°C is electrical-discharge machining (EDM). EDM is a controlled metal-removal process that is used to remove metal by means of electric spark erosion. In this process an electric spark (which can cause temperatures to reach 8000°C) is used as the cutting tool to cut the sample. Although the process takes place in a dielectric fluid and no releases are expected to occur, the regulations require the material exposed to EDM to all be released (emission factor = 1) for purposes of calculating dose.

The volume (V) of material expected to be exposed to EDM annually can be approximated as the cut (kerf) volume from making 100 cuts of 1/2 in. tubing (OD = 0.5 in. [1.27 cm]) with 1/8 in. wall thickness (ID = 1/4 in. [0.635 cm]) and a kerf width (W) of 0.021 cm.

$$V = \left[\frac{\pi}{4}(OD^2 - ID^2) \times W\right]\frac{cm^3}{cut} \times 100 \frac{cuts}{yr} = \frac{\pi}{4}(1.27^2 - 0.635^2) \times 0.021 \times 100 = 2\frac{cm^3}{yr}$$

Given a density of 8 g/cm³ for Type 316 SS, the mass of material impacted by EDM annually is approximately 0.016 kg.

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$$Mass = \rho \; x \; V = 8\frac{g}{cm^3} \; x \; 2\frac{cm^3}{yr} = 16\frac{g}{yr} \; or \; 0.016\frac{kg}{yr}.$$

Thus the fraction of the source term expected to be exposed each year to EDM is 0.016 kg/30 kg = 0.00053 (0.053%). The dose from releasing the activity in 16 g of kerf material is 0.021 mrem/year. This is shown on Figure 3 as a dashed red line because it is not a function of temperature. An emission factor of 1 is used for this material. The dose from the 99.947% of the source term that is not exposed to EDM, but could potentially be heated to any temperature less than or equal to 1400 C, is shown by the solid blue line. This is essentially the same line from Figure 2. The total dose is the solid purple line which is simply the sum of the solid blue line and the dashed red line. The maximum dose is 0.05 mrem/year and occurs only if the material not exposed to EDM is heated to temperatures greater than about 1250°C and less than 1400°C.

Figure 3 shows that from T = 0°C to about 250°C, the dose is dominated by the material exposed to EDM. From 250 to 1250°C the dose is due mostly to the activity in the EDM material, with a small contribution from P-32 from activity in the non-EDM material. This is because 90% of the boiling point for phosphorus is 252°C, and above that temperature, the emission factor for phosphorus changes from 0.001 to 1. Above 1250°C, the dose is due mostly to the activity in EDM material and the Mn-54 and P-32 activity in the non-EDM material. The melting point of manganese is 1242°C, and above that temperature, the emission factor for Mn-54 changes from 1E-06 to 0.001. The dose from activity in the EDM material is due to the same radionuclides from Figure 2, which dominate the dose at high temperatures (Co-58 [9%], Co-60 [34%], Fe-55 [10%] and Mn-54 [39%]).

Figure 3. Annual total dose (mrem/year) for non-EDM material as function of temperature and the EDM material (heated to very high temperature). Radionuclides from the non-EDM material that contribute significantly to the dose are shown on the figure for each temperature range.

Calculations were performed to determine the amount of material that could be impacted by EDM and keep the total dose less than 0.1 mrem/year (i.e., 1% of the regulatory limit). The calculations show that

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the mass of EDM material could be as high as 56 g, and the total dose would not exceed
0.1 mrem/year, even if the non-EDM material were heated to 1400°C, the melting point of the stainless
steel (see Figure 4). Fifty-six grams of material is 3.5 times the expected kerf volume and less than
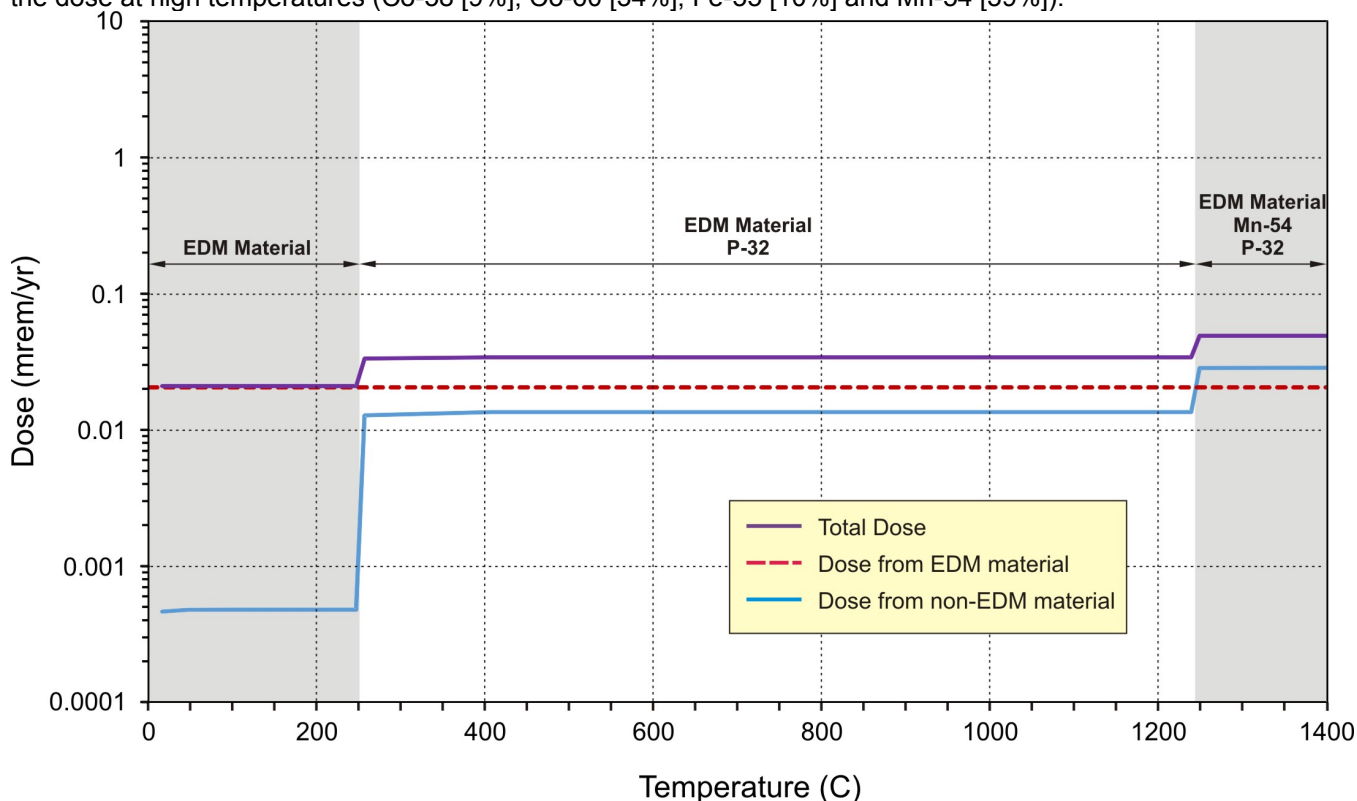0.2% of the source term mass.
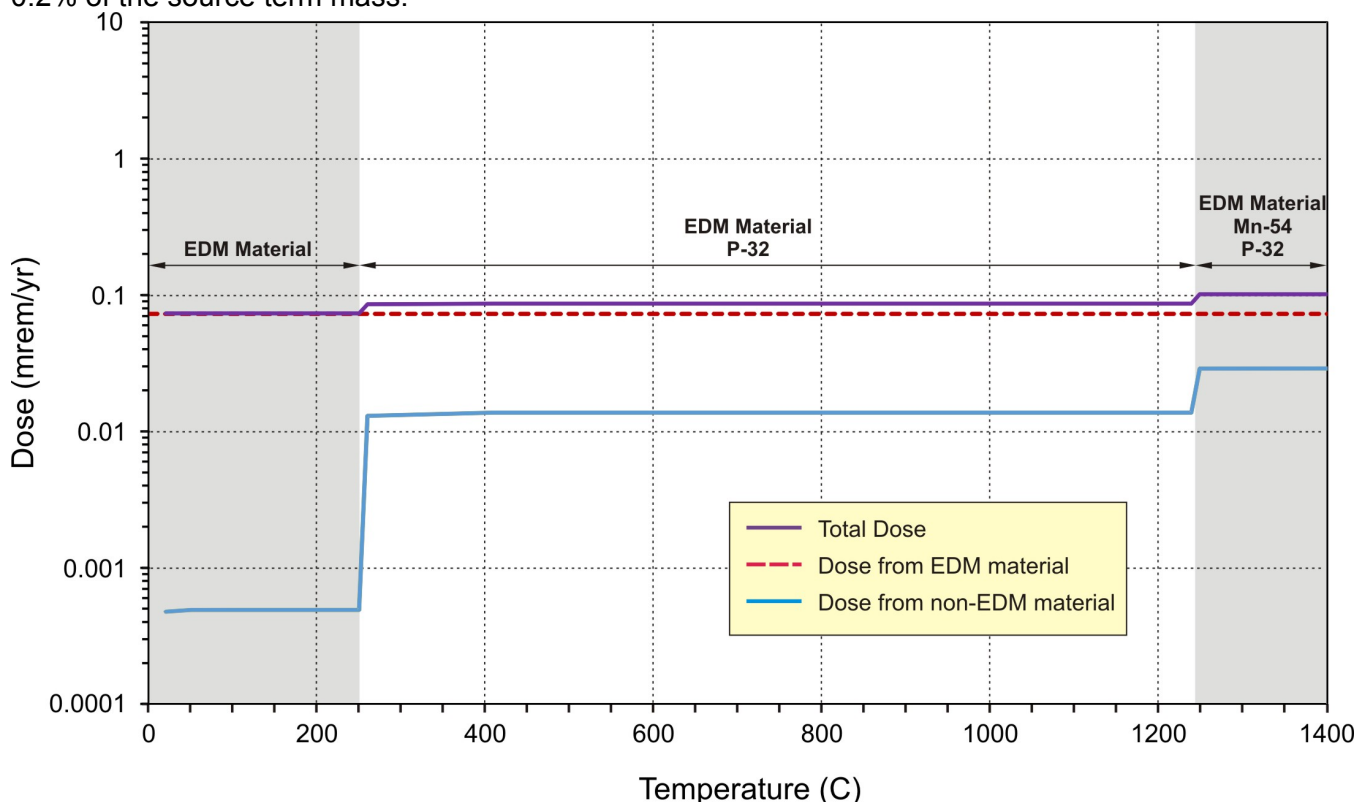
Figure 4. Annual total dose (mrem/year) from non-EDM material as function of temperature and EDM
material (heated to very high temperature). Radionuclides from the non-EDM material that contribute
significantly to the dose are shown on the figure for each temperature range.

CONCLUSION

Potential radionuclide emissions from anticipated operations at SPL and subsequent doses from low-level
chronic exposure were estimated using methodologies and assumptions consistent with 40 CFR 61,
Appendix D and additional guidance and approval by EPA Region 10 (see Dossett to Safford, CCN 241475)
for solid materials that undergo heating. The annual source term was represented and assumed bounded by
the radionuclide activities in 30 kg of Type 316 stainless steel irradiated to a fluence of 5×10^{21}
neutrons/cm^2, with a decay time of 30 days (ECAR-4023 2018). The EPA-approved computer code CAP88-
PC was used to model atmospheric dispersion and calculate dose at potential public receptor locations.

The potential maximum dose to a member of the public was calculated to be 0.02 mrem/year, based on an
estimated 16 g of the 30 kg source term (0.053%) being exposed to very high temperatures associated with
EDM and the remaining material heated to 100°C. Calculations show the maximum dose could be as high
as 0.05 mrem/year if the remaining material were heated to 1400°C, the melting point of stainless steel.

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The potential maximum dose to a public receptor from emissions at SPL is not expected to exceed 0.1 mrem/year, one percent of the standard, so long as the material impacted by EDM does not exceed 56 g (3.5 times the expected mass of 16 g and less than 0.2% of the total source term) and the remaining material is not heated to temperatures greater than 1400°C.

It should be noted that credit for HEPA filtration does not impact the dose results because the dose is dominated by radionuclides that have exceeded their boiling point; thus, no credit for HEPA filtration may be applied to the emission factor.

APPENDIXES

Appendix A, Emission Factors

Appendix B, CAP88-PC Windfile (EBRL6-15.WND)

Appendix C, Perl Scripts and Input Files for Pre- and Post-Processing: CAP88-PC Input/Output

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Appendix A

Emission Factors

Title: Estimation of dose from potential radionuclide emissions from the Sample Preparation Laboratory at the Materials and Fuels Complex

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Table A-1. Emission factors for radionuclides in Type 316 stainless steel.

Temperature (C)

Nuclide	20	50	100	120	250	260	410	420	670	820	1090	1240	1250	1490	1500	1530	1540	1850	1860	2400	2410	2570	2580	2630	2640	3500	4500
Al-28	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1	1	1	1	1	1	1	1
C-14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Co-58	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1	1	1	1
Co-60	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1	1	1
Cr-51	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	1	1	1	1	1	1	1
Cu-64	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1	1	1	1	1	1	1	1
Cu-66	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001		1	1	1	1	1	1	1
Fe-55	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1	1	1	1	1
Fe-59	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1	1	1	1
H-3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mn-54	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	1	1	1	1	1	1	1	1	1
Mo-93	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	1
Mo-93m	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	1
Mo-99	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	1
Nb-92	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	1
Nb-94	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	1
Nb-95	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	1
Nb-95m	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	1
Nb-96	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	1
Nb-97	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	1
Ni-59	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1	1	1	1
Ni-63	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1	1	1	1
Ni-66	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1	1	1	1
P-32	1E-06	0.001	0.001	0.001	0.001	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P-33	1E-06	0.001	0.001	0.001	0.001	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ru-103	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	1	1
S-35	1E-06	1E-06	1E-06	0.001	0.001	0.001	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Sc-47	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	1	1	1	1
Sc-48	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	1	1	1	1	1
Tc-99	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1
Y-89m	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1	1
Y-90	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1	1
Zn-65	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Zr-89	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1
Zr-95	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1
Zr-97	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	1E-06	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	1

Nb-97m not included due to short half life.

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Appendix B

CAP88-PC Windfile (EBRL6-15.WND)

Title: Estimation of dose from potential radionuclide emissions from the Sample Preparation
Laboratory at the Materials and Fuels Complex

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2.9342.4472.1082.2922.2701.7622.2461.9591.7901.5761.8262.3102.3142.7672.8542.970
4.0353.5682.4232.5462.4342.0512.4482.3292.1622.3113.0253.6443.4263.4974.0283.992
3.5283.1502.2242.1522.1112.3993.0653.3353.4973.5233.9424.2544.0855.9256.1514.929
2.2992.7871.7751.6951.9492.1832.0691.8771.3511.3381.4941.7141.9541.7232.1832.487
1.014 .950 .934 .915 .9331.0021.0241.015 .973 .9561.001 .9981.025 .9971.0331.020
 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000
2.0212.0021.8161.8581.7151.8621.9871.9101.8131.6911.5751.6561.9252.0632.0282.028
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4.7034.2993.6043.8063.6813.2933.3443.0613.0293.4374.0264.3674.1304.2834.7994.775
5.4674.5533.3843.4653.2753.5624.3094.9825.1984.8885.1115.2165.1157.4977.5166.495
3.1763.6532.8302.6792.9102.9862.8152.7161.9542.0292.0422.2822.4242.3893.1533.381
1.3851.2541.2191.1741.2151.3641.4061.3881.3031.2671.3621.3551.4071.3531.4221.398
 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000
         .0389      .0356      .0719      .5157      .2176      .1203      .0000
         .0462      .0238      .0344      .3812      .3562      .1583      .0000
         .0905      .0312      .0346      .2215      .2356      .3867      .0000
         .1118      .0313      .0308      .2106      .2034      .4120      .0000
         .0854      .0281      .0246      .2555      .3028      .3036      .0000
         .0701      .0329      .0451      .3648      .3118      .1754      .0000
         .0732      .0570      .0984      .4754      .1794      .1166      .0000
         .0997      .0700      .1278      .4610      .1254      .1160      .0000
         .1466      .0853      .1197      .4346      .0737      .1400      .0000
         .2236      .0845      .1013      .3690      .0595      .1622      .0000
         .3038      .0798      .0988      .2817      .0443      .1916      .0000
         .3100      .0874      .1033      .2438      .0437      .2118      .0000
         .2765      .1034      .1075      .2609      .0404      .2113      .0000
         .0879      .0593      .0924      .6258      .0314      .1032      .0000
         .0380      .0339      .0854      .7380      .0459      .0589      .0000
         .0328      .0366      .1034      .6224      .1293      .0755      .0000
extended data
StationName=EBRL6-15
State=ID
Latitude=0
Longitude=0
TimeZone=0
RecordPeriod=
AveragePeriodTemperature=0
Comments=
```

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Appendix C

Perl Scripts and Input Files for Pre- and Post-Processing CAP88-PC Input/Output

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mkFiles.pl

```perl
# mkFiles.pl
# This script inserts the current wind file in the template file and then concatentate the template file
# with the nuclide file to create all the CAP88 input files. It also replaces the second line of the template
# file with the filename sans the "dat" (e.g. Ac227A.). A second file is created that is used by subsequent
# scripts. This file contains a list of nuclide file names and the name of the nuclide


# ====================================================================================================
# REQUIRED USER INPUT

# --- Update with new met files? (Y/N)
      $update="Y";

# --- Working Directory (each facility directory is below this directory)
      $templatef="C:\\projects\\fy2018\\NESHAPv4\\CAP88\\";

# --- Path to the wind files
      $windpath="C:\\projects\\fy2018\\NESHAP\\WindFiles\\";

# --- Path to the nuclide template files
      $nuctemplate="C:\\CAP88NucTempv4\\";

# --- Names of the template files - same name for each facility
      @tempfnames = ("v4TempA.dat","v4TempB.dat","v4TempC.dat","v4TempD.dat");

# --- Input File containing list of nuclides to be processed
      $NuclideList = "NucList.inp";      # nuclide names

# --- Output File containing the CAP88 nuclide input files names and name of nuclide
      $NuclideFile = "NucFiles.inp";

# --- Output File containing the CAP88 nuclide output file names and name of nuclide
      $OutputFile = "OutputFiles.inp";

# --- Input File containing all the facility names and wind file names
      $FacAndWnd = "Facility.inp";        # facility and wind file names

# --- Facility name and wind file format
#      Facility          WindFile  header (discarded)
#      CFA               690L08.WND
#      CITRC             PBFL08.WND
#      INTEC             GRIL08.WND
#      .
#      .
#      .
# ====================================================================================================

# Get list of facilities and wind files

      open (INFILE, "<$FacAndWnd");
      $line=<INFILE>;                        # read and discard header
      $nfac=0;
      while ($line=<INFILE>)
      {
        $line =~ s/^[ ]+//;                  # delete initial spaces
        chop ($line);                        # remove carrige return
        @field = split /[ \t]+/, $line;      # split field
        $facID[$nfac]=$field[0];
        $wndfile[$nfac]=$field[1];
        $nfac=$nfac+1;
      }
      close (INFILE);

# get list of nuclides
      open(INFILE,"<$NuclideList");
      $nnuc=0;
      while ($line=<INFILE>)
      {
        $line =~ s/^[ ]+//;                  # delete initial spaces
```

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```perl
    chop ($line);                      # remove carrige return
    @field = split /[ \t]+/, $line;    # split field
    $nucnames[$nnuc]=$field[0];
    $nnuc=$nnuc+1;
  }
  close (INFILE);


# Loop through the files and insert current met file
   if($update eq "Y")
   {
     for $i (0..$nfac-1)
     {
       print "$facID[$i] \n";

# update template files with new met dat

       for $k (0..3)
       {

         $fname=$templatef.$facID[$i]."\\".$tempfnames[$k];
         open (TFILE,"<$fname");
         $n=0;
         while ($line=<TFILE>)
         {
           $tline[$n]=$line;
           $n=$n+1;
         }
         close(TFILE);
         system ("del $fname");

         open (TFILE,">$fname");
         for $j (0..$n)
         {
           if ($j==22)
           {
             $wfile=$windpath.$wndfile[$i];
             print TFILE "$wfile \n";
           }
           else
           {
             print TFILE "$tline[$j]";
           }

         }
         close (TFILE);
       }

     }
   }


# Now append nuclide files to each template file and write template files and nuclide name to $NuclideFile
     open(NLIST,">$NuclideFile");
     open(OLIST,">$OutputFile");

     for $i (0..$nfac-1)
     {
       print "$facID[$i]\n";

       for $j (0..$nnuc-1)
       {
         $fname=$nucnames[$j];
         $fname =~ s/-//;

         $ffname=$fname."A.dat";
         $outfile=$fname."A.SUM";
         if($i==0)
         {
           print OLIST "$outfile $nucnames[$j] \n";
           print NLIST "$ffname $nucnames[$j] \n";
         }
```

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```
         $ofile=$templatef.$facID[$i]."\\".$ffname." \n";
         $cmd="del ".$ofile;
#        print "$cmd \n";
         system $cmd;

         $cmd="copy ".$templatef.$facID[$i]."\\".$tempfnames[0]." + ".$nuctemplate.$fname.".dat ".$ofile;
#        print "$cmd \n";
         system $cmd;

# AJS added following lines to replace 2nd line of cap88 input file with nucname (reqd by v4)
# Not terribly efficient, but it works. It reads every line of the file, then writes it back replacing line 2.
         open (OFILE,"<$ofile");
         $n=0;
         while ($line=<OFILE>)
         {
           $zline[$n]=$line;
           $n=$n+1;
         }
         close(OFILE);
         system ("del $ofile");
         open (OFILE,">$ofile");
         for $l (0..$n)
         {
           if ($l==1)
           {
             $capname=$fname."A.";
            print OFILE "$capname \n";
           }
           else
           {
             print OFILE "$zline[$l]";
           }
         }
# AJS End of AJS changes

         $ffname=$fname."B.dat";
         $outfile=$fname."B.SUM";
         if($i==0)
         {
           print OLIST "$outfile $nucnames[$j] \n";
           print NLIST "$ffname $nucnames[$j] \n";
         }
         $ofile=$templatef.$facID[$i]."\\".$ffname." \n";
         $cmd="del ".$ofile;
#        print "$cmd \n";
         system $cmd;
         $cmd="copy ".$templatef.$facID[$i]."\\".$tempfnames[1]." + ".$nuctemplate.$fname.".dat ".$ofile;
#        print "$cmd \n";
         system $cmd;

# AJS added following lines to replace 2nd line of cap88 input file with nucname (reqd by v4)
# Not terribly efficient, but it works. It reads every line of the file, then writes it back replacing line 2.
         open (OFILE,"<$ofile");
         $n=0;
         while ($line=<OFILE>)
         {
           $zline[$n]=$line;
           $n=$n+1;
         }
         close(OFILE);
         system ("del $ofile");

         open (OFILE,">$ofile");
         for $l (0..$n)
         {
           if ($l==1)
           {
             $capname=$fname."B.";
            print OFILE "$capname \n";
           }
           else
           {
             print OFILE "$zline[$l]";
           }
         }
```

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```
# AJS End of AJS changes

        $ffname=$fname."C.dat";
        $outfile=$fname."C.SUM";
        if($i==0)
        {
          print OLIST "$outfile $nucnames[$j] \n";
          print NLIST "$ffname $nucnames[$j] \n";
        }
        $ofile=$templatef.$facID[$i]."\\".$ffname." \n";
        $cmd="del ".$ofile;
#       print "$cmd \n";
        system $cmd;
        $cmd="copy ".$templatef.$facID[$i]."\\".$tempfnames[2]." + ".$nuctemplate.$fname.".dat ".$ofile;
#       print "$cmd \n";
        system $cmd;

# AJS added following lines to replace 2nd line of cap88 input file with nucname (reqd by v4)
# Not terribly efficient, but it works. It reads every line of the file, then writes it back replacing line 2.
        open (OFILE,"<$ofile");
        $n=0;
        while ($line=<OFILE>)
        {
          $zline[$n]=$line;
          $n=$n+1;
        }
        close(OFILE);
        system ("del $ofile");

        open (OFILE,">$ofile");
        for $l (0..$n)
        {
          if ($l==1)
          {
            $capname=$fname."C.";
           print OFILE "$capname \n";
          }
           else
          {
            print OFILE "$zline[$l]";
          }
        }
# AJS End of AJS changes

        $ffname=$fname."D.dat";
        $outfile=$fname."D.SUM";
        if($i==0)
        {
          print OLIST "$outfile $nucnames[$j] \n";
          print NLIST "$ffname $nucnames[$j] \n";
        }
        $ofile=$templatef.$facID[$i]."\\".$ffname." \n";
        $cmd="del ".$ofile;
#       print "$cmd \n";
        system $cmd;
        $cmd="copy ".$templatef.$facID[$i]."\\".$tempfnames[3]." + ".$nuctemplate.$fname.".dat ".$ofile;
#       print "$cmd \n";
        system $cmd;

# AJS added following lines to replace 2nd line of cap88 input file with nucname (reqd by v4)
# Not terribly efficient, but it works. It reads every line of the file, then writes it back replacing line 2.
        open (OFILE,"<$ofile");
        $n=0;
        while ($line=<OFILE>)
        {
          $zline[$n]=$line;
          $n=$n+1;
        }
        close(OFILE);
        system ("del $ofile");
        open (OFILE,">$ofile");
        for $l (0..$n)
        {
          if ($l==1)
          {
```

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```
        $capname=$fname."D.";
        print OFILE "$capname \n";
      }
      else
      {
        print OFILE "$zline[$l]";
      }
    }
  }
# AJS End of AJS changes
      }
    }

    close (NLIST);
    close (OLIST);
```

Facility.inp (input file for mkFiles.pl)

```
Facility        WindFile
MFC             EBRL6-15.WND
```

NucList.inp (input file for mkFiles.pl)

```
Al-28
C-14
Co-58
Co-60
Cr-51
Cu-64
Cu-66
Fe-55
Fe-59
H-3
Mn-54
Mo-93
Mo-93m
Mo-99
Nb-92
Nb-94
Nb-95
Nb-95m
Nb-96
Nb-97
Ni-59
Ni-63
Ni-66
P-32
P-33
Ru-103
S-35
Sc-47
Sc-48
Tc-99
Y-89m
Y-90
Zn-65
Zr-89
Zr-95
Zr-97
```

RunFiles.pl

```
# RunFiles.pl
# This script runs all the CAP88 files in a given directory


# =================================================================================================
# REQUIRED USER INPUT

# --- Path to the input files (excluding specific facility name)
    $templatef="C:\\projects\\fy2018\\NESHAPv4\\CAP88\\";
    $wrkdir="C:\\projects\\fy2018\\NESHAPv4\\CAP88\\Scripts";
```

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```perl
# --- File containing all the facility names - These names correspond to directories for each calcilites
      $FacAndWnd = "Facility.inp";        # facility and wind file names

# --- Path to the wind files
      $windpath="C:\\projects\\fy2018\\NESHAPv4\\WindFiles\\";

# --- Facility name and wind file format
#        Facility        WindFile  header (discarded)
#        CFA             690L08.WND
#        CITRC           PBFL08.WND
#        INTEC-ICDF      GRIL08.WND
#        .
#        .
#        .

# --- File containing all the nuclide file names
      $NuclideFile = "NucFiles.inp";
# =========================================================================================================
# END OF USER INPUT


# Get list of facilities

      open (INFILE, "<$FacAndWnd");
      $line=<INFILE>;                          # read and discard header
      $nfac=0;
      while ($line=<INFILE>)
      {
        $line =~ s/^[ ]+//;                    # delete initial spaces
        chop ($line);                          # remove carrige return
        @field = split /[ \t]+/, $line;        # split field
        $facID[$nfac]=$field[0];
        $wndfile[$nfac]=$field[1];
        $nfac=$nfac+1;
      }
      close (INFILE);

# get list of nuclides
      open(INFILE,"<$NuclideFile");
      $nnuc=0;
      while ($line=<INFILE>)
      {
        $line =~ s/^[ ]+//;                    # delete initial spaces

        chop ($line);                          # remove carrige return
        @field = split /[ \t]+/, $line;        # split field
        $nucfiles[$nnuc]=$field[0];
        $nnuc=$nnuc+1;
      }
      close (INFILE);



# Loop through each facility, write a batch file to run CAP88, and run batch file


      $batfile="run.bat";
      for $i (0..$nfac-1)
      {
        print "$facID[$i] \n";
        $wfile=$windpath.$wndfile[$i];
         print "$wfile \n";
        for $j (0..$nnuc-1)
        {

# --- open batch file
        open (BATFILE,">$batfile");

        $nucf=$templatef.$facID[$i]."\\".$nucfiles[$j];
        $nucname=substr($nucfiles[$j],0,-4);
#        print $nucname;
        $sumfile=$templatef.$facID[$i]."\\preSSEfix\\".substr($nucfiles[$j],0,-4).".SUM";
        print BATFILE "cd C:\\Users\\AJS\\Documents\\CAP88\\Fortran\n";
        print BATFILE "copy $nucf INPUT.DAT\n";
```

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```
 print BATFILE "copy $wfile INPUT.WND\n";
print BATFILE "Cap88v4Fortran.exe\n";
print BATFILE "cd output\n";
print BATFILE "copy $nucname.SUM $sumfile\n";
print BATFILE "DEL $nucname.*\n";
print BATFILE "cd $wrkdir\n";

close (BATFILE);
system "run.bat";

   }

  }
```

getCAP88dose2.pl

```
# getCAP88dose.pl
# This script extracts doses from the CAP88 *.SUM file and writes it to a text file
# The file containing list of output files ($filein) is generated in the script mkfiles.pl

# ================================================================================
# REQUIRED USER INPUT
#     Working Directory
        $wrkdir="C:\\projects\\fy2018\\NESHAPv4\\CAP88\\";
#     File containing list of output files
        $filein="OutputFiles.inp";
# --- File containing all the facility names - These names correspond to directories for each facilites
        $FacAndWnd = "Facility.inp";       # facility and wind file names
# --- Output File
        $fileout="tempdoses.txt";
# --- Number of MEI locations
        $nmei=62;
# --- MEI File
        $meifile="MEI.dat";
# ================================================================================
#   if($ARGV[0] eq "?")
#   {
#      print "usage getCAP88dose.pl [file name containing files to process] [output file] [facility name] \n";
#      die;
#   }
#   $filein=$ARGV[0];
#   $fileout=$ARGV[1];
#   $facility_name=$ARGV[2];
#   print "$filein \n";

# Open and store file containing list of output files and make nuclide names

      open (INFILE, "<$filein");
      $nf=0;

      while ($line=<INFILE>)
      {
        $line =~ s/^[ ]+//; # delete initial spaces
        chop ($line); # remove carrige return
        @field = split /[ \t]+/, $line;     #split field
        $files[$nf]=$field[0];
        $nname[$nf]=$field[1];
#        $nname[$nf]=substr($files[$nf],0,-5);
        $nf=$nf+1;
      }
      close (INFILE);
      $nf=$nf-1;

# Open and store file containing list of facilities

      open (INFILE, "<$FacAndWnd");
      $line=<INFILE>;                         # read and discard header
      $nfac=0;
      while ($line=<INFILE>)
      {
        $line =~ s/^[ ]+//;                    # delete initial spaces
        chop ($line);                          # remove carrige return
        @field = split /[ \t]+/, $line;     # split field
        $facID[$nfac]=$field[0];
```

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```
    $nfac=$nfac+1;
    }
    close (INFILE);
    $nfac=$nfac-1;


# load MEI locations
    open (INFILE, "<$meifile");
    $line=<INFILE>;                        # read and discard header
# --- There are 62 MEI locations per facility - so for each faility, store each location

    $i=1;
    while ($line=<INFILE>)
    {
      $line =~ s/^[ ]+//; # delete initial spaces
      chop ($line); # remove carrige return
      @field = split /[ \t]+/, $line;      #split field

      $mei_dir{$field[0]}{$i}=$field[1];
      $mei_dist{$field[0]}{$i}=$field[2];
      $i=$i+1;
      if($i>$nmei) {$i=1;}

    }

    close (INFILE);


# Open output file
    open (OUTFILE, ">$fileout");

    print " Number of Files:        $nf \n";
    print " Number of Facilities:    $nfac \n";
    print " Number of MEI Locations: $nmei \n";

    $n1=0;
    $n2=1;

    for $j (0..$nfac)
    {
      print "[$j] \n";
      print "Facility: $facID[$j] \n";
      $cnt=0;
      for $i (0..$nf)
      {
        if ($i % 5 == 0) { print STDERR "$i"; }
        else { print STDERR ".";}

        $filein=$wrkdir.$facID[$j]."\\".$files[$i];
        open (INFILE, "<$filein");
        while ($line=<INFILE>)
        {

          if($line=~ /INDIVIDUAL LIFETIME RISK/)
          {last;}


          if($line=~ /Distance/)
          {

            @field=(-1,-1,-1,-1,-1,-1,-1,-1);
            $line=<INFILE>;   # skip 2 lines
            $line=<INFILE>;
# get distances
            $line=<INFILE>;

            $line =~ s/^[ ]+//; # delete initial spaces
            chop ($line); # remove carrige return
            @field = split /[ \t]+/, $line;     #split field

# find number of values
            $nvals=0;
            for $k (1..7)
            {
              if($field[$k] >0 )
```

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```
            {
              $nvals=$nvals+1;
              $dist[$nvals]=$field[$k];
            }
        }

        $line=<INFILE>;   # skip 2 lines
        $line=<INFILE>;
# get dose values
        for $k (1..16)
        {
          $line=<INFILE>;
          $line =~ s/^[ ]+//; # delete initial spaces
          chop ($line); # remove carrige return
          @field = split /[ \t]+/, $line;     #split field
          $direct=$field[0];

          for $m (1..$nvals)
          {

# --- Loop through all MEIs to the facility. if the location is an MEI and print it.
            for $kk (1..$nmei)
            {
              if($dist[$m]==$mei_dist{$facID[$j]}{$kk} && $direct eq $mei_dir{$facID[$j]}{$kk})
              {
                print OUTFILE
"$facID[$j],$nname[$i],$mei_dir{$facID[$j]}{$kk},$mei_dist{$facID[$j]}{$kk},$field[$m] \n";
              }

            }
          }      # end of distance loop

        }        # end of direction loop

      }          # end of if statement

    }            # end of line search loop
    close (INFILE);

  }                # end of file loop

}                  # end of facility loop


# Close output file and terminate

  close OUTFILE;
```