Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy.

Disclaimer:

This work was prepared under an agreement with and funded by the U.S. Government. Neither the U. S. Government or its employees, nor any of its contractors, subcontractors or their employees, makes any express or implied: 1. warranty or assumes any legal liability for the accuracy, completeness, or for the use or results of such use of any information, product, or process disclosed; or 2. representation that such use or results of such use would not infringe privately owned rights; or 3. endorsement or recommendation of any specifically identified commercial product, process, or service. Any views and opinions of authors expressed in this work do not necessarily state or reflect those of the United States Government, or its contractors, or subcontractors.

ASSESSMENT OF RADIONUCLIDE DATABASES IN CAP88 MAINFRAME VERSION 1.0 AND WINDOWS-BASED VERSION 3.0

Elizabeth D. LaBone[*], Eduardo B. Farfán[†], Patricia L. Lee[†],

G. Timothy Jannik[†], Elizabeth H. Donnelly[‡], and Trevor Q. Foley[†]

Address for Correspondence:

Eduardo B. Farfán, Ph.D.
Environmental Science and Biotechnology
Environmental Analysis Section
Savannah River National Laboratory
Savannah River Nuclear Solutions, LLC
773-42A, Room 236
Aiken, SC 29808

E-mail: Eduardo.Farfan@srnl.doe.gov
Phone: (803) 725-2257
Fax: (803) 725-7673

ASSESSMENT OF RADIONUCLIDE DATABASES IN CAP88 MAINFRAME VERSION 1.0 AND WINDOWS-BASED VERSION 3.0

Abstract - In this study the radionuclide databases for two versions of the Clean Air Act Assessment Package-1988 (CAP88) computer model were assessed in detail. CAP88 estimates radiation dose and the risk of health effects to human populations from radionuclide emissions to air. This program is used by several Department of Energy (DOE) facilities to comply with National Emission Standards for Hazardous Air Pollutants (NESHAP) regulations. CAP88 Mainframe, referred to as Version 1.0 on the Environmental Protection Agency (EPA) website (http://www.epa.gov/radiation/assessment/CAP88/), was the very first CAP88 version released in 1988. Some DOE facilities including the Savannah River Site still employ this version (1.0) while others use the more user-friendly personal computer Windows-based Version 3.0 released in December 2007. Version 1.0 uses the program RADRISK based on International Commission on Radiological Protection (ICRP) Publication 30 as its radionuclide database. Version 3.0 uses half-life, dose and risk factor values based on Federal Guidance Report 13. Differences in these values could cause different results for the same input exposure data (same scenario), depending on which version of CAP88 is used. Consequently, the differences between the two versions are being assessed in detail at Savannah River National Laboratory. The version 1.0 and 3.0 database files contain 496 and 838 radionuclides, respectively, and though one would expect the newer version to include all the 496 radionuclides, thirty-five radionuclides are listed in version 1.0 that are not included in version 3.0. The majority of these has either extremely short or long half-lives or is no longer in production; however, some of the short-lived radionuclides might produce progeny of great interest at DOE sites. In addition, one hundred and twenty-two radionuclides

were found to have different half-lives in the two versions, with 21 over 3 percent different and 12 over 10 percent different.

Key words: Radionuclide emissions, CAP88, NESHAP, regulations, compliance

INTRODUCTION

In support of the Environmental Services Section's Environmental Permitting and Monitoring at the Savannah River Site (SRS), dosimetry assessments (maximally exposed individual and collective doses) for the SRS Radionuclide Air Emissions Annual Report for National Emission Standards for Hazardous Air Pollutants (NESHAP) (EPA 2006) are performed by the Savannah River National Laboratory (SRNL) Environmental Dosimetry Group based on the SRS radiological source term. The SRS Environmental Report for 2007 was prepared by Mamatey et al. (2008) for the U.S. Department of Energy (DOE). The purpose of this report is to 1) present summary environmental data that characterize site environmental management performance; 2) confirm compliance with environmental standards and requirements; 3) highlight significant programs and efforts; and 4) assess the impact of SRS operations on the public and the environment.

The calculations for this report are performed annually using the IBM Mainframe version (1.0) of the Clean Air Act Assessment Package-1988 (CAP88) dosimetry code, the EPA-approved model for demonstration of compliance with EPA standards for radionuclide emissions to the atmosphere (EPA 2006). CAP88 is an atmospheric dispersion and dose calculation computer code that combines stack radionuclide emissions with meteorological and population data. CAP88 estimates “health impacts from the inhalation, ingestion, air immersion, and ground

surface irradiation pathways" (Beres 1990). It is one of the programs that is approved for compliance to the Code of Federal Regulations (CFR) Title 40 Part 61 [40 CFR 61, Protection of Environment - NESHAP (EPA 2006)][§]. 40 CFR 61 limits the dose received by any member of the public due to releases by nuclear facilities to 0.1 mSv y^{-1} (EPA 2006). The very first version of the program, released in 1988 and referred to as version 1.0 on the EPA website (Beres 1990), was in a DOS[**] environment and is still used with a mainframe[††] at facilities such as the SRS. Other sites use newer versions such as Windows[‡‡]-based version 3.0 released in December 2007 (Rosnick 2007), which includes more radionuclides and half-life values based on Federal Guidance Report 13 (FRG 13). It would be advisable for those facilities still using version 1.0[§§] to migrate to version 3.0 to take advantage of the added radionuclides and to negate the need to work with the much less user-friendly mainframe program. In addition, it will allow use of the current agricultural productivity factors, organ and weighting factors, and radionuclide transfer factors that version 3.0 offers. The differences in the radionuclide databases between the two versions can cause different results with the same input scenario. For this reason, the differences in radionuclide half-lives between the two databases have been assessed in detail in this study.

The differences between the radionuclide databases used by these codes is caused by the fact that version 3.0 uses FGR 13 for dose and risk factors, organ weighting factors, and decay chains where as version 1.0 uses the program RADRISK[***] based on ICRP 30 (1979) for dose and risk factors and "Limits for Intakes of Radionuclides by Workers" for organ dose factors (Beres 1990; Dunning et al. 1980). Radionuclide transfer factors have been updated according to National Council on Radiation Protection and Measurements (NCRP) Report 123 (1996) for version 3.0. There are also differences in how agricultural data can be input. Version 1.0 allows for data to be input for a specific area, such as SRS, where there is a region where no crops are

grown or livestock raised. Only the State average can be used in version 3.0, which does not allow for areas with no agriculture. The population and wind files from version 1.0 are still usable in version 3.0 with minor modifications. All the database differences in versions 1.0 and 3.0 are currently being considered at SRS to accomplish the migration from one CAP88 version to another. The extensive migration process and the Software Quality Assurance (SQA) Plan involve the following major tasks:

1. Verify and validate successful execution of version 3.0 using SRS site-specific information.
2. Benchmark version 3.0 against version 1.0 to understand the differences between the two versions.
    a. Quantify the differences by nuclide and pathway.
    b. Document the findings and differences.
3. Develop a version 3.0 user's manual for SRNL.
4. Update the SQA documentation.

Because of the magnitude of the migration process from version 1.0 to 3.0, this study focuses only on the differences between the radionuclide half-life databases in the two versions.

METHODS AND MATERIALS

The files for both versions of CAP88 were downloaded and then searched for those that contained the radionuclide databases. The two files, ALLRAD88 for 1.0 and FGR13CD.NDX for 3.0, were then compared to determine the differences in the half-lives. ALLRAD88 contains element- and radionuclide-specific data based on ICRP Publication 30 (1979) and

FGR13CD.NDX is comprised of half-life values based on Federal Guidance Report 13 (FGR 13). For half-life values that had different units of time, the half-life was converted to the unit that was used in the mainframe version.

The calculated percent difference between the two values is shown in Table 1, which also includes percent differences of the half-life values for versions 1.0 and 3.0 as compared to the values from Brookhaven National Laboratory (BNL)[† † †]. The half-live values listed in Table 1 include all the significant figures specified in the versions 1.0 and 3.0. The percent differences in Table 1 were calculated for half-life differences greater than 1.0 %, which helped determine that 41 radionuclides have different half-lives at this percent difference. Some radionuclides were included in version 1.0, but not in version 3.0. These radionuclides with their half-lives and progeny are shown in Table 2.

RESULTS

The versions 1.0 and 3.0 database files contain 496 and 838 radionuclides, respectively. The calculated percent difference between the two versions is shown in Table 1, which also includes percent differences of the half-life values for versions 1.0 and 3.0 as compared to the values from the National Nuclear Data Center at BNL (http://www.nndc.bnl.gov/chart/).

It was determined that 122 radionuclides exist in the two CAP88 versions with different half-life values as shown in Table 1. There were 44, 21, 13, and 12 radionuclides with 1%, 3%, 5%, and 10% percent difference, respectively. The largest percent difference was 184%, where the half-life for ^{67}Cu had 61.88 days for the version 1.0 and 61.86 hours for version 3.0. The difference for ^{67}Cu seems to be a typographical error. Americium-246 had the next highest

difference, 43.75%. Version 1.0 has a value of 25 minutes and version 3.0 of 39 minutes. The half-life for ^{246m}Am is 25 minutes, which version 1.0 is using for ^{246}Am. The ^{246}Am difference might be attributed to confusion with ^{246m}Am. The half-life difference for ^{41}Ca is 30%; 1.03 x 10^{+05} and 1.40 x 10^{+05} y for versions 1.0 and 3.0, respectively.

Comparing some of the half-lives found in the CAP88 databases to values from BNL, several were found that varied by at least 10%. For ^{115}In, the values for 1.0 and 3.0 had 10.31% difference and there was over 165% difference comparing versions 1.0 and 3.0 to the value from BNL, which varied by one order of magnitude. Another radionuclide that varied greatly among the three different values was ^{32}Si. The values were all of the same order of magnitude, but varied by at least 30.8% when comparing ^{32}Si half-lives in versions 1.0 and 3.0.

For ^{246}Am, ^{67}Cu, and ^{231}Pa, the only difference greater than ten percent occurred when version 1.0 was compared to values of version 3.0 and BNL. When comparing version 3.0 to version 1.0 and BNL, it was determined that another three radionuclides (^{207}Bi, ^{41}Ca, and ^{129m}Xe) had differences higher than 10%. Two radionuclides, ^{205}Pb and ^{121}Te, had half-lives that had greater than 10% difference when the BNL value was compared to versions 1.0 and 3.0.

Some radionuclides were included in version 1.0, but not in version 3.0. These 35 radionuclides with their progeny and half-lives are shown in Table 2. Most have either very short or very long half-lives. The shortest was 7.13 s for ^{16}N and the longest half-life was 2.00 x 10^{+15} y for ^{186}Os. Some of these radionuclides have not been released from DOE sites for several years due to international agreements to cease the production of nuclear weapons materials. Of the others, the ones with very short half-lives would be almost completely decayed by the time they reached the population from the release site, so they have very little affect if any on the dose to the population, and the long-lived radionuclides do not add to the annually calculated doses. It

was also noted that a few short-lived radionuclides omitted from version 3.0, but included in version 1.0, have progeny that includes radionuclides of great interest at DOE sites such as ^{90}Rb and ^{137}Xe, which produce the daughters ^{90}Sr and ^{137}Cs, respectively.

CONCLUSIONS

CAP88 is an important tool used at various DOE sites for compliance. Throughout the DOE complex, a variety of versions of CAP88 are currently used. Presently, SRS uses the mainframe version 1.0 and SRNL researchers are working on the transition from this version to the latest version (3.0). In this process, a number of procedures are involved to ensure the testing, verification, validation, and documentation of the adapted methodology. This study covered only one of the several aspects considered in the transition process; comparison between half-life databases of the two versions. Since these CAP88 versions are currently used by DOE sites at the same time, the encountered differences in half-life values in the two versions analyzed in this study might trigger differences in results even for similar input exposure data.

The majority of the differences in half-lives between the two versions is most likely caused by differences in rounding or slight variation due to different sources. There were some, such as ^{67}Cu, where the differences were most likely caused by typographical errors. Errors in radionuclide half-lives were determined to occur in both versions, though errors in one version are usually not the same as those in the other version. Both versions contained three errors that were greater than 10%. The differences for version 1.0 tend to be larger, with 184% and 43.75% for version 1.0, than those in version 3.0. The largest difference for 3.0 was 31.40%.

Version 1.0 and 3.0 have 27 and 29 radionuclide half-lives, respectively, that differ from the BNL nuclear database. The greatest percent difference is for ^{67}Cu (version 1.0 vs. BNL) and the second greatest difference is for ^{115}In; 165% and 168% for version 1.0 vs. BNL and version 3.0 vs BNL, respectively. Since CAP88 is used at SRNL to estimate annual doses, relatively large differences in half-life values for the same radionuclide in versions 1.0 and 3.0 might not cause large differences in dose when the half-lives considered are extremely long (e.g., thousands of years). However, differences in half-life values will cause different doses when considering short half-lives (e.g. a few days or weeks).

Finally, other aspects being considered during the transition process involve new capabilities of version 3.0; for example, new recommendations implemented in version 3.0 to calculate tritium dose and a new methodology for ingestion calculations. These new capabilities are not currently described in the manual of version 3.0. Some issues encountered during the transition include possible incorrect units in organ-specific dose conversion factors in version 3.0 and potentially erroneous calculation of ground surface dose for gamma-emitting radionuclides such as ^{60}Co.

Acknowledgements – The study represents a portion of a larger study to implement CAP88 version 3.0 at the Savannah River Site. The authors express their gratitude to Drs. Thomas J. Overcamp and Timothy A. DeVol from Clemson University who are participating in various aspects of the transition from one CAP88 version into another.

Disclaimer – Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the authors or their corresponding organizations.

REFERENCES

Beres DA. The Clean Air Act Assessment Package-1988 (CAP-88), A Dose and Risk Assessment Methodology for Radionuclide Emissions to Air Volume 1 User's Manual. Washington, D.C.: U.S. Environmental Protection Agency; 1990. Available at: http://www.epa.gov/radiation/docs/cap88/cap88mf_guide.html. Accessed 14 April 2009.

Dunning DE Jr., Leggett RW, and Yalcintas MG. A Combined Methodology for Estimating Dose Rates and Health Effects from Exposure to Radioactive Pollutants. ORNL/TM-7105; December 1980.

Federal Guidance Report 13. Cancer Risk Coefficients for Environmental Exposure to Radionuclides., USEPA Office of Radiation and Indoor Air, Washington, D.C.: EPA 402-R-99-001; 1999.

International Commission on Radiological Protection. Limits for Intakes of Radionuclides by Workers. New York: Pergamon Press; ICRP Publication 30, Part 1, Ann. ICRP, 2 (3/4); 1979.

Mamatey AR, Fledderman P, Jannik GT. Savannah River Site Environmental Report for 2007. Washington Savannah River Company. WSRC-STI-2008-00057. Available at: http://www.srs.gov/general/pubs/ERsum/. Accessed 14 April 2009.

National Council on Radiation Protection and Measurements. Screening Models for Releases of Radionuclides to Atmosphere, Surface Water and Ground. Report 123; 1996. Available at http://www.ncrppublications.org/Reports/123. Accessed 14 April 2009.

National Nuclear Data Center. Brookhaven National Laboratory [online]. Available at: http://www.nndc.bnl.gov/chart/. Accessed 14 April 2009.

Rosnick R. CAP88-PC Version 3.0 User Guide. Trinity Engineering Associates, Inc; 2007.

US Environmental Protection Agency (EPA). National Emissions Standards for Hazardous Air Pollutants; Radionuclides. Washington, D.C.: Title 40 Code of the Federal Regulations, Part 61; 2006.

Tables:

Table 1 - Radionuclide half-life percent differences.

Table 2 - Mainframe radionuclides not included in CAP88 PC v. 3.0.

Footnotes (Table 1):

[a] Percent difference values are shown only for differences greater than 1.0%.

[b] MF = CAP88 Mainframe v. 1.0 (very first version).

[c] PC = CAP88 PC v. 3.0 (released in December 2007).

[d] BNL = National Nuclear Data Center at Brookhaven National Laboratory

(http://www.nndc.bnl.gov/chart/).

Footnotes (Text):

[*] University of South Carolina, Columbia, SC 29208.
[†] Savannah River National Laboratory, Savannah River Nuclear Solutions, LLC. Bldg. 773-42A, Aiken, SC 29808.
[‡] Centers for Disease Control and Prevention (CDC), 4770 Buford Highway, NE. MS F03. Atlanta, GA 30341.
[§] Code of Federal Regulations is available online via the National Archives and Records Administration (http://www.access.gpo.gov/nara/cfr/cfr-table-search.html)
[**] DOS (Disk Operating System) was widely used between 1981 and 1995.
[† †] A mainframe is a computer used mainly by large companies to process large amounts of data.
[‡‡] Windows. Microsoft Corporation. One Microsoft Way, Redmond, WA 98052-6399.
[§§] Throughout this paper, CAP88 version 1.0 is a reference to the mainframe version released in 1988, but note that a PC version 1.0 of CAP88, released a couple of years after the original mainframe version, also exists. The various CAP88 versions can be found at http://www.epa.gov/radiation/assessment/CAP88/index.html
[***] RADRISK is a computer program that estimates radiation doses and health effects from inhalation or ingestion of radionuclides. RADRISK can be obtained from the Radiation Safety Information Computational Center (RSICC) at Oak Ridge National Laboratory (http://www-rsicc.ornl.gov/).
[† † †] National Nuclear Data Center, Brookhaven National Laboratory (BNL), P.O. Box 5000, Upton, NY 11973-5000, http://www.nndc.bnl.gov/

Table 1. Radionuclide half-life percent differences.

		Half-lives			Percent Difference[a]		
Radionuclide	**Units**	**MF[b]**	**PC[c]**	**BNL[d]**	**MF vs PC**	**MFvsBNL**	**PC vs BNL**
^{110}Ag	s	24.57	24.6	24.6			
^{110m}Ag	d	249.85	249.9	249.76			
^{111}Ag	d	7.46	7.45	7.45			
^{26}Al	y	7.20 x10^{+05}	7.16 x10^{+05}	7.17x10^{+05}			
^{245}Am	min	122.4	123	123			
^{246}Am	min	25	39	39	43.75%	43.75%	
^{195m}Au	s	30.6	30.5	30.5			
^{133}Ba	y	10.5	10.74	10.52329	2.26%		2.02%
^{139}Ba	min	83.1	82.7	83.06			
^{140}Ba	d	12.789	12.74	12.752			
^{142}Ba	min	10.7	10.6	10.6			
^{7}Be	d	53.44	53.3	53.22			
^{207}Bi	y	33.4	38	32.9	12.89%	1.51%	14.39%
^{210}Bi	d	5.013	5.012	5.012			
^{211}Bi	min	2.13	2.14	2.14			
^{77}Br	h	57.04	56	57.036	1.84%		1.83%
^{11}C	min	20.48	20.38	20.334			
^{41}Ca	y	1.03 x10^{+05}	1.40 x10^{+05}	1.02 x10^{+05}	30.45%		31.40%
^{45}Ca	d	162.7	163	162.61			
^{47}Ca	d	4.536	4.53	4.536			
^{49}Ca	min	8.719	8.716	8.718			
^{113m}Cd	y	13.7	13.6	14.1		2.88%	3.61%
^{251}Cf	y	9.00 x10^{+02}	898	898			
^{252}Cf	y	2.639	2.638	2.645			
^{242}Cm	d	163.2	162.8	162.8			
^{246}Cm	y	4.75 x10^{+03}	4730	4760			
^{131}Cs	d	9.688	9.69	9.689			
^{136}Cs	d	13.16	13.1	13.04			
^{137}Cs	y	30.17	30	30.03			
^{67}Cu	d	61.88	2.58	2.58	184.00%	184.01%	
^{157}Dy	h	8.06	8.1	8.14			
^{169}Er	d	9.4	9.3	9.392	1.07%		
^{253}Es	d	20.467	20.47	20.47			
^{152}Eu	y	13.6	13.33	13.506	2.01%		1.31%
^{18}F	min	109.74	109.77	109.746			
^{59}Fe	d	44.63	44.529	44.495			
^{152}Gd	y	1.10 x10^{+14}	1.08 x10^{+14}	1.08 x10^{+14}	1.83%	1.83%	
^{3}H	y	12.28	12.35	12.32			
^{181}Hf	d	42.39	42.4	42.39			
^{197}Hg	h	64.14	64.1	64.14			
^{123}I	h	13.13	13.2	13.2235			
^{126}I	d	12.93	13.02	12.93			
^{115}In	y	4.60 x10^{+15}	5.10 x10^{+15}	4.41 x10^{+14}	10.31%	165.01%	168.16%

Table 1. Radionuclide half-life percent differences (Cont.).

		Half-lives			Percent Difference[a]		
Radionuclide	**Units**	**MF[b]**	**PC[c]**	**Radionuclide**	**Units**	**MF[b]**	**PC[c]**
^{115m}In	h	4.36	4.486	4.486	2.85%	2.85%	
^{190}Ir	d	11.78	12.1	11.78	2.68%		2.68%
^{190m}Ir	h	3.2	3.1	3.087	3.17%	3.59%	
^{140}La	h	40.22	40.272	40.2744			
^{141}La	h	3.94	3.93	3.92			
^{142}La	min	95.4	92.5	91.1	3.09%	4.61%	1.53%
^{177m}Lu	d	160.1	160.9	160.44			
^{52m}Mn	min	21.4	21.1	21.1	1.41%	1.41%	
^{54}Mn	d	312.7	312.5	312.12			
^{101}Mo	min	14.61	14.62	14.61			
^{99}Mo	h	66.02	66	65.9736			
^{13}N	min	9.97	9.965	9.965			
^{93m}Nb	y	14.6	13.6	16.13	7.09%	9.96%	17.02%
^{95}Nb	d	35.06	35.15	34.991			
^{63}Ni	y	100.1	96	100.1	4.18%		4.18%
^{185}Os	d	93.6	94	93.6			
^{231}Pa	y	$3.73 \times 10^{+04}$	$3.28 \times 10^{+04}$	$3.28 \times 10^{+04}$	12.85%	12.85%	
^{203}Pb	h	52.02	52.05	51.92			
^{204m}Pb	min	66.9	67.2	67.2			
^{205}Pb	y	$1.51 \times 10^{+07}$	$1.43 \times 10^{+07}$	$1.73 \times 10^{+07}$	5.44%	13.58%	18.99%
^{210}Pb	y	22.26	22.3	22.2			
^{212}Pb	h	10.643	10.64	10.64			
^{103}Pd	d	16.961	16.96	16.991			
^{109}Pd	h	13.453	13.427	13.7012		1.83%	2.02%
^{210}Po	d	138.378	138.38	138.376			
^{212}Po	s	2.98×10^{-07}	3.05×10^{-07}	2.99×10^{-07}	2.32%		1.99%
^{216}Po	s	0.146	0.15	0.145	2.70%		3.39%
^{191}Pt	d	2.71	2.8	2.802	3.27%	3.34%	
^{238}Pu	y	87.75	87.74	87.7			
^{239}Pu	y	24131	24065	24110			
^{240}Pu	y	6569	6537	6561			
^{242}Pu	y	$3.76 \times 10^{+05}$	$3.76 \times 10^{+05}$	$3.75 \times 10^{+05}$			
^{245}Pu	h	10.57	10.5	10.5			
^{224}Ra	d	3.62	3.66	3.6319	1.10%		
^{82}Rb	min	1.25	1.3	1.273	3.92%	1.82%	2.10%
^{84}Rb	d	32.9	32.77	33.1			1.00%
^{87}Rb	y	$4.73 \times 10^{+10}$	$4.70 \times 10^{+10}$	$4.97 \times 10^{+10}$		4.95%	5.58%
^{89}Rb	min	15.44	15.2	15.15	1.57%	1.90%	
^{184m}Re	d	169	165	169	2.40%		2.40%
^{187}Re	y	$4.70 \times 10^{+10}$	$5.00 \times 10^{+10}$	$4.12 \times 10^{+10}$	6.19%	13.15%	19.30%
^{103m}Rh	min	56.119	56.12	56.114			
^{106}Rh	s	29.8	29.9	29.8			
^{220}Rn	s	55.61	55.6	55.6			

Table 1. Radionuclide half-life percent differences (Cont.).

		Half-lives			Percent Difference[a]		
Radionuclide	**Units**	**MF[b]**	**PC[c]**	**BNL[d]**	**MF vs PC**	**MFvsBNL**	**PC vs BNL**
^{103}Ru	d	39.35	39.28	39.26			
^{129}Sb	h	4.4	4.32	4.4	1.83%		1.83%
^{47}Sc	d	3.422	3.351	3.3492	2.10%	2.15%	
^{75}Se	d	119.78	119.8	119.79			
^{32}Si	y	$3.30 \times 10^{+02}$	$4.50 \times 10^{+02}$	153	30.77%	73.29%	98.51%
^{117m}Sn	d	13.6	13.61	13.76		1.17%	1.10%
^{85m}Sr	min	67.66	69.5	67.63	2.68%		2.73%
^{89}Sr	d	50.55	50.5	50.57			
^{90}Sr	y	28.6	29.12	28.9	1.80%	1.04%	
^{182}Ta	d	114.74	115	114.43			
^{97m}Tc	d	89	87	91.4	2.27%	2.66%	4.93%
^{121}Te	d	16.8	17	19.16	1.18%	13.13%	11.95%
^{228}Th	y	1.9132	1.9131	1.9116			
^{201}Tl	h	73.06	73.056	73.0104			
^{208}Tl	min	3.053	3.07	3.053			
^{233}U	y	$1.59 \times 10^{+05}$	$1.59 \times 10^{+05}$	$1.59 \times 10^{+05}$			
^{239}U	min	23.4	23.54	23.45			
^{48}V	d	15.971	16.238	15.9735	1.66%		1.64%
^{181}W	d	120.95	121.2	121.2			
^{187}W	h	23.83	23.9	23.72			
^{123}Xe	h	2.14	2.08	2.08	2.84%	2.84%	
^{125}Xe	h	16.8	17	16.9	1.18%		
^{127}Xe	d	36.406	36.41	36.4			
^{129m}Xe	d	8.89	8	8.88	10.54%		10.43%
^{131m}Xe	d	11.84	11.9	11.84			
^{133m}Xe	d	2.19	2.188	2.19			
^{135}Xe	h	9.11	9.09	9.14			
^{135m}Xe	min	15.36	15.29	15.29			
^{138}Xe	min	14.13	14.17	14.08			
^{88}Y	d	106.6	106.64	106.626			
^{90}Y	h	64.1	64	64.053			
^{169}Yb	d	31.97	32.01	32.026			
^{65}Zn	d	244.4	243.9	243.66			
^{69}Zn	min	55.6	57	56.4	2.49%	1.43%	1.06%
^{69m}Zn	h	13.756	13.76	13.76			
^{95}Zr	d	64.02	63.98	64.032			

[a] Percent difference values are shown only for differences greater than 1.0%.
[b] MF = CAP88 Mainframe v. 1.0 (very first version).
[c] PC = CAP88 PC v. 3.0 (released in December 2007).
[d] BNL = National Nuclear Data Center at Brookhaven National Laboratory (http://www.nndc.bnl.gov/chart/).

Table 2. Mainframe radionuclides not included in CAP88 PC v. 3.0.

Radionuclide		Half life		Progeny	
1	^{196}Au	6.183	d		
2	^{208}Bi	$3.68 \times 10^{+05}$	y		
3	^{251}Bk	57	min	^{251}Cf	
4	^{85}Br	172	s	^{85}Kr	^{85m} Kr
5	^{111m}Cd	48.7	min		
6	^{139}Cs	9.4	min	^{139}Ba	
7	^{255}Es	39.8	d		
8	^{256}Fm	157.6	min	^{252}Cf	
9	^{162}Gd	9.7	min	^{162}Tb	
10	^{136}I	83	s		
11	^{193m}Ir	11.9	d		
12	^{89}Kr	3.16	min	^{89}Rb	
13	^{90}Kr	32.32	s	^{90}Rb	^{90m}Rb
14	^{27}Mg	9.458	min		
15	^{57}Mn	1.47	min		
16	^{91}Mo	15.49	min	^{91}Nb	
17	^{16}N	7.13	s		
18	^{91}Nb	$1.00 \times 10^{+04}$	y		
19	^{91m}Nb	61	d		
20	^{92}Nb	$3.60 \times 10^{+07}$	y		
21	^{92m}Nb	10.15	d		
22	^{94m} Nb	6.26	min	^{94}Nb	
23	^{186}Os	$2.00 \times 10^{+15}$	y		
24	^{90}Rb	157	s	^{90}Sr	
25	^{90m} Rb	258	s	^{90}Rb	^{90}Sr
26	^{183}Re	70	d		
27	^{105m}Rh	45	s	^{105}Rh	
28	^{46m}Sc	18.72	s	^{46}Sc	
29	^{93}Sr	7.3	min	^{93}Y	
30	^{162}Tb	7.76	min		
31	^{101}Tc	14.2	min		
32	^{233}Th	22.3	min	^{233}Pa	
33	^{51}Ti	5.752	min		
34	^{52}V	3.75	min		
35	^{137}Xe	3.83	min	^{137}Cs	