

USER'S MANUAL: DECAY HEAT AND RADIOTOXICITY CALCULATIONS

Prepared: 16 January 2019

1. INTRODUCTION

Decay heat and radiotoxicity are caused by the decay of actinides and fission products, and thus they mainly depend on fuel type, i.e. UO_2 fuel, MOX fuel (plutonium containing fuel) or thorium (ThO_2) fuel. The NFCSS (Nuclear Fuel Cycle Simulation System) does not model all fission product nuclides but 18 actinide nuclides contained in spent fuel. Thus, supplementary tools (in Excel spreadsheets) are separately provided to calculate decay heat and radiotoxicity of spent fuel, respectively.

Relevant theories are described in IAEA's new TECDOC entitled "Nuclear Fuel Cycle Simulation System: Improvements and Applications", which is in press (as of January 2019).

2. GENERAL INFORMATION

2.1 Spread Sheet Overview

This User's Manual describes the method how to use the Excel spreadsheets, which will enable the calculation of the decay heat and radiotoxicity after a simulation of nuclear fuel cycle scenario with NFCSS. These spreadsheets need only three input parameters to define the characteristics of the spent fuel, which are obtained from NFCSS output. However, these spreadsheets enable stand-alone operation independent of NFCSS if these input parameter values are provided by users.

2.2 Organization of the User's Guide

User's Manual NFCSS DH RT v.0

2.3 Acronyms and Abbreviations

- NFCSS: Nuclear Fuel Cycle Simulation System
- DH: Decay Heat
- Rad: Radiotoxicity
- SNF: Spent Nuclear Fuel

2.4 Limitations

- Users need to download the Excel spreadsheets from 'Help' tab in the NFCSS web page (<https://infcis.iaea.org/NFCSS/About.cshtml>).
- Decay heat and radiotoxicity are calculated from the first year of the reactor operation up to 1 million years.
- Operation period of reactors in the Excel spreadsheets must be up to 200 years, as same as NFCSS limitation.
- Best practice to prepare required input is to use the output from the NFCSS, but it is possible to use user-generated input.
- Decay heat and radiotoxicity can be calculated only for PWR and BWR at this moment. However other reactor types can be handled by overlaying built-in data with user-generated data.
- Decay heat and radiotoxicity can be calculated only for UO₂, ThO₂, and MOX fuel. However other fuel types can be handled by overlaying built-in data with user-generated data.
- Discharge burnup between 30GWd/t and 60GWd/t is recommended. But if it is out of this range, calculation is done by extrapolation automatically.

3. SPREAD SHEET SUMMARY

This section provides a general overview of the Excel spreadsheets. The following summary outlines the function of each sheet in the Excel file.

3.1 Tab "Table 32" (or "Table 45")

Tab "Table 32" contains reference data of decay heat calculated by ORIGEN2 for a burnup of 45 GWd/t-HM in PWR and BWR (see Appendix-1).

Tab "Table 45" contains reference data of radiotoxicity calculated by ORIGEN2 for a burnup of 45 GWd/t-HM in PWR and BWR (see Appendix-2).

These lookup table data values are basis for interpolation calculations in terms of burnup and cooling year. These lookup table data values should remain frozen, unless users need to expand the current application.

3.2 Tab "Users input"

The following three inputs are required to define the characteristics of the spent fuel:

- Specific operation year (For example 1990, 1991... to 2190)
- Spent fuel weight at a specific year (tHM, ton of Heavy Metals)
- Discharged Burnup at a specific year (GWd/t)

The values of these three input parameters can be collected from NFCSS output; details refer to Section 4.

3.3 Tab “cal_UO2”

This sheet shows the interpolation calculation results for UO₂ fuel for burnup of 45 GW/t-HM in PWR and BWR based on the lookup table. Users do not change the data nor calculation formula in this sheet. This table is only for information.

3.4 Tab “DH_UO2” (or “Rad_UO2”)

This sheet shows decay heat (or radiotoxicity) calculation results for UO₂ fuel. Users do not change the data nor calculation formula in this sheet. This table is only for information.

3.5 Tab “cal_ThO2”

This sheet shows the interpolation calculation results for ThO₂ fuel for burnup of 45 GW/t-HM in PWR and BWR based on the lookup table. Users do not change the data nor calculation formula in this sheet. This table is only for information.

3.6 Tab “DH_ThO2” (or “Rad_ThO2”)

This sheet shows decay heat (or radiotoxicity) calculation results for ThO₂ fuel. Users do not change the data nor calculation formula in this sheet. This table is only for information.

3.7 Tab “cal_MOX”

This sheet shows the interpolation calculation results for MOX fuel for burnup of 45 GW/t-HM in PWR and BWR based on the lookup table. Users do not change the data nor calculation formula in this sheet. This table is only for information.

3.8 Tab “DH_MOX” (or “[Rad_MOX”)

This sheet shows decay heat (or radiotoxicity) calculation results for MOX fuel. Users do not change the data nor calculation formula in this sheet. This table is only for information.

3.9 Tab “DH_calculation results” (or “Rad_calculation results”)

This sheet shows the decay heat (or radiotoxicity) calculation results based on all calculations done through sheet 3.1 to 3.8.

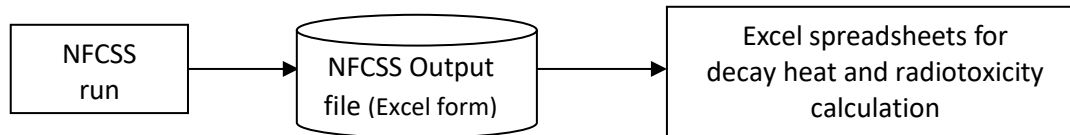
4. GETTING STARTED

This section provides a general walkthrough of the spreadsheets from the beginning to the end. The logical arrangement of the information would enable the users to understand the sequence and flow of the spreadsheets. Screen shots are shown under each heading to depict examples.

4.1 NFCSS Output File

NFCSS output file is required to start the calculation. (As shown in NFCSS manual, click “Export to Excel” button at “Scenario Description” tab of “NFCSS Scenario Page”.)

Data flow is as follows. Specific operation year, spent fuel weight, and discharged burnup must be transferred.



4.2 Copy Operation Year

- Open NFCSS output file and click the tab “After Cooling”.
- Also open the “NFCSS_Decay Heat.xls” and/or “NFCSS_Radiotoxicity.xls” file.
- Copy the operation year data from NFCSS output file.

Year	Type	Capacity	Electricity (G F2Share (%)	Enri_1 (%)	Bu_1 (GWd/t)Rep_1 (%)	Enri_2 (%)	Bu_2 (GWd/t)Rep_2 (%)	NatU (tHM)	ConversionL
1970	1000	7008	0	4	45	0	0	0	530.855957
1971	1000	7008	0	4	45	0	0	0	177.0175476
1972	1000	7008	0	4	45	0	0	0	177.0175476
1973	1000	7008	0	4	45	0	0	0	177.0175476
1974	1000	7008	0	4	45	0	0	0	177.0175476
1975	1000	7008	0	4	45	0	0	0	177.0175476
1976	1000	7008	0	4	45	0	0	0	177.0175476
1977	1000	7008	0	4	45	0	0	0	177.0175476
1978	1000	7008	0	4	45	0	0	0	177.0175476
1979	1000	7008	0	4	45	0	0	0	177.0175476
1980	1000	7008	0	4	45	0	0	0	177.0175476
1981	1000	7008	0	4	45	0	0	0	177.0175476
1982	1000	7008	0	4	45	0	0	0	177.0175476
1983	1000	7008	0	4	45	0	0	0	177.0175476
1984	1000	7008	0	4	45	0	0	0	177.0175476
1985	1000	7008	0	4	45	0	0	0	177.0175476
1986	1000	7008	0	4	45	0	0	0	177.0175476
1987	1000	7008	0	4	45	0	0	0	177.0175476
1988	1000	7008	0	4	45	0	0	0	177.0175476
1989	1000	7008	0	4	45	0	0	0	177.0175476
1990	1000	7008	0	4	45	0	0	0	177.0175476
1991	1000	7008	0	4	45	0	0	0	177.0175476
1992	1000	7008	0	4	45	0	0	0	177.0175476
1993	1000	7008	0	4	45	0	0	0	177.0175476
1994	1000	7008	0	4	45	0	0	0	177.0175476
1995	1000	7008	0	4	45	0	0	0	177.0175476
1996	1000	7008	0	4	45	0	0	0	177.0175476
1997	1000	7008	0	4	45	0	0	0	177.0175476
1998	1000	7008	0	4	45	0	0	0	177.0175476
1999	1000	7008	0	4	45	0	0	0	177.0175476
2000	1000	7008	0	4	45	0	0	0	177.0175476
2001	1000	7008	0	4	45	0	0	0	177.0175476
2002	1000	7008	0	4	45	0	0	0	177.0175476
2003	1000	7008	0	4	45	0	0	0	177.0175476
2004	1000	7008	0	4	45	0	0	0	177.0175476

- In the calculation sheet, paste the copied data to the cells below “Time[Year]” in “User input” tab.

A	B	C	D	E	F	G	H
NFCSS Results for Reactor Type:							
		UO ₂ fuel	ThO ₂ fuel	MOX fuel	UO ₂ fuel	ThO ₂ fuel	MOX fuel
#	Time [Year]	SFS (tHM)	SFS (tHM)	SFS (tHM)	GWd/t	GWd/t	GWd/t
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
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21							
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36							
37							
38							
39							
40							
41							

Paste the copied data to these selected cells.

4.3 Copy SNF Weights

- Copy the SNF (Spent Nuclear Fuel) weight output of each year from NFCSS output file.

	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
1	Back End																
2	NatUSaveRe SFD1 (tHM) SFD2 (tHM) SFD (tHM) SFS1 (tHM) SFS2 (tHM) SFS (tHM) SFSStock1 (t) SFSStock2 (t) SFSStock (t) SFRS1 (tHM) SFRS2 (tHM) SFRS (tHM) SFRSCP1 (t) SFRSCP2 (t) SFRSCP (t) SFRSCP (t) SFRSCP (t)																
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	19.66329956	0	19.66329956	0	0	0	0	0	0	0
6	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	39.32659912	0	39.32659912	0	0	0	0	0	0	0
7	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	58.98999608	0	58.98999608	0	0	0	0	0	0	0
8	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	78.65319624	0	78.65319624	0	0	0	0	0	0	0
9	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	98.3164978	0	98.3164978	0	0	0	0	0	0	0
10	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	117.9797974	0	117.9797974	0	0	0	0	0	0	0
11	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	137.6430969	0	137.6430969	0	0	0	0	0	0	0
12	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	157.3063865	0	157.3063865	0	0	0	0	0	0	0
13	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	176.969696	0	176.969696	0	0	0	0	0	0	0
14	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	196.6329956	0	196.6329956	0	0	0	0	0	0	0
15	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	216.2962952	0	216.2962952	0	0	0	0	0	0	0
16	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	235.956947	0	235.956947	0	0	0	0	0	0	0
17	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	255.6228943	0	255.6228943	0	0	0	0	0	0	0
18	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	275.2861938	0	275.2861938	0	0	0	0	0	0	0
19	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	294.9494934	0	294.9494934	0	0	0	0	0	0	0
20	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	314.612793	0	314.612793	0	0	0	0	0	0	0
21	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	334.2760925	0	334.2760925	0	0	0	0	0	0	0
22	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	353.9393921	0	353.9393921	0	0	0	0	0	0	0
23	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	373.6026917	0	373.6026917	0	0	0	0	0	0	0
24	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	393.2659912	0	393.2659912	0	0	0	0	0	0	0
25	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	412.9292908	0	412.9292908	0	0	0	0	0	0	0
26	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	432.5925903	0	432.5925903	0	0	0	0	0	0	0
27	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	452.2558999	0	452.2558999	0	0	0	0	0	0	0
28	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	471.9191895	0	471.9191895	0	0	0	0	0	0	0
29	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	491.582489	0	491.582489	0	0	0	0	0	0	0
30	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	511.2457886	0	511.2457886	0	0	0	0	0	0	0
31	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	530.9091187	0	530.9091187	0	0	0	0	0	0	0
32	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	550.5723877	0	550.5723877	0	0	0	0	0	0	0
33	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	570.2356907	0	570.2356907	0	0	0	0	0	0	0
34	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	589.8989908	0	589.8989908	0	0	0	0	0	0	0
35	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	609.5622559	0	609.5622559	0	0	0	0	0	0	0
36	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	629.2255659	0	629.2255659	0	0	0	0	0	0	0
37	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	648.888916	0	648.888916	0	0	0	0	0	0	0
38	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	668.5521851	0	668.5521851	0	0	0	0	0	0	0
39	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	688.2154851	0	688.2154851	0	0	0	0	0	0	0
40	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	707.8787851	0	707.8787851	0	0	0	0	0	0	0
41	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	727.5420851	0	727.5420851	0	0	0	0	0	0	0
42	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	747.2053851	0	747.2053851	0	0	0	0	0	0	0
43	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	766.8686851	0	766.8686851	0	0	0	0	0	0	0
44	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	786.5319851	0	786.5319851	0	0	0	0	0	0	0
45	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	806.1952851	0	806.1952851	0	0	0	0	0	0	0
46	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	825.8585851	0	825.8585851	0	0	0	0	0	0	0
47	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	845.5218851	0	845.5218851	0	0	0	0	0	0	0
48	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	865.1851851	0	865.1851851	0	0	0	0	0	0	0
49	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	884.8484851	0	884.8484851	0	0	0	0	0	0	0
50	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	904.5117851	0	904.5117851	0	0	0	0	0	0	0
51	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	924.1750851	0	924.1750851	0	0	0	0	0	0	0
52	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	943.8383851	0	943.8383851	0	0	0	0	0	0	0
53	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	963.5016851	0	963.5016851	0	0	0	0	0	0	0
54	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	983.1649851	0	983.1649851	0	0	0	0	0	0	0
55	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1002.8282851	0	1002.8282851	0	0	0	0	0	0	0
56	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1022.4915851	0	1022.4915851	0	0	0	0	0	0	0
57	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1042.1548851	0	1042.1548851	0	0	0	0	0	0	0
58	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1061.8181851	0	1061.8181851	0	0	0	0	0	0	0
59	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1081.4814851	0	1081.4814851	0	0	0	0	0	0	0
60	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1101.1447851	0	1101.1447851	0	0	0	0	0	0	0
61	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1120.8080851	0	1120.8080851	0	0	0	0	0	0	0
62	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1140.4713851	0	1140.4713851	0	0	0	0	0	0	0
63	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1160.1346851	0	1160.1346851	0	0	0	0	0	0	0
64	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1179.7979851	0	1179.7979851	0	0	0	0	0	0	0
65	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1199.4612851	0	1199.4612851	0	0	0	0	0	0	0
66	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1219.1245851	0	1219.1245851	0	0	0	0	0	0	0
67	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1238.7878851	0	1238.7878851	0	0	0	0	0	0	0
68	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1258.4511851	0	1258.4511851	0	0	0	0	0	0	0
69	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1278.1144851	0	1278.1144851	0	0	0	0	0	0	0
70	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1297.7777851	0	1297.7777851	0	0	0	0	0	0	0
71	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1317.4410851	0	1317.4410851	0	0	0	0	0	0	0
72	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1337.1043851	0	1337.1043851	0	0	0	0	0	0	0
73	0	19.66329956	0	19.66329956	19.66329956	0	19.66329956	1356.7676851	0	1356.7676851	0	0	0	0	0	0	0
74	0	19.66329956	0	19.663													

Copy the data from these selected cells: SFD1 (tHM).

In the calculation sheet, paste the copied data to the cells below SNF weight.*

*If your simulation is for UO₂, copy the data to the cells below “UO₂ fuel”.

	A	B	C	D	E	F	G	H
1	NFCSS Results for Reactor Type:							
2			UO ₂ fuel	ThO ₂ fuel	MOX fuel	UO ₂ fuel	ThO ₂ fuel	MOX fuel
3	#	Time [Year]	SFS (tHM)	SFS (tHM)	SFS (tHM)	GWd/t	GWd/t	GWd/t
4	1	1970	19.66					
5	2	1971	19.66					
6	3	1972	19.66					
7	4	1973	19.66					
8	5	1974	19.66					
9	6	1975	19.66					
10	7	1976	19.66					
11	8	1977	19.66					
12	9	1978	19.66					
13	10	1979	19.66					
14	11	1980	19.66					
15	12	1981	19.66					
16	13	1982	19.66					
17	14	1983	19.66					
18	15	1984	19.66					
19	16	1985	19.66					
20	17	1986	19.66					
21	18	1987	19.66					
22	19	1988	19.66					
23	20	1989	19.66					
24	21	1990	19.66					
25	22	1991	19.66					
26	23	1992	19.66					
27	24	1993	19.66					
28	25	1994	19.66					
29	26	1995	19.66					
30	27	1996	19.66					
31	28	1997	19.66					
32	29	1998	19.66					
33	30	1999	19.66					
34	31	2000	19.66					
35	32	2001	19.66					
36	33	2002	19.66					
37	34	2003	19.66					
38	35	2004	19.66					
39	36	2005	19.66					
40	37	2006	19.66					
41	38	2007	19.66					
42	39	2008	19.66					
43	40	2009	19.66					
44	41	2010	80.81					
45	42	2011						

Paste the copied data to these selected cells.

4.4 Copy discharged burnup

- Copy the discharged burnup output of each year from NFCSS output file.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	NFCSS Results for Reactor Type:												
2						Typical MOX							
3	Year	Type	Capacit	Electricity (GF2Share (%)	Enri_1 (%)	Bu_1 (GWd/t Rep_1 (%)	Enri_2 (%)	Bu_2 (GWd/t Rep_2 (%)	Natu (tHM)	ConversionU	ConversionU		
4	1970	1000	7008	30	4	45	0	7	0	0	371.5991516	371.5991516	0
5	1971	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
6	1972	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
7	1973	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
8	1974	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
9	1975	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
10	1976	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
11	1977	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
12	1978	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
13	1979	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
14	1980	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
15	1981	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
16	1982	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
17	1983	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
18	1984	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
19	1985	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
20	1986	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
21	1987	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
22	1988	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
23	1989	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
24	1990	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
25	1991	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
26	1992	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
27	1993	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
28	1994	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
29	1995	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
30	1996	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
31	1997	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
32	1998	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
33	1999	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
34	2000	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
35	2001	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
36	2002	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
37	2003	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
38	2004	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
39	2005	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
40	2006	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
41	2007	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
42	2008	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
43	2009	1000	7008	30	4	45	0	7	0	0	177.0175476	177.0175476	0
44	2010	0	0	30	4	45	0	7	0	0	0	0	0
45	2011	0	0	30	4	45	0	7	0	0	0	0	0

Copy the data from these selected cells: Bu_1 (GWd/t).

- In the calculation sheet, paste the copied data to the cells below “GWd/t”. *
- *If your simulation is for UO₂, copy the data to the cells below “UO₂ fuel”.

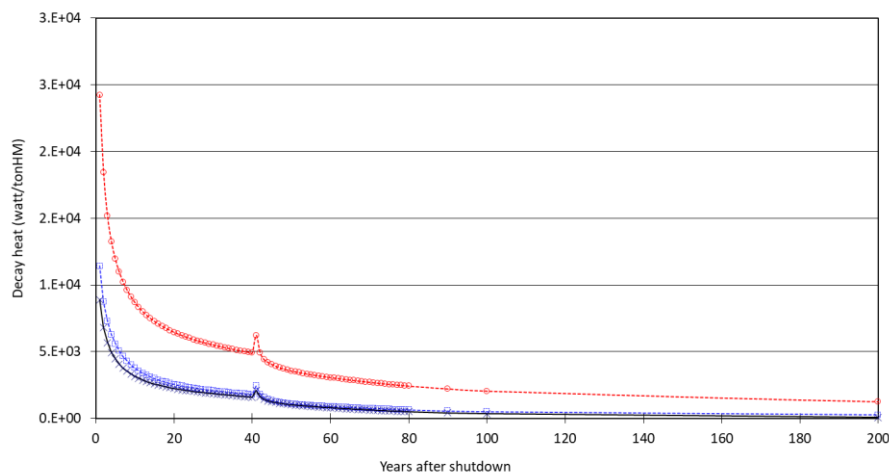
NFCSS Results for Reactor Type:							
		UO ₂ fuel	ThO ₂ fuel	MOX fuel	UO ₂ fuel	ThO ₂ fuel	MOX fuel
		SFS (tHM)	SFS (tHM)	SFS (tHM)	GWd/t	GWd/t	GWd/t
#	Time [Year]						
1	1970	19.66			45		
2	1971	19.66			45		
3	1972	19.66			45		
4	1973	19.66			45		
5	1974	19.66			45		
6	1975	19.66			45		
7	1976	19.66			45		
8	1977	19.66			45		
9	1978	19.66			45		
10	1979				45		
11	1980				45		
12	1981				45		
13	1982				45		
14	1983				45		
15	1984	19.66			45		
16	1985	19.66			45		
17	1986	19.66			45		
18	1987	19.66			45		
19	1988	19.66			45		
20	1989	19.66			45		
21	1990	19.66			45		
22	1991	19.66			45		
23	1992	19.66			45		
24	1993	19.66			45		
25	1994	19.66			45		
26	1995	19.66			45		
27	1996	19.66			45		
28	1997	19.66			45		
29	1998	19.66			45		
30	1999	19.66			45		
31	2000	19.66			45		
32	2001	19.66			45		
33	2002	19.66			45		
34	2003	19.66			45		
35	2004	19.66			45		
36	2005	19.66			45		
37	2006	19.66			45		
38	2007	19.66			45		
39	2008	19.66			45		
40	2009	19.66			45		
41	2010	80.81			45		

Paste the copied data to these selected cells.

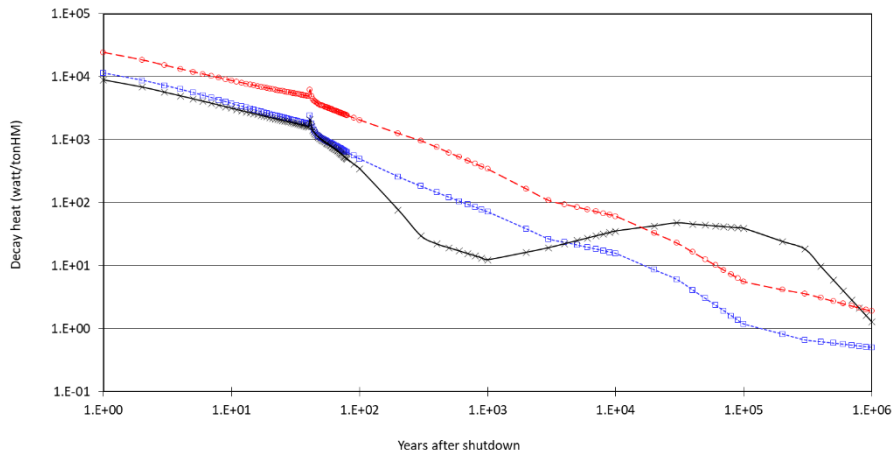
4.5 Calculation Results for DH

You will earn the calculation results soon after you paste the data. Results of each data shows:

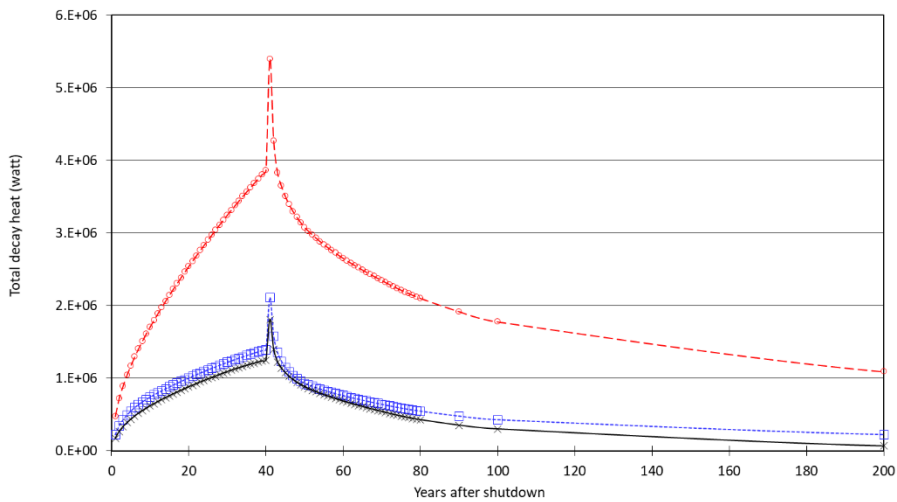
- Decay heat (watt/tonHM) of spent fuels discharged up to the specified year till the end of reactor operation in linear scales. After the end of reactor operation till 200 years, DH of all discharged fuels.



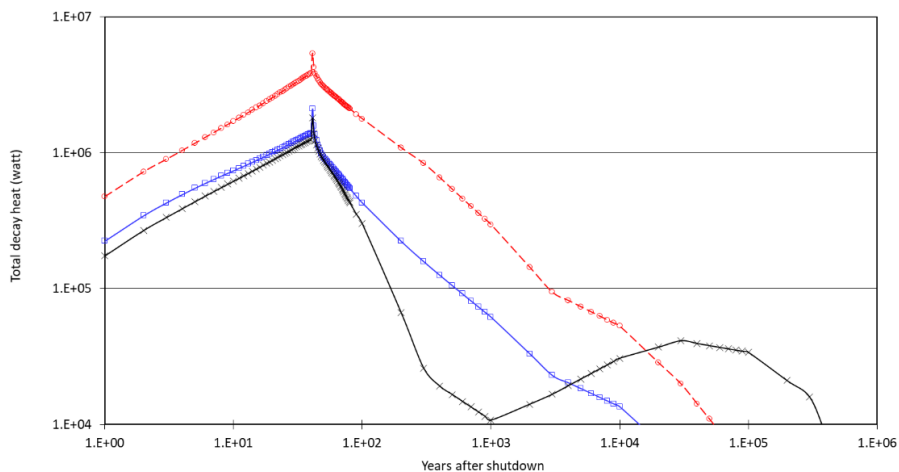
- Decay heat (watt/tonHM) same as above till 1 million years in logarithmic scales.



- Decay heat (watt) similar to the above. The above figures show the averaged value for the discharged fuels (watt/tHM), but the following figures show total DH (watt). Since all fuels in the core are discharged at the end of reactor operation, it shows higher value there.



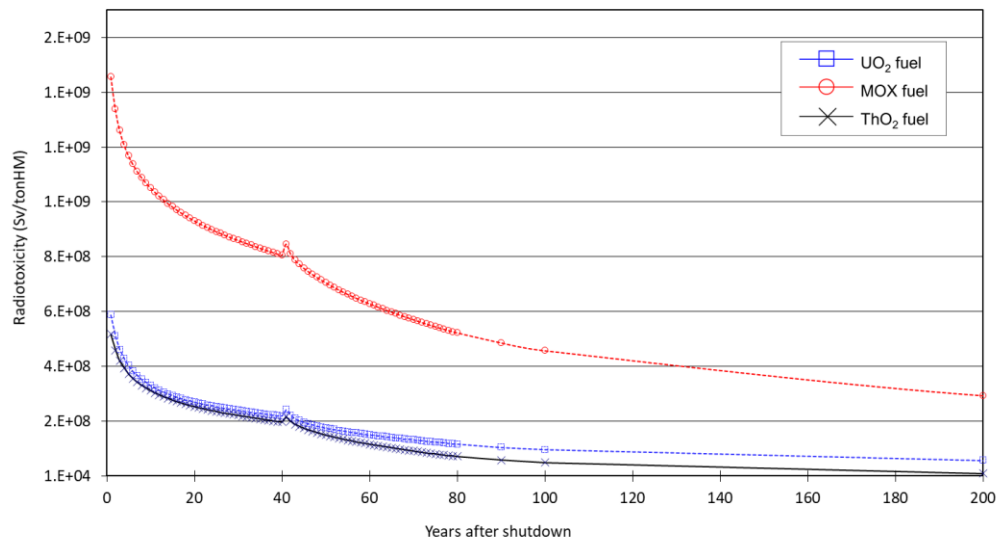
- Decay heat (watt) same as above till 1 million years in logarithmic scales.



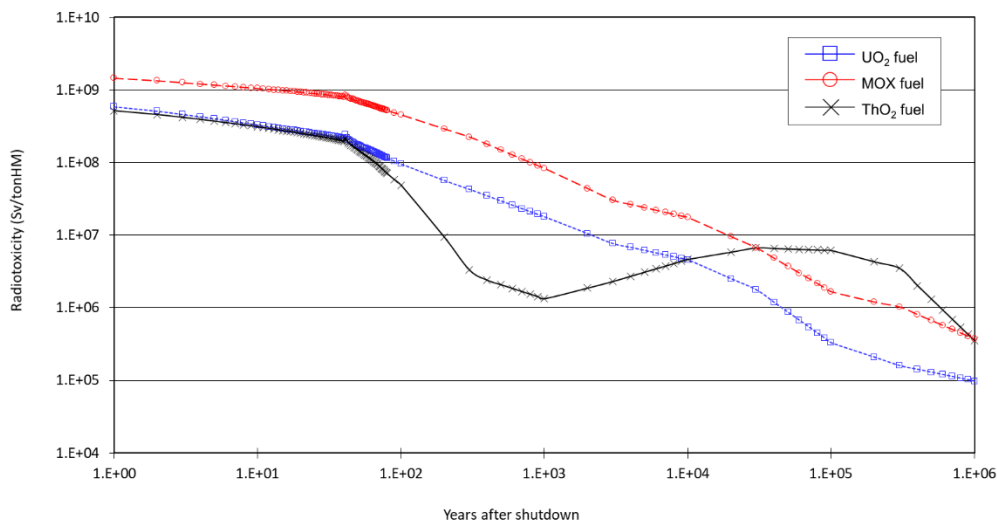
4.6 Calculation Results for Radiotoxicity

You will earn the calculation results soon after you paste the data. Results of each data shows:

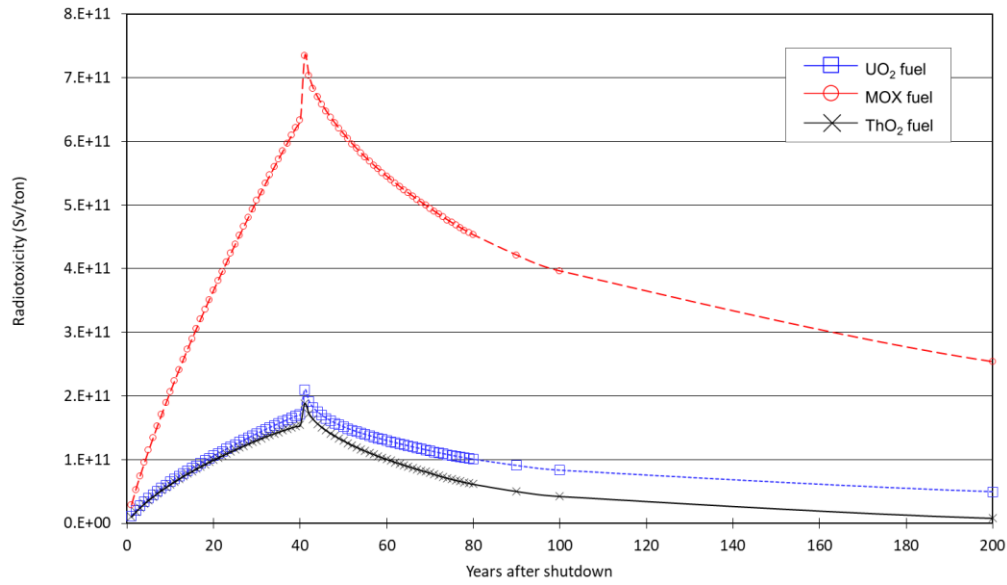
- Radiotoxicity (Sv/tonHM: Sievert per ton of Heavy metals) of spent fuels discharged up to the specified year till the end of reactor operation in linear scales. After the end of reactor operation till 200 years, Rad. of all discharged fuels.



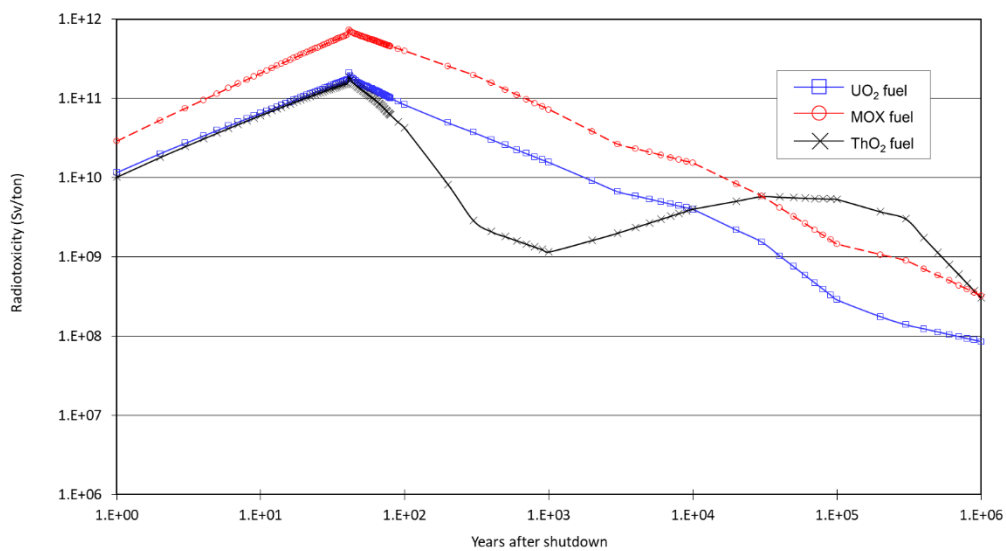
- Radiotoxicity (Sv/tonHM) same as above till 1 million years in logarithmic scales.



- Radiotoxicity (Sv) similar to the above. The above figures show the averaged value for the discharged fuels (Sv/tHM), but the following figures show total Rad. (Sv). Since all fuels in the core are discharged at the end of reactor operation, it shows higher value there.



- Radiotoxicity (Sv) same as above till 1 million years in logarithmic scales.



ACKNOWLEDGEMENT

These Excel spreadsheets have been generated by E. Minari (Tokyo Institute of Technology) under supervision of R. Yoshioka (International Thorium Molten-Salt Forum, Japan).

CONTACT

Users do not hesitate to contact IAEA Scientific Secretary, K. Sim (k.s.sim@iaea.org), for any question or comment.

APPENDIXES

The following appendixes are provided only for background information, and not necessary to see for using the above Excel programs.

Appendix-1. Decay Heat Reference Data for LWR Fuels

Appendix-2. Radiotoxicity Reference Data for LWR Fuels

Appendix-3. Decay Heat for Actinides and FPs by ORIGEN2 Code

Appendix-4. Radiotoxicity for Actinides and FPs by ORIGEN2 Code

Appendix-5. Verification of Excel Program for Decay Heat

Appendix-6. Verification of Excel Program for Radiotoxicity

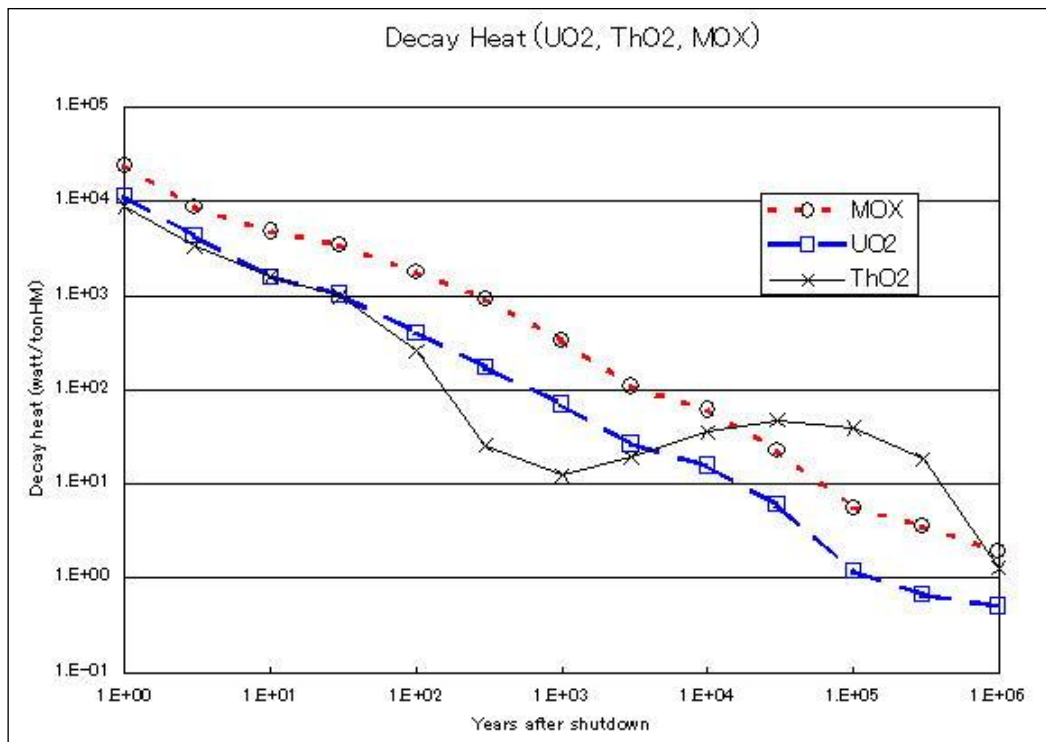
Appendix-1. Decay Heat Data for LWR Fuels

Table.32 and Figure.44 in the new TECDOC for NFCSS show decay heat data for a burnup of 45 GW/tHM fuel in PWR and BWR. In order to achieve better interpolation, the following more precise table is used in Excel calculations. Since the difference between PWR and BWR is small, this table can be applied to both PWR and BWR. This lookup table is interpolated in terms of cooling year and burnup. Interpolation in terms of cooling year is done by linear interpolation in log-log scale, and interpolation/extrapolation in terms of burnup is done using the equation: $DH = [DH \text{ at } 45\text{GWd/t}] \times BU / 45$.

Revised Table 32. Decay heat data for a burnup of 45 GW/tHM fuel in PWR and BWR.

Year	1.E+00	3.E+00	1.E+01	3.E+01	1.E+02	3.E+02	1.E+03
UO ₂	1.141E+04	4.243E+03	1.580E+03	1.022E+03	4.038E+02	1.724E+02	7.017E+01
ThO ₂	8.881E+03	3.331E+03	1.595E+03	9.839E+02	2.574E+02	2.546E+01	1.225E+01
MOX	2.424E+04	8.616E+03	4.823E+03	3.413E+03	1.781E+03	9.190E+02	3.359E+02

Year	3.E+03	1.E+04	3.E+04	1.E+05	3.E+05	1.E+06
UO ₂	2.650E+01	1.560E+01	6.019E+00	1.184E+00	6.605E-01	5.018E-01
ThO ₂	1.933E+01	3.549E+01	4.774E+01	3.920E+01	1.834E+01	1.289E+00
MOX	1.079E+02	6.118E+01	2.297E+01	5.609E+00	3.608E+00	1.896E+00



Revised Figure 44. Decay heat data for a burnup of 45 GW/tHM fuel in PWR and BWR

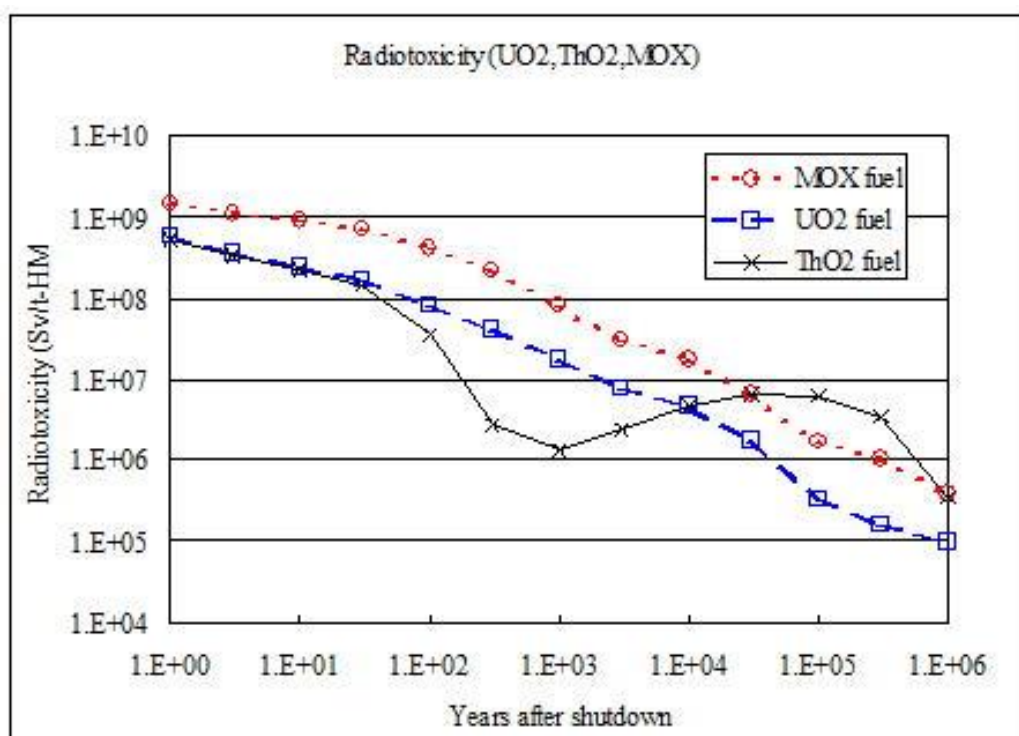
APPENDIX-2. RADIOTOXICITY REFERENCE DATA FOR LWR FUELS

Table.42 and Figure.55 in the new TECDOC for NFCSS show radiotoxicity data for a burnup of 45 GW/tHM fuel in PWR and BWR. In order to achieve better interpolation, the following more precise table is used in Excel calculations. Since the difference between PWR and BWR is small, this table can be applied to both PWR and BWR. This lookup table is interpolated in terms of cooling year and burnup. Interpolation in terms of cooling year is done by linear interpolation in log-log scale, and interpolation/extrapolation in terms of burnup is done using the equation: $\text{Rad} = [\text{Rad at 45GWd/t}] \times \text{BU} / 45$.

Revised Table.42. Radiotoxicity data for a burnup of 45 GW/tHM fuel in LWR (Sv/tHM)

Year	1.E+00	3.E+00	1.E+01	3.E+01	1.E+02	3.E+02	1.E+03
UO ₂	5.878E+08	3.620E+08	2.358E+08	1.697E+08	8.181E+07	4.093E+07	1.770E+07
ThO ₂	5.175E+08	3.427E+08	2.316E+08	1.464E+08	3.570E+07	2.776E+06	1.321E+06
MOX	1.457E+09	1.105E+09	8.967E+08	6.880E+08	4.082E+08	2.162E+08	8.205E+07

Year	3.E+03	1.E+04	3.E+04	1.E+05	3.E+05	1.E+06
UO ₂	7.676E+06	4.591E+06	1.772E+06	3.297E+05	1.601E+05	9.797E+04
ThO ₂	2.319E+06	4.651E+06	6.690E+06	6.161E+06	3.489E+06	3.513E+05
MOX	3.025E+07	1.757E+07	6.721E+06	1.672E+06	1.030E+06	3.728E+05



Revised Figure 44. Radiotoxicity data for a burnup of 45 GW/tHM fuel in LWR

APPENDIX-3. DEACY HEAT FOR ACTINIDES AND FPS BY ORIGEN2 CODE

Decay heat in the new TECDOC is shown only for the summation of all related actinides and FPS. (Meanwhile, radiotoxicity data is shown for each nuclide of all related actinides and FPS.) In order to expand this Excel program for future applications, decay heat from each element for all related actinides and FPS are shown below. These data are generated by the ORIGEN2 code for UO₂, ThO₂, and MOX fuel, and details are shown in the new TECDOC. The first table of each fuel is decay heat from each actinide, and the second table is decay heat from each FP.

There is a small remark in the second table, that is, decay heat from gaseous FPS (Kr and Xe) is included in the table, because they are generated in spent fuels. (Meanwhile, radiotoxicity table in the new TECDOC does not include them, because radiotoxicity is defined only for nuclides which can be ingested by human body. That is, inhalation by the gaseous FPS is not included in radiotoxicity, as is described in the Section-7 of the new TECDOC.)

3-1) Decay heat (watt/tHM) for PWR 45GWd/t (UO₂-HBU-LIBRARY-219, 4.0%U235)

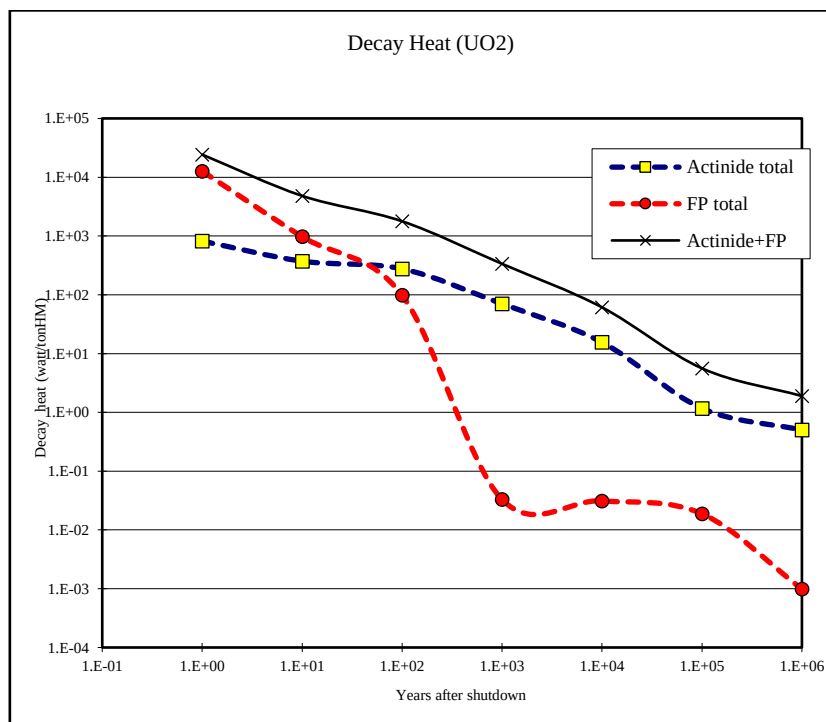
Year:	1.E+00	1.E+01	1.E+02	1.E+03	1.E+04	1.E+05	1.E+06
Tl	5.505E-05	3.813E-04	1.983E-04	1.158E-06	1.917E-05	2.847E-04	5.609E-04
Pb	1.240E-05	8.586E-05	4.475E-05	1.079E-05	4.117E-04	3.704E-03	3.106E-03
Bi	1.107E-04	7.670E-04	3.999E-04	5.711E-05	1.893E-03	1.648E-02	1.336E-02
Po	4.876E-04	3.377E-03	1.758E-03	3.440E-04	1.388E-02	1.295E-01	1.173E-01
At	4.443E-09	5.024E-09	5.098E-08	8.048E-06	1.046E-03	2.558E-02	5.637E-02
Rn	2.472E-04	1.712E-03	8.916E-04	1.070E-04	3.760E-03	2.950E-02	1.574E-02
Fr	4.021E-09	4.573E-09	4.704E-08	7.291E-06	9.461E-04	2.314E-02	5.099E-02
Ra	2.235E-04	1.548E-03	8.059E-04	9.317E-05	3.292E-03	2.612E-02	1.463E-02
Ac	3.682E-09	4.514E-09	5.430E-08	6.761E-06	8.579E-04	2.095E-02	4.616E-02
Th	3.487E-04	1.611E-03	9.171E-04	5.712E-04	4.974E-03	4.366E-02	5.402E-02
Pa	2.620E-03	2.630E-03	2.950E-03	4.890E-03	5.546E-03	6.045E-03	5.265E-03
U	2.676E-02	2.819E-02	4.444E-02	6.542E-02	6.895E-02	7.760E-02	7.165E-02
Np	9.545E-02	9.551E-02	9.904E-02	1.184E-01	8.397E-02	5.091E-02	3.803E-02
Pu	1.809E+02	1.712E+02	9.758E+01	2.758E+01	1.496E+01	7.169E-01	1.377E-02
Am	1.679E+01	8.029E+01	1.741E+02	4.236E+01	4.272E-01	9.449E-05	1.322E-08
Cm	6.205E+02	1.213E+02	4.173E+00	2.165E-02	8.055E-03	4.772E-06	3.301E-08
Bk	1.648E-06	1.333E-09	1.521E-16	1.467E-16	1.025E-16	2.842E-18	7.641E-34
Cf	1.480E-05	4.041E-06	6.259E-07	1.124E-07	1.481E-11	1.520E-17	4.089E-33
Es	2.925E-09	7.529E-13	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Actinide tot.	8.183E+02	3.729E+02	2.760E+02	7.015E+01	1.558E+01	1.170E+00	5.009E-01

Year	1.E+00	1.E+01	1.E+02	1.E+03	1.E+04	1.E+05	1.E+06
H	2.162E-02	1.305E-02	8.349E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
He	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

Li	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Be	4.590E-09	4.590E-09	4.590E-09	4.588E-09	4.570E-09	4.396E-09	2.976E-09
C	4.522E-08	4.517E-08	4.468E-08	4.007E-08	1.349E-08	2.518E-13	0.000E+00
S	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Co	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ni	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Cu	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Zn	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ga	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ge	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
As	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Se	1.322E-04	1.322E-04	1.321E-04	1.308E-04	1.188E-04	4.548E-05	3.070E-09
Br	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Kr	1.731E+01	9.672E+00	2.874E-02	1.025E-10	9.950E-11	7.392E-11	3.783E-12
Rb	4.425E-06	2.386E-08	2.386E-08	2.386E-08	2.386E-08	2.386E-08	2.386E-08
Sr	1.219E+02	8.912E+01	1.046E+01	5.203E-09	0.000E+00	0.000E+00	0.000E+00
Y	5.615E+02	4.256E+02	4.998E+01	2.485E-08	0.000E+00	0.000E+00	0.000E+00
Zr	1.079E+02	2.794E-04	2.794E-04	2.792E-04	2.781E-04	2.670E-04	1.776E-04
Nb	2.234E+02	1.853E-04	4.048E-04	4.068E-04	4.045E-04	3.869E-04	2.573E-04
Mo	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Tc	8.260E-03	8.260E-03	8.258E-03	8.233E-03	7.996E-03	5.966E-03	3.190E-04
Ru	2.275E+01	3.666E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Rh	2.891E+03	5.916E+00	9.996E-13	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Pd	7.991E-06	7.991E-06	7.991E-06	7.990E-06	7.982E-06	7.906E-06	7.182E-06
Ag	3.034E+01	3.327E-03	2.703E-07	1.991E-09	9.272E-31	0.000E+00	0.000E+00
Cd	8.002E-02	4.745E-02	6.595E-04	1.774E-22	0.000E+00	0.000E+00	0.000E+00
In	5.752E-05	1.059E-14	1.059E-14	1.059E-14	1.059E-14	1.059E-14	1.059E-14
Sn	1.058E+00	1.607E-03	1.202E-03	1.034E-03	9.717E-04	5.207E-04	1.023E-06
Sb	3.246E+01	3.409E+00	1.278E-02	1.270E-02	1.194E-02	6.396E-03	1.256E-05
Te	4.553E+00	2.228E-01	3.687E-11	2.523E-16	2.523E-16	2.523E-16	2.523E-16
I	1.886E-05	1.886E-05	1.886E-05	1.886E-05	1.885E-05	1.878E-05	1.805E-05
Xe	9.016E-08	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Cs	1.905E+03	2.050E+02	1.503E+01	1.775E-04	1.770E-04	1.723E-04	1.313E-04
Ba	4.971E+02	4.034E+02	5.225E+01	4.697E-08	0.000E+00	0.000E+00	0.000E+00
La	1.189E-05	1.632E-11	1.632E-11	1.632E-11	1.632E-11	1.632E-11	1.632E-11
Ce	3.313E+02	1.092E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Pr	3.678E+03	1.211E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Nd	1.866E-08	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Pm	3.635E+01	3.332E+00	7.758E-08	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Sm	4.634E-02	4.324E-02	2.162E-02	2.118E-05	7.347E-08	7.346E-08	7.340E-08
Eu	1.269E+02	6.028E+01	4.174E-02	8.598E-16	0.000E+00	0.000E+00	0.000E+00
Gd	1.763E-02	1.437E-06	6.706E-15	6.725E-15	6.725E-15	6.725E-15	6.725E-15
Tb	2.130E-01	4.387E-15	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Dy	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ho	4.082E-05	4.061E-05	3.855E-05	2.293E-05	1.267E-07	0.000E+00	0.000E+00

Er	9.209E-17	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Tm	1.396E-05	4.787E-09	3.708E-23	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Yb	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
FP total	1.059E+04	1.207E+03	1.278E+02	2.303E-02	2.191E-02	1.378E-02	9.200E-04

Year	1.E+00	1.E+01	1.E+02	1.E+03	1.E+04	1.E+05	1.E+06
Actinide total	8.183E+02	3.729E+02	2.760E+02	7.015E+01	1.558E+01	1.170E+00	5.009E-01
FP total	1.059E+04	1.207E+03	1.278E+02	2.303E-02	2.191E-02	1.378E-02	9.200E-04
Actinide+FP	1.141E+04	1.580E+03	4.038E+02	7.017E+01	1.560E+01	1.184E+00	5.018E-01



3-2) Decay heat (watt/tHM) for PWR 45GWd/t (Th-Lib-214) Th232+ 233U4.0w/o

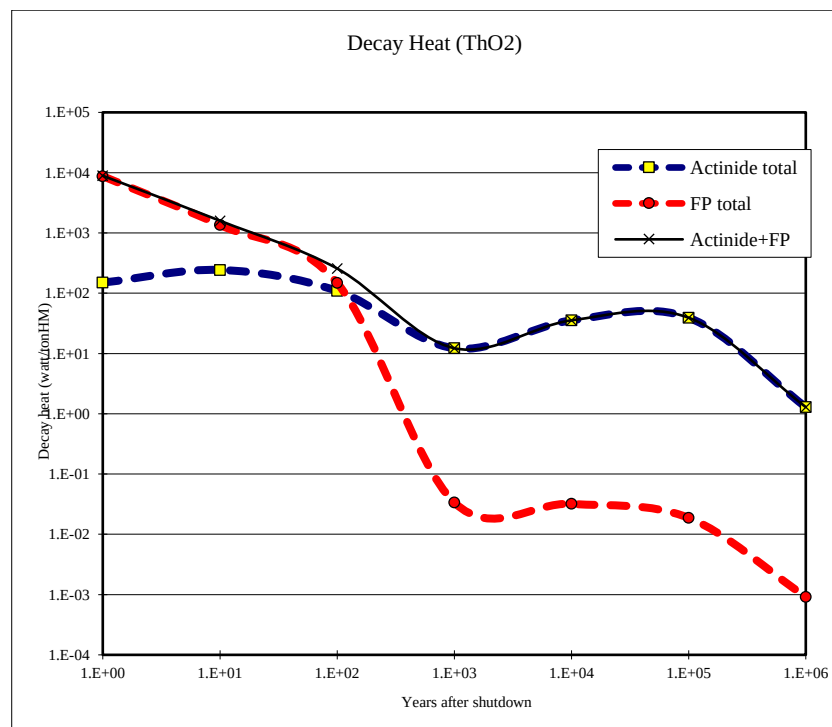
Year	1.E+00	1.E+01	1.E+02	1.E+03	1.E+04	1.E+05	1.E+06
Tl	4.203E+00	8.309E+00	3.583E+00	1.710E-02	5.621E-02	5.699E-02	1.945E-03
Pb	9.469E-01	1.873E+00	8.157E-01	3.249E-02	1.688E-01	2.253E-01	1.169E-02
Bi	8.460E+00	1.674E+01	7.309E+00	2.025E-01	6.906E-01	8.710E-01	4.994E-02
Po	3.723E+01	7.362E+01	3.189E+01	1.157E+00	7.012E+00	9.217E+00	4.258E-01
At	3.281E-03	1.150E-02	9.327E-02	8.722E-01	5.766E+00	6.552E+00	1.280E-01
Rn	1.888E+01	3.733E+01	1.616E+01	1.257E-01	1.613E-01	4.782E-01	8.182E-02
Fr	2.974E-03	1.043E-02	8.446E-02	7.889E-01	5.215E+00	5.926E+00	1.158E-01
Ra	1.706E+01	3.375E+01	1.461E+01	1.225E-01	2.342E-01	5.243E-01	7.353E-02
Ac	3.053E-03	1.047E-02	7.857E-02	7.162E-01	4.722E+00	5.365E+00	1.057E-01
Th	1.624E+01	3.216E+01	1.399E+01	7.425E-01	4.290E+00	5.108E+00	1.642E-01
Pa	4.994E+00	8.699E-02	8.683E-02	8.519E-02	7.043E-02	1.053E-02	4.238E-05
U	4.164E+01	3.879E+01	2.058E+01	7.350E+00	7.075E+00	4.850E+00	1.296E-01
Np	6.429E-05	6.429E-05	6.430E-05	6.432E-05	6.413E-05	6.229E-05	4.654E-05

Pu	2.499E-01	2.327E-01	1.144E-01	2.179E-04	7.892E-05	4.656E-06	5.873E-09
Am	1.767E-05	1.181E-04	2.672E-04	6.381E-05	6.721E-08	1.442E-11	7.298E-17
Cm	1.402E-04	6.289E-06	2.857E-07	1.763E-09	2.020E-10	1.247E-13	1.492E-16
Bk	5.294E-15	4.282E-18	2.854E-25	2.753E-25	1.915E-25	5.305E-27	0.000E+00
Cf	8.692E-15	4.751E-15	1.670E-15	2.840E-16	8.402E-21	2.837E-26	5.693E-42
Es	2.745E-19	7.066E-23	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Actinide tot.	1.499E+02	2.429E+02	1.094E+02	1.221E+01	3.546E+01	3.918E+01	1.288E+00

Year	1.E+00	1.E+01	1.E+02	1.E+03	1.E+04	1.E+05	1.E+06
H	2.000E-02	1.207E-02	7.722E-05	0.000E+00	0.000E+00	0.000E+00	0.000E+00
He	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Li	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Be	4.152E-09	4.152E-09	4.152E-09	4.150E-09	4.134E-09	3.976E-09	2.692E-09
C	4.090E-08	4.086E-08	4.042E-08	3.625E-08	1.220E-08	2.278E-13	0.000E+00
S	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Co	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ni	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Cu	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Zn	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ga	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ge	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
As	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Se	3.432E-04	3.432E-04	3.428E-04	3.396E-04	3.085E-04	1.181E-04	7.971E-09
Br	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Kr	3.502E+01	1.957E+01	5.816E-02	1.420E-10	1.378E-10	1.024E-10	5.239E-12
Rb	2.967E-05	4.447E-08	4.447E-08	4.447E-08	4.447E-08	4.447E-08	4.447E-08
Sr	1.997E+02	1.250E+02	1.467E+01	7.296E-09	0.000E+00	0.000E+00	0.000E+00
Y	8.377E+02	5.969E+02	7.008E+01	3.485E-08	0.000E+00	0.000E+00	0.000E+00
Zr	1.917E+02	3.251E-04	3.251E-04	3.250E-04	3.237E-04	3.107E-04	2.067E-04
Nb	4.087E+02	2.155E-04	4.756E-04	4.778E-04	4.741E-04	4.504E-04	2.994E-04
Mo	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Tc	6.257E-03	6.257E-03	6.255E-03	6.237E-03	6.057E-03	4.519E-03	2.416E-04
Ru	5.521E+00	5.235E-03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Rh	4.120E+02	8.451E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Pd	8.360E-07	8.360E-07	8.360E-07	8.359E-07	8.351E-07	8.271E-07	7.514E-07
Ag	3.537E+00	3.878E-04	2.504E-09	1.842E-11	8.583E-33	0.000E+00	0.000E+00
Cd	3.748E-02	1.912E-02	2.657E-04	7.144E-23	0.000E+00	0.000E+00	0.000E+00
In	3.728E-05	1.237E-14	1.237E-14	1.237E-14	1.237E-14	1.237E-14	1.237E-14
Sn	1.504E+00	2.963E-03	2.262E-03	1.969E-03	1.850E-03	9.916E-04	1.935E-06
Sb	5.478E+01	5.771E+00	2.434E-02	2.420E-02	2.273E-02	1.218E-02	2.380E-05
Te	9.911E+00	3.770E-01	6.238E-11	9.439E-17	9.439E-17	9.439E-17	9.439E-17
I	2.925E-05	2.925E-05	2.925E-05	2.925E-05	2.924E-05	2.912E-05	2.799E-05
Xe	1.860E-08	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Cs	1.450E+03	1.793E+02	1.448E+01	1.573E-04	1.569E-04	1.527E-04	1.164E-04
Ba	4.790E+02	3.891E+02	4.863E+01	4.526E-08	0.000E+00	0.000E+00	0.000E+00

La	8.791E-05	3.163E-12	3.163E-12	3.163E-12	3.163E-12	3.163E-12	3.163E-12
Ce	3.764E+02	1.239E-01	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Pr	4.160E+03	1.373E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Nd	1.405E-07	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Pm	4.360E+01	3.919E+00	1.846E-10	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Sm	1.456E-02	1.359E-02	6.794E-03	6.704E-06	7.211E-08	7.211E-08	7.211E-08
Eu	6.207E+01	2.963E+01	2.062E-02	9.801E-25	0.000E+00	0.000E+00	0.000E+00
Gd	7.900E-03	6.438E-07	2.330E-15	2.335E-15	2.335E-15	2.335E-15	2.335E-15
Tb	2.987E-02	6.152E-16	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Dy	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ho	1.549E-06	1.540E-06	1.462E-06	8.696E-07	4.803E-09	0.000E+00	0.000E+00
Er	1.145E-17	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Tm	1.645E-07	4.206E-11	3.258E-25	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Yb	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
FP total	8.731E+03	1.352E+03	1.480E+02	3.374E-02	3.193E-02	1.875E-02	9.187E-04

Year	1.E+00	1.E+01	1.E+02	1.E+03	1.E+04	1.E+05	1.E+06
Actinide total	1.499E+02	2.429E+02	1.094E+02	1.221E+01	3.546E+01	3.918E+01	1.288E+00
FP total	8.731E+03	1.352E+03	1.480E+02	3.374E-02	3.193E-02	1.875E-02	9.187E-04
Actinide+FP	8.881E+03	1.595E+03	2.574E+02	1.225E+01	3.549E+01	3.920E+01	1.289E+00



3-3) Decay heat (watt/tHM) for PWR 45GWd/t (MOX-LIBRARY-210, PWR-PuPu, 7.50%Put)

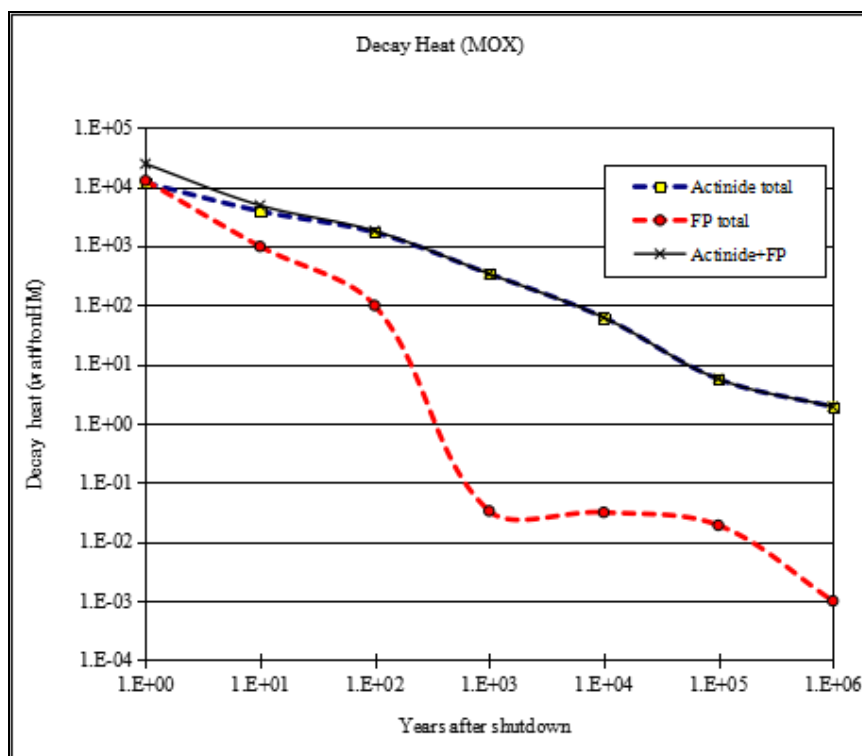
Year	1.E+00	1.E+01	1.E+02	1.E+03	1.E+04	1.E+05	1.E+06
TI	1.649E-05	1.024E-04	5.295E-05	2.331E-07	3.664E-05	9.354E-04	1.996E-03

Pb	3.713E-06	2.307E-05	1.213E-05	7.933E-05	3.205E-03	2.659E-02	1.113E-02
Bi	3.317E-05	2.060E-04	1.074E-04	3.506E-04	1.411E-02	1.163E-01	4.577E-02
Po	1.460E-04	9.072E-04	4.750E-04	2.665E-03	1.084E-01	9.158E-01	4.277E-01
At	1.400E-09	1.540E-09	2.667E-08	2.198E-05	4.005E-03	1.006E-01	2.221E-01
Rn	7.404E-05	4.599E-04	2.398E-04	7.631E-04	3.002E-02	2.317E-01	5.035E-02
Fr	1.268E-09	1.404E-09	2.416E-08	1.988E-05	3.622E-03	9.102E-02	2.009E-01
Ra	6.693E-05	4.158E-04	2.167E-04	6.653E-04	2.622E-02	2.036E-01	4.750E-02
Ac	1.172E-09	1.407E-09	2.235E-08	1.800E-05	3.279E-03	8.240E-02	1.818E-01
Th	1.873E-04	5.216E-04	4.388E-04	3.594E-03	3.587E-02	2.699E-01	2.024E-01
Pa	1.672E-03	1.737E-03	3.461E-03	1.374E-02	1.682E-02	1.732E-02	1.396E-02
U	5.510E-02	6.814E-02	2.245E-01	4.024E-01	4.103E-01	3.931E-01	2.084E-01
Np	1.201E+00	1.200E+00	1.212E+00	1.250E+00	6.719E-01	2.007E-01	1.498E-01
Pu	1.311E+03	1.254E+03	6.663E+02	9.868E+01	5.325E+01	2.939E+00	1.315E-01
Am	1.744E+02	4.875E+02	9.408E+02	2.350E+02	6.379E+00	1.446E-03	2.209E-07
Cm	1.011E+04	2.106E+03	7.406E+01	5.145E-01	1.944E-01	1.186E-04	4.620E-07
Bk	2.339E-05	1.892E-08	6.805E-16	6.566E-16	4.587E-16	1.272E-17	3.420E-33
Cf	6.182E-05	2.992E-05	8.198E-06	1.408E-06	7.404E-11	6.802E-17	1.830E-32
Es	3.217E-09	8.280E-13	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Actinide tot.	1.160E+04	3.849E+03	1.683E+03	3.359E+02	6.115E+01	5.591E+00	1.895E+00

Year	1.E+00	1.E+01	1.E+02	1.E+03	1.E+04	1.E+05	1.E+06
H	2.815E-02	1.699E-02	1.087E-04	0.000E+00	0.000E+00	0.000E+00	0.000E+00
He	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Li	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Be	4.596E-09	4.596E-09	4.595E-09	4.594E-09	4.576E-09	4.401E-09	2.980E-09
C	4.527E-08	4.522E-08	4.473E-08	4.012E-08	1.350E-08	2.521E-13	0.000E+00
S	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Co	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ni	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Cu	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Zn	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ga	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ge	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
As	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Se	1.214E-04	1.213E-04	1.212E-04	1.201E-04	1.091E-04	4.175E-05	2.819E-09
Br	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Kr	1.023E+01	5.715E+00	1.699E-02	2.103E-10	2.041E-10	1.516E-10	7.760E-12
Rb	8.068E-06	1.193E-08	1.193E-08	1.193E-08	1.193E-08	1.193E-08	1.193E-08
Sr	6.526E+01	4.337E+01	5.092E+00	2.532E-09	0.000E+00	0.000E+00	0.000E+00
Y	2.915E+02	2.072E+02	2.432E+01	1.210E-08	0.000E+00	0.000E+00	0.000E+00
Zr	1.394E+02	2.007E-04	2.007E-04	2.006E-04	1.998E-04	1.918E-04	1.276E-04
Nb	2.976E+02	1.366E-04	2.949E-04	2.962E-04	2.936E-04	2.781E-04	1.848E-04
Mo	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Tc	8.774E-03	8.774E-03	8.771E-03	8.746E-03	8.493E-03	6.337E-03	3.389E-04
Ru	4.596E+01	7.212E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00

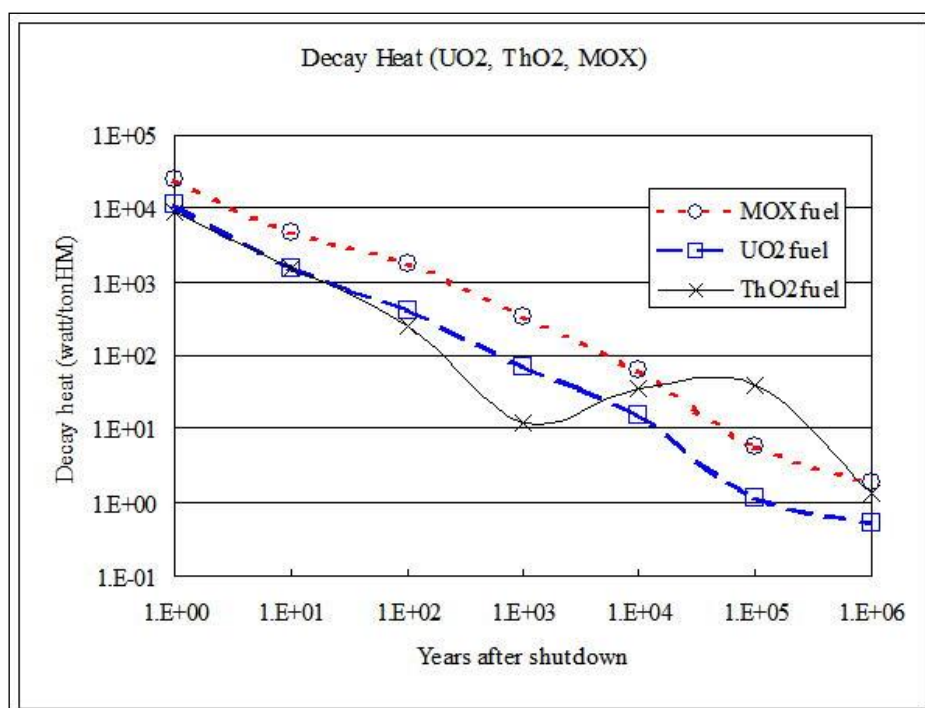
Rh	5.680E+03	1.166E+01	1.667E-12	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Pd	1.933E-05	1.933E-05	1.933E-05	1.933E-05	1.931E-05	1.912E-05	1.737E-05
Ag	7.154E+01	7.844E-03	7.204E-07	5.302E-09	2.470E-30	0.000E+00	0.000E+00
Cd	1.486E-01	8.650E-02	1.202E-03	3.233E-22	0.000E+00	0.000E+00	0.000E+00
In	1.489E-04	2.164E-14	2.164E-14	2.164E-14	2.164E-14	2.164E-14	2.164E-14
Sn	1.592E+00	2.971E-03	2.096E-03	1.735E-03	1.630E-03	8.734E-04	1.703E-06
Sb	5.634E+01	5.914E+00	2.144E-02	2.131E-02	2.002E-02	1.072E-02	2.096E-05
Te	7.704E+00	3.865E-01	6.396E-11	2.704E-16	2.704E-16	2.704E-16	2.704E-16
I	2.876E-05	2.876E-05	2.876E-05	2.876E-05	2.875E-05	2.863E-05	2.752E-05
Xe	2.487E-07	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Cs	1.644E+03	1.981E+02	1.572E+01	3.672E-04	3.662E-04	3.564E-04	2.717E-04
Ba	5.201E+02	4.224E+02	5.281E+01	4.914E-08	0.000E+00	0.000E+00	0.000E+00
La	7.814E-05	5.403E-13	5.403E-13	5.403E-13	5.403E-13	5.403E-13	5.403E-13
Ce	2.995E+02	9.857E-02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Pr	3.310E+03	1.093E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Nd	1.679E-07	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Pm	4.679E+01	4.205E+00	7.494E-08	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Sm	1.001E-01	9.341E-02	4.671E-02	4.568E-05	9.045E-08	9.044E-08	9.038E-08
Eu	1.566E+02	7.409E+01	5.196E-02	4.495E-15	0.000E+00	0.000E+00	0.000E+00
Gd	4.343E-02	3.539E-06	2.880E-14	2.888E-14	2.888E-14	2.888E-14	2.888E-14
Tb	6.349E-01	1.307E-14	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Dy	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ho	6.315E-05	6.283E-05	5.964E-05	3.547E-05	1.959E-07	0.000E+00	0.000E+00
Er	2.151E-15	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Tm	2.469E-05	4.346E-09	3.366E-23	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Yb	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
FP total	1.265E+04	9.745E+02	9.809E+01	3.290E-02	3.116E-02	1.885E-02	9.907E-04

Year	1.E+00	1.E+01	1.E+02	1.E+03	1.E+04	1.E+05	1.E+06
Actinide total	1.160E+04	3.849E+03	1.683E+03	3.359E+02	6.115E+01	5.591E+00	1.895E+00
FP total	1.265E+04	9.745E+02	9.809E+01	3.290E-02	3.116E-02	1.885E-02	9.907E-04
Actinide+FP	2.424E+04	4.823E+03	1.781E+03	3.359E+02	6.118E+01	5.609E+00	1.896E+00



Total Decay Heat (watt/tHM) for UO₂, ThO₂, and MOX
(Identical to Table-32 and Figure-44 of the new TECDOC)

Year	1.E+00	1.E+01	1.E+02	1.E+03	1.E+04	1.E+05	1.E+06
UO ₂ fuel	1.141E+04	1.580E+03	4.038E+02	7.017E+01	1.560E+01	1.184E+00	5.018E-01
ThO ₂ fuel	8.881E+03	1.595E+03	2.574E+02	1.225E+01	3.549E+01	3.920E+01	1.289E+00
MOX fuel	2.424E+04	4.823E+03	1.781E+03	3.359E+02	6.118E+01	5.609E+00	1.896E+00



APPENDIX-4. RADIOTOXICITY FOR ACTINIDES AND FPS BY ORIGEN2 CODE

Radiotoxicity in the new TECDOC is shown for each nuclide of all related actinides and FPS. In order to expand this Excel program for future applications, those data will be used. Those data are generated by the ORIGEN2 code for UO_2 , ThO_2 , and MOX fuel. Since digital data are already shown in the new TECDOC, those data are not repeated here.

There is a small remark in those data. Radiotoxicity from gaseous FPS (Kr and Xe) is NOT included in the table, because radiotoxicity is defined only for nuclides which can be ingested by human body. That is, inhalation by the gaseous FPS is not included in radiotoxicity, as is described in the Section-7 of the new TECDOC.

APPENDIX-5. VERIFICATION OF EXCEL PROGRAM FOR DECAY HEAT

Since there are no similar fuel cycle codes which provide decay heat, “Verification” in its exact definition is impossible. Only “Validation” is possible, which means that calculation in the Excel program is performed correctly following the program specification in the new TECDOC. Current Excel program provides the average decay heat in the unit of “watt/ton”, which is the average of the decay heat of all discharged fuels at a certain year as shown below. If the reactor is operated 40 years and if $X=100$, then decay heat at year- X is the summation of decay heat of discharged fuels with 100 years cooling to 60 years cooling. Therefore, comparison between input decay heat and Excel output is not equivalent, because Excel output decay heat is evaluated from the start to the end of reactor operation and cooling times are not identical. Of course, if year- X is large enough, for example 1000 years, then the above difference of cooling times becomes negligible.

Therefore, the following figures have a meaning after say 100 years, and an exact comparison is possible from 1000 years to 1 million years. Considering the above effect, they show perfect agreement from 1000 years to 1 million years, and even in the period shorter than that, Excel output reproduces the trend of input data.

As a conclusion, Excel is performed correctly using the program specification in the new TECDOC.

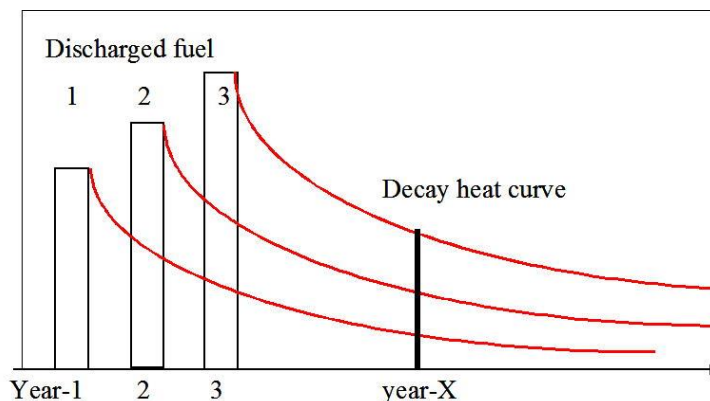
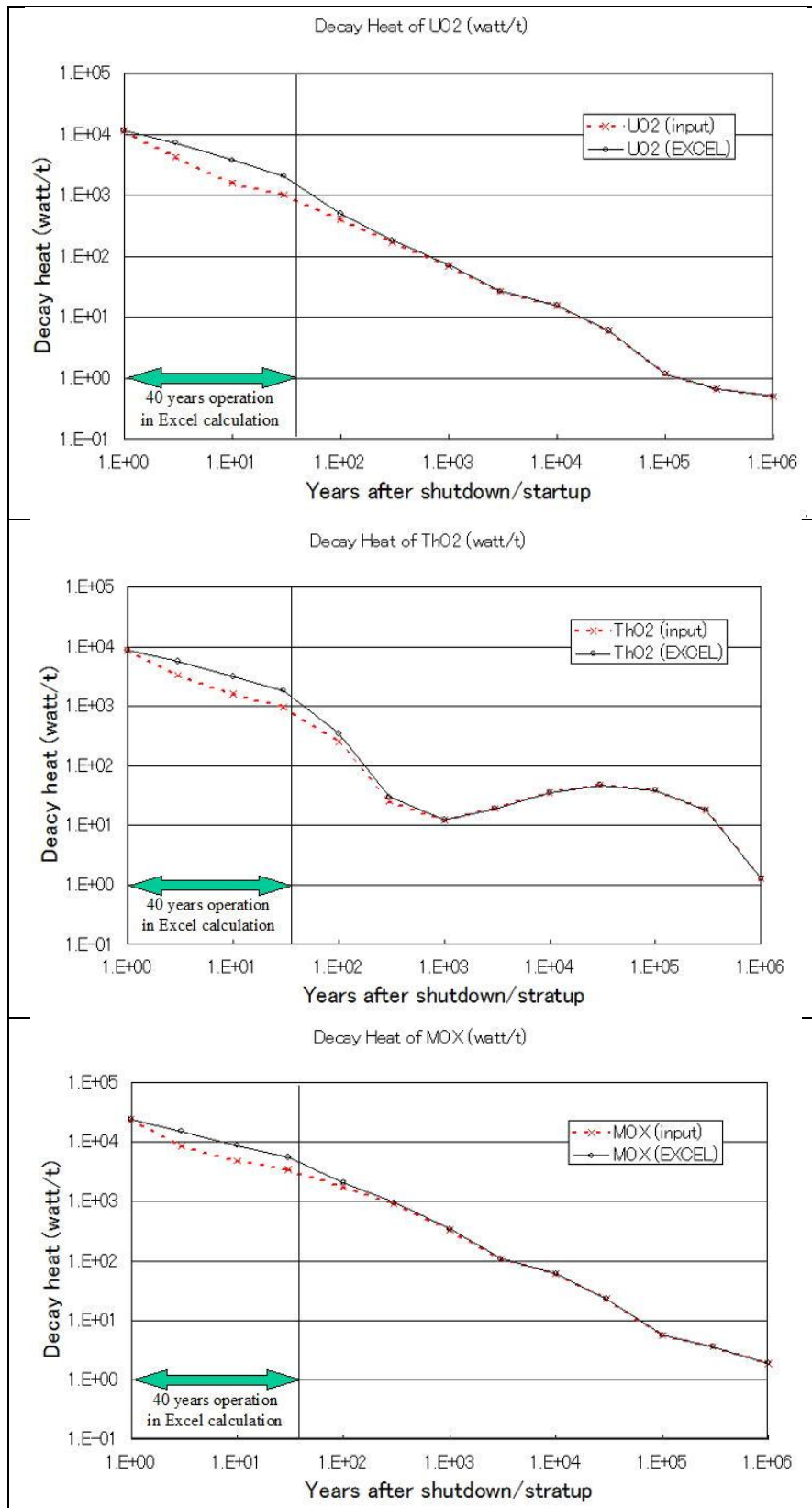


FIG.I-16 Schematic diagram to calculate decay heat (ANEX-I of new TECDOC).

The following 3 figures are comparisons between Excel results and input data (Table.32 of the new TECDOC) for UO_2 , ThO_2 , and MOX fuel.



APPENDIX-6. VERIFICATION OF EXCEL PROGRAM FOR RADIOTOXICITY

Since there are no similar fuel cycle codes which provide radiotoxicity, “Verification” in its exact definition is impossible. Only “Validation” is possible, which means that calculation in the Excel program is performed correctly following the program specification in the new TECDOC.

Current Excel program provides the average radiotoxicity in the unit of “Sv/ton” (Sievert/ton), which is the average of the radiotoxicity of all discharged fuels at a certain year as shown below. If the reactor is operated 40 years and if $X=100$, then radiotoxicity at year-X is the summation of radiotoxicity of discharged fuels with 100 years cooling to 60 years cooling. Therefore, comparison between input radiotoxicity and Excel output is not equivalent, because Excel output radiotoxicity is evaluated from the start to the end of reactor operation and cooling times are not identical. Of course, if year-X is large enough, for example 1000 years, then the above difference of cooling times becomes negligible.

Therefore, the following figures have a meaning after say 100 years, and an exact comparison is possible from 1000 years to 1 million years. Considering the above effect, they show perfect agreement from 1000 years to 1 million years, and even in the period shorter than that, Excel output reproduces the trend of input data.

As a conclusion, Excel is performed correctly using the program specification in the new TECDOC.

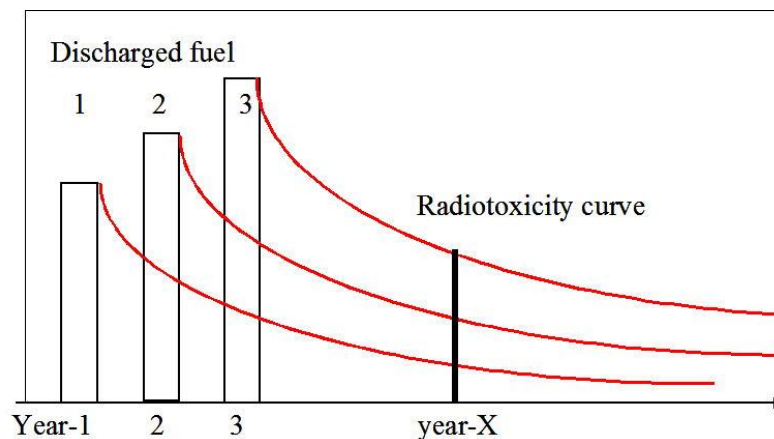


FIG.I-17 Schematic diagram to calculate radiotoxicity (ANEX-I of new TECDOC).

The following 3 figures are comparisons between Excel results and input data (Table.42 of the new TECDOC) for UO_2 , ThO_2 , and MOX fuel.

