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Validation of the updated decay data libraries of the ANITA-2000 activation code package on experimental data produced by FSN-JAERI

Manuela Frisoni

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VALIDATION OF THE UPDATED DECAY DATA LIBRARIES OF THE ANITA-2000 ACTIVATION CODE PACKAGE ON EXPERIMENTAL DATA PRODUCED BY FNS-JAERI

Manuela Frisoni - ENEA

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Sommario

ANITA-2000 is a code package for the activation characterization of materials exposed to neutron irradiation released by ENEA to OECD-NEADB (NEA-1638) and ORNL-RSICC (CCC-693). The package contains: a) the activation code ANITA-4M, based on the original code developed at CEC JRC Ispra, able to compute the radioactive inventory of a material exposed to neutron irradiation, continuous or stepwise, b) two activation cross section libraries, c) the decay data library (file "fl1") containing the quantities describing the decay properties of unstable nuclides and d) the library (file "fl2") containing the gamma ray spectra emitted by the radioactive nuclei in the ORNL-SCALE 18-γ energy group structure. The data contained in the "fl1" and "fl2" libraries of the ANITA-2000 code package have been recently updated on the basis of the JEFF-3.1.1 Radioactive Decay Data Library. The present report summarises the results of the validation of the updated decay data libraries, using the ANITA-4M code, through the comparison with the decay heat experimental results related to the material samples irradiated in the 14 MeV neutron flux of the Fusion Neutronics Source (FNS), JAERI (Japan Atomic Energy Research Institute, actually JAEA), Tokai, Japan.

Note

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Manuela Frisoni

September 2015

1 INTRODUCTION

ANITA-2000 is a code package for the activation characterization of materials exposed to neutron irradiation developed by ENEA and freely distributed at OECD-NEADB [1] and ORNL-RSICC [2]. It has been widely used, improved and validated in the past by ENEA [3] [4] [5] [6] [7] [8] [9] [10] [11]. ANITA-2000 has been also utilized in M*AN*C*IN*T*A*P, a computational "4D rigorous-2-step" tool, developed at Ansaldo Nucleare, that automatically combines neutron transport calculations (via MCNP5) with activation calculations (via ANITA-2000) in order to evaluate decay gamma dose rates due to activated materials [12][13].

The main component of the ANITA-2000 package is the activation code ANITA-4M that computes the radioactive inventory of a material exposed to neutron irradiation, continuous or stepwise. It traces back to the ANITA code (Analysis of Neutron Induced Transmutation and Activation) [14]. The ANITA-4M code provides activity, atomic density, decay heat, biological hazard, clearance index and decay gamma-ray sources versus cooling time. Results are given as for each nuclide as for the material.

The ANITA-2000 code package is provided with a complete data base allowing to perform calculations for all the elements with the atomic number up to 94. The libraries contained in the code package are:

1) Neutron activation cross section data libraries
2) Decay, Hazard and Clearance data library ("fl1" file)
3) Gamma library ("fl2" file)

Two neutron activation cross section data libraries are contained in the ANITA-2000 code package based on the European Activation File EAF-99 [15] and on the Fusion Evaluated Nuclear Activation Data Library FENDL/A-2.0 [16], respectively. The data contained in the libraries "fl1" and "fl2" are based on the Fusion Evaluated Nuclear Decay Data Library FENDL/D-2.0 [17].

The Decay, Hazard and Clearance data library ("fl1" file) and the Gamma library ("fl2" file) have been recently updated on the basis of the JEFF-3.1.1 Radioactive Decay Data Library [18].

The ANITA-4M code actually uses the neutron cross section European Activation File EAF-2010 [19] contained in the EASY-2010 code package [20].

In this report the validation of the new data libraries is presented, following the work already made in the past [4][10], through the comparison of the ANITA-4M results against decay heat measurements, performed for ITER-relevant materials in the frame of an international benchmark exercise launched in the late 1990s, using the Fusion Neutronics Source (FNS) at the Japan Atomic Energy Research Institute (JAERI), (actually JAEA), Tokai, Japan [21][22].

2 ANITA-4M ACTIVATION CODE

The package ANITA-2000 includes the activation code ANITA-4M that computes the radioactive inventory of a material exposed to neutron irradiation, continuous or stepwise. The ANITA-4M code provides activity, atomic density, decay heat, biological hazard, clearance index and decay gamma-ray source spectra at shutdown and at different cooling times. It treats all the elements with the atomic number up to 94.

The ANITA-4M activation code requires the following data libraries:

- Decay, Hazard and Clearance data library (file "fl1")
- Gamma library (file "fl2")
- Neutron activation cross section data library (file "lib175")

The schematic block diagram of the data/libraries required by the ANITA-4M code is shown in Figure 1.

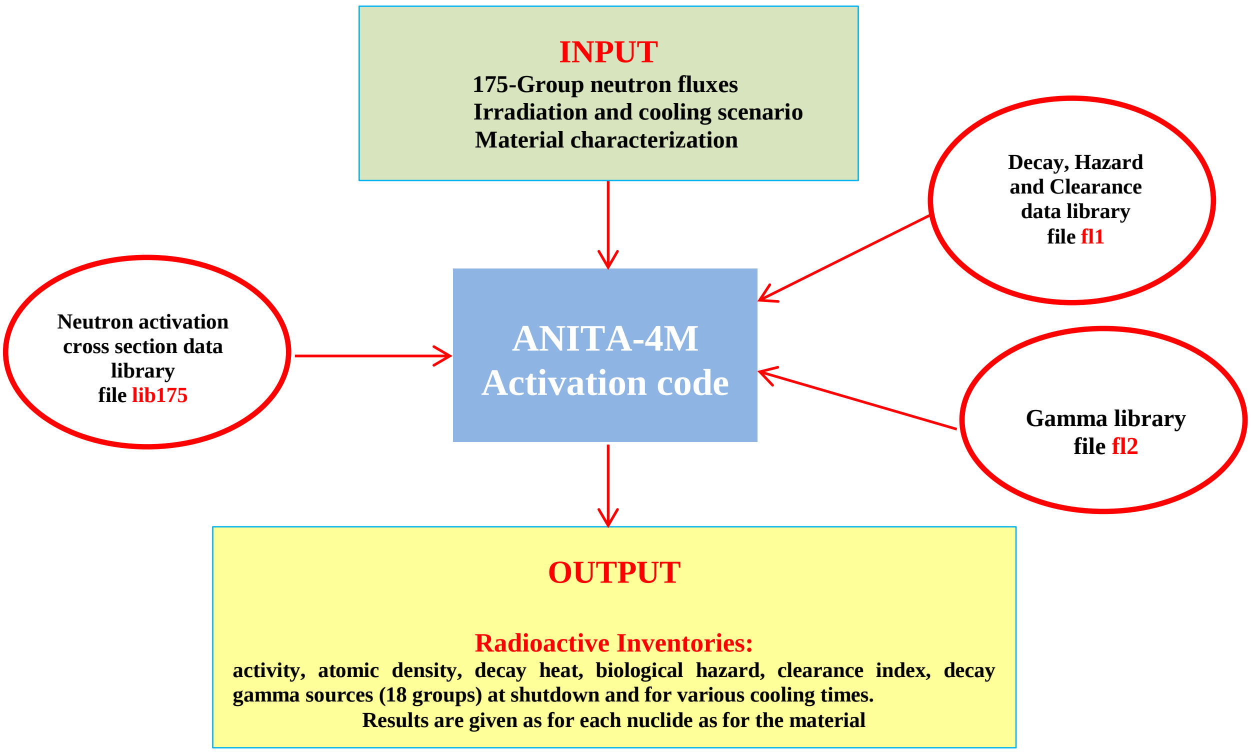

Figure 1 – Anita-4M activation code block diagram

2.1 Decay, Hazard and Clearance Data library (file "fl1")

This library contains the information describing the decay properties of unstable nuclides useful for the calculations performed by ANITA-4M.

For each nuclide, the decay data, as the decay mode, the decay constant (s^{-1}), the total energy (MeV) released in the decay and the energy (MeV) released in the form of gamma or X-rays are provided. Different competitive decay modes are taken into account when contemporary.

The file contains also the hazard data (ALI) for each radionuclide describing its potential biological impact on human beings. The ALI quantities are defined as the Annual Limit of Intake (Bq) by ingestion or inhalation for the public or workers.

The library contains also the clearance level for each radionuclide.

The fl1 file has been completely updated and actually contains data for 3433 nuclides. The description of the data contained in the file and their sources are described in the following.

2.1.1 Decay data

The decay data have been taken from the JEFF-3.1.1 Radioactive Decay Data library [18]. The standard library JEFF-3.1.1 is in ENDF-6 [23] format. The radioactive decay data are given in the section identified by MF=8, MT=457 (in ENDF-6 standard format notation). This section is restricted to single nuclides in their ground state or an isomeric state (a "long lived" excited state of the nucleus). The main purpose of MT=457 is to describe the energy spectra resulting from radioactive decay and give average parameters useful for applications such as decay heat and waste disposal studies, shielding, etc. For each isotope the following decay data are given: nuclide identification, half-life, number of decay modes, fractions of decay in each decay mode (branching ratio), energy released by the decay, gamma-ray intensity and energy spectrum in each decay mode. The standard library contains data for 3853 nuclei, ranging from the neutron (0-nn-1) to roentgenium 272 (111-Rg-272).

In the fl1 file used by ANITA-4M code the following basic decay data are included for each unstable nuclide:

- nuclide identification
- decay mode
- decay constant
- total energy released in the decay (MeV) used to calculate decay heat
- energy released in the form of gamma or X-rays (MeV)

For the stable nuclides the isotopic abundances from Ref. [24] are given.

The new fl1 file contains data for the nuclei ranging from 1-H-1 to 94-Pu-247.

2.1.2 Hazard data

The ALI quantities were obtained from the “eaf_haz_20100” file contained in the EASY-2010 code package [25]. In the fl1 file used by the ANITA- 4M code, the ALI values by ingestion for the public are given. A conversion factor of 0.001 (Sv/y) has been adopted to convert the dose coefficients from Ref. 25 to the ALI quantities. The ALI quantity is provided only for the 2006 nuclides contained in the “eaf_haz_20100” file.

2.1.3 Clearance level data

The fl1 file provides also for each radionuclide the clearance level C_L (Bq/g). This value allows to establish if a radioactive material can be potentially moved out of the originating facility and recycled.

The safe handling of radioactive waste is recognized as crucial to ensure protection of human health and the environment. IAEA publish regulations on these issues and Ref. [26] gives information on suggested clearance level values for a set of important radionuclides.

The clearance level data contained in the new fl1 file have been produced by including the information contained in [26].

The clearance levels for the 242 nuclides up to Pu-244 contained in Table 2 of Ref. [26] were included in the file fl1. The clearance level C_L=10 has been attributed to ^{40}K as suggested in Table 1 of Ref. [26].

Following the suggestion of Table 1 of Ref. [26], moreover, the clearance level C_L=1 has been attributed to radionuclides of natural origin. The list of the “Radioactive Nuclides in Nature” has been taken from Ref. [24].

For any other nuclide the clearance level was calculated by using the following Eq. (6) taken from Ref. [27]:

$$C_L=\min\{1/(E_\gamma + 0.1 \times E_\beta)\ ;\ ALI_{inhaled}/10^3\ ;\ ALI_{ingested}/10^5\} \qquad (6)$$

The values of E_γ and E_β in Eq. (6) have been taken from the JEFF-3.1.1 library [18].

The ALI quantities in Eq. (6) have been obtained from the “eaf_haz_20100” file of EASY-2010 [25]. The conversion factor of 0.020 (Sv/y) has been adopted to convert the dose coefficients from Ref. [25] to the ALI quantities.

2.1.4 Nuclide and Material Clearance Indexes

The Isotope Clearance Index (ICI) of a single nuclide is calculated in ANITA-4M as:

$$Isotope\quad Clearance\quad Index = \frac{C_i}{C_{Li}} \qquad (7)$$

where C_i is the specific activity of the radionuclide "i" in the material and C_{Li} is the clearance level for that radionuclide.

In Eq. (7) activities and clearance levels have units of Bq g^{-1}.

When a material contains several nuclides, the equation given below, and suggested in [27], is used to evaluate in ANITA-4M the Material Clearance Index (MCI) :

$$Material \quad Clearance \quad Index = \sum_{i=1}^{n} \frac{C_i}{C_{Li}} \tag{8}$$

If MCI ≤ 1 then it is possible to clear the material.

2.2 Gamma Library (file “fl2”)

This data base contains the gamma ray spectra emitted by the radioactive nuclei in the ORNL-SCALE 18-γ energy group structure given in Table 1.

Group	Energy	Group	Energy
1	10-100 KeV	10	1.66-2.0 MeV
2	.1-.2 MeV	11	2.0-2.5 MeV
3	.2-.4 MeV	12	2.5-3.0 MeV
4	.4-.6 MeV	13	3.0-4.0 MeV
5	.6-.8 MeV	14	4.0-5.0 MeV
6	.8-1. MeV	15	5.0-6.5 MeV
7	1.0-1.22 MeV	16	6.5-8.0 MeV
8	1.22-1.44 MeV	17	8.0-10.0 MeV
9	1.44-1.66 MeV	18	10.-20. MeV

Table 1 – ORNL-SCALE 18-γ energy group structure

The data contained in the library are based on the JEFF-3.1.1 evaluated decay data file (gamma radiation spectra). In the gamma library of ANITA-4M in each group the contribution in MeV of the total γ energy emitted is given. The gamma spectra include both the γ-rays spectra and the x-rays and annihilation radiation spectra (photons not arising as transitions between nuclear states) (STYP=0 and STYP=9 in the ENDF-6 standard format). In the library, four cards are given for each nuclide: the first one contains the identification number IDNUC (Z*10000+A*10+M), the alphanumeric symbol and the total energy E_γ calculated as the sum over the 18-group values. Then three cards follow for the 18-group values.

The data given in the gamma library are used in ANITA-4M to compute the intensity and the energy distribution of the gamma-rays emitted by the irradiated composition. This gamma-ray source (Photons/cm^3 s) in the ORNL-SCALE 18-γ energy group structure (see Table 1) may be given as input to a radiation transport code to compute the space and energy distribution of the decay gamma-rays and the relative dose equivalent rate.

2.3 Neutron activation cross section data library (file "lib175")

As shown in Figure 1 the ANITA-4M code requires a neutron activation cross section data library, defined as "lib175" in binary format, in order to perform the activation calculations.

In the ANITA-2000 code package in free distribution at NEADB and RSICC two different libraries are included:

- The activation library "eaf99_lib", based on the EAF-99 neutron activation cross section data library [15]. It contains 12,039 activation reactions, up to Pu-247, in the 175- group VITAMIN-J neutron energy structure.
- The activation library "fendl2a_lib", based on the Fusion Evaluated Nuclear Data File FENDL/A-2.0 [16]. It contains 12,392 activation reactions, up to Pu-247, in the 175- group VITAMIN-J neutron energy structure.

The format of these multi-group libraries (VITAMIN-J 175 neutron groups structure [28]) is the LIBOUT format of the code FOUR ACES (ENEA Bologna) with two additional comment lines for each reaction. For the reaction numbers the ENDF-6 reaction number MT multiplied by 10 has been adopted, with the convention that for the excitation of each isomeric state the reaction number is increased by one. The material numbers consist of Z,A and an identifier, LIS, to indicate ground or isomeric target (MAT=Z*10000+A*10+LIS). The order of the cross sections is in accordance with increasing Z,A,LIS and MT. The cross section values of each reaction MT are in accordance with decreasing energy of the 175 VITAMIN-J group structure.

These libraries are given in card-image format. The MODBIN module, provided in the package, makes the conversion to lib175 in binary format as required by ANITA-4M code

The updating of the fl1 file, that now contains data for more nuclides than the original one, allows ANITA-4M code to perform activation calculations by using the neutron-induced cross section library EAF-2010 [19] contained in the package EASY-2010 [20], named "eaf-ngxs_175_fus_20100". This cross section library contains 66,256 excitation functions involving 816 different targets from ^{1}H to ^{257}Fm, atomic numbers 1 to 100, in the energy range 10^{-5} eV to 20 MeV. It was obtained at Culham by processing the point-wise file with a micro-flux weighting spectrum combining a thermal Maxwellian at low energies, a 1/E function at intermediate energies, and a velocity exponential fusion peak spectrum with a peak at 14.07 MeV, in the 175-group VITAMIN-J 175 neutron energy structure.

The card image library "eaf2010_lib" for ANITA-4M has been derived from the file "eaf-ngxs_175_fus_20100" of EASY-2010 package. It contains 63,512 activation reactions, up to Pu-247, in the 175- group VITAMIN-J neutron energy structure. The MODBIN module must be used for the conversion of the card image file to lib175 in binary format as required by ANITA-4M code.

3 VALIDATION OF THE UPDATED DECAY LIBRARIES AGAINST DECAY HEAT MEASUREMENTS AT FUSION NEUTRON SOURCE FNS-JAERI

The aim of this assessment is the validation of the ANITA-4M activation code using the updated libraries based on the JEFF-3.1.1 Radioactive Decay Data Library and the EAF-2010 neutron activation cross section library.

The ANITA-4M calculations are compared with the experimental decay heat results related to the material samples irradiated in the 14 MeV neutron flux of the Fusion Neutronics Source (FNS) of the Japan Atomic Energy Research Institute (JAERI), (actually JAEA), Tokai, Japan. These measurements were performed for ITER-relevant materials in the frame of an international benchmark exercise launched in the late 1990s in order to validate nuclear data and codes used for activation calculations. Several codes and data libraries available at that time were involved in this international benchmark (see [22]).

3.1 Experiment description

The Fusion Neutronics Source (FNS) at Tokai was used to irradiate in a 14 MeV neutron flux samples of various materials. The decay heat in the samples was measured at a series of times after the irradiation (cooling times). The experiments included measurements of decay heat for 32 different materials. However the benchmark comparisons have concentrated on those materials relevant to ITER safety studies, namely stainless steel 316, copper and nickel-chromium alloy. Furthermore most attention has been given to the time scale of interest in loss-of-cooling accident scenarios, up to three days decay following the longer irradiation in FNS. The overall experimental uncertainty totals generally between 6% - 10%. A detailed description of the experiments is given in [21].

Irradiations were performed in two series, with durations of either 5 min or 7 hours. After the irradiation, each sample was transferred to a Whole Energy Absorption Spectrometer (WEAS) for measurement of decay energy , up to about one hour, for the 5 min irradiation, and 100 days, for the 7 hour irradiation. The experiments included measurements of decay heat for the following 32 materials:

Al, B_4C, $BaCO_3$, Bi, CaO_3, CF_2, Co, Cr, Cu, Fe, Inconel, K_2CO_3, Mn, Mo, Na_2CO_3, Nb, Ni, NiCr, Pb, Re, S, SiO_2, SnO_2, $SrCO_3$, SS304, SS316, Ta, Ti, V, W, $Y2O_3$, Zr.

The sample material wt. % compositions provided by the experimental group and used for the activation calculations are:

- Aluminum : Al 100;
- Boron carbide (B_4C): B 78.26, C 21.74;

- Barium Carbonate ($BaCO_3$): C 6.09, O 24.32, Ba 69.59;
- Bismuth: Bi 100;
- Calcium Oxide (CaO) : O 28.53, Ca 71.47;
- PTFE, Teflon (CF_2): C 24.02, F 75.98;
- Cobalt: Co 100;
- Chromium: Cr 100;
- Copper: Cu 100;
- Iron: Fe 100;
- Inconel-600 : Cr 15,97, Mn 0.39, Fe 7.82, Ni 75.82;
- Potassium carbonate (K_2CO_3): C 8.69, O 34.73, K 56.58 ;
- Manganese: Mn 100;
- Molybdenum : Mo 100;
- Sodium carbonate (Na2CO3) : C 11.33, O 45.29, Na 43.38;
- Niobium: Nb 100;
- Nicrome (Nicr): Cr 19.64, Fe 0.06, Ni 80.30;
- Nickel : Ni 100;
- Lead : Pb 199;
- Rhenium. Re 100;
- Sulfur : S 100;
- Silicon Dioxide (SiO_2): O 53.26, Si 46.74;
- Tin Dioxide (SnO_2): O 21.23, Sn 78.77;
- Strontium Carbonate ($SrCO_3$): C 8.14, O 32.51, Sr 59.35;
- Stainless Steel SS304: Si 0.55, Cr 18.02, Mn 1.44, Fe 71.17, Ni 8.82;
- Stainless Steel AISI 316: Si 0.96, Cr 18.28, Mn 1.44, Fe 63.72, Ni 13.49, Mo 2.11;
- Tantalum : Ta 100;
- Titanium : Ti 100;
- Vanadium: V 100;
- Yttrium Oxide (Y_2O_3): O 21.26, Y 78.74;
- Zirconium: Zr 100.

No material impurities content information was provided by the experimental team.

3.2 Calculation approach

Neutron energy spectrum, in the 175-group VITAMIN-J energy structure, and source neutron intensity were provided by the experimental group.

In this report two ANITA calculations are presented for each sample: 1) using the original libraries included in the ANITA-2000 package, that is the FENDL/A-2 neutron activation library and the decay data library fl1 based on FENDL/D-2 data, 2) using the new decay data library fl1 based on JEFF-3.1.1 data and the activation library “eaf2010_lib” based on the “eaf-ngxs_175_fus_20100” file of EASY-2010 package.

4 CALCULATION-EXPERIMENT COMPARISON: RESULTS AND DISCUSSION

The decay heat (E) (µW/g) of the material samples irradiated for 5-minutes was measured (at 20 discrete points in times) up to about one hour after the end of the irradiation at the FNS.

The decay heat (E) (µW/g) of the material samples irradiated for 7-hours was measured (at 7 discrete points in times) up to about one hundred days after the end of the irradiation at the FNS.

The measured decay data for all the material samples are included into Table 2 to Table 32. The same tables list also the calculated values, obtained by ANITA-4M code using the FENDL/A-2 with FENDL/D-2 and EAF-2010 with JEFF-3.1.1 libraries, respectively.

To estimate the discrepancy between the calculated and the experimental decay heat values, the percentage ratios (C-E)/E % have been evaluated. They are plotted in Figure 2 to Figure 60.

In these plots, the points connected by black solid lines correspond to the ANITA-4M calculations using the FENDL/A-2 neutron activation library and the decay data library based on FENDL/D-2 data. The points connected by red dotted lines refer to calculations performed using the EAF-2010 neutron activation library and the updated decay data library based on JEFF-3.1.1 data.

N.B. For sake of simplicity the two ANITA calculations performed by using FENDL/A-2+FENDL/D-2 and EAF-2010+JEFF-3.1.1 are referred to as FENDL/A-2 and EAF-2010, respectively.

Aluminum (Al)

Material composition : Al 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	microW/g	microW/g		microW/g	
1.4 (m)	1.20E+00	1.19E+00	-1.2	1.19E+00	-1.1
1.6 (m)	1.18E+00	1.16E+00	-1.4	1.17E+00	-1.3
1.9 (m)	1.15E+00	1.14E+00	-1.0	1.14E+00	-1.0
2.3 (m)	1.12E+00	1.10E+00	-1.2	1.10E+00	-1.2
2.9 (m)	1.07E+00	1.05E+00	-1.1	1.05E+00	-1.2
3.5 (m)	1.02E+00	1.01E+00	-1.4	1.01E+00	-1.6
4.4 (m)	9.60E-01	9.47E-01	-1.4	9.45E-01	-1.6
5.5 (m)	8.85E-01	8.75E-01	-1.2	8.73E-01	-1.4
6.7 (m)	8.16E-01	8.10E-01	-0.8	8.07E-01	-1.1
8.3 (m)	7.32E-01	7.24E-01	-1.0	7.22E-01	-1.4
10.4 (m)	6.35E-01	6.29E-01	-0.9	6.26E-01	-1.4
12.5 (m)	5.51E-01	5.48E-01	-0.4	5.45E-01	-0.9
14.6 (m)	4.80E-01	4.79E-01	-0.2	4.77E-01	-0.7
17.7 (m)	4.00E-01	3.96E-01	-0.9	3.94E-01	-1.5
21.8 (m)	3.18E-01	3.12E-01	-1.7	3.10E-01	-2.4
25.9 (m)	2.54E-01	2.49E-01	-2.0	2.47E-01	-2.7
30.0 (m)	2.10E-01	2.03E-01	-3.3	2.01E-01	-4.2
37.1 (m)	1.57E-01	1.49E-01	-5.3	1.47E-01	-6.2
47.2 (m)	1.15E-01	1.07E-01	-6.3	1.06E-01	-7.4
57.3 (m)	9.43E-02	8.70E-02	-7.7	8.59E-02	-8.9

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	microW/g	microW/g		microW/g	
15.7 (h)	2.31E+00	2.76E+00	19.5	2.74E+00	18.6
1.3 (d)	1.46E+00	1.30E+00	-10.8	1.29E+00	-11.6
2.9 (d)	2.25E-01	2.25E-01	0.0	2.22E-01	-1.2
6.9 (d)	2.69E-03	2.60E-03	-3.2	2.55E-03	-5.0
12.9 (d)	5.78E-05	3.50E-06	-93.9	3.40E-06	-94.1
23.9 (d)	4.40E-05	3.02E-08	-99.9	2.96E-08	-99.9
49.7 (d)	6.28E-05	3.01E-08	-100.0	2.95E-08	-100.0

Table 2 – Aluminum decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

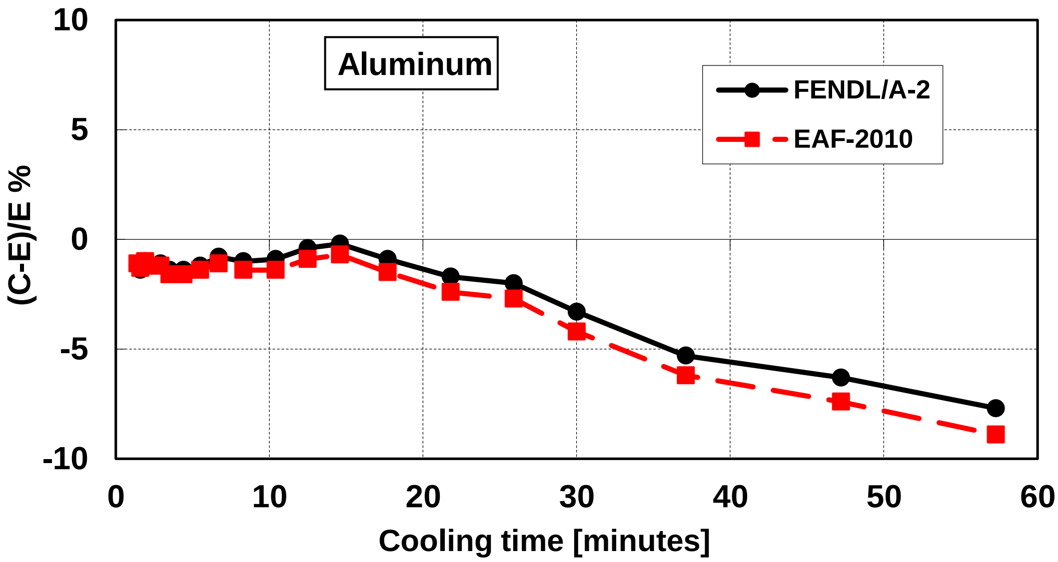

Figure 2 – Decay heat vs. cooling time of Aluminum sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

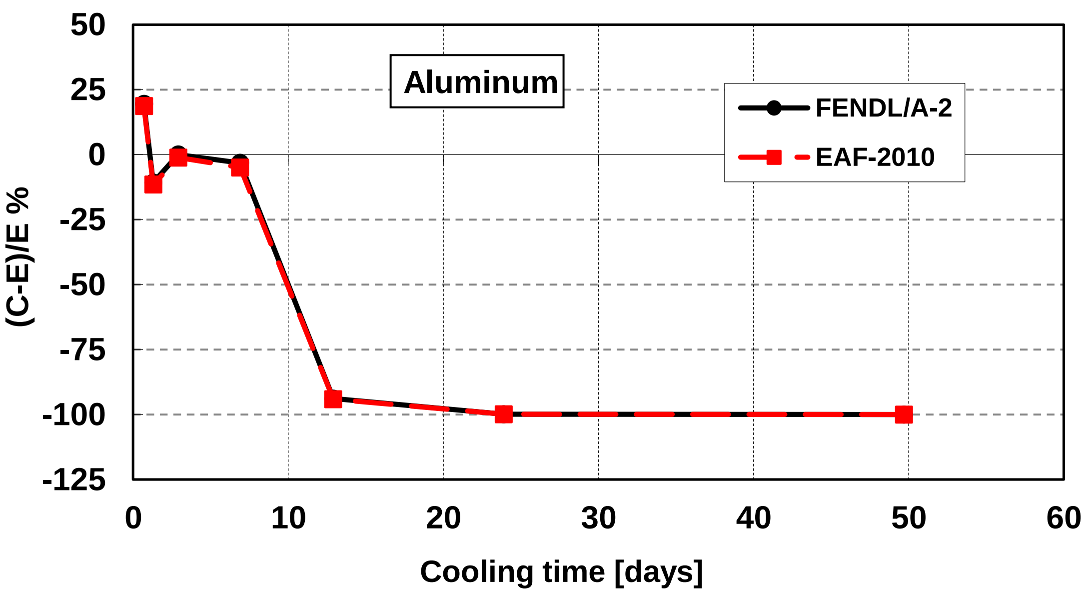

Figure 3 – Decay heat vs. cooling time of Aluminum sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Boron Carbide (B_4C)

Material composition : B 78.26, C 21.74

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF2010 JEFF-3.1.1	(C-E)/E %
CoolingTime	μW/g	μW/g		μW/g	
1.2 (m)	4.98E-02	5.09E-02	2.2	5.09E-02	2.1
1.5 (m)	2.72E-02	2.28E-02	-16.1	2.28E-02	-16.2
1.8 (m)	1.63E-02	1.02E-02	-37.3	1.02E-02	-37.4
2.2 (m)	1.06E-02	2.64E-03	-75.2	2.63E-03	-75.2
2.8 (m)	8.20E-03	4.11E-04	-95.0	4.11E-04	-95.0
3.4 (m)	7.06E-03	6.43E-05	-99.1	6.42E-05	-99.1
4.3 (m)	6.20E-03	4.50E-06	-99.9	4.50E-06	-99.9
5.4 (m)	5.29E-03	1.63E-07	-100.0	1.63E-07	-100.0
6.6 (m)	4.53E-03	1.23E-08	-100.0	1.30E-08	-100.0
8.2 (m)	3.97E-03	6.90E-09	-100.0	7.61E-09	-100.0
10.3 (m)	3.32E-03	6.90E-09	-100.0	7.61E-09	-100.0
12.4 (m)	2.88E-03	6.90E-09	-100.0	7.61E-09	-100.0
14.6 (m)	2.61E-03	6.90E-09	-100.0	7.61E-09	-100.0
17.7 (m)	2.23E-03	6.90E-09	-100.0	7.61E-09	-100.0
21.8 (m)	1.86E-03	6.90E-09	-100.0	7.61E-09	-100.0
25.9 (m)	1.56E-03	6.90E-09	-100.0	7.61E-09	-100.0
30.0 (m)	1.28E-03	6.90E-09	-100.0	7.61E-09	-100.0
37.1 (m)	9.61E-04	6.90E-09	-100.0	7.61E-09	-100.0
47.2 (m)	5.91E-04	6.90E-09	-100.0	7.61E-09	-100.0
57.2 (m)	2.43E-04	6.90E-09	-100.0	7.61E-09	-100.0

Table 3 – Boron Carbide decay heat calculation-experiment comparison
(5 minutes irradiation)

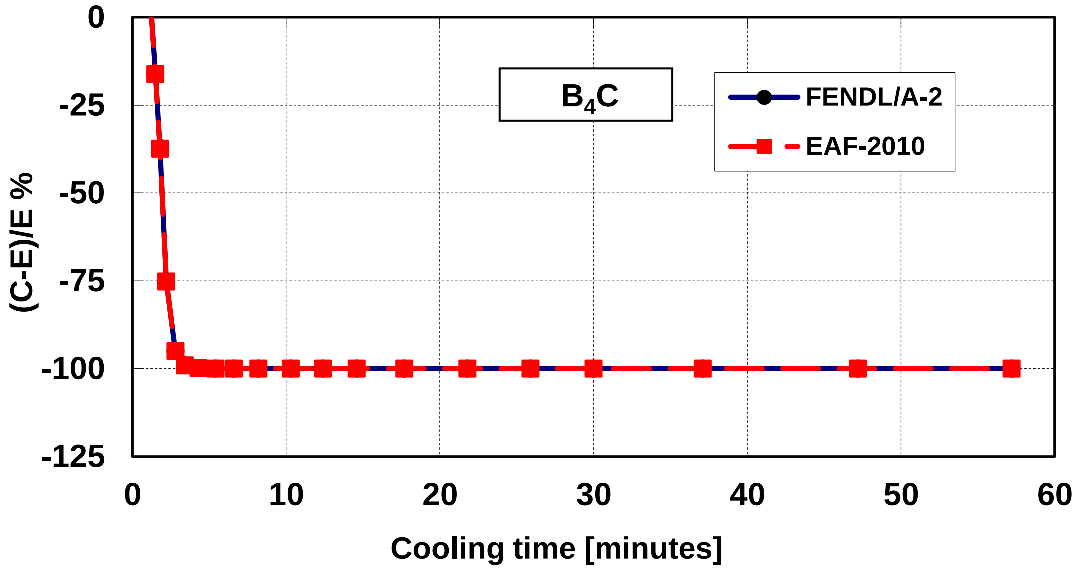

Figure 4 – Decay heat vs. cooling time of Boron Carbide sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

Barium Carbonate ($BaCO_3$)

Material composition : C 6.09, O 24.32, Ba 69.59

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	1.31E+00	1.35E+00	2.8	1.20E+00	-8.6
1.4 (m)	1.22E+00	1.25E+00	2.3	1.11E+00	-9.2
1.6 (m)	1.14E+00	1.16E+00	1.7	1.03E+00	-9.7
2.1 (m)	1.01E+00	1.02E+00	1.0	9.10E-01	-10.3
2.7 (m)	8.76E-01	8.79E-01	0.3	7.81E-01	-10.9
3.3 (m)	7.48E-01	7.44E-01	-0.6	6.61E-01	-11.6
4.2 (m)	5.92E-01	5.83E-01	-1.4	5.19E-01	-12.3
5.3 (m)	4.44E-01	4.32E-01	-2.9	3.84E-01	-13.5
6.4 (m)	3.35E-01	3.20E-01	-4.6	2.85E-01	-15.0
8.1 (m)	2.28E-01	2.06E-01	-9.5	1.84E-01	-19.1
10.2 (m)	1.40E-01	1.17E-01	-16.5	1.05E-01	-24.9
12.2 (m)	9.09E-02	6.79E-02	-25.3	6.16E-02	-32.3
14.4 (m)	6.25E-02	3.92E-02	-37.3	3.61E-02	-42.2
17.5 (m)	4.19E-02	1.82E-02	-56.7	1.74E-02	-58.5
21.6 (m)	3.10E-02	7.55E-03	-75.7	7.89E-03	-74.6
25.7 (m)	2.72E-02	3.98E-03	-85.4	4.65E-03	-82.9
29.9 (m)	2.49E-02	2.69E-03	-89.2	3.41E-03	-86.3
36.9 (m)	2.36E-02	1.97E-03	-91.6	2.65E-03	-88.8
47.0 (m)	2.15E-02	1.61E-03	-92.5	2.17E-03	-89.9
57.2 (m)	1.92E-02	1.38E-03	-92.8	1.84E-03	-90.4

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.7 (d)	1.57E-02	1.67E-02	6.6	1.68E-02	7.1
1.7 (d)	8.33E-03	9.12E-03	9.4	9.15E-03	9.8
3.9 (d)	2.58E-03	2.85E-03	10.6	2.85E-03	10.5
6.7 (d)	6.90E-04	6.95E-04	0.7	6.84E-04	-0.9
12.2 (d)	1.18E-04	1.22E-04	3.4	1.11E-04	-5.8
24.2 (d)	3.60E-05	4.81E-05	33.5	4.21E-05	16.9

Table 4 – Barium Carbonate decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

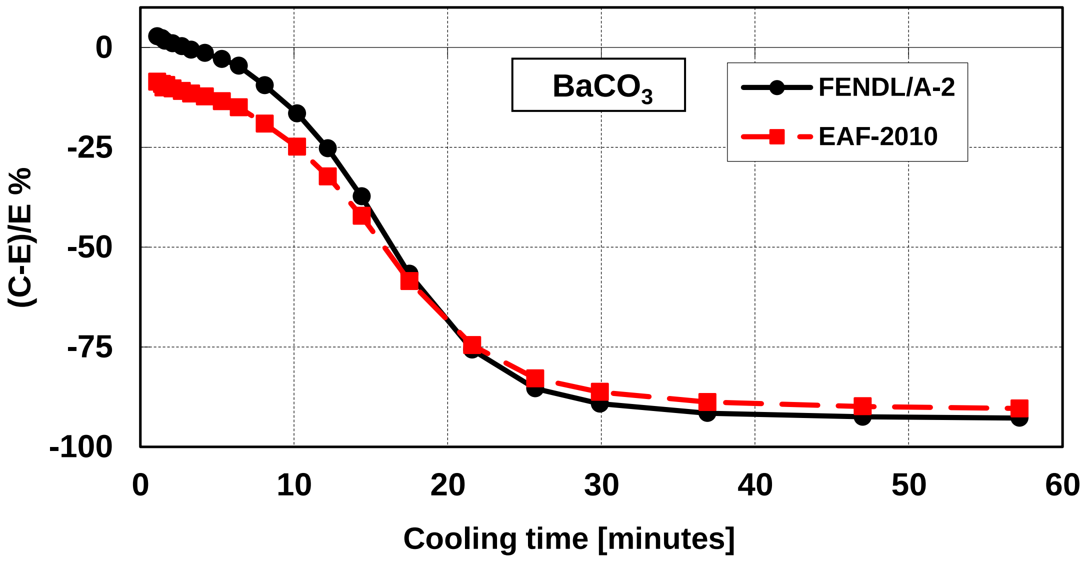

Figure 5 – Decay heat vs. cooling time of Barium Carbonate sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

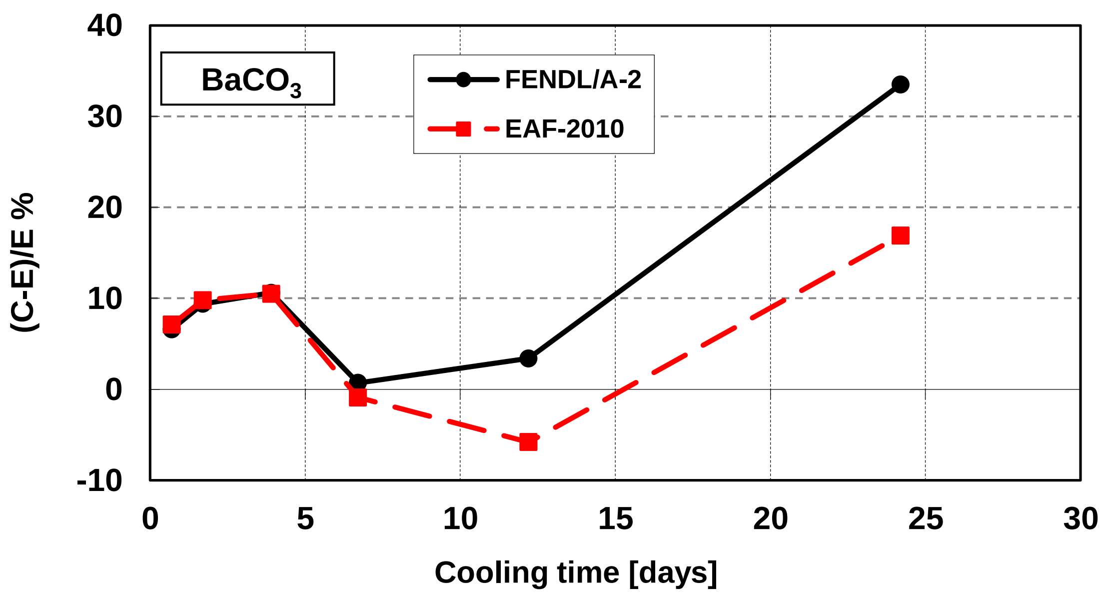

Figure 6 – Decay heat vs. cooling time of Barium Carbonate sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Bismuth (Bi)

Material composition : Bi 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	8.15E-04	8.25E-04	1.3	1.15E-03	40.9
1.4 (m)	7.23E-04	7.90E-04	9.3	1.10E-03	52.1
1.6 (m)	6.38E-04	7.57E-04	18.6	1.05E-03	65.2
2.1 (m)	6.92E-04	7.03E-04	1.6	9.80E-04	41.6
2.7 (m)	7.50E-04	6.37E-04	-15.1	8.88E-04	18.4
3.3 (m)	6.69E-04	5.76E-04	-13.9	8.04E-04	20.2
4.2 (m)	5.54E-04	5.00E-04	-9.7	6.99E-04	26.2
5.3 (m)	4.04E-04	4.18E-04	3.4	5.85E-04	44.9
6.4 (m)	2.56E-04	3.52E-04	37.3	4.93E-04	92.7
8.0 (m)	2.48E-04	2.71E-04	9.4	3.82E-04	54.2
10.1 (m)	1.71E-04	1.95E-04	13.7	2.76E-04	61.3
12.2 (m)	9.24E-05	1.42E-04	53.5	2.03E-04	119.4
14.3 (m)	1.06E-04	1.04E-04	-2.7	1.49E-04	40.4
17.4 (m)	4.34E-05	6.67E-05	53.9	9.83E-05	126.7
21.5 (m)	3.00E-05	3.93E-05	31.3	6.00E-05	100.4
25.7 (m)	2.40E-05	2.53E-05	5.7	4.04E-05	68.7
29.8 (m)	3.10E-05	1.82E-05	-41.4	3.03E-05	-2.1
36.9 (m)	3.50E-05	1.29E-05	-63.1	2.29E-05	-34.7
47.0 (m)	4.90E-05	1.08E-05	-78.0	1.97E-05	-59.8
57.0 (m)	4.27E-05	1.01E-05	-76.3	1.86E-05	-56.5

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.7 (d)	1.39E-05	8.56E-05	516.5	9.90E-05	613.1
1.7 (d)	2.03E-06	6.51E-05	3104.9	6.39E-05	3048.8
3.9 (d)	2.00E-06	5.77E-05	2784.4	5.66E-05	2732.4
6.7 (d)	2.28E-06	5.06E-05	2115.1	4.97E-05	2076.5
12.2 (d)	3.73E-06	4.25E-05	1038.0	4.18E-05	1019.5

Table 5 – Bismuth decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

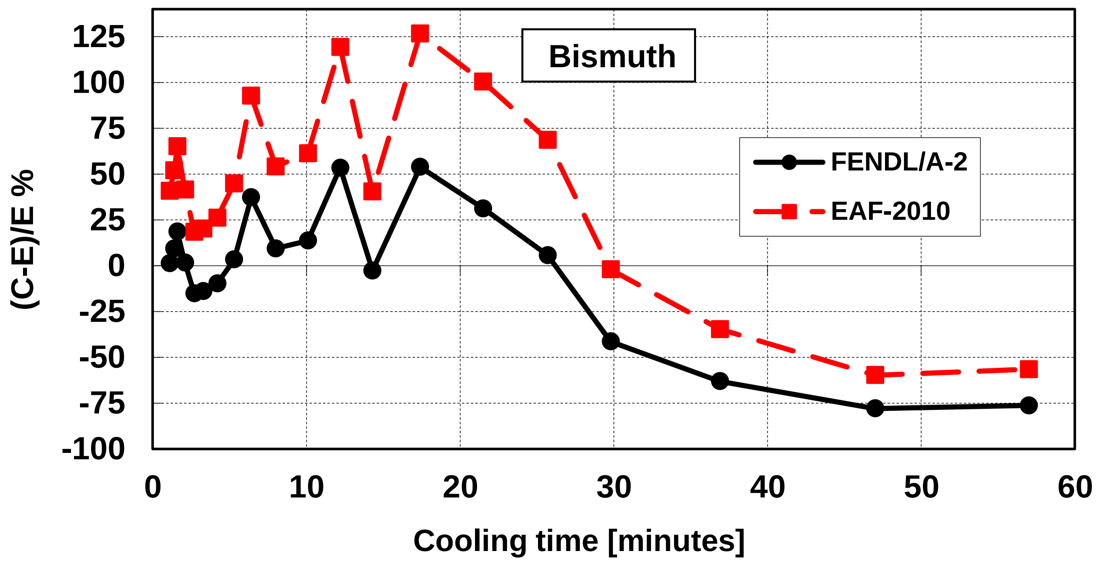

Figure 7 – Decay heat vs. cooling time of Bismuth sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

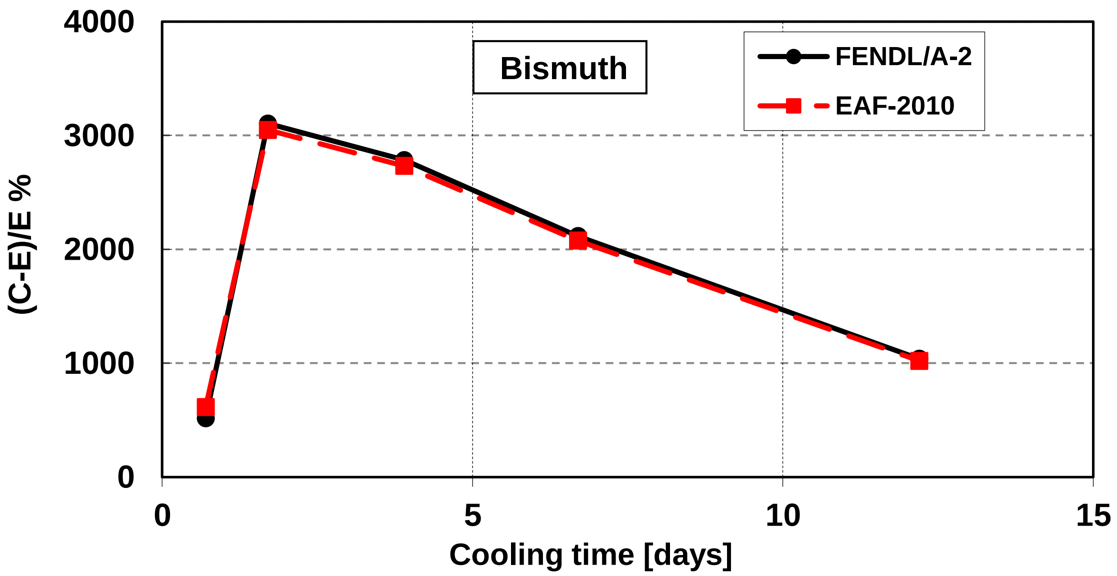

Figure 8 – Decay heat vs. cooling time of Bismuth sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Calcium Oxide (CaO)

Material composition : O 28.53, Ca 71.47

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	µW/g	µW/g		µW/g	
1.1 (m)	2.42E-02	8.60E-01	3453.7	1.62E-02	-33.1
1.4 (m)	1.79E-02	8.34E-01	4570.0	1.02E-02	-43.0
1.6 (m)	1.58E-02	8.13E-01	5035.9	8.84E-03	-44.1
2.1 (m)	1.50E-02	7.80E-01	5091.7	8.41E-03	-44.0
2.7 (m)	1.49E-02	7.38E-01	4863.0	8.23E-03	-44.6
3.3 (m)	1.47E-02	6.98E-01	4632.0	8.08E-03	-45.2
4.2 (m)	1.40E-02	6.47E-01	4521.4	7.88E-03	-43.7
5.2 (m)	1.29E-02	5.88E-01	4461.3	7.64E-03	-40.7
6.3 (m)	1.17E-02	5.31E-01	4428.6	7.39E-03	-37.0
8.0 (m)	1.15E-02	4.59E-01	3904.4	7.05E-03	-38.4
10.1 (m)	1.05E-02	3.80E-01	3522.5	6.64E-03	-36.7
12.2 (m)	9.68E-03	3.14E-01	3140.4	6.24E-03	-35.5
14.2 (m)	9.09E-03	2.61E-01	2767.8	5.89E-03	-35.2
17.4 (m)	7.90E-03	1.97E-01	2393.4	5.39E-03	-31.8
21.5 (m)	7.01E-03	1.37E-01	1855.5	4.81E-03	-31.3
25.6 (m)	6.07E-03	9.52E-02	1468.4	4.30E-03	-29.2
29.7 (m)	5.16E-03	6.62E-02	1182.1	3.84E-03	-25.6
36.8 (m)	4.48E-03	3.59E-02	702.2	3.18E-03	-28.8
46.9 (m)	3.47E-03	1.55E-02	345.9	2.46E-03	-29.1
57.0 (m)	2.28E-03	7.13E-03	212.6	1.93E-03	-15.3

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	µW/g	µW/g		µW/g	
0.7 (d)	8.41E-03	6.73E-03	-19.9	6.87E-03	-18.3
1.7 (d)	3.40E-03	2.70E-03	-20.5	2.81E-03	-17.3
3.9 (d)	1.47E-03	1.13E-03	-23.0	1.21E-03	-17.6
6.7 (d)	9.49E-04	7.26E-04	-23.5	7.79E-04	-18.0
12.2 (d)	4.32E-04	3.59E-04	-16.9	3.84E-04	-11.2
24.2 (d)	9.00E-05	8.11E-05	-9.9	8.51E-05	-5.4

Table 6 – Calcium Oxide decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

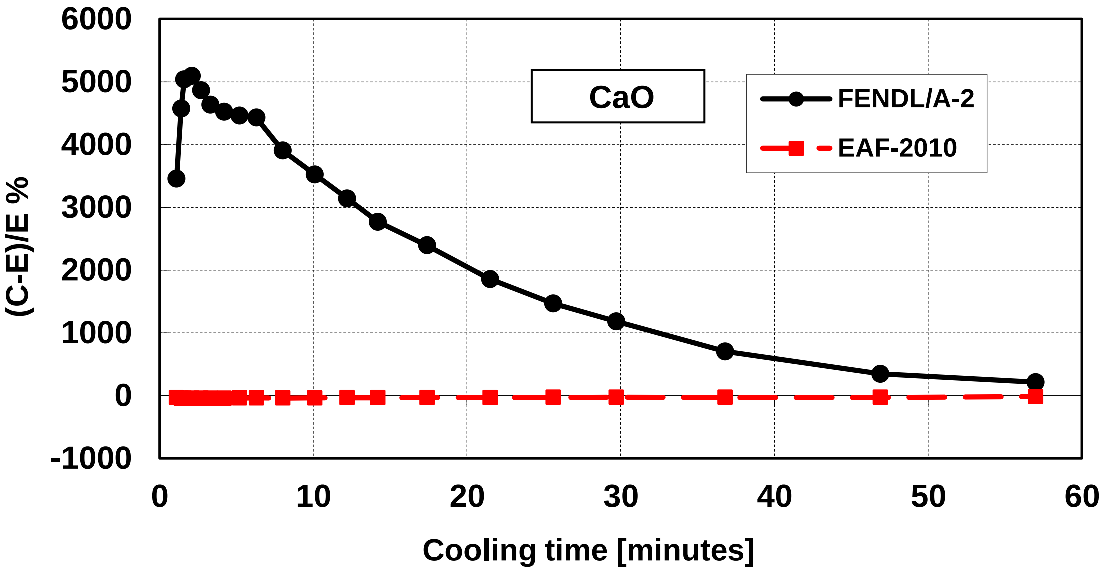

Figure 9 – Decay heat vs. cooling time of Calcium Oxide sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

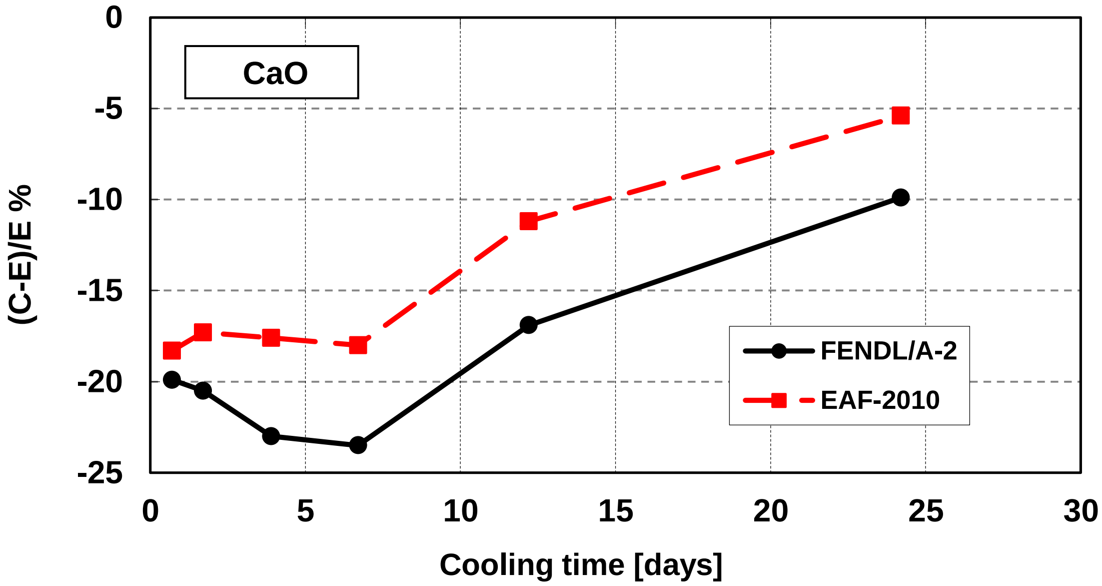

Figure 10 – Decay heat vs. cooling time of Calcium Oxide sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

PTFE Teflon (CF_2)

Material composition : C 24.02, F 75.98

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	4.52E-01	4.32E-01	-4.4	4.29E-01	-5.2
1.4 (m)	3.19E-01	3.03E-01	-4.9	3.01E-01	-5.7
1.6 (m)	2.31E-01	2.24E-01	-3.3	2.22E-01	-4.1
2.1 (m)	1.53E-01	1.49E-01	-2.4	1.48E-01	-3.1
2.7 (m)	1.03E-01	1.02E-01	-1.6	1.01E-01	-2.3
3.3 (m)	8.29E-02	8.29E-02	0.0	8.23E-02	-0.7
4.2 (m)	7.27E-02	7.40E-02	1.7	7.35E-02	1.0
5.3 (m)	6.95E-02	7.11E-02	2.2	7.06E-02	1.5
6.4 (m)	6.83E-02	7.01E-02	2.8	6.97E-02	2.0
8.1 (m)	6.78E-02	6.93E-02	2.3	6.89E-02	1.6
10.2 (m)	6.68E-02	6.84E-02	2.4	6.79E-02	1.7
12.3 (m)	6.59E-02	6.75E-02	2.4	6.70E-02	1.7
14.4 (m)	6.49E-02	6.66E-02	2.6	6.61E-02	1.9
17.6 (m)	6.34E-02	6.53E-02	3.0	6.48E-02	2.3
21.6 (m)	6.19E-02	6.36E-02	2.9	6.32E-02	2.2
25.8 (m)	6.01E-02	6.20E-02	3.1	6.16E-02	2.4
29.9 (m)	5.84E-02	6.04E-02	3.4	6.00E-02	2.6
37.0 (m)	5.57E-02	5.78E-02	3.6	5.74E-02	2.9
47.0 (m)	5.22E-02	5.42E-02	3.9	5.38E-02	3.2
57.2 (m)	4.89E-02	5.08E-02	4.1	5.05E-02	3.3

Table 7 – PTFE Teflon decay heat calculation-experiment comparison
(5 minutes irradiation)

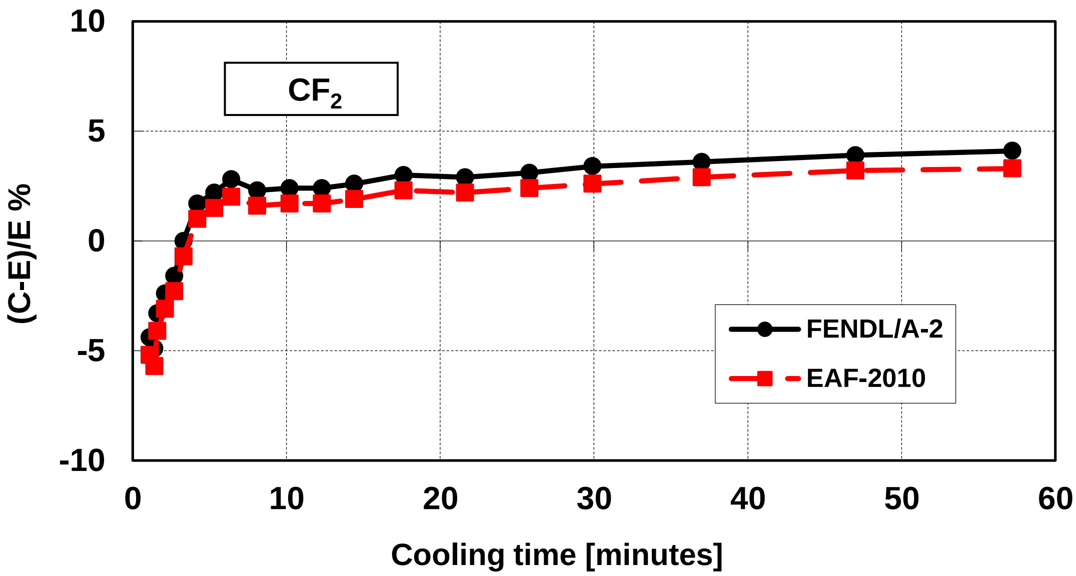

Figure 11 – Decay heat vs. cooling time of PTFE Teflon sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

Cobalt (Co)

Material composition : Co 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	3.11E-02	3.13E-02	0.5	3.26E-02	4.8
1.4 (m)	3.20E-02	3.12E-02	-2.6	3.25E-02	1.6
1.6 (m)	3.16E-02	3.11E-02	-1.5	3.24E-02	2.8
2.1 (m)	3.15E-02	3.10E-02	-1.8	3.23E-02	2.5
2.7 (m)	3.12E-02	3.08E-02	-1.4	3.21E-02	2.9
3.3 (m)	3.09E-02	3.06E-02	-1.0	3.19E-02	3.3
4.2 (m)	3.08E-02	3.03E-02	-1.6	3.17E-02	2.8
5.3 (m)	3.08E-02	3.00E-02	-2.5	3.14E-02	1.9
6.4 (m)	3.05E-02	2.97E-02	-2.4	3.11E-02	2.1
8.0 (m)	3.04E-02	2.93E-02	-3.6	3.07E-02	0.9
10.1 (m)	2.98E-02	2.89E-02	-3.3	3.02E-02	1.2
12.2 (m)	2.95E-02	2.84E-02	-3.9	2.97E-02	0.6
14.3 (m)	2.93E-02	2.80E-02	-4.7	2.93E-02	-0.2
17.4 (m)	2.87E-02	2.74E-02	-4.7	2.87E-02	-0.1
21.5 (m)	2.83E-02	2.67E-02	-5.6	2.80E-02	-1.0
25.6 (m)	2.76E-02	2.61E-02	-5.6	2.73E-02	-0.9
29.7 (m)	2.72E-02	2.55E-02	-6.2	2.67E-02	-1.5
36.9 (m)	2.64E-02	2.46E-02	-7.0	2.58E-02	-2.4
46.9 (m)	2.51E-02	2.34E-02	-6.9	2.46E-02	-2.2
57.0 (m)	2.41E-02	2.24E-02	-7.1	2.35E-02	-2.4

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.6 (d)	5.90E-02	7.66E-02	29.7	8.08E-02	36.8
1.3 (d)	4.28E-02	4.61E-02	7.7	4.69E-02	9.5
2.9 (d)	4.33E-02	4.06E-02	-6.3	4.05E-02	-6.6
6.9 (d)	4.19E-02	3.87E-02	-7.6	3.85E-02	-8.0
12.8 (d)	3.94E-02	3.64E-02	-7.7	3.62E-02	-8.1
23.8 (d)	3.52E-02	3.24E-02	-7.8	3.23E-02	-8.2
49.7 (d)	2.69E-02	2.48E-02	-7.9	2.47E-02	-8.3
99.9 (d)	1.63E-02	1.48E-02	-9.0	1.48E-02	-9.4

Table 8 – Cobalt decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

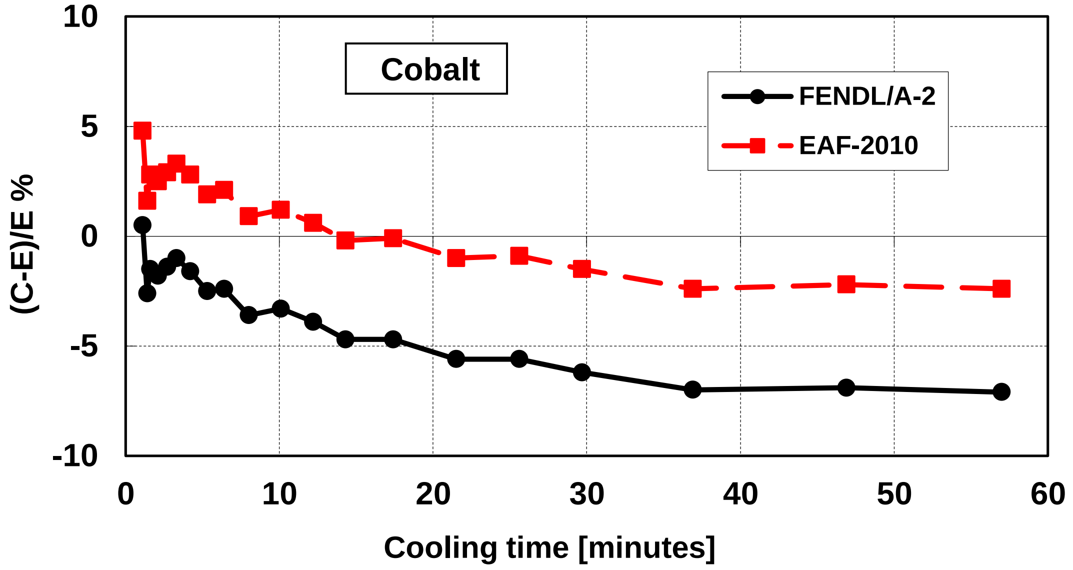

Figure 12 – Decay heat vs. cooling time of Cobalt sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

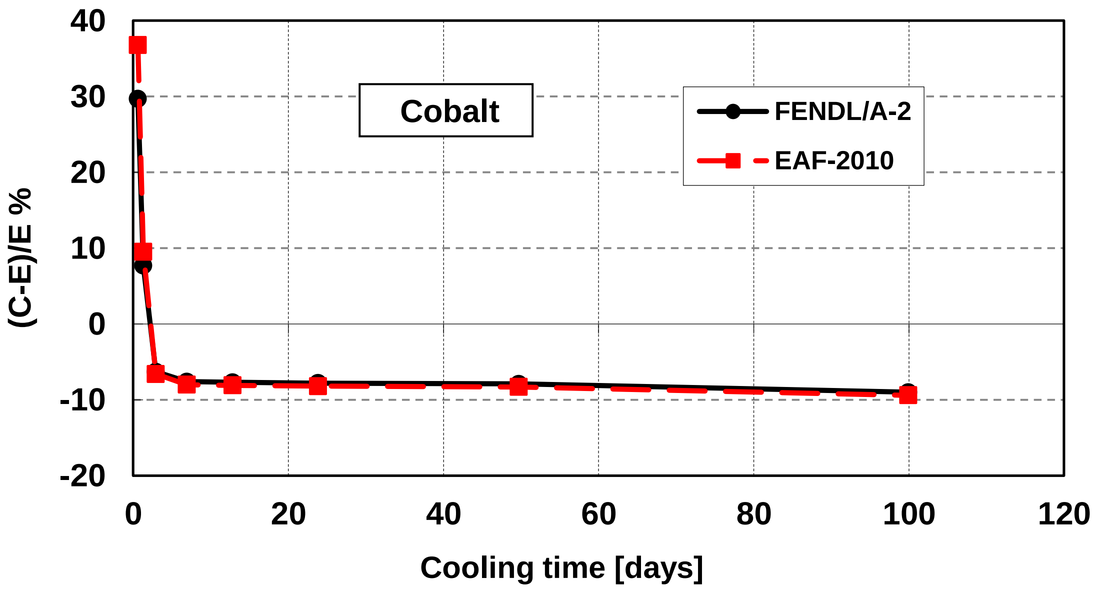

Figure 13 – Decay heat vs. cooling time of Cobalt sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Chromium (Cr)

Material composition : Cr 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	1.81E+00	1.56E+00	-13.8	1.58E+00	-12.4
1.4 (m)	1.71E+00	1.48E+00	-13.8	1.50E+00	-12.4
1.6 (m)	1.62E+00	1.40E+00	-13.4	1.42E+00	-12.1
2.1 (m)	1.48E+00	1.28E+00	-13.8	1.29E+00	-12.5
2.7 (m)	1.31E+00	1.13E+00	-13.9	1.14E+00	-12.7
3.3 (m)	1.16E+00	1.00E+00	-13.9	1.01E+00	-12.7
4.2 (m)	9.82E-01	8.43E-01	-14.2	8.54E-01	-13.1
5.3 (m)	7.93E-01	6.80E-01	-14.2	6.89E-01	-13.1
6.5 (m)	6.42E-01	5.49E-01	-14.5	5.56E-01	-13.4
8.1 (m)	4.82E-01	4.08E-01	-15.3	4.13E-01	-14.2
10.2 (m)	3.28E-01	2.75E-01	-16.1	2.79E-01	-15.0
12.3 (m)	2.24E-01	1.86E-01	-17.2	1.88E-01	-16.0
14.4 (m)	1.55E-01	1.26E-01	-18.6	1.27E-01	-17.5
17.5 (m)	9.11E-02	7.11E-02	-22	7.21E-02	-20.8
21.7 (m)	4.60E-02	3.39E-02	-26.3	3.45E-02	-25.0
25.8 (m)	2.48E-02	1.68E-02	-32.3	1.71E-02	-30.9
29.9 (m)	1.46E-02	8.58E-03	-41.1	8.81E-03	-39.5
37.0 (m)	7.87E-03	3.20E-03	-59.3	3.36E-03	-57.3
47.1 (m)	4.89E-03	1.39E-03	-71.6	1.50E-03	-69.3
57.2 (m)	3.89E-03	9.72E-04	-75	1.07E-03	-72.6

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.7 (d)	1.40E-02	1.47E-03	-89.5	1.49E-03	-89.3
1.7 (d)	5.39E-03	1.43E-03	-73.5	1.45E-03	-73.1
3.9 (d)	1.83E-03	1.36E-03	-25.8	1.37E-03	-24.7
6.8 (d)	1.37E-03	1.26E-03	-7.6	1.28E-03	-6.4
12.2 (d)	1.14E-03	1.10E-03	-3.6	1.12E-03	-2.3
24.2 (d)	8.31E-04	8.16E-04	-1.9	8.27E-04	-0.6
50.0 (d)	4.04E-04	4.29E-04	6.3	4.34E-04	7.6
100.1 (d)	1.15E-04	1.23E-04	7.4	1.24E-04	8.3

Table 9 – Chromium decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

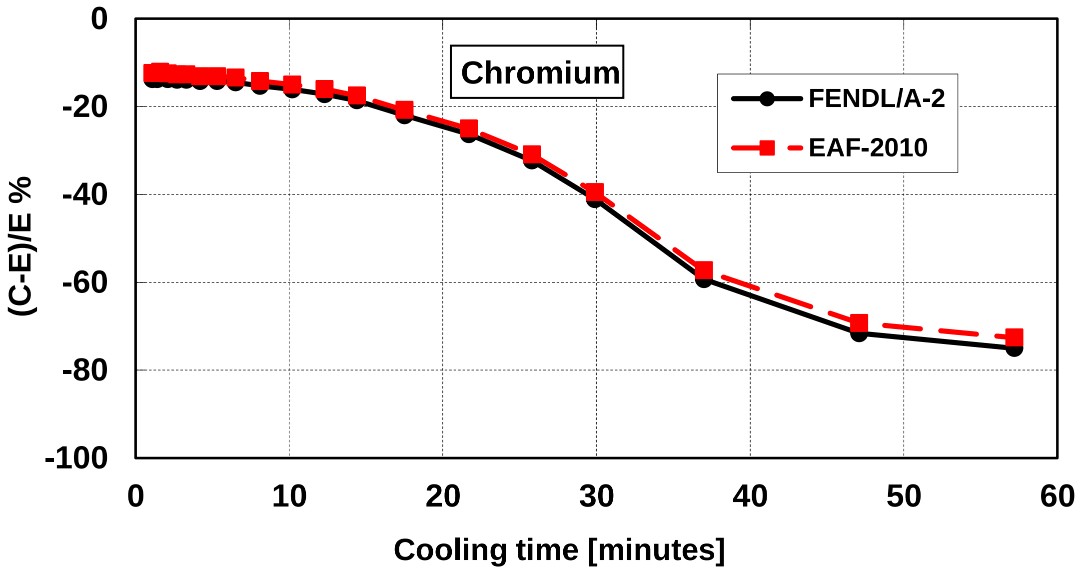

Figure 14 – Decay heat vs. cooling time of Chromium sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

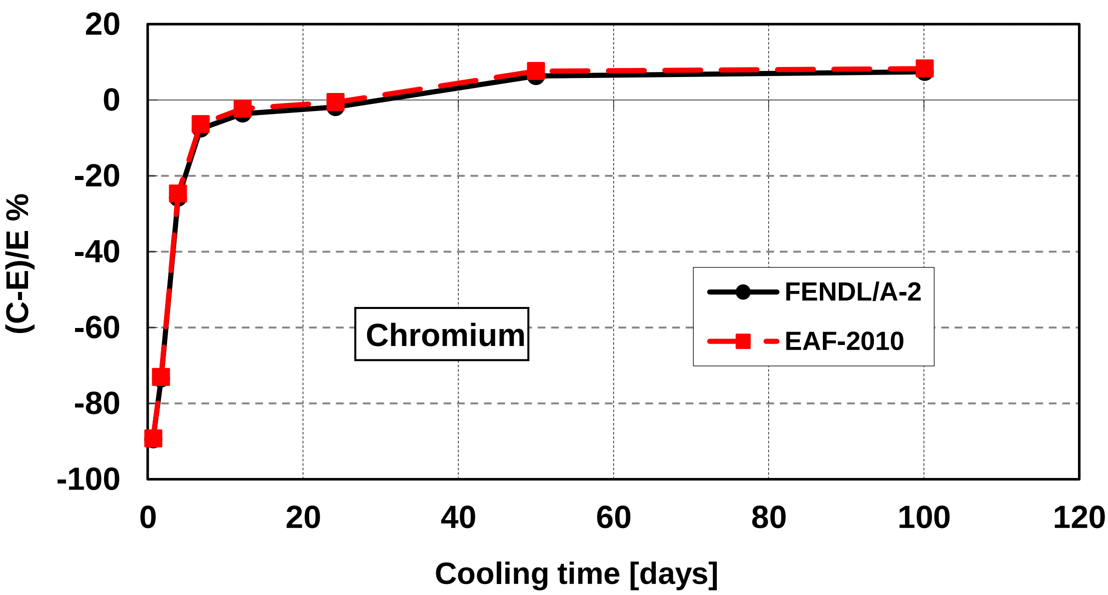

Figure 15 – Decay heat vs. cooling time of Chromium sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Copper (Cu)

Material composition : Cu 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	µW/g	µW/g		µW/g	
1.1 (m)	4.16E+00	3.77E+00	-9.4	3.88E+00	-6.6
1.4 (m)	4.08E+00	3.69E+00	-9.6	3.81E+00	-6.8
1.6 (m)	3.99E+00	3.61E+00	-9.5	3.73E+00	-6.6
2.1 (m)	3.86E+00	3.49E+00	-9.6	3.61E+00	-6.6
2.7 (m)	3.69E+00	3.33E+00	-9.7	3.45E+00	-6.6
3.3 (m)	3.53E+00	3.18E+00	-9.9	3.29E+00	-6.7
4.2 (m)	3.30E+00	2.98E+00	-9.6	3.09E+00	-6.3
5.3 (m)	3.05E+00	2.76E+00	-9.6	2.86E+00	-6.2
6.4 (m)	2.82E+00	2.55E+00	-9.7	2.64E+00	-6.3
8.0 (m)	2.51E+00	2.27E+00	-9.8	2.35E+00	-6.3
10.1 (m)	2.15E+00	1.95E+00	-9.5	2.03E+00	-6.0
12.2 (m)	1.85E+00	1.68E+00	-9.5	1.74E+00	-5.9
14.4 (m)	1.59E+00	1.44E+00	-9.4	1.50E+00	-5.8
17.5 (m)	1.28E+00	1.16E+00	-9.5	1.21E+00	-5.9
21.5 (m)	9.62E-01	8.70E-01	-9.5	9.06E-01	-5.8
25.6 (m)	7.22E-01	6.52E-01	-9.7	6.79E-01	-6.0
29.8 (m)	5.38E-01	4.89E-01	-9.1	5.09E-01	-5.3
36.9 (m)	3.33E-01	2.98E-01	-10.5	3.11E-01	-6.7
47.0 (m)	1.66E-01	1.50E-01	-9.5	1.57E-01	-5.6
57.1 (m)	8.44E-02	7.75E-02	-8.2	8.09E-02	-4.2

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	µW/g	µW/g		µW/g	
0.7 (d)	1.95E-01	2.04E-01	4.4	2.04E-01	4.5
1.3 (d)	8.31E-02	8.39E-02	1.0	8.40E-02	1.1
2.9 (d)	1.07E-02	1.07E-02	-0.4	1.07E-02	0.0
6.9 (d)	1.96E-04	1.71E-04	-12.5	2.02E-04	3.0
12.9 (d)	1.42E-04	1.12E-04	-20.7	1.43E-04	0.7
23.9 (d)	1.40E-04	1.12E-04	-20.0	1.42E-04	1.6
49.7 (d)	1.51E-04	1.11E-04	-26.7	1.41E-04	-6.9
99.9 (d)	1.48E-04	1.09E-04	-26.2	1.38E-04	-6.3

Table 10 – Copper decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

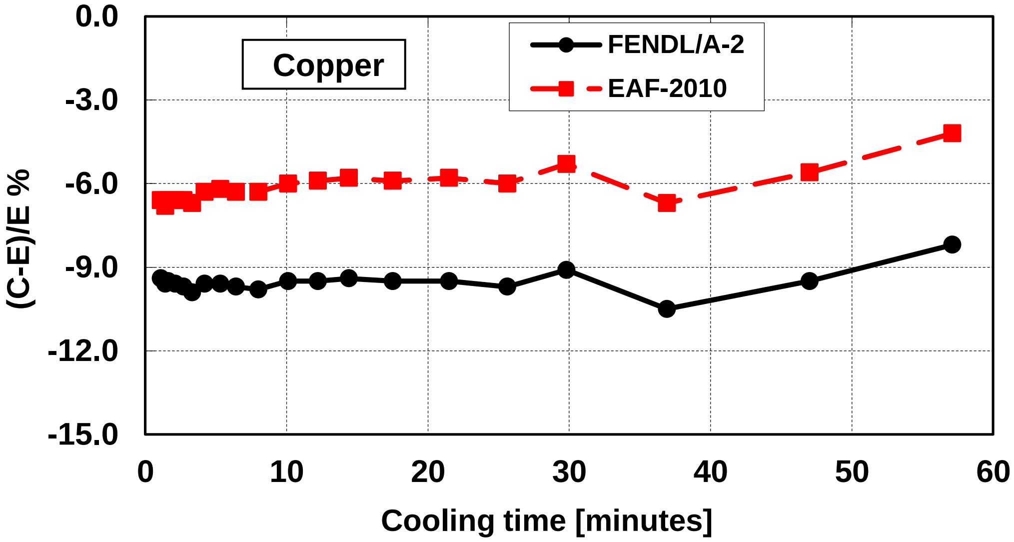

Figure 16 – Decay heat vs. cooling time of Copper sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

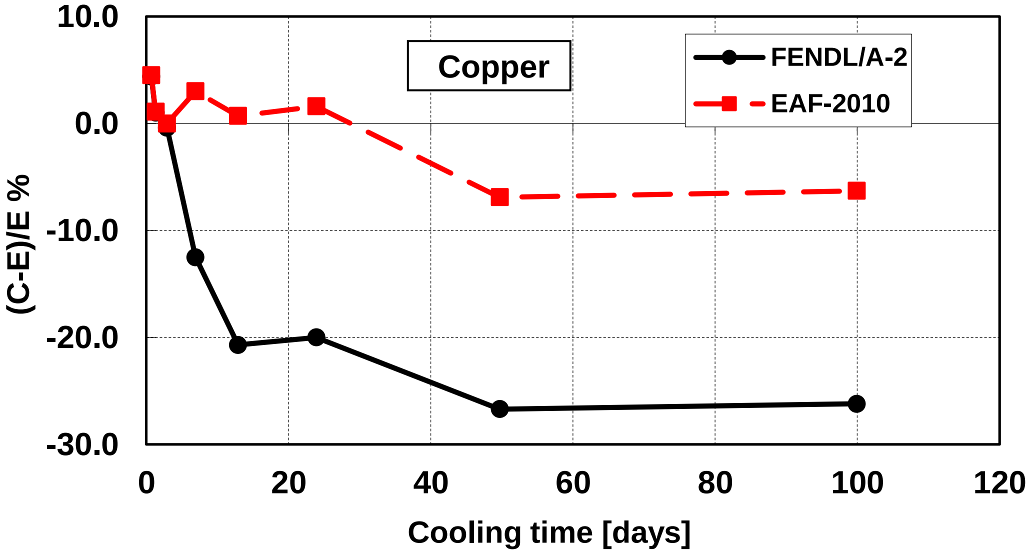

Figure 17 – Decay heat vs. cooling time of Copper sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Iron (Fe)

Material composition : Fe 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	1.28E-01	1.32E-01	2.9	1.20E-01	-6.7
1.4 (m)	1.26E-01	1.29E-01	2.2	1.18E-01	-7.0
1.6 (m)	1.26E-01	1.27E-01	0.2	1.16E-01	-8.5
2.1 (m)	1.22E-01	1.23E-01	1.2	1.13E-01	-7.2
2.7 (m)	1.17E-01	1.19E-01	1.9	1.10E-01	-5.8
3.2 (m)	1.15E-01	1.16E-01	0.8	1.08E-01	-6.3
4.1 (m)	1.11E-01	1.12E-01	0.3	1.05E-01	-6.0
5.2 (m)	1.08E-01	1.08E-01	0.2	1.02E-01	-5.5
6.3 (m)	1.05E-01	1.05E-01	0.4	1.00E-01	-4.8
7.9 (m)	1.03E-01	1.02E-01	-0.5	9.78E-02	-5.0
10.1 (m)	9.98E-02	9.95E-02	-0.3	9.55E-02	-4.3
12.1 (m)	9.80E-02	9.72E-02	-0.8	9.36E-02	-4.4
14.2 (m)	9.58E-02	9.53E-02	-0.6	9.20E-02	-4.0
17.3 (m)	9.38E-02	9.28E-02	-1.1	8.98E-02	-4.2
21.4 (m)	9.06E-02	9.00E-02	-0.6	8.73E-02	-3.6
25.5 (m)	8.80E-02	8.76E-02	-0.5	8.51E-02	-3.3
29.6 (m)	8.58E-02	8.54E-02	-0.5	8.31E-02	-3.1
36.8 (m)	8.26E-02	8.21E-02	-0.7	8.00E-02	-3.2
46.9 (m)	7.84E-02	7.80E-02	-0.6	7.62E-02	-2.9
57.0 (m)	7.51E-02	7.43E-02	-1.0	7.26E-02	-3.3

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.6 (d)	6.58E-02	6.44E-02	-2.1	6.44E-02	-2.2
1.3 (d)	1.23E-03	1.09E-03	-11.4	1.10E-03	-10.4
2.9 (d)	2.53E-04	2.28E-04	-10.0	2.37E-04	-6.4
6.9 (d)	2.30E-04	2.23E-04	-3.0	2.32E-04	1.2
12.9 (d)	2.25E-04	2.17E-04	-3.6	2.27E-04	0.9
23.9 (d)	2.14E-04	2.07E-04	-3.4	2.18E-04	1.5
49.7 (d)	2.03E-04	1.90E-04	-6.3	2.00E-04	-1.4
99.9 (d)	1.67E-04	1.66E-04	-0.7	1.75E-04	4.7

Table 11 – Iron decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

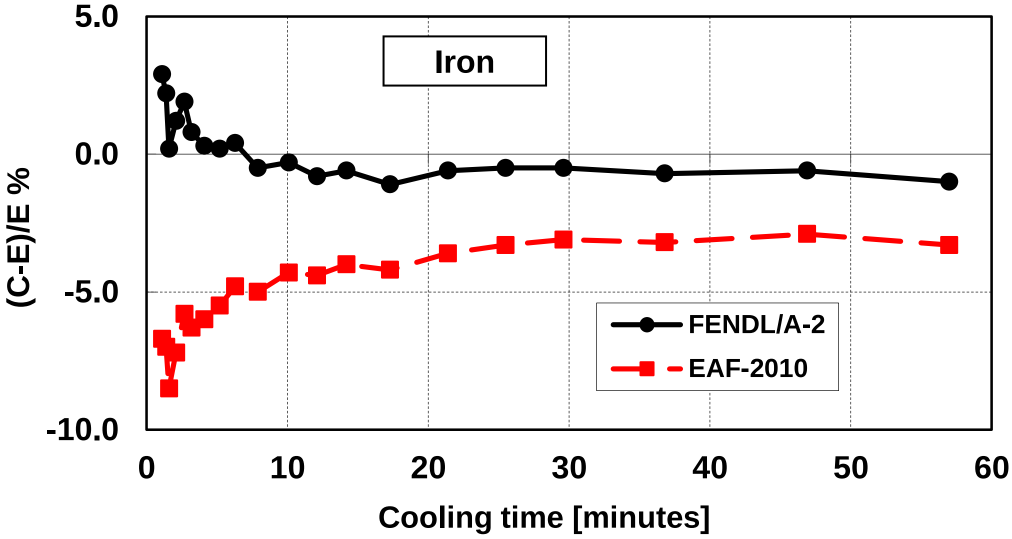

Figure 18 – Decay heat vs. cooling time of Iron sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

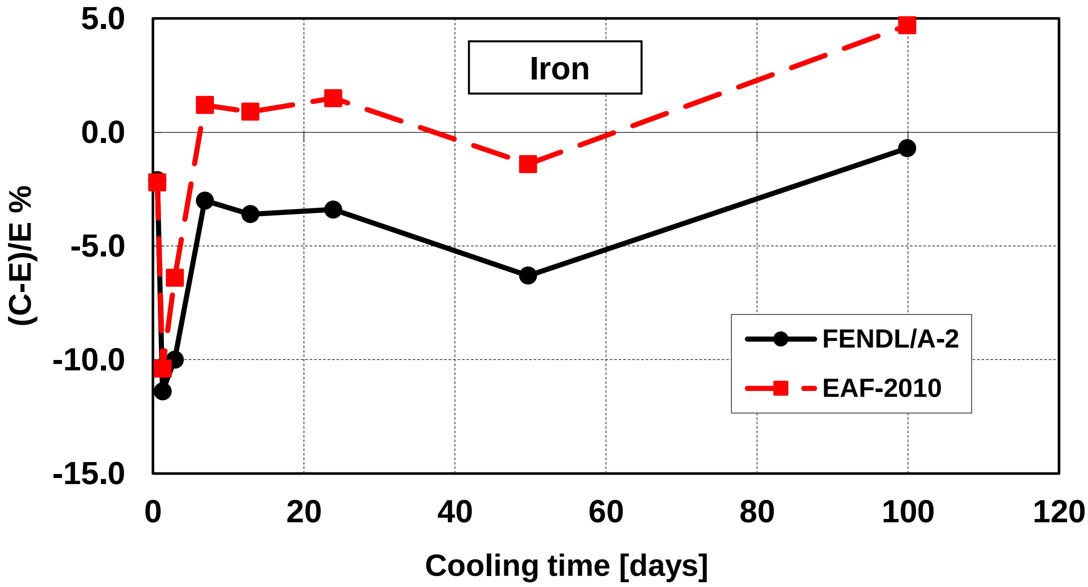

Figure 19 – Decay heat vs. cooling time of Iron sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Inconel-600 (Inconel)

Material composition : Cr 15.97, Mn 0.39, Fe 7.82, Ni 75.82

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	4.07E-01	2.91E-01	-28.4	2.95E-01	-27.5
1.4 (m)	3.81E-01	2.76E-01	-27.5	2.80E-01	-26.6
1.6 (m)	3.62E-01	2.61E-01	-27.8	2.65E-01	-26.8
2.0 (m)	3.29E-01	2.39E-01	-27.2	2.43E-01	-26.2
2.7 (m)	2.89E-01	2.12E-01	-26.6	2.15E-01	-25.6
3.3 (m)	2.56E-01	1.88E-01	-26.4	1.91E-01	-25.3
4.2 (m)	2.15E-01	1.60E-01	-25.8	1.62E-01	-24.6
5.3 (m)	1.74E-01	1.31E-01	-25.1	1.33E-01	-23.9
6.4 (m)	1.43E-01	1.08E-01	-24.8	1.10E-01	-23.4
8.0 (m)	1.09E-01	8.23E-02	-24.5	8.40E-02	-22.9
10.1 (m)	7.82E-02	5.96E-02	-23.8	6.10E-02	-22.0
12.3 (m)	5.76E-02	4.41E-02	-23.4	4.52E-02	-21.5
14.4 (m)	4.35E-02	3.36E-02	-22.7	3.45E-02	-20.6
17.5 (m)	3.11E-02	2.40E-02	-22.9	2.47E-02	-20.8
21.6 (m)	2.16E-02	1.70E-02	-21.4	1.75E-02	-19.1
25.7 (m)	1.67E-02	1.34E-02	-20.0	1.37E-02	-17.8
29.8 (m)	1.38E-02	1.14E-02	-17.1	1.17E-02	-15.3
37.0 (m)	1.14E-02	9.71E-03	-14.5	9.85E-03	-13.3
47.1 (m)	9.58E-03	8.60E-03	-10.3	8.64E-03	-9.8
57.2 (m)	8.70E-03	7.95E-03	-8.6	7.93E-03	-8.8

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.6 (d)	8.29E-02	8.12E-02	-2.1	8.14E-02	-1.9
1.3 (d)	5.70E-02	5.56E-02	-2.5	5.63E-02	-1.3
2.9 (d)	3.11E-02	3.09E-02	-0.6	3.15E-02	1.5
6.9 (d)	1.22E-02	1.24E-02	1.4	1.27E-02	4.4
12.9 (d)	8.55E-03	8.68E-03	1.4	8.94E-03	4.5
23.8 (d)	7.47E-03	7.64E-03	2.3	7.87E-03	5.3
49.7 (d)	5.92E-03	6.02E-03	1.8	6.21E-03	4.8
99.9 (d)	3.68E-03	3.87E-03	5.2	3.99E-03	8.5

Table 12 – Inconel-600 decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

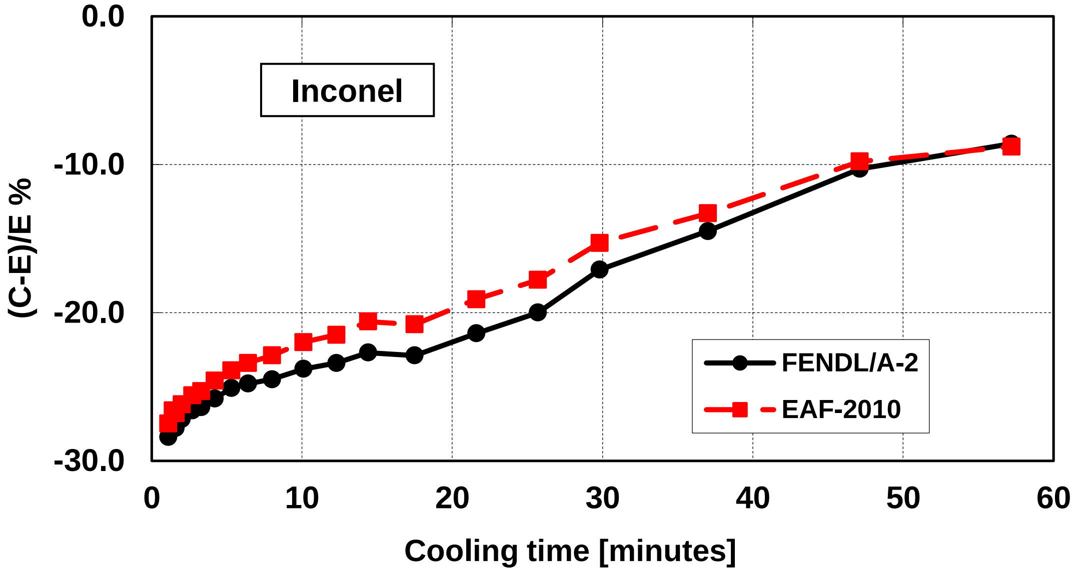

Figure 20 – Decay heat vs. cooling time of Inconel-600 sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

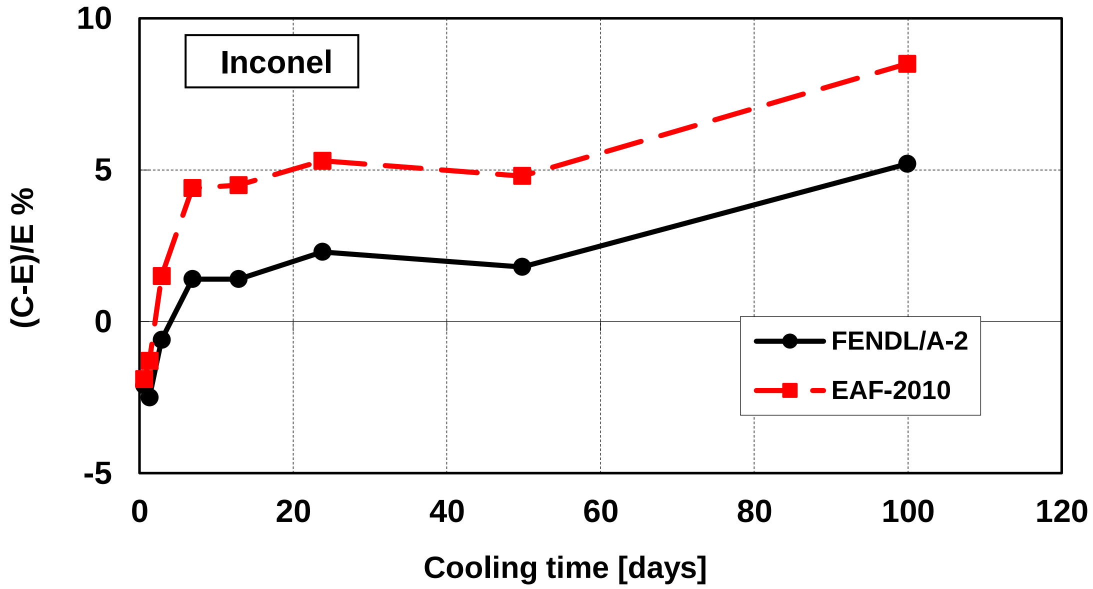

Figure 21 – Decay heat vs. cooling time of Inconel-600 sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Potassium Carbonate (K_2CO_3)

Material composition : C 8.69, O 34.73, K 56.58

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	1.25E-01	9.68E-02	-22.4	1.53E-01	23.0
1.4 (m)	1.11E-01	8.76E-02	-21.1	1.43E-01	28.9
1.6 (m)	1.06E-01	8.42E-02	-20.7	1.38E-01	30.3
2.1 (m)	1.02E-01	8.08E-02	-20.7	1.33E-01	30.4
2.7 (m)	9.64E-02	7.68E-02	-20.3	1.26E-01	30.6
3.3 (m)	9.19E-02	7.32E-02	-20.3	1.20E-01	30.2
4.1 (m)	8.55E-02	6.85E-02	-19.9	1.12E-01	30.4
5.2 (m)	7.79E-02	6.27E-02	-19.5	1.02E-01	30.4
6.4 (m)	7.10E-02	5.74E-02	-19.1	9.25E-02	30.3
8.0 (m)	6.22E-02	5.06E-02	-18.7	8.09E-02	29.9
10.1 (m)	5.25E-02	4.32E-02	-17.8	6.80E-02	29.6
12.2 (m)	4.46E-02	3.71E-02	-17.0	5.77E-02	29.2
14.3 (m)	3.78E-02	3.19E-02	-15.6	4.88E-02	29.2
17.5 (m)	2.99E-02	2.57E-02	-14.0	3.84E-02	28.4
21.6 (m)	2.28E-02	1.98E-02	-13.0	2.85E-02	25.1
25.7 (m)	1.74E-02	1.56E-02	-10.4	2.16E-02	23.6
29.8 (m)	1.40E-02	1.26E-02	-9.6	1.67E-02	19.3
37.0 (m)	1.00E-02	9.23E-03	-7.9	1.13E-02	12.6
47.1 (m)	6.73E-03	6.60E-03	-1.9	7.36E-03	9.5
57.2 (m)	4.99E-03	5.17E-03	3.6	5.43E-03	8.8

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.7 (d)	4.21E-04	3.84E-04	-8.7	3.90E-04	-7.4
1.7 (d)	6.62E-05	4.69E-05	-29.2	5.24E-05	-20.8
3.9 (d)	2.07E-05	5.09E-06	-75.4	1.10E-05	-47.0
6.7 (d)	1.40E-05	2.70E-06	-80.8	8.43E-06	-39.9
12.2 (d)	1.09E-05	2.64E-06	-75.7	8.10E-06	-25.4
24.2 (d)	6.72E-06	2.63E-06	-60.8	7.60E-06	13.1
49.9 (d)	2.68E-06	2.63E-06	-1.9	6.81E-06	154.6
100.1 (d)	3.53E-07	2.62E-06	640.0	5.84E-06	1553.1

Table 13 – Potassium Carbonate decay heat calculation-experiment comparison (5 minutes and 7 hours irradiation)

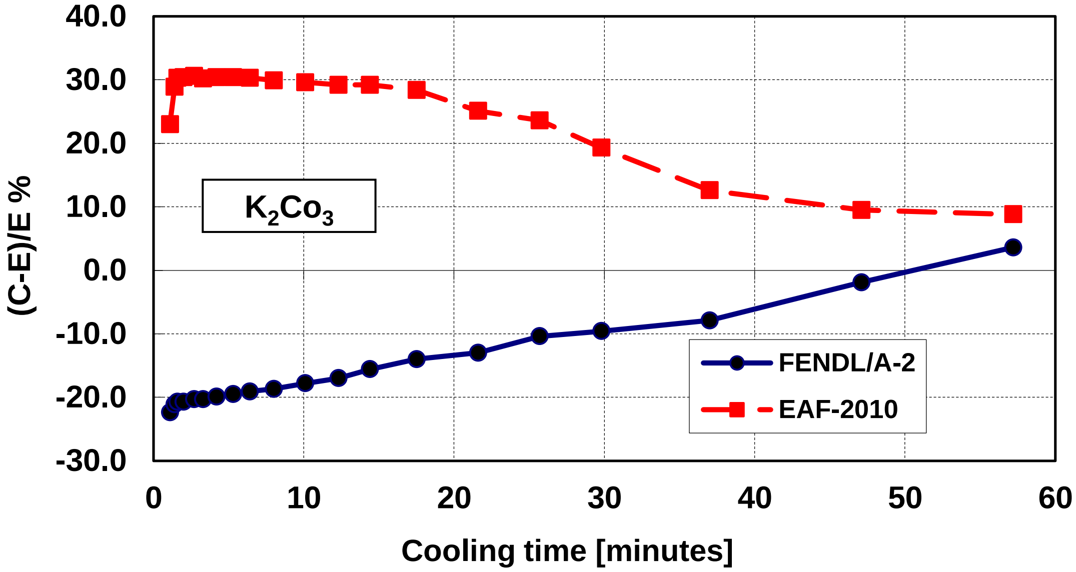

Figure 22 – Decay heat vs. cooling time of Potassium Carbonate sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

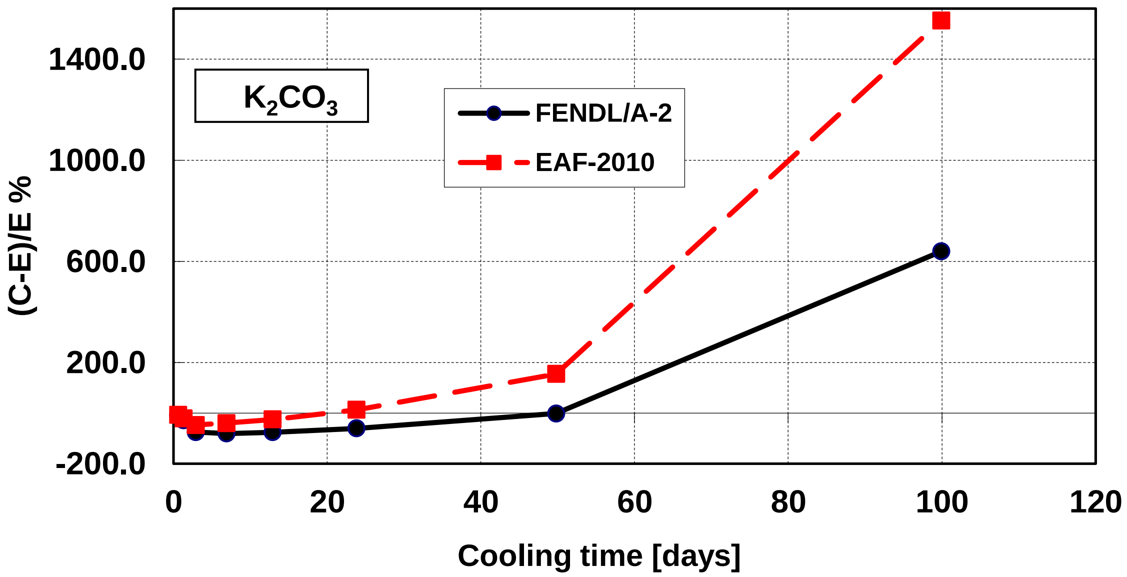

Figure 23 – Decay heat vs. cooling time of Potassium Carbonate sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Manganese (Mn)

Material composition : Mn 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	8.11E-01	9.78E-01	20.7	9.03E-01	11.4
1.4 (m)	7.67E-01	9.31E-01	21.3	8.59E-01	11.9
1.6 (m)	7.34E-01	8.85E-01	20.6	8.17E-01	11.2
2.1 (m)	6.74E-01	8.13E-01	20.6	7.50E-01	11.2
2.7 (m)	6.00E-01	7.24E-01	20.7	6.68E-01	11.3
3.3 (m)	5.33E-01	6.45E-01	21.0	5.95E-01	11.6
4.2 (m)	4.51E-01	5.45E-01	20.9	5.03E-01	11.5
5.3 (m)	3.67E-01	4.43E-01	20.6	4.08E-01	11.2
6.4 (m)	2.98E-01	3.59E-01	20.6	3.31E-01	11.0
8.1 (m)	2.22E-01	2.66E-01	19.4	2.44E-01	9.8
10.2 (m)	1.51E-01	1.80E-01	19.8	1.66E-01	10.0
12.3 (m)	1.03E-01	1.23E-01	19.0	1.12E-01	8.9
14.4 (m)	7.07E-02	8.37E-02	18.4	7.63E-02	7.9
17.6 (m)	4.20E-02	4.88E-02	16.0	4.40E-02	4.8
21.7 (m)	2.24E-02	2.53E-02	13.2	2.24E-02	0.3
25.8 (m)	1.30E-02	1.44E-02	11.1	1.24E-02	-4.4
29.9 (m)	8.65E-03	9.43E-03	9.0	7.83E-03	-9.5
37.0 (m)	5.97E-03	6.13E-03	2.7	4.82E-03	-19.1
47.2 (m)	4.79E-03	4.96E-03	3.7	3.79E-03	-20.8
57.3 (m)	4.16E-03	4.61E-03	10.9	3.50E-03	-15.7

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.7 (d)	8.58E-03	8.27E-03	-3.6	8.41E-03	-2.0
1.7 (d)	7.64E-03	7.71E-03	0.9	7.98E-03	4.5
3.9 (d)	7.52E-03	7.67E-03	2.0	7.94E-03	5.6
6.8 (d)	7.43E-03	7.62E-03	2.6	7.89E-03	6.2
12.2 (d)	7.25E-03	7.53E-03	3.8	7.80E-03	7.5
24.2 (d)	7.19E-03	7.33E-03	2.0	7.59E-03	5.6
50.0 (d)	6.74E-03	6.93E-03	2.7	7.17E-03	6.3
100.1 (d)	5.93E-03	6.20E-03	4.5	6.41E-03	8.2

Table 14 – Manganese decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

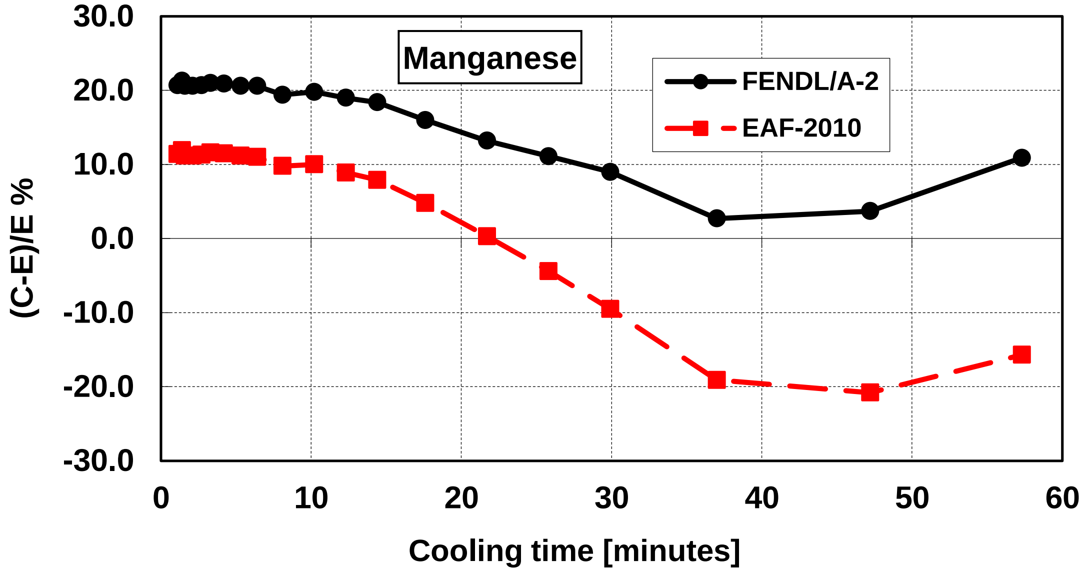

Figure 24 – Decay heat vs. cooling time of Manganese sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

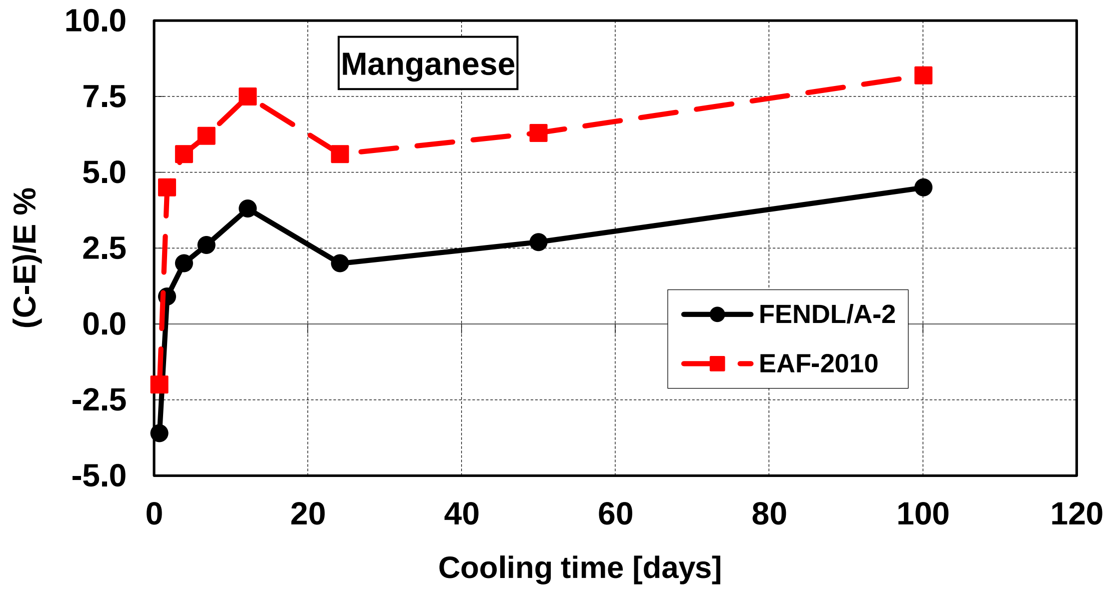

Figure 25 – Decay heat vs. cooling time of Manganese sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Molybdenum (Mo)

Material composition : Mo 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	2.32E-01	2.62E-01	12.8	2.90E-01	24.6
1.4 (m)	2.24E-01	2.54E-01	13.4	2.78E-01	23.9
1.6 (m)	2.17E-01	2.47E-01	14.1	2.67E-01	23.5
2.1 (m)	2.06E-01	2.37E-01	15.2	2.53E-01	23.0
2.7 (m)	1.95E-01	2.25E-01	15.6	2.37E-01	21.7
3.3 (m)	1.85E-01	2.16E-01	16.6	2.25E-01	21.4
4.2 (m)	1.75E-01	2.04E-01	16.5	2.11E-01	20.1
5.3 (m)	1.64E-01	1.92E-01	17.2	1.97E-01	20.0
6.3 (m)	1.55E-01	1.82E-01	17.5	1.86E-01	19.9
8.0 (m)	1.44E-01	1.68E-01	17.1	1.71E-01	19.2
10.1 (m)	1.30E-01	1.53E-01	17.3	1.56E-01	19.4
12.2 (m)	1.19E-01	1.40E-01	17.5	1.42E-01	19.5
14.3 (m)	1.08E-01	1.27E-01	17.2	1.29E-01	19.2
17.4 (m)	9.47E-02	1.11E-01	17.2	1.13E-01	19.3
21.5 (m)	7.96E-02	9.29E-02	16.7	9.46E-02	18.9
25.6 (m)	6.67E-02	7.76E-02	16.3	7.92E-02	18.6
29.6 (m)	5.62E-02	6.52E-02	15.8	6.65E-02	18.2
36.8 (m)	4.20E-02	4.81E-02	14.4	4.92E-02	17.0
46.9 (m)	2.80E-02	3.15E-02	12.5	3.23E-02	15.5
57.0 (m)	1.89E-02	2.09E-02	10.1	2.15E-02	13.6

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.6 (d)	8.87E-02	8.07E-02	-9.1	8.59E-02	-3.2
1.3 (d)	7.23E-02	6.51E-02	-10.0	6.97E-02	-3.6
2.9 (d)	4.54E-02	4.10E-02	-9.7	4.42E-02	-2.8
6.9 (d)	1.71E-02	1.52E-02	-10.7	1.64E-02	-4.1
12.9 (d)	4.71E-03	4.31E-03	-8.5	4.48E-03	-4.8
23.9 (d)	9.95E-04	1.03E-03	3.0	9.55E-04	-4.0
49.7 (d)	3.14E-04	3.73E-04	18.8	3.15E-04	0.1
99.9 (d)	1.07E-04	1.54E-04	44.0	1.24E-04	15.8

Table 15 – Molybdenum decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

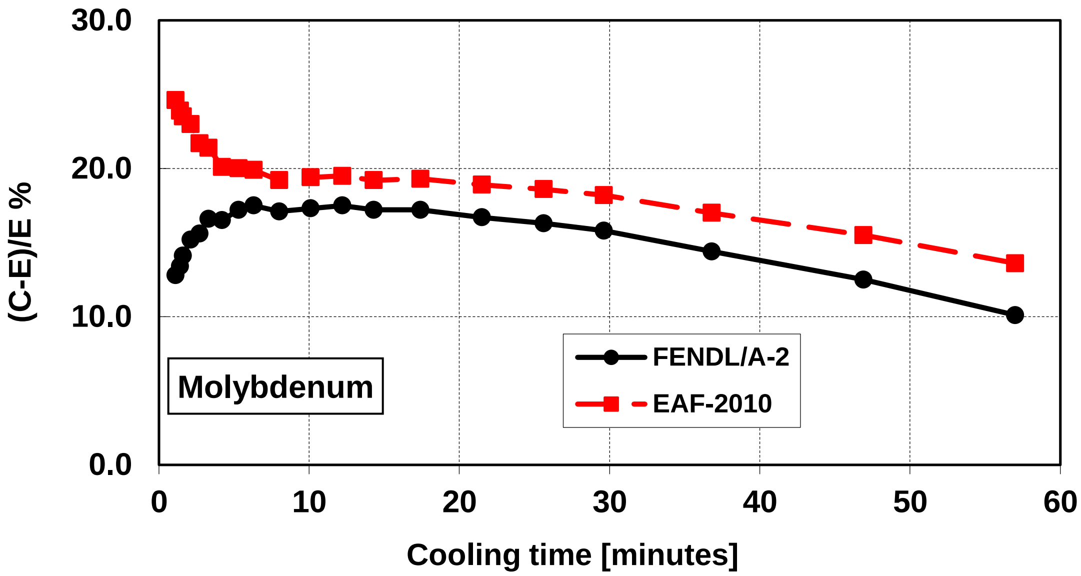

Figure 26 – Decay heat vs. cooling time of Molybdenum sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

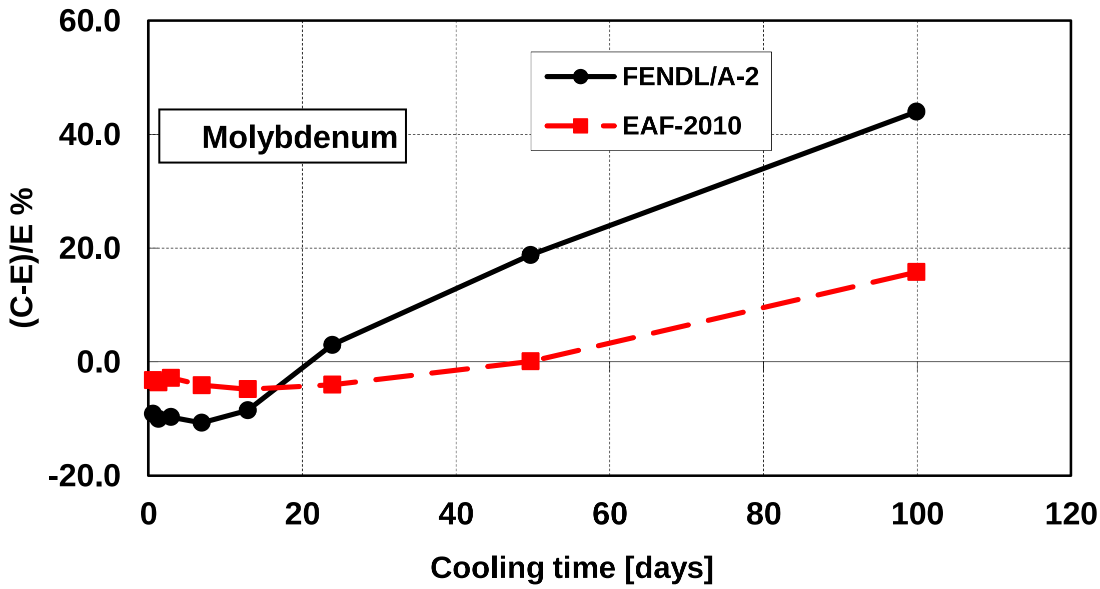

Figure 27 – Decay heat vs. cooling time of Molybdenum sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Sodium Carbonate (Na_2CO_3)

Material composition : C 11.33, O 45.29, Na 43.38

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.2 (m)	5.55E-01	4.92E-01	-11.2	5.24E-01	-5.4
1.5 (m)	3.68E-01	3.17E-01	-13.8	3.39E-01	-7.9
1.7 (m)	2.59E-01	2.18E-01	-15.6	2.34E-01	-9.5
2.2 (m)	1.53E-01	1.25E-01	-18.3	1.34E-01	-12.3
2.8 (m)	7.62E-02	6.17E-02	-19.1	6.63E-02	-13.0
3.4 (m)	3.85E-02	3.09E-02	-19.8	3.32E-02	-13.7
4.3 (m)	1.55E-02	1.16E-02	-25.5	1.25E-02	-19.6
5.4 (m)	4.97E-03	3.38E-03	-32.0	3.68E-03	-25.9
6.5 (m)	2.08E-03	1.09E-03	-47.6	1.22E-03	-41.4
8.1 (m)	1.08E-03	2.53E-04	-76.6	3.20E-04	-70.3
10.2 (m)	7.92E-04	1.07E-04	-86.5	1.63E-04	-79.4
12.4 (m)	7.82E-04	9.32E-05	-88.1	1.48E-04	-81.1
14.5 (m)	7.49E-04	9.18E-05	-87.7	1.47E-04	-80.4
17.6 (m)	6.82E-04	9.15E-05	-86.6	1.46E-04	-78.6
21.7 (m)	6.67E-04	9.12E-05	-86.3	1.46E-04	-78.1
25.8 (m)	5.93E-04	9.09E-05	-84.7	1.45E-04	-75.5
29.9 (m)	5.28E-04	9.07E-05	-82.8	1.45E-04	-72.6
37.0 (m)	5.28E-04	9.02E-05	-82.9	1.44E-04	-72.7
47.1 (m)	4.95E-04	8.95E-05	-81.9	1.43E-04	-71.1
57.2 (m)	3.42E-04	8.89E-05	-74.0	1.42E-04	-58.5

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.7 (d)	3.73E-03	2.04E-03	-45.2	4.11E-03	10.2
1.7 (d)	1.29E-03	8.45E-04	-34.5	1.46E-03	13.2
3.9 (d)	4.55E-04	3.55E-04	-22.0	3.81E-04	-16.4
6.7 (d)	3.82E-04	3.07E-04	-19.7	2.76E-04	-27.7
12.2 (d)	3.73E-04	3.04E-04	-18.7	2.71E-04	-27.5
24.2 (d)	3.77E-04	3.01E-04	-20.2	2.68E-04	-28.8
49.9 (d)	3.82E-04	2.95E-04	-22.7	2.63E-04	-31.1
100.1 (d)	3.49E-04	2.85E-04	-18.4	2.54E-04	-27.2

Table 16 – Sodium Carbonate decay heat calculation-experiment comparison (5 minutes and 7 hours irradiation)

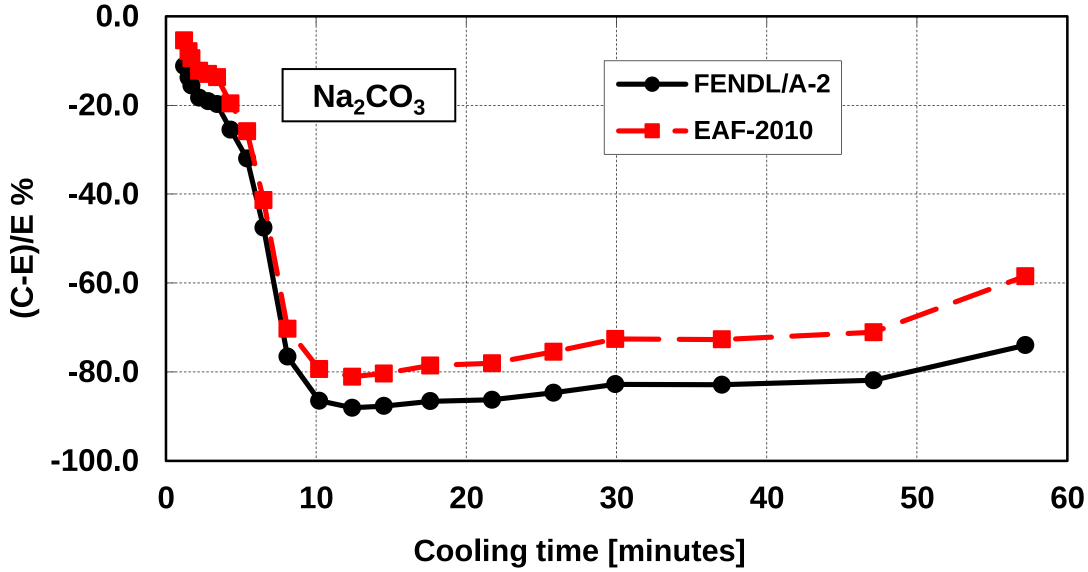

Figure 28 – Decay heat vs. cooling time of Sodium Carbonate sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

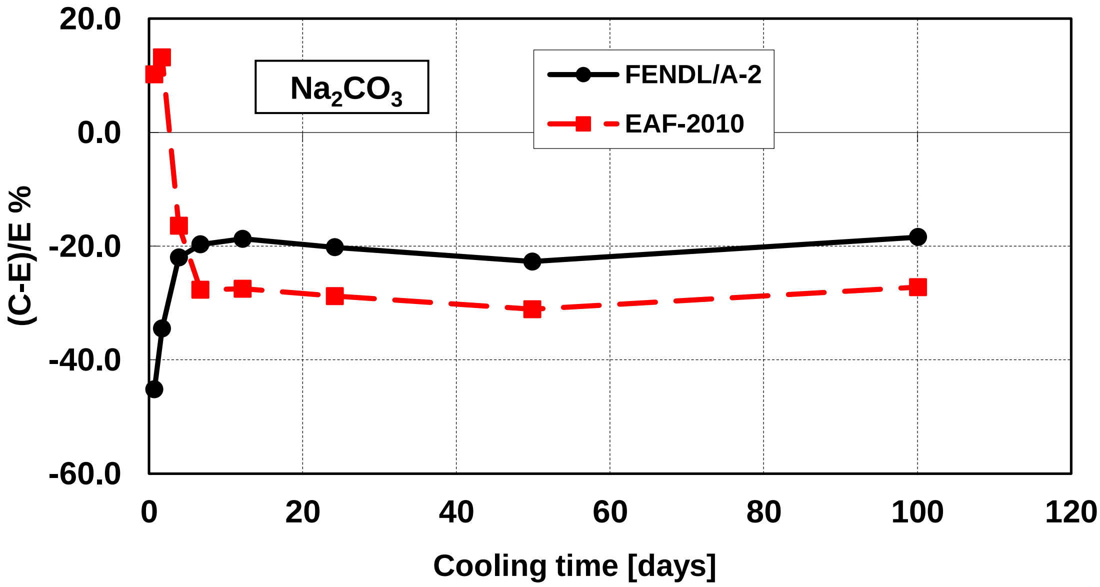

Figure 29 – Decay heat vs. cooling time of Sodium Carbonate sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Niobium (Nb)

Material composition : Nb 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.0 (m)	3.73E-03	3.84E-03	3.0	4.90E-03	31.6
1.3 (m)	3.07E-03	3.30E-03	7.5	3.88E-03	26.4
1.5 (m)	2.63E-03	3.01E-03	14.3	3.35E-03	27.3
2.0 (m)	2.38E-03	2.79E-03	17.1	2.97E-03	25.0
2.6 (m)	2.29E-03	2.66E-03	16.5	2.80E-03	22.3
3.2 (m)	2.26E-03	2.59E-03	14.8	2.72E-03	20.2
4.1 (m)	2.23E-03	2.52E-03	13.0	2.64E-03	18.3
5.2 (m)	2.21E-03	2.44E-03	10.4	2.55E-03	15.7
6.3 (m)	2.13E-03	2.36E-03	10.7	2.48E-03	16.1
7.9 (m)	2.10E-03	2.27E-03	7.9	2.38E-03	13.3
10.1 (m)	2.03E-03	2.17E-03	6.6	2.28E-03	12.0
12.2 (m)	1.99E-03	2.08E-03	4.7	2.19E-03	10.1
14.2 (m)	1.98E-03	2.02E-03	2.3	2.13E-03	7.7
17.4 (m)	1.92E-03	1.95E-03	1.4	2.05E-03	6.9
21.5 (m)	1.88E-03	1.88E-03	-0.3	1.98E-03	5.2
25.6 (m)	1.83E-03	1.83E-03	0.1	1.93E-03	5.6
29.7 (m)	1.81E-03	1.80E-03	-0.3	1.90E-03	5.2
36.8 (m)	1.78E-03	1.76E-03	-0.8	1.86E-03	4.7
46.9 (m)	1.74E-03	1.73E-03	-0.7	1.83E-03	4.8
57.0 (m)	1.71E-03	1.71E-03	-0.1	1.80E-03	5.3

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.6 (d)	1.09E-01	1.05E-01	-4.1	1.08E-01	-1.4
1.3 (d)	1.03E-01	9.83E-02	-4.7	1.01E-01	-2.3
2.9 (d)	9.08E-02	8.70E-02	-4.1	8.87E-02	-2.3
6.9 (d)	6.81E-02	6.50E-02	-4.5	6.57E-02	-3.5
12.9 (d)	4.48E-02	4.26E-02	-5.0	4.28E-02	-4.4
23.9 (d)	2.10E-02	2.00E-02	-4.9	2.01E-02	-4.6
49.7 (d)	3.62E-03	3.42E-03	-5.5	3.43E-03	-5.3
99.9 (d)	1.25E-04	1.12E-04	-10.9	1.12E-04	-10.6

Table 17 – Niobium decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

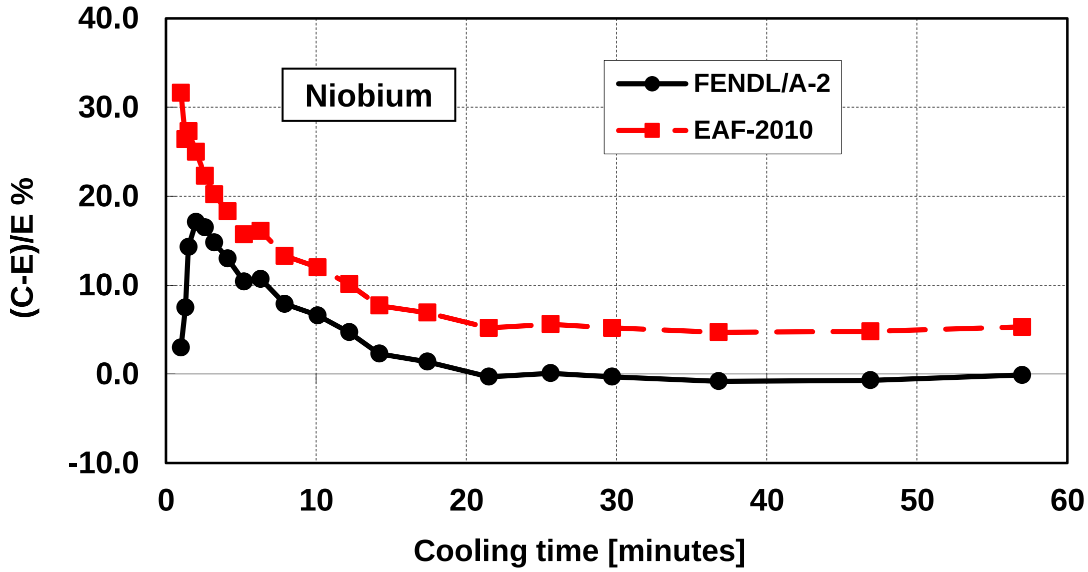

Figure 30 – Decay heat vs. cooling time of Niobium sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

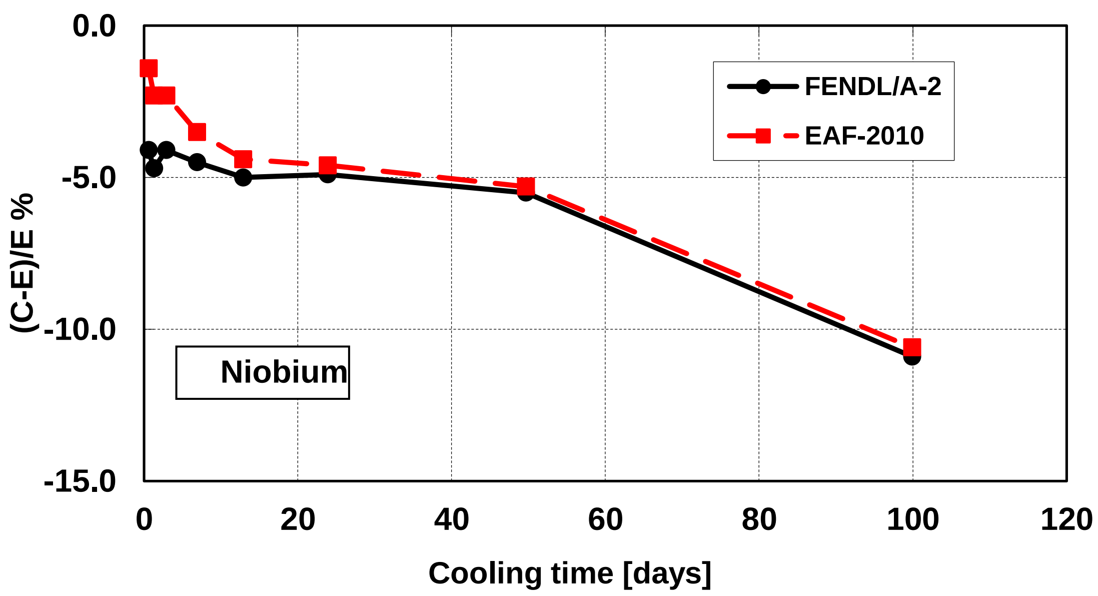

Figure 31 – Decay heat vs. cooling time of Niobium sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Nickel (Ni)

Material composition : Ni 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling ime	μW/g	μW/g		μW/g	
1.1 (m)	4.37E-02	3.79E-02	-13.2	3.83E-02	-12.2
1.4 (m)	4.04E-02	3.51E-02	-13.1	3.57E-02	-11.5
1.6 (m)	3.61E-02	3.24E-02	-10.0	3.32E-02	-7.9
2.1 (m)	3.15E-02	2.86E-02	-9.3	2.96E-02	-6.2
2.7 (m)	2.68E-02	2.44E-02	-8.9	2.56E-02	-4.6
3.3 (m)	2.31E-02	2.13E-02	-7.9	2.26E-02	-2.3
4.2 (m)	1.95E-02	1.78E-02	-8.5	1.92E-02	-1.3
5.3 (m)	1.66E-02	1.49E-02	-10.2	1.63E-02	-1.3
6.4 (m)	1.45E-02	1.29E-02	-11.4	1.44E-02	-1.3
8.0 (m)	1.27E-02	1.10E-02	-13.2	1.24E-02	-1.9
10.1 (m)	1.12E-02	9.44E-03	-15.7	1.08E-02	-3.9
12.3 (m)	1.01E-02	8.38E-03	-16.9	9.60E-03	-4.9
14.4 (m)	9.26E-03	7.57E-03	-18.2	8.68E-03	-6.3
17.5 (m)	8.02E-03	6.64E-03	-17.3	7.59E-03	-5.3
21.5 (m)	6.92E-03	5.68E-03	-18.0	6.46E-03	-6.6
25.6 (m)	5.99E-03	4.92E-03	-17.9	5.57E-03	-7.1
29.8 (m)	5.16E-03	4.33E-03	-16.0	4.85E-03	-5.9
36.9 (m)	4.10E-03	3.59E-03	-12.5	3.95E-03	-3.7
47.0 (m)	3.15E-03	2.93E-03	-7.0	3.15E-03	-0.2
57.1 (m)	2.59E-03	2.55E-03	-1.6	2.67E-03	3.1

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.6 (d)	9.17E-02	1.01E-01	9.6	1.01E-01	9.8
1.3 (d)	7.01E-02	7.29E-02	4.1	7.38E-02	5.3
2.9 (d)	3.96E-02	4.04E-02	1.9	4.12E-02	4.0
6.9 (d)	1.59E-02	1.60E-02	0.1	1.64E-02	3.1
12.9 (d)	1.13E-02	1.11E-02	-1.1	1.15E-02	2.0
23.8 (d)	9.92E-03	9.83E-03	-0.9	1.01E-02	2.1
49.7 (d)	7.87E-03	7.79E-03	-1.0	8.03E-03	2.0
99.9 (d)	4.93E-03	5.02E-03	2.0	5.18E-03	5.2

Table 18 – Nickel decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

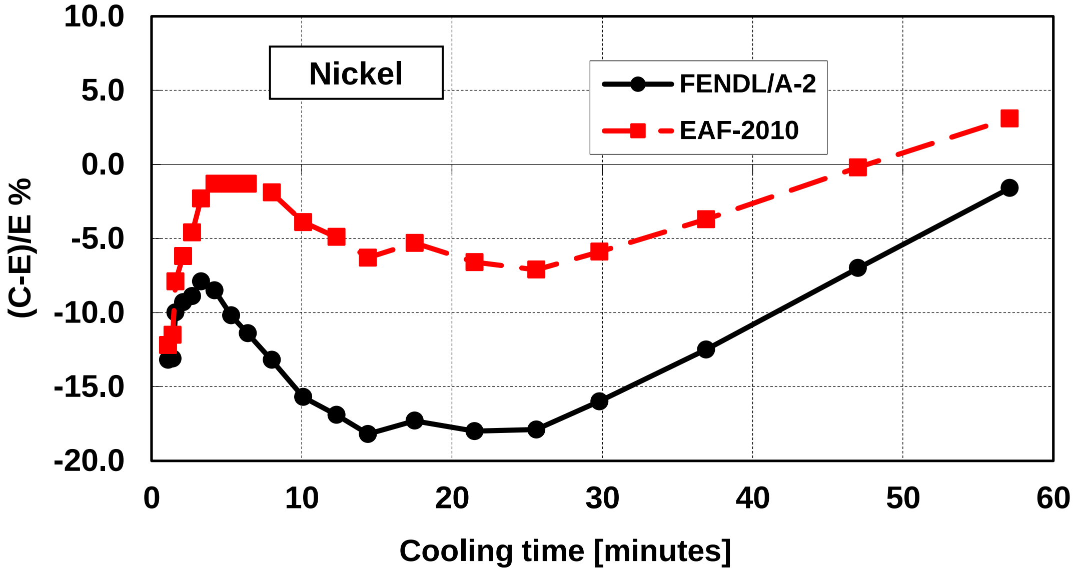

Figure 32 – Decay heat vs. cooling time of Nickel sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

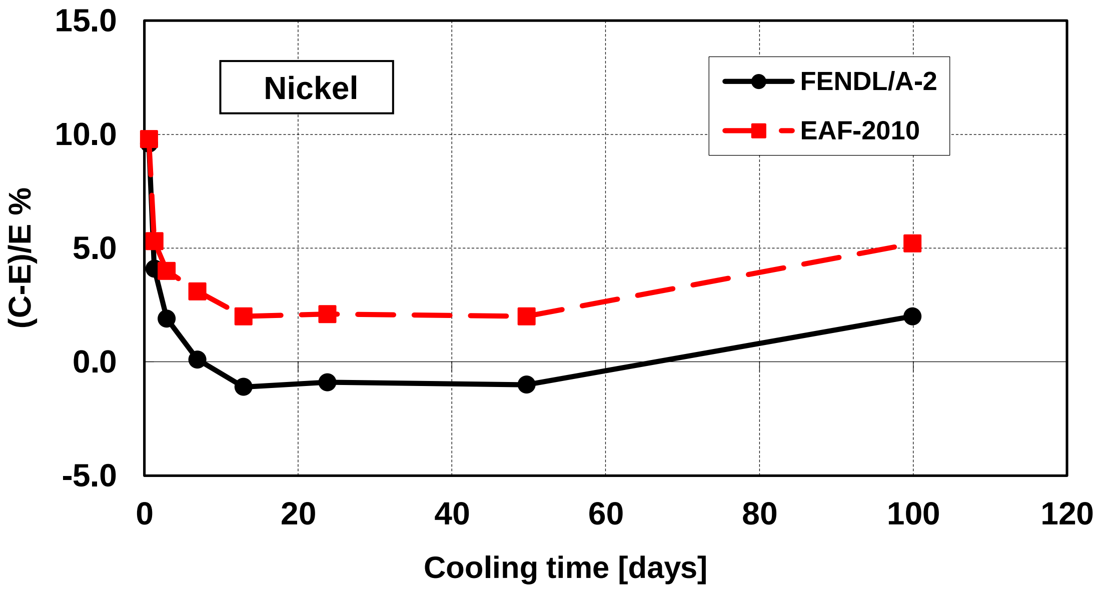

Figure 33 – Decay heat vs. cooling time of Nickel sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Nichrome (NiChro)

Material composition : Cr 19.64, Fe 0.06, Ni 80.30

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	4.22E-01	3.36E-01	-20.6	3.42E-01	-19.1
1.4 (m)	3.96E-01	3.17E-01	-20.1	3.23E-01	-18.6
1.6 (m)	3.75E-01	3.00E-01	-20.1	3.05E-01	-18.6
2.1 (m)	3.35E-01	2.73E-01	-18.6	2.78E-01	-17.0
2.7 (m)	2.96E-01	2.40E-01	-19.0	2.45E-01	-17.5
3.3 (m)	2.57E-01	2.12E-01	-17.4	2.16E-01	-15.7
4.2 (m)	2.18E-01	1.79E-01	-18.0	1.83E-01	-16.3
5.3 (m)	1.78E-01	1.46E-01	-17.7	1.49E-01	-15.8
6.4 (m)	1.44E-01	1.19E-01	-17.2	1.22E-01	-15.2
8.0 (m)	1.07E-01	8.95E-02	-16.3	9.20E-02	-14.0
10.1 (m)	7.32E-02	6.20E-02	-15.3	6.40E-02	-12.6
12.2 (m)	5.15E-02	4.36E-02	-15.4	4.52E-02	-12.3
14.4 (m)	3.65E-02	3.10E-02	-14.9	3.24E-02	-11.3
17.5 (m)	2.31E-02	1.95E-02	-15.4	2.05E-02	-10.9
21.6 (m)	1.35E-02	1.14E-02	-15.2	1.22E-02	-9.4
25.7 (m)	8.42E-03	7.38E-03	-12.4	7.98E-03	-5.2
29.8 (m)	5.89E-03	5.29E-03	-10.2	5.77E-03	-2.0
37.0 (m)	4.02E-03	3.63E-03	-9.5	3.97E-03	-1.1
47.1 (m)	2.93E-03	2.74E-03	-6.5	2.96E-03	0.8
57.2 (m)	2.47E-03	2.35E-03	-5.2	2.48E-03	0.4

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.6 (d)	7.40E-02	7.94E-02	7.4	7.97E-02	7.7
1.3 (d)	5.75E-02	5.90E-02	2.6	5.98E-02	3.8
2.9 (d)	3.26E-02	3.28E-02	0.6	3.35E-02	2.7
6.9 (d)	1.31E-02	1.31E-02	0.2	1.35E-02	3.1
12.8 (d)	9.18E-03	9.17E-03	-0.1	9.45E-03	2.9
23.8 (d)	8.07E-03	8.07E-03	0.0	8.31E-03	3.0
49.7 (d)	6.37E-03	6.35E-03	-0.3	6.54E-03	2.7
99.9 (d)	3.96E-03	4.06E-03	2.6	4.19E-03	5.8

Table 19 – Nichrome decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

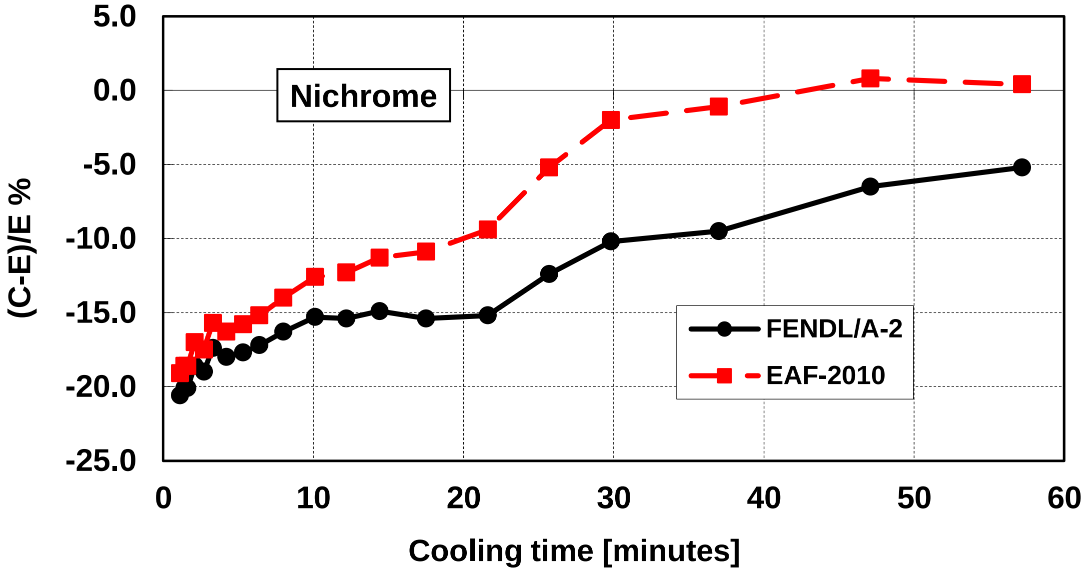

Figure 34 – Decay heat vs. cooling time of Nichrome sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

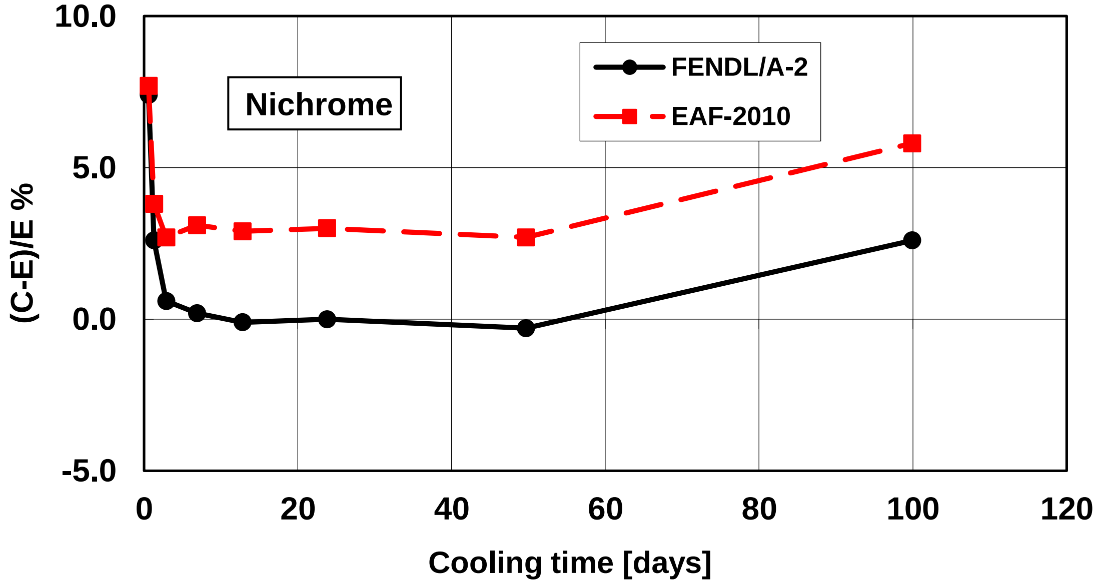

Figure 35 – Decay heat vs. cooling time of Nichrome sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Lead (Pb)

Material composition : Pb 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	1.04E-02	7.68E-03	-26.2	7.12E-03	-31.7
1.4 (m)	1.01E-02	7.31E-03	-27.5	6.75E-03	-33.1
1.6 (m)	9.40E-03	6.94E-03	-26.1	6.38E-03	-32.0
2.1 (m)	8.45E-03	6.42E-03	-24.1	5.86E-03	-30.7
2.7 (m)	7.59E-03	5.77E-03	-23.9	5.21E-03	-31.3
3.3 (m)	6.77E-03	5.20E-03	-23.1	4.65E-03	-31.3
4.2 (m)	5.71E-03	4.50E-03	-21.2	3.96E-03	-30.7
5.3 (m)	4.74E-03	3.80E-03	-19.8	3.28E-03	-30.9
6.4 (m)	3.93E-03	3.21E-03	-18.2	2.71E-03	-31.1
8.0 (m)	3.05E-03	2.55E-03	-16.4	2.08E-03	-32.0
10.1 (m)	2.20E-03	1.97E-03	-10.6	1.53E-03	-30.4
12.2 (m)	1.73E-03	1.56E-03	-9.9	1.16E-03	-33.0
14.3 (m)	1.36E-03	1.29E-03	-5.3	9.17E-04	-32.5
17.5 (m)	1.05E-03	1.03E-03	-2.4	6.96E-04	-33.7
21.5 (m)	8.10E-04	8.36E-04	3.2	5.44E-04	-32.8
25.6 (m)	7.01E-04	7.29E-04	4.1	4.66E-04	-33.6
29.8 (m)	6.32E-04	6.64E-04	5.0	4.21E-04	-33.4
36.8 (m)	5.61E-04	5.96E-04	6.2	3.78E-04	-32.7
47.0 (m)	4.89E-04	5.33E-04	8.9	3.40E-04	-30.5
57.1 (m)	4.21E-04	4.84E-04	14.9	3.11E-04	-26.1

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.6 (d)	4.46E-03	4.22E-03	-5.3	4.09E-03	-8.3
1.3 (d)	3.52E-03	3.35E-03	-5.0	3.24E-03	-8.0
2.9 (d)	2.08E-03	2.02E-03	-2.7	1.95E-03	-5.9
6.9 (d)	5.83E-04	5.69E-04	-2.5	5.48E-04	-6.1
12.9 (d)	9.62E-05	8.46E-05	-12.0	8.07E-05	-16.1
23.9 (d)	9.09E-06	3.34E-06	-63.3	2.89E-06	-68.2
49.7 (d)	1.11E-05	5.91E-07	-94.7	3.72E-07	-96.7

Table 20 – Lead decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

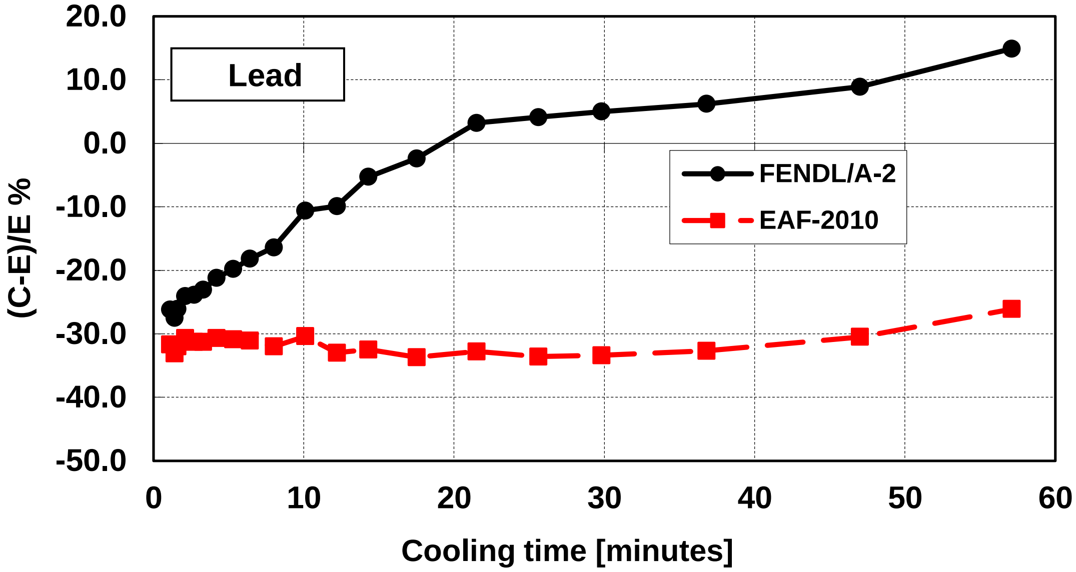

Figure 36 – Decay heat vs. cooling time of Lead sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

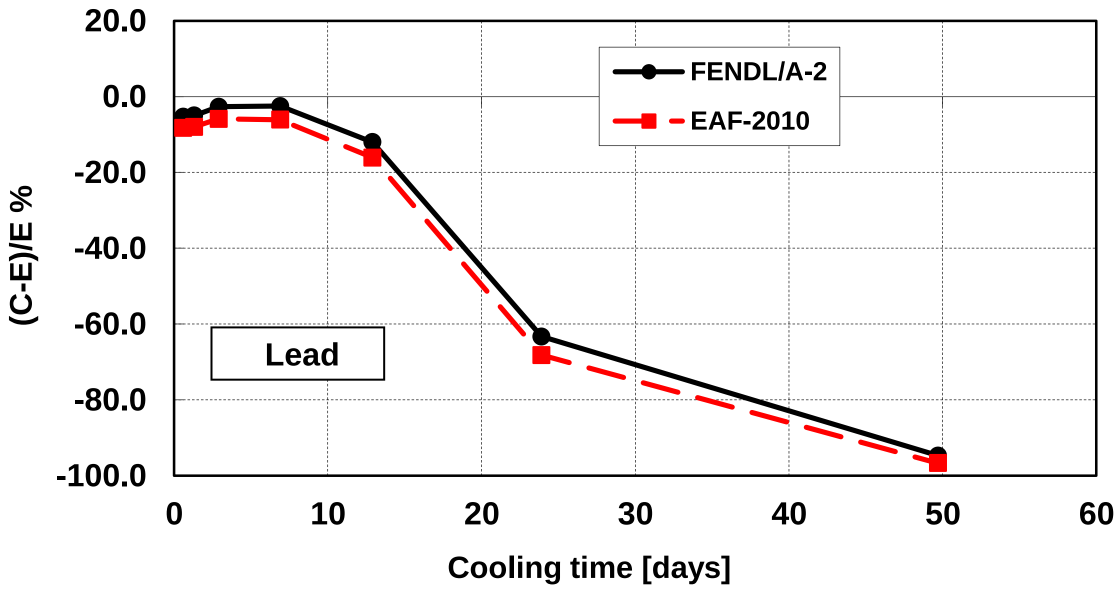

Figure 37 – Decay heat vs. cooling time of Lead sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Rhenium (Re)

Material composition : Re 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	µW/g	µW/g		µW/g	
1.1 (m)	3.72E-03	3.14E-03	-15.7	3.11E-03	-16.4
1.4 (m)	2.83E-03	3.07E-03	8.5	3.05E-03	7.5
1.6 (m)	2.52E-03	3.01E-03	19.5	2.99E-03	18.3
2.1 (m)	2.55E-03	2.93E-03	14.6	2.90E-03	13.4
2.6 (m)	2.20E-03	2.84E-03	28.9	2.81E-03	27.5
3.3 (m)	2.30E-03	2.76E-03	19.8	2.73E-03	18.4
4.2 (m)	2.29E-03	2.67E-03	16.5	2.64E-03	15.2
5.3 (m)	2.03E-03	2.60E-03	28.0	2.57E-03	26.5
6.4 (m)	2.02E-03	2.55E-03	26.1	2.52E-03	24.7
8.0 (m)	2.04E-03	2.50E-03	22.6	2.47E-03	21.2
10.1 (m)	2.00E-03	2.46E-03	23.1	2.44E-03	21.9
12.2 (m)	2.00E-03	2.43E-03	21.6	2.41E-03	20.6
14.3 (m)	2.10E-03	2.41E-03	14.7	2.39E-03	13.8
17.4 (m)	2.00E-03	2.39E-03	19.3	2.37E-03	18.6
21.5 (m)	1.93E-03	2.36E-03	22.4	2.35E-03	21.9
25.7 (m)	1.93E-03	2.34E-03	21.0	2.33E-03	20.7
29.8 (m)	1.88E-03	2.32E-03	23.3	2.31E-03	23.1
36.9 (m)	1.94E-03	2.29E-03	18.1	2.29E-03	18.1
47.0 (m)	1.89E-03	2.25E-03	19.0	2.26E-03	19.3
57.0 (m)	1.84E-03	2.23E-03	21.3	2.24E-03	21.8

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	µW/g	µW/g		µW/g	
0.7 (d)	1.14E-01	1.10E-01	-3.9	1.13E-01	-1.2
1.7 (d)	9.32E-02	9.07E-02	-2.7	9.31E-02	-0.1
3.9 (d)	6.71E-02	6.52E-02	-2.8	6.61E-02	-1.5
6.8 (d)	4.61E-02	4.46E-02	-3.3	4.40E-02	-4.4
12.2 (d)	2.61E-02	2.52E-02	-3.4	2.36E-02	-9.6
24.2 (d)	1.37E-02	1.33E-02	-2.9	1.15E-02	-16.2
50.0 (d)	7.88E-03	7.95E-03	0.9	6.72E-03	-14.7
100.1 (d)	3.39E-03	3.69E-03	8.8	3.10E-03	-8.4

Table 21 – Rhenium decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

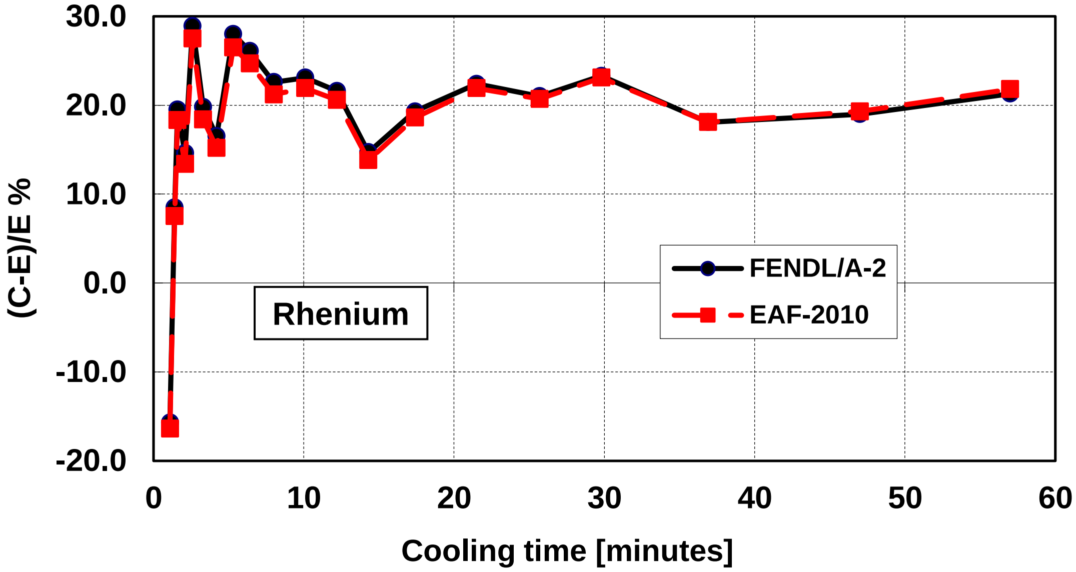

Figure 38 – Decay heat vs. cooling time of Rhenium sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

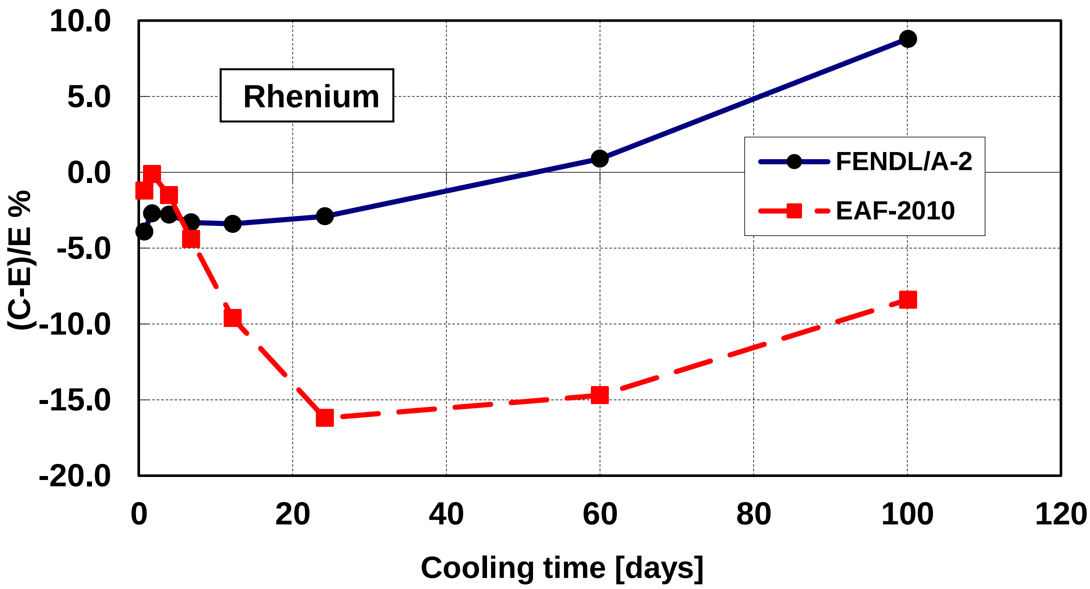

Figure 39 – Decay heat vs. cooling time of Rhenium sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Sulfur (S)

Material composition : S 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	1.36E-02	1.57E-02	15.2	1.33E-02	-2.1
1.4 (m)	9.54E-03	1.16E-02	21.9	9.46E-03	-0.9
1.6 (m)	7.28E-03	9.66E-03	32.6	7.64E-03	4.8
2.1 (m)	6.60E-03	8.31E-03	25.9	6.52E-03	-1.2
2.7 (m)	6.43E-03	7.57E-03	17.8	6.06E-03	-5.8
3.3 (m)	6.42E-03	7.11E-03	10.8	5.82E-03	-9.3
4.1 (m)	6.14E-03	6.62E-03	7.9	5.59E-03	-9.0
5.2 (m)	5.70E-03	6.12E-03	7.4	5.35E-03	-6.2
6.4 (m)	5.43E-03	5.75E-03	5.9	5.17E-03	-4.8
8.0 (m)	5.15E-03	5.37E-03	4.4	4.98E-03	-3.3
10.1 (m)	5.08E-03	5.06E-03	-0.3	4.82E-03	-5.1
12.2 (m)	4.89E-03	4.87E-03	-0.4	4.71E-03	-3.7
14.4 (m)	4.85E-03	4.75E-03	-2.1	4.64E-03	-4.4
17.4 (m)	4.61E-03	4.64E-03	0.6	4.56E-03	-1.2
21.5 (m)	4.49E-03	4.54E-03	1.1	4.48E-03	-0.3
25.6 (m)	4.37E-03	4.46E-03	2.2	4.41E-03	0.9
29.7 (m)	4.26E-03	4.39E-03	3.2	4.34E-03	2.0
36.8 (m)	4.17E-03	4.28E-03	2.7	4.23E-03	1.4
46.9 (m)	3.99E-03	4.13E-03	3.6	4.08E-03	2.3
57.0 (m)	3.89E-03	3.98E-03	2.4	3.93E-03	1.1

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.7 (d)	6.87E-02	6.64E-02	-3.4	6.63E-02	-3.6
1.7 (d)	6.38E-02	6.12E-02	-4.0	6.12E-02	-4.1
3.9 (d)	5.77E-02	5.51E-02	-4.4	5.51E-02	-4.5
6.8 (d)	5.02E-02	4.80E-02	-4.5	4.80E-02	-4.5
12.2 (d)	3.84E-02	3.68E-02	-4.1	3.68E-02	-4.1
24.2 (d)	2.17E-02	2.05E-02	-5.5	2.06E-02	-5.5
50.0 (d)	6.13E-03	5.88E-03	-4.1	5.89E-03	-4.0
100.1 (d)	5.27E-04	5.17E-04	-2.0	5.18E-04	-1.6

Table 22 – Sulfur decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

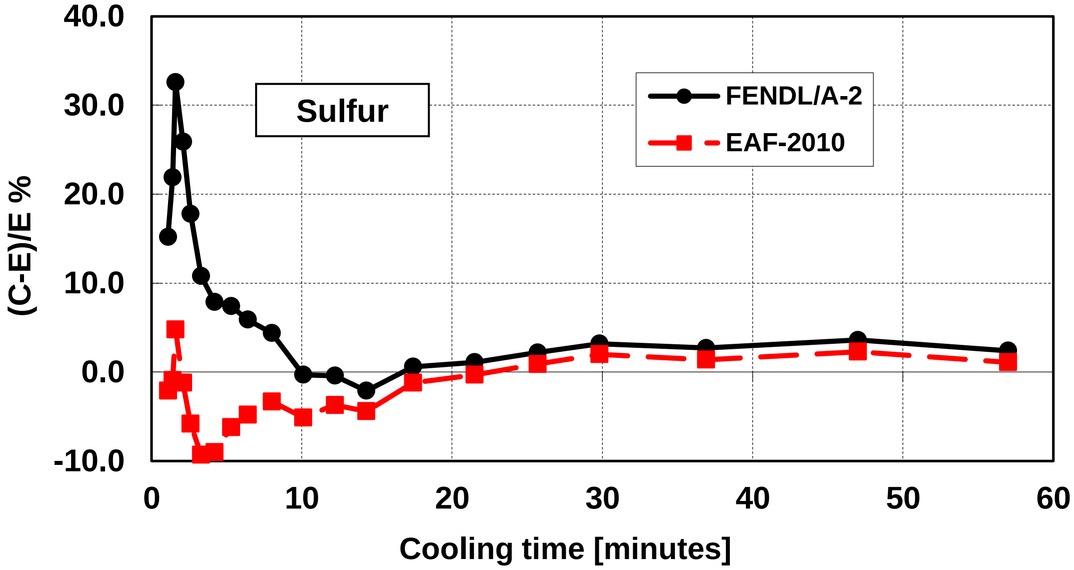

Figure 40 – Decay heat vs. cooling time of Sulfur sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

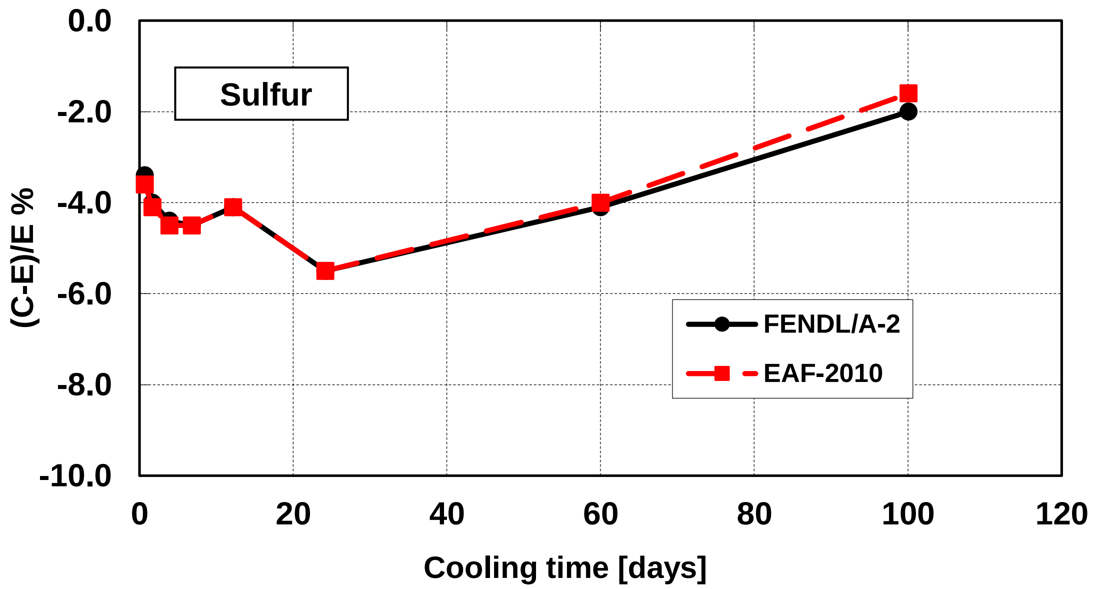

Figure 41 – Decay heat vs. cooling time of Sulfur sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Silicon Dioxide (SiO_2)

Material composition : O 53.26, Si 46.74

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	7.55E+00	6.31E+00	-16.4	6.01E+00	-20.3
1.4 (m)	6.94E+00	5.82E+00	-16.2	5.54E+00	-20.3
1.7 (m)	6.37E+00	5.36E+00	-15.8	5.10E+00	-19.9
2.1 (m)	5.59E+00	4.70E+00	-15.9	4.47E+00	-20.1
2.7 (m)	4.63E+00	3.91E+00	-15.7	3.70E+00	-20.1
3.4 (m)	3.83E+00	3.23E+00	-15.7	3.05E+00	-20.3
4.2 (m)	2.95E+00	2.49E+00	-15.4	2.35E+00	-20.3
5.3 (m)	2.11E+00	1.79E+00	-15.3	1.68E+00	-20.6
6.4 (m)	1.53E+00	1.30E+00	-15.1	1.21E+00	-20.9
8.1 (m)	9.59E-01	8.10E-01	-15.5	7.45E-01	-22.3
10.1 (m)	5.24E-01	4.53E-01	-13.6	4.08E-01	-22.2
12.2 (m)	2.89E-01	2.56E-01	-11.5	2.24E-01	-22.6
14.4 (m)	1.63E-01	1.50E-01	-8.2	1.26E-01	-22.7
17.5 (m)	7.77E-02	7.39E-02	-4.9	5.81E-02	-25.3
21.5 (m)	3.28E-02	3.40E-02	3.7	2.42E-02	-26.2
25.6 (m)	1.68E-02	1.82E-02	8.3	1.20E-02	-28.5
29.7 (m)	1.09E-02	1.09E-02	0.5	6.93E-03	-36.1
36.8 (m)	6.04E-03	5.04E-03	-16.6	3.19E-03	-47.2
46.9 (m)	3.53E-03	1.86E-03	-47.4	1.22E-03	-65.3
57.0 (m)	2.13E-03	7.11E-04	-66.6	4.96E-04	-76.7

Table 23 – Silicon Dioxide decay heat calculation-experiment comparison
(5 minutes irradiation)

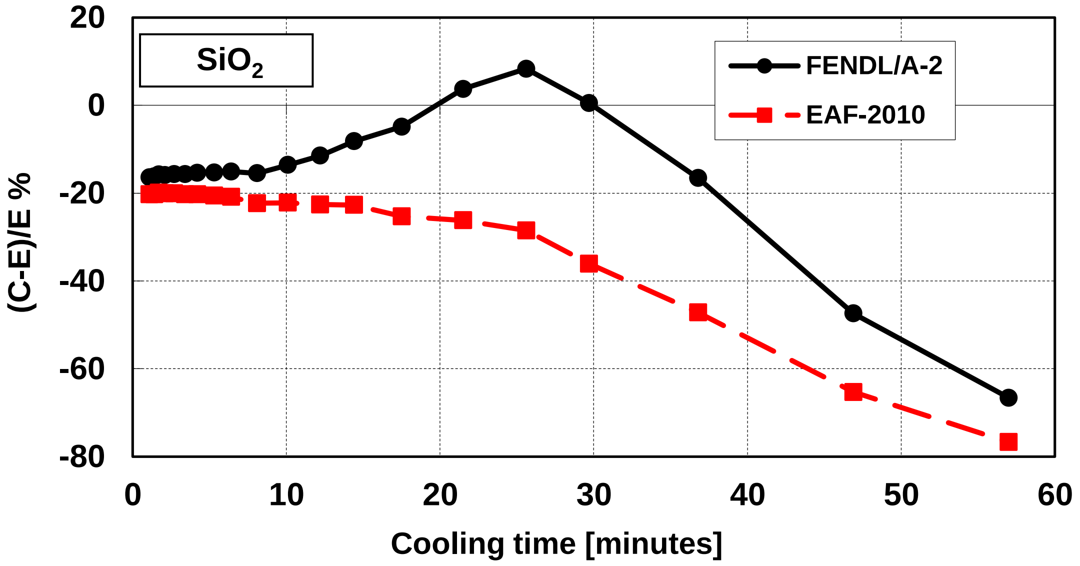

Figure 42 – Decay heat vs. cooling time of Silicon Dioxide sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

Tin Dioxide (SnO_2)

Material composition : O 21.23, Sn 78.77

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	7.07E-02	4.70E-02	-33.5	6.56E-02	-7.1
1.4 (m)	6.61E-02	3.90E-02	-41.0	5.67E-02	-14.3
1.6 (m)	6.31E-02	3.54E-02	-43.9	5.21E-02	-17.3
2.1 (m)	5.78E-02	3.18E-02	-45.0	4.73E-02	-18.3
2.7 (m)	5.32E-02	2.86E-02	-46.2	4.27E-02	-19.7
3.3 (m)	4.88E-02	2.65E-02	-45.7	3.95E-02	-19.1
4.2 (m)	4.45E-02	2.43E-02	-45.3	3.61E-02	-18.8
5.3 (m)	3.92E-02	2.24E-02	-42.8	3.31E-02	-15.7
6.4 (m)	3.55E-02	2.11E-02	-40.7	3.08E-02	-13.2
8.1 (m)	3.21E-02	1.95E-02	-39.5	2.82E-02	-12.4
10.2 (m)	2.80E-02	1.78E-02	-36.4	2.55E-02	-9.0
12.3 (m)	2.52E-02	1.65E-02	-34.3	2.34E-02	-7.0
14.4 (m)	2.31E-02	1.55E-02	-33.1	2.18E-02	-6.0
17.6 (m)	2.06E-02	1.42E-02	-31.1	1.98E-02	-4.0
21.7 (m)	1.82E-02	1.29E-02	-29.0	1.78E-02	-1.9
25.8 (m)	1.62E-02	1.18E-02	-27.4	1.62E-02	-0.2
29.9 (m)	1.47E-02	1.09E-02	-25.9	1.49E-02	1.4
37.0 (m)	1.29E-02	9.53E-03	-26.2	1.30E-02	0.4
47.0 (m)	1.07E-02	7.97E-03	-25.2	1.08E-02	0.8
57.2 (m)	8.42E-03	6.69E-03	-20.5	8.95E-03	6.3

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.7 (d)	1.49E-02	1.13E-02	-24.5	1.08E-02	-27.6
1.7 (d)	1.19E-02	9.14E-03	-23.2	8.97E-03	-24.7
3.9 (d)	8.88E-03	6.83E-03	-23.1	6.90E-03	-22.3
6.8 (d)	6.93E-03	5.33E-03	-23.1	5.48E-03	-21.0
12.2 (d)	4.94E-03	3.85E-03	-22.0	3.99E-03	-19.1
24.2 (d)	2.83E-03	2.21E-03	-21.8	2.30E-03	-18.5
50.0 (d)	9.57E-04	8.67E-04	-9.3	9.08E-04	-5.1
100.1 (d)	3.20E-04	3.49E-04	9.1	3.66E-04	14.5

Table 24 – Tin Dioxide decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

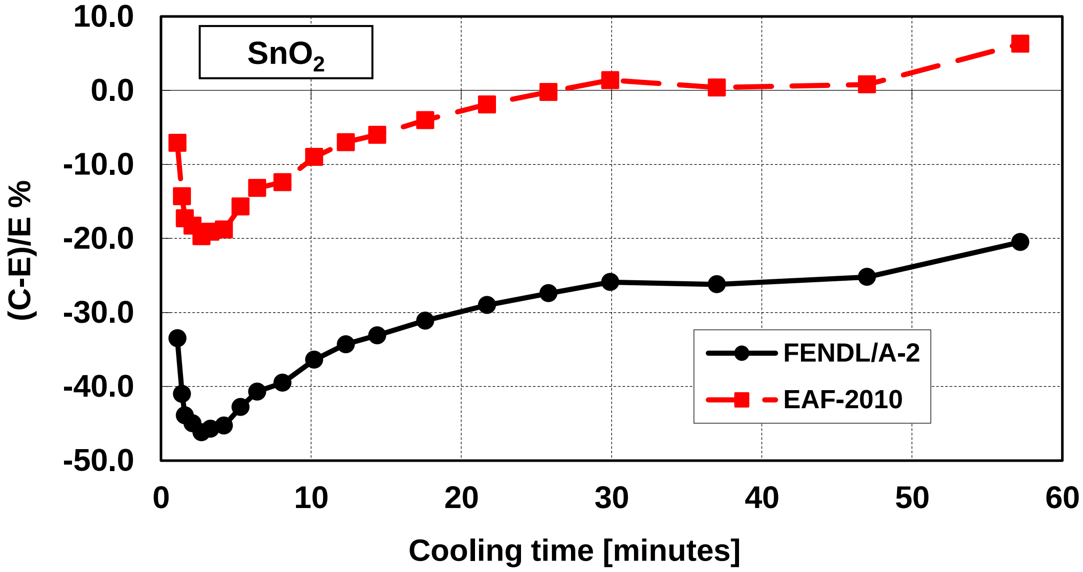

Figure 43 – Decay heat vs. cooling time of Tin Dioxide sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

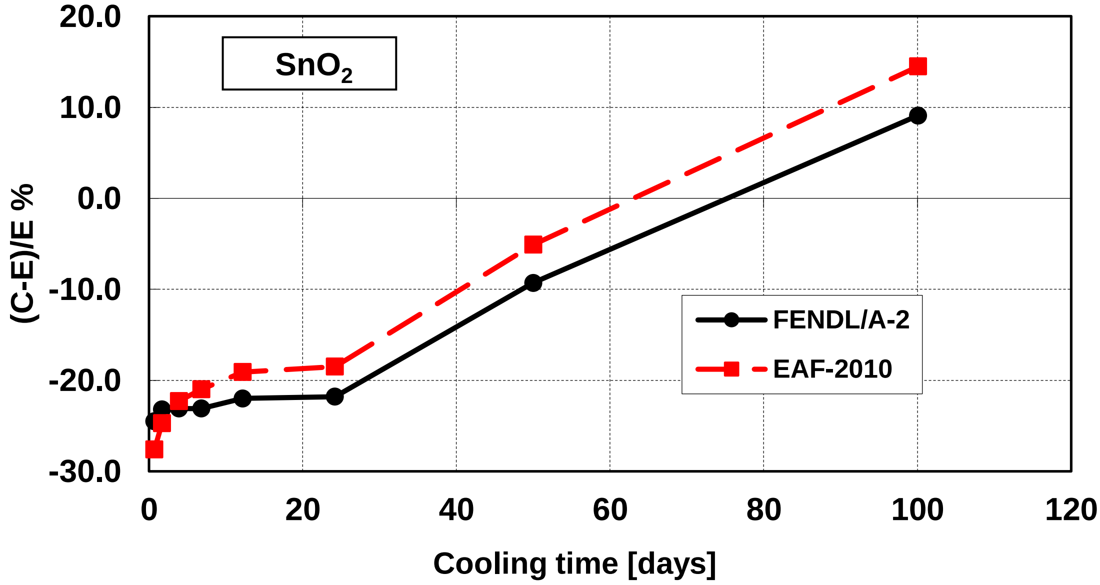

Figure 44 – Decay heat vs. cooling time of Tin Dioxide sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Strontium Carbonate ($SrCO_3$)

Material composition : C 8.14, O 32.51, Sr 59.35

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	7.48E-02	5.01E-02	-33.1	6.19E-02	-17.2
1.4 (m)	7.14E-02	4.25E-02	-40.5	5.43E-02	-23.9
1.6 (m)	6.92E-02	4.04E-02	-41.7	5.22E-02	-24.6
2.1 (m)	6.75E-02	3.90E-02	-42.2	5.07E-02	-24.8
2.6 (m)	6.61E-02	3.79E-02	-42.7	4.95E-02	-25.2
3.2 (m)	6.32E-02	3.69E-02	-41.7	4.83E-02	-23.6
4.1 (m)	6.08E-02	3.56E-02	-41.4	4.69E-02	-22.8
5.2 (m)	5.79E-02	3.42E-02	-40.9	4.53E-02	-21.8
6.3 (m)	5.45E-02	3.29E-02	-39.6	4.37E-02	-19.7
7.9 (m)	5.20E-02	3.11E-02	-40.3	4.17E-02	-19.9
10.0 (m)	4.80E-02	2.89E-02	-39.8	3.92E-02	-18.4
12.1 (m)	4.48E-02	2.69E-02	-39.9	3.69E-02	-17.6
14.2 (m)	4.23E-02	2.52E-02	-40.5	3.49E-02	-17.5
17.4 (m)	3.86E-02	2.27E-02	-41.1	3.21E-02	-16.8
21.5 (m)	3.45E-02	1.99E-02	-42.2	2.89E-02	-16.2
25.6 (m)	3.07E-02	1.75E-02	-42.9	2.61E-02	-15.0
29.7 (m)	2.76E-02	1.55E-02	-43.8	2.37E-02	-14.1
36.8 (m)	2.36E-02	1.26E-02	-46.6	2.03E-02	-14.0
46.9 (m)	1.91E-02	9.63E-03	-49.7	1.67E-02	-12.7
57.0 (m)	1.58E-02	7.55E-03	-52.2	1.41E-02	-10.4

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.7 (d)	1.31E-02	6.25E-03	-52.2	1.19E-02	-9.4
1.7 (d)	2.76E-03	2.72E-03	-1.6	2.83E-03	2.8
3.9 (d)	1.73E-03	1.77E-03	2.3	1.87E-03	8.0
6.7 (d)	1.34E-03	1.37E-03	2.2	1.47E-03	9.3
12.2 (d)	1.14E-03	1.18E-03	3.0	1.27E-03	10.8
24.2 (d)	9.61E-04	9.87E-04	2.6	1.07E-03	11.1
50.0 (d)	7.01E-04	7.04E-04	0.5	7.69E-04	9.6
100.1 (d)	3.76E-04	3.92E-04	4.3	4.31E-04	14.7

Table 25 – Strontium Carbonate decay heat calculation-experiment comparison (5 minutes and 7 hours irradiation)

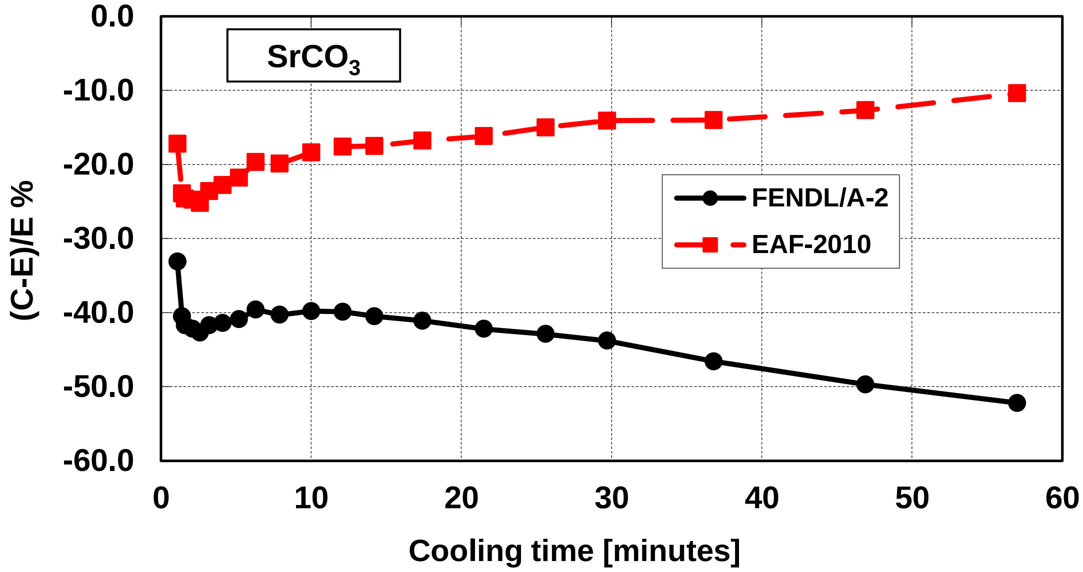

Figure 45 – Decay heat vs. cooling time of Strontium Carbonate sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

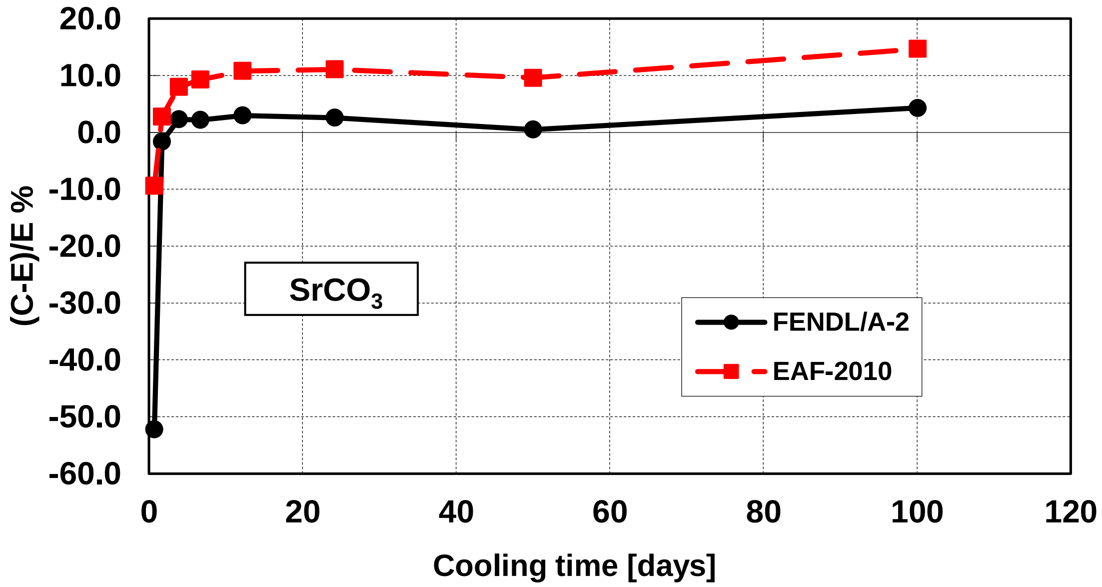

Figure 46 – Decay heat vs. cooling time of Strontium Carbonate sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Stainless Steel SS-304 (SS304)

Material composition : Si 0.55, Cr 18.02, Mn 1.44, Fe 71.17, Ni 8.82

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	5.33E-01	4.66E-01	-12.6	4.58E-01	-14.2
1.4 (m)	5.02E-01	4.44E-01	-11.7	4.36E-01	-13.3
1.6 (m)	4.80E-01	4.22E-01	-12.1	4.14E-01	-13.7
2.1 (m)	4.39E-01	3.88E-01	-11.6	3.81E-01	-13.2
2.7 (m)	3.93E-01	3.47E-01	-11.7	3.41E-01	-13.3
3.3 (m)	3.54E-01	3.13E-01	-11.5	3.07E-01	-13.1
4.1 (m)	3.08E-01	2.73E-01	-11.4	2.68E-01	-13.0
5.2 (m)	2.59E-01	2.31E-01	-11.1	2.26E-01	-12.7
6.3 (m)	2.23E-01	1.99E-01	-11.0	1.95E-01	-12.6
7.9 (m)	1.82E-01	1.63E-01	-10.5	1.60E-01	-12.2
10.0 (m)	1.43E-01	1.30E-01	-8.8	1.28E-01	-10.6
12.1 (m)	1.18E-01	1.09E-01	-7.8	1.07E-01	-9.8
14.2 (m)	1.02E-01	9.49E-02	-6.9	9.27E-02	-9.1
17.4 (m)	8.70E-02	8.15E-02	-6.4	7.94E-02	-8.8
21.5 (m)	7.57E-02	7.16E-02	-5.4	6.98E-02	-7.8
25.6 (m)	6.95E-02	6.63E-02	-4.6	6.46E-02	-7.0
29.7 (m)	6.59E-02	6.30E-02	-4.4	6.14E-02	-6.8
36.8 (m)	6.21E-02	5.95E-02	-4.3	5.80E-02	-6.6
47.0 (m)	5.85E-02	5.61E-02	-4.1	5.48E-02	-6.3
57.1 (m)	5.57E-02	5.34E-02	-4.2	5.22E-02	-6.3

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.6 (d)	5.90E-02	5.72E-02	-3.0	5.72E-02	-3.0
1.3 (d)	7.85E-03	7.64E-03	-2.6	7.74E-03	-1.4
2.9 (d)	4.32E-03	4.12E-03	-4.8	4.21E-03	-2.7
6.9 (d)	2.02E-03	1.92E-03	-5.0	1.98E-03	-2.3
12.8 (d)	1.54E-03	1.46E-03	-5.5	1.50E-03	-2.7
23.8 (d)	1.35E-03	1.28E-03	-4.8	1.32E-03	-1.9
49.7 (d)	1.07E-03	1.01E-03	-6.0	1.04E-03	-2.9
99.9 (d)	7.03E-04	6.79E-04	-3.3	7.03E-04	0.1

Table 26 – Stainless Steel SS304 decay heat calculation-experiment comparison (5 minutes and 7 hours irradiation)

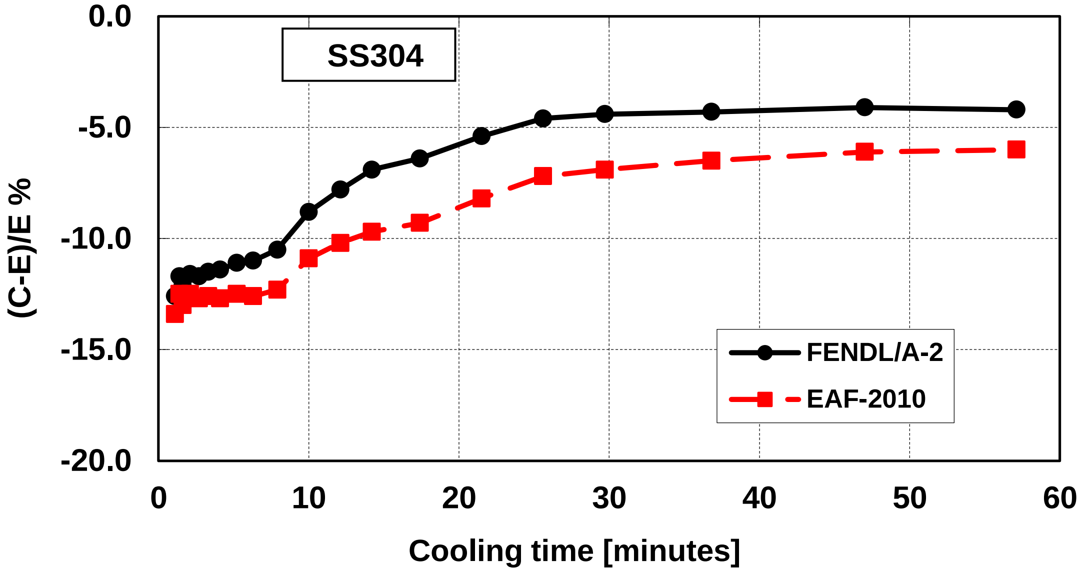

Figure 47 – Decay heat vs. cooling time of Stainless Steel SS304 sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

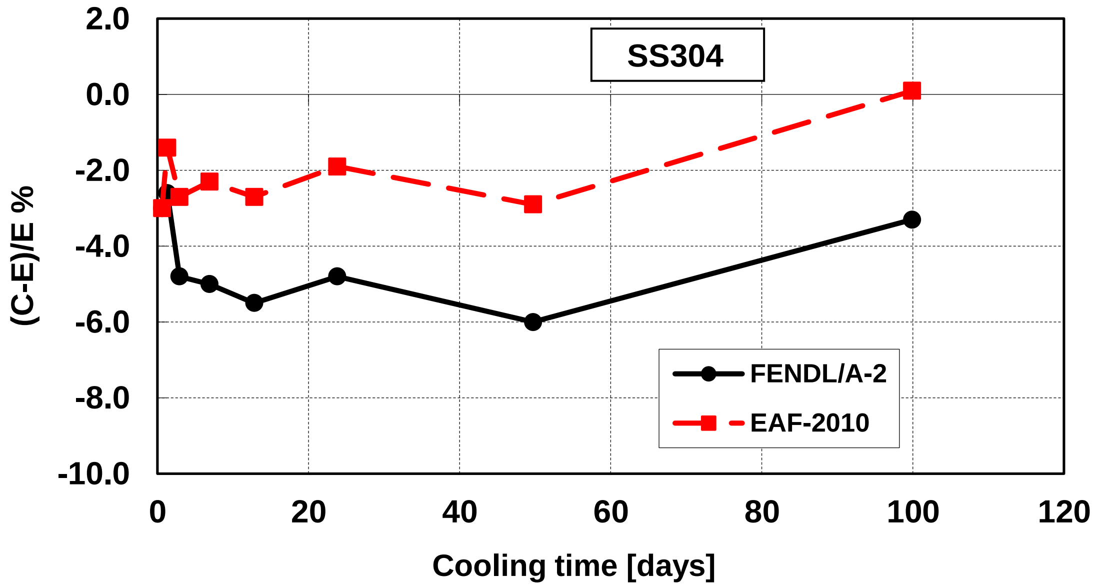

Figure 48 – Decay heat vs. cooling time of Stainless Steel SS304 sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Stainless Steel AISI 316 (SS316)

Material composition : Si 0.96, Cr 18.28, Mn 1.44, Fe 63.72, Ni 13.49, Mo 2.11

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	5.65E-01	5.20E-01	-8.1	5.10E-01	-9.8
1.4 (m)	5.33E-01	4.92E-01	-7.9	4.82E-01	-9.6
1.7 (m)	5.05E-01	4.65E-01	-7.9	4.57E-01	-9.6
2.1 (m)	4.62E-01	4.26E-01	-8.0	4.17E-01	-9.7
2.8 (m)	4.12E-01	3.77E-01	-8.5	3.70E-01	-10.2
3.4 (m)	3.67E-01	3.36E-01	-8.4	3.30E-01	-10.1
4.3 (m)	3.15E-01	2.87E-01	-8.9	2.82E-01	-10.6
5.4 (m)	2.65E-01	2.40E-01	-9.5	2.35E-01	-11.2
6.5 (m)	2.24E-01	2.03E-01	-9.6	1.99E-01	-11.3
8.1 (m)	1.80E-01	1.63E-01	-9.5	1.60E-01	-11.2
10.2 (m)	1.40E-01	1.28E-01	-8.2	1.26E-01	-10.1
12.4 (m)	1.14E-01	1.06E-01	-7.3	1.04E-01	-9.4
14.4 (m)	9.80E-02	9.13E-02	-6.9	8.92E-02	-9.0
17.6 (m)	8.26E-02	7.73E-02	-6.4	7.54E-02	-8.7
21.7 (m)	7.12E-02	6.72E-02	-5.6	6.55E-02	-8.0
25.8 (m)	6.48E-02	6.16E-02	-4.9	6.01E-02	-7.2
29.9 (m)	6.09E-02	5.82E-02	-4.5	5.68E-02	-6.8
37.1 (m)	5.70E-02	5.45E-02	-4.4	5.32E-02	-6.6
47.1 (m)	5.31E-02	5.11E-02	-3.9	4.99E-02	-6.0
57.2 (m)	5.01E-02	4.84E-02	-3.5	4.73E-02	-5.6

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.6 (d)	6.24E-02	5.97E-02	-4.5	5.98E-02	-4.2
1.3 (d)	1.30E-02	1.24E-02	-5.1	1.26E-02	-3.3
2.9 (d)	7.24E-03	6.87E-03	-5.1	7.07E-03	-2.4
6.8 (d)	3.17E-03	2.98E-03	-6.0	3.08E-03	-2.8
12.8 (d)	2.19E-03	2.06E-03	-6.2	2.12E-03	-3.3
23.8 (d)	1.84E-03	1.75E-03	-4.6	1.80E-03	-1.8
49.7 (d)	1.45E-03	1.37E-03	-5.8	1.41E-03	-3
99.9 (d)	9.31E-04	9.05E-04	-2.7	9.35E-04	0.5

Table 27 – Stainless Steel AISI 316 decay heat calculation-experiment comparison (5 minutes and 7 hours irradiation)

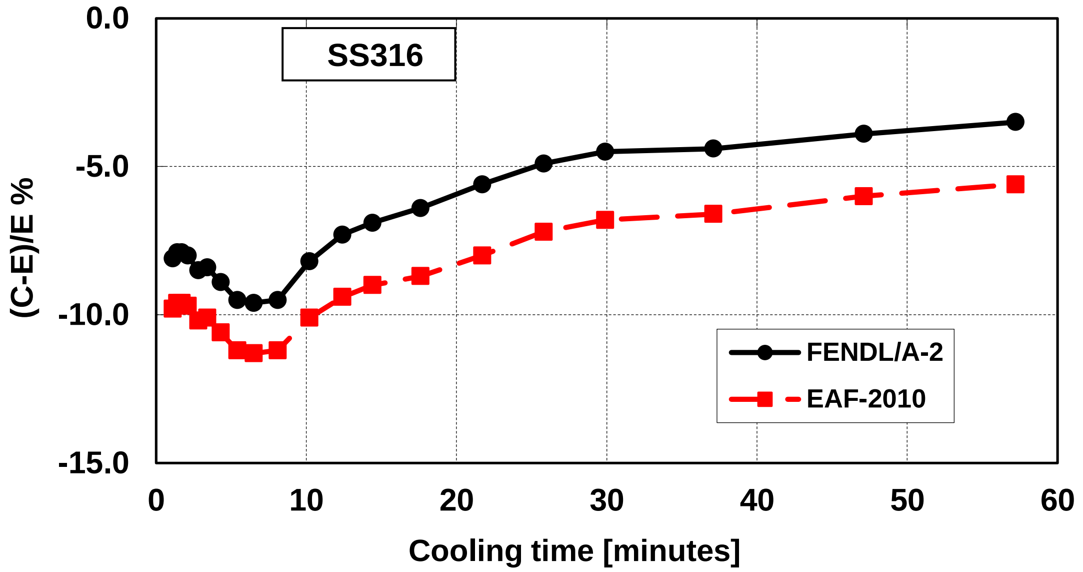

Figure 49 – Decay heat vs. cooling time of Stainless Steel AISI 316 sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

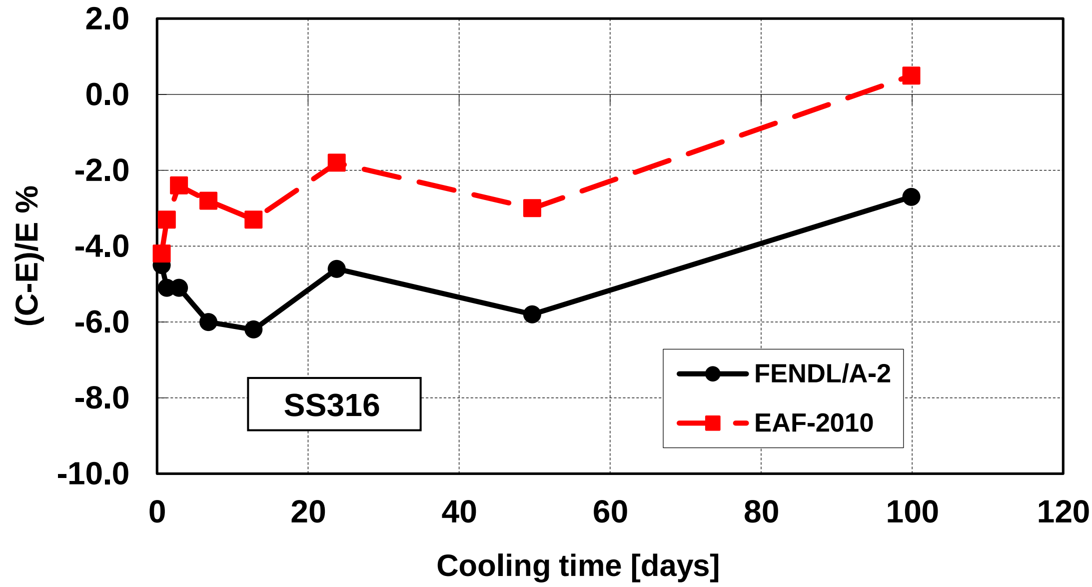

Figure 50 – Decay heat vs. cooling time of Stainless Steel AISI 316 sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Tantalum (Ta)

Material composition : Ta 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	4.48E-03	7.94E-03	77.1	5.37E-03	19.8
1.4 (m)	4.41E-03	7.93E-03	79.7	5.36E-03	21.6
1.6 (m)	4.48E-03	7.92E-03	76.7	5.36E-03	19.5
2.1 (m)	4.41E-03	7.91E-03	79.2	5.35E-03	21.2
2.7 (m)	4.41E-03	7.89E-03	78.7	5.34E-03	20.9
3.3 (m)	4.34E-03	7.87E-03	81.4	5.33E-03	22.7
4.2 (m)	4.36E-03	7.85E-03	80.2	5.31E-03	21.9
5.3 (m)	4.26E-03	7.82E-03	83.6	5.29E-03	24.2
6.4 (m)	4.22E-03	7.79E-03	84.7	5.27E-03	24.9
8.0 (m)	4.17E-03	7.75E-03	85.9	5.24E-03	25.7
10.1 (m)	4.13E-03	7.70E-03	86.2	5.20E-03	25.9
12.2 (m)	4.00E-03	7.65E-03	91.2	5.17E-03	29.3
14.3 (m)	3.94E-03	7.60E-03	92.7	5.14E-03	30.3
17.4 (m)	3.85E-03	7.53E-03	95.7	5.09E-03	32.3
21.5 (m)	3.83E-03	7.44E-03	94.4	5.03E-03	31.4
25.6 (m)	3.75E-03	7.36E-03	96.5	4.98E-03	32.9
29.7 (m)	3.67E-03	7.29E-03	98.8	4.93E-03	34.4
36.8 (m)	3.57E-03	7.16E-03	101.0	4.84E-03	35.8
46.9 (m)	3.43E-03	7.01E-03	104.3	4.74E-03	38.1
57.0 (m)	3.33E-03	6.86E-03	106.3	4.64E-03	39.5

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.6 (h)	6.79E-02	1.44E-01	111.4	9.60E-02	41.4
1.3 (d)	1.62E-02	3.20E-02	98.0	2.14E-02	32.4
2.9 (d)	8.64E-04	1.47E-03	70.6	1.04E-03	20.5
6.9 (d)	2.74E-04	2.38E-04	-13.0	2.17E-04	-20.7
12.9 (d)	2.63E-04	2.24E-04	-14.7	2.05E-04	-21.9
23.9 (d)	2.36E-04	2.02E-04	-14.4	1.86E-04	-21.2
49.7 (d)	2.04E-04	1.60E-04	-21.5	1.50E-04	-26.5
99.9 (d)	1.38E-04	1.06E-04	-23.1	1.02E-04	-26.2

Table 28 – Tantalum decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

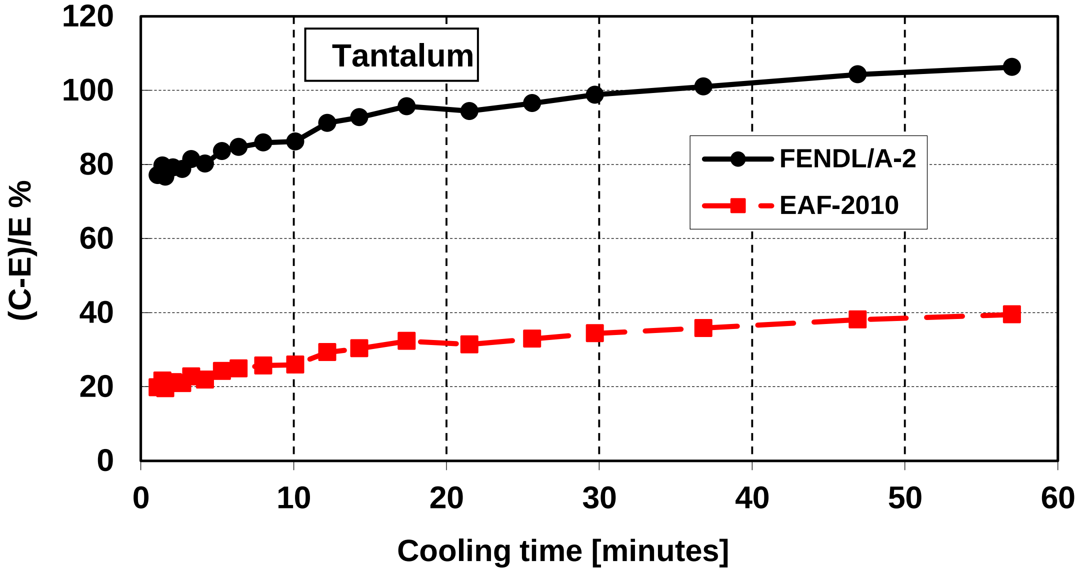

Figure 51 – Decay heat vs. cooling time of Tantalum sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

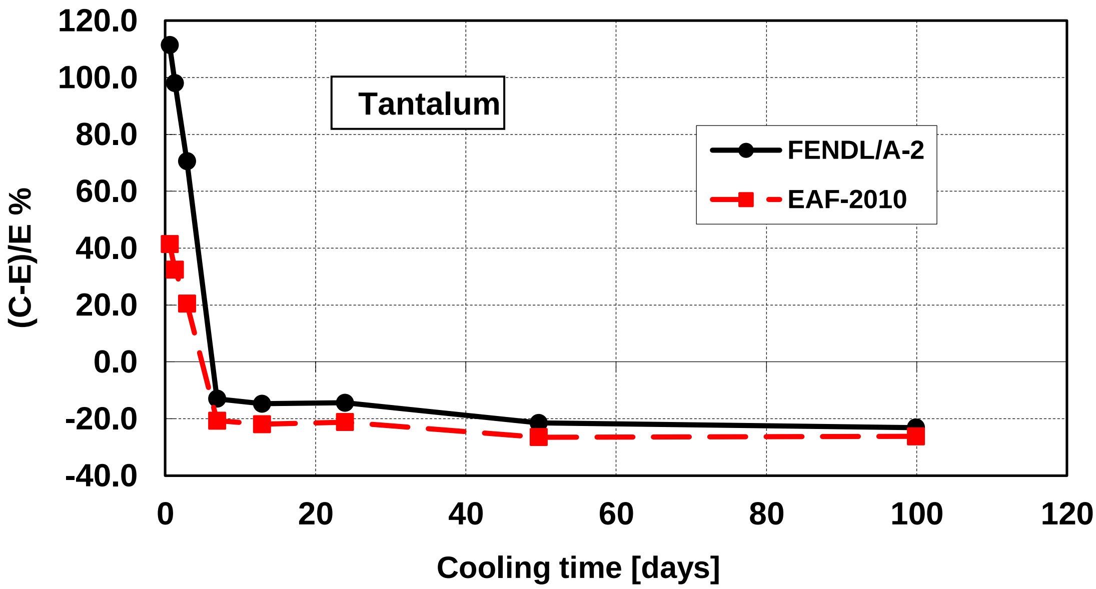

Figure 52 – Decay heat vs. cooling time of Tantalum sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Titanium (Ti)

Material composition : Ti 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.1 (m)	5.49E-02	6.24E-02	13.7	5.03E-02	-8.4
1.4 (m)	4.97E-02	5.63E-02	13.1	4.56E-02	-8.3
1.6 (m)	4.51E-02	5.10E-02	13.1	4.16E-02	-7.8
2.1 (m)	3.95E-02	4.36E-02	10.5	3.59E-02	-9.0
2.7 (m)	3.30E-02	3.63E-02	10.0	3.03E-02	-8.3
3.3 (m)	2.80E-02	3.01E-02	7.5	2.54E-02	-9.0
4.2 (m)	2.28E-02	2.35E-02	3.2	2.03E-02	-10.7
5.3 (m)	1.81E-02	1.79E-02	-1.1	1.60E-02	-11.7
6.4 (m)	1.53E-02	1.44E-02	-6.1	1.32E-02	-13.5
8.0 (m)	1.27E-02	1.13E-02	-10.7	1.09E-02	-14.4
10.1 (m)	1.08E-02	9.42E-03	-13.0	9.37E-03	-13.4
12.2 (m)	1.00E-02	8.56E-03	-14.6	8.68E-03	-13.4
14.4 (m)	9.61E-03	8.16E-03	-15.1	8.35E-03	-13.1
17.5 (m)	9.19E-03	7.88E-03	-14.3	8.11E-03	-11.8
21.6 (m)	8.95E-03	7.70E-03	-13.9	7.94E-03	-11.3
25.7 (m)	8.74E-03	7.58E-03	-13.3	7.81E-03	-10.7
29.8 (m)	8.56E-03	7.47E-03	-12.7	7.70E-03	-10.1
36.9 (m)	8.25E-03	7.30E-03	-11.5	7.52E-03	-8.9
47.0 (m)	8.05E-03	7.09E-03	-12.0	7.29E-03	-9.4
57.1 (m)	7.79E-03	6.89E-03	-11.5	7.09E-03	-9.0

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.7 (d)	3.38E-01	3.00E-01	-11.3	3.03E-01	-10.3
1.3 (d)	2.54E-01	2.32E-01	-8.5	2.35E-01	-7.6
2.9 (d)	1.41E-01	1.30E-01	-8.2	1.31E-01	-7.4
6.9 (d)	3.45E-02	3.17E-02	-8.0	3.18E-02	-7.8
12.9 (d)	6.16E-03	5.94E-03	-3.5	5.76E-03	-6.5
23.9 (d)	2.43E-03	2.46E-03	1.0	2.27E-03	-6.6
49.7 (d)	1.85E-03	1.89E-03	2.4	1.75E-03	-5.6
99.9 (d)	1.25E-03	1.26E-03	0.6	1.16E-03	-7.2

Table 29 – Titanium decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

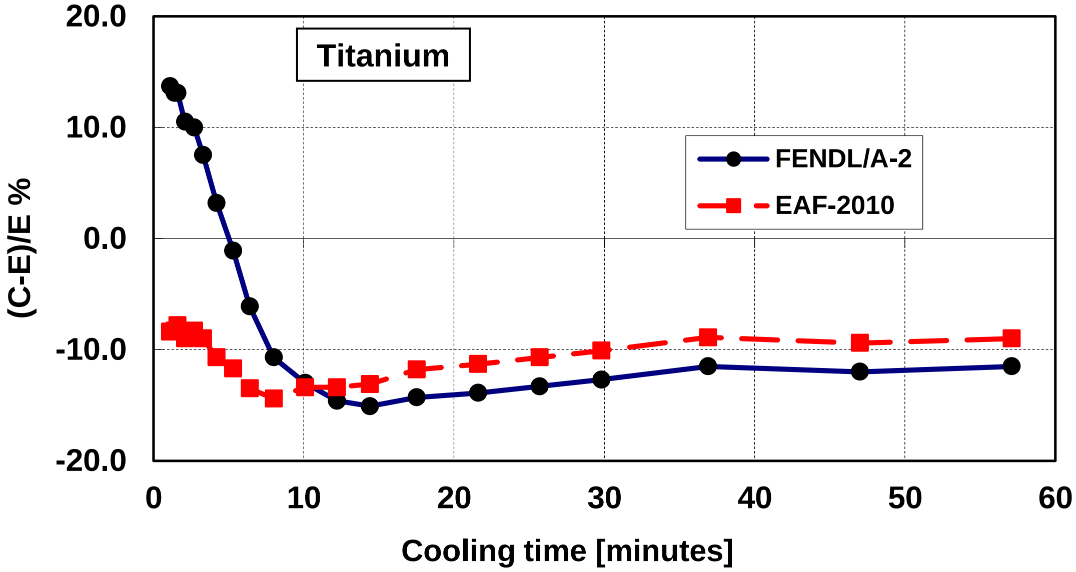

Figure 53 – Decay heat vs. cooling time of Titanium sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

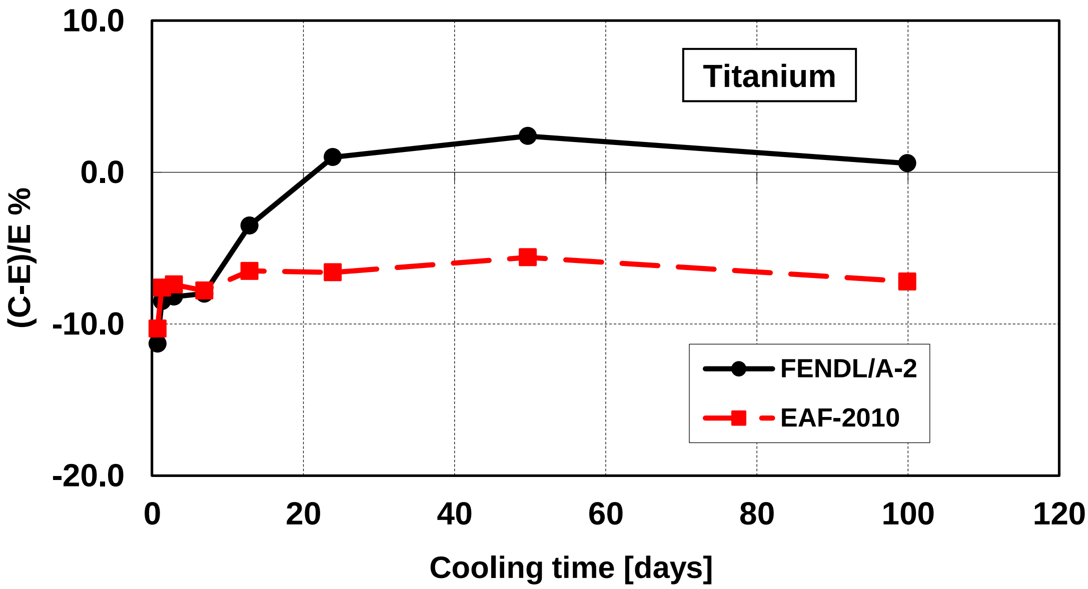

Figure 54 – Decay heat vs. cooling time of Titanium sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Vanadium (V)

Material composition : V 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Colling Time	μW/g	μW/g		μW/g	
1.4 (m)	3.14E-01	3.08E-01	-2.0	3.06E-01	-2.7
1.6 (m)	3.03E-01	2.98E-01	-1.8	2.95E-01	-2.5
1.9 (m)	2.92E-01	2.88E-01	-1.4	2.86E-01	-2.1
2.3 (m)	2.76E-01	2.72E-01	-1.4	2.70E-01	-2.1
3.0 (m)	2.56E-01	2.51E-01	-1.9	2.50E-01	-2.6
3.6 (m)	2.36E-01	2.33E-01	-1.5	2.31E-01	-2.2
4.4 (m)	2.12E-01	2.08E-01	-1.7	2.07E-01	-2.5
5.6 (m)	1.85E-01	1.81E-01	-2.3	1.80E-01	-3.0
6.7 (m)	1.61E-01	1.57E-01	-2.1	1.56E-01	-2.8
8.3 (m)	1.33E-01	1.29E-01	-3.0	1.28E-01	-3.7
10.4 (m)	1.03E-01	9.93E-02	-3.3	9.86E-02	-4.0
12.6 (m)	7.97E-02	7.66E-02	-3.9	7.60E-02	-4.6
14.7 (m)	6.15E-02	5.93E-02	-3.6	5.89E-02	-4.3
17.8 (m)	4.35E-02	4.11E-02	-5.6	4.08E-02	-6.2
21.9 (m)	2.73E-02	2.54E-02	-7.0	2.53E-02	-7.5
26.0 (m)	1.75E-02	1.60E-02	-8.6	1.59E-02	-9.0
30.1 (m)	1.16E-02	1.03E-02	-10.8	1.03E-02	-11.0
37.2 (m)	6.28E-03	5.24E-03	-16.6	5.25E-03	-16.3
47.2 (m)	3.46E-03	2.60E-03	-24.9	2.64E-03	-23.7
57.4 (m)	2.68E-03	1.81E-03	-32.4	1.86E-03	-30.7

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
CoolingTime	μW/g	μW/g		μW/g	
0.7 (d)	1.08E-01	9.65E-02	-10.6	9.84E-02	-8.9
1.3 (d)	8.42E-02	7.48E-02	-11.2	7.62E-02	-9.5
2.9 (d)	4.61E-02	4.09E-02	-11.1	4.18E-02	-9.3
6.9 (d)	1.02E-02	9.03E-03	-11.6	9.23E-03	-9.6
12.9 (d)	1.06E-03	9.22E-04	-12.8	9.49E-04	-10.3
23.9 (d)	1.86E-05	1.42E-05	-23.6	1.55E-05	-16.5
49.7 (d)	5.62E-06	3.97E-08	-99.3	1.02E-07	-98.2

Table 30 – Vanadium decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

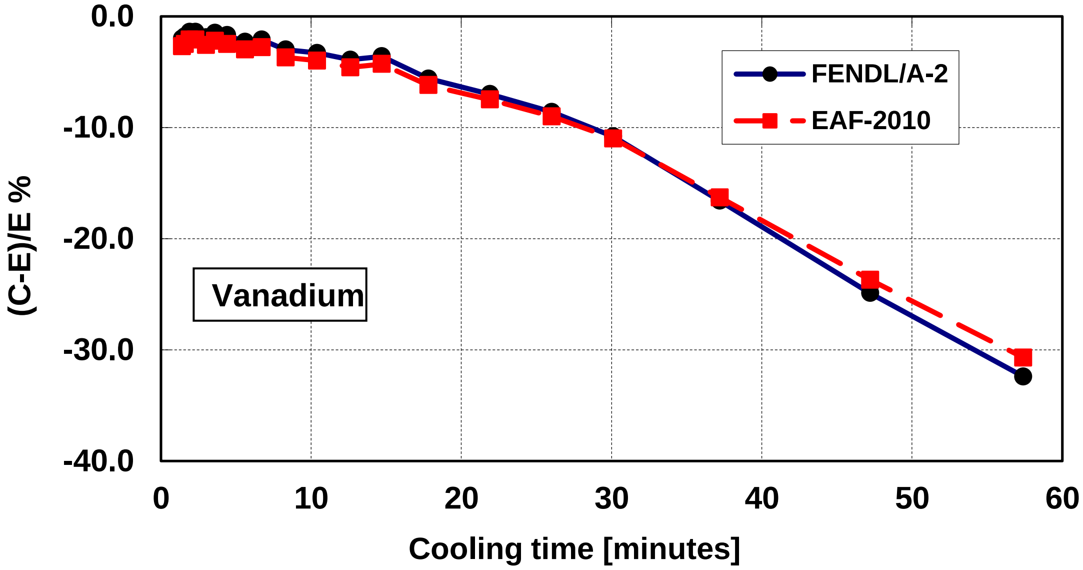

Figure 55 – Decay heat vs. cooling time of Vanadium sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

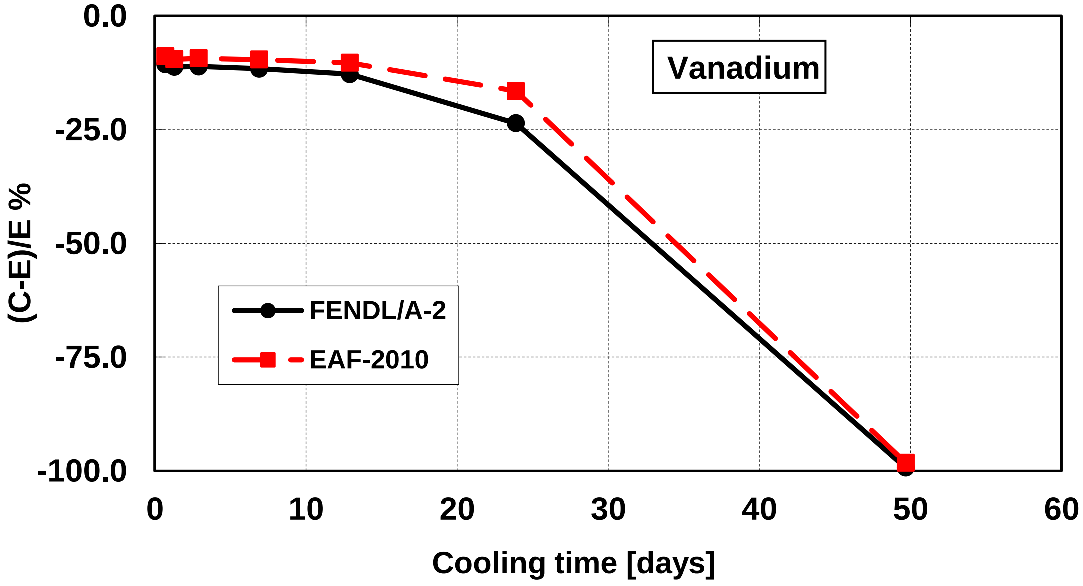

Figure 56 – Decay heat vs. cooling time of Vanadium sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Yttrium Oxide (Y_2O_3)

Material composition : O 21.26, Y 78.74

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	µW/g	µW/g		µW/g	
1.1 (m)	2.28E-01	2.20E-01	-3.5	1.79E-01	-21.6
1.4 (m)	1.17E-01	1.10E-01	-6.3	8.85E-02	-24.4
1.6 (m)	6.08E-02	5.54E-02	-8.9	4.49E-02	-26.2
2.1 (m)	2.32E-02	1.81E-02	-21.8	1.53E-02	-34.1
2.7 (m)	8.30E-03	4.57E-03	-45.0	4.52E-03	-45.5
3.3 (m)	4.90E-03	1.79E-03	-63.5	2.17E-03	-55.7
4.2 (m)	3.36E-03	9.03E-04	-73.1	1.22E-03	-63.6
5.3 (m)	2.42E-03	7.08E-04	-70.8	8.75E-04	-63.9
6.4 (m)	1.85E-03	6.48E-04	-65.1	7.33E-04	-60.5
8.0 (m)	1.65E-03	6.14E-04	-62.8	6.50E-04	-60.6
10.1 (m)	1.46E-03	6.01E-04	-58.7	6.20E-04	-57.4
12.3 (m)	1.17E-03	5.98E-04	-48.7	6.12E-04	-47.5
14.3 (m)	1.21E-03	5.97E-04	-50.7	6.10E-04	-49.6
17.5 (m)	1.05E-03	5.96E-04	-43.0	6.09E-04	-41.7
21.5 (m)	9.76E-04	5.96E-04	-39.0	6.08E-04	-37.7
25.7 (m)	9.06E-04	5.95E-04	-34.3	6.08E-04	-32.9
29.8 (m)	7.81E-04	5.94E-04	-23.9	6.07E-04	-22.3
36.9 (m)	8.59E-04	5.93E-04	-30.9	6.06E-04	-29.5
47.0 (m)	8.39E-04	5.92E-04	-29.5	6.04E-04	-28.0
57.1 (m)	5.41E-04	5.91E-04	9.2	6.02E-04	11.4

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	µW/g	µW/g		µW/g	
0.7 (d)	5.35E-02	4.54E-02	-15.0	4.56E-02	-14.7
1.7 (d)	5.27E-02	4.48E-02	-15.0	4.50E-02	-14.5
3.9 (d)	5.14E-02	4.38E-02	-14.8	4.41E-02	-14.2
6.8 (d)	5.00E-02	4.27E-02	-14.5	4.31E-02	-13.8
12.2 (d)	4.76E-02	4.10E-02	-13.8	4.14E-02	-13.0
24.2 (d)	4.45E-02	3.78E-02	-15.1	3.81E-02	-14.3
50.0 (d)	3.81E-02	3.19E-02	-16.4	3.21E-02	-15.8
100.1 (d)	2.68E-02	2.29E-02	-14.4	2.31E-02	-13.8

Table 31 – Yttrium Oxide decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

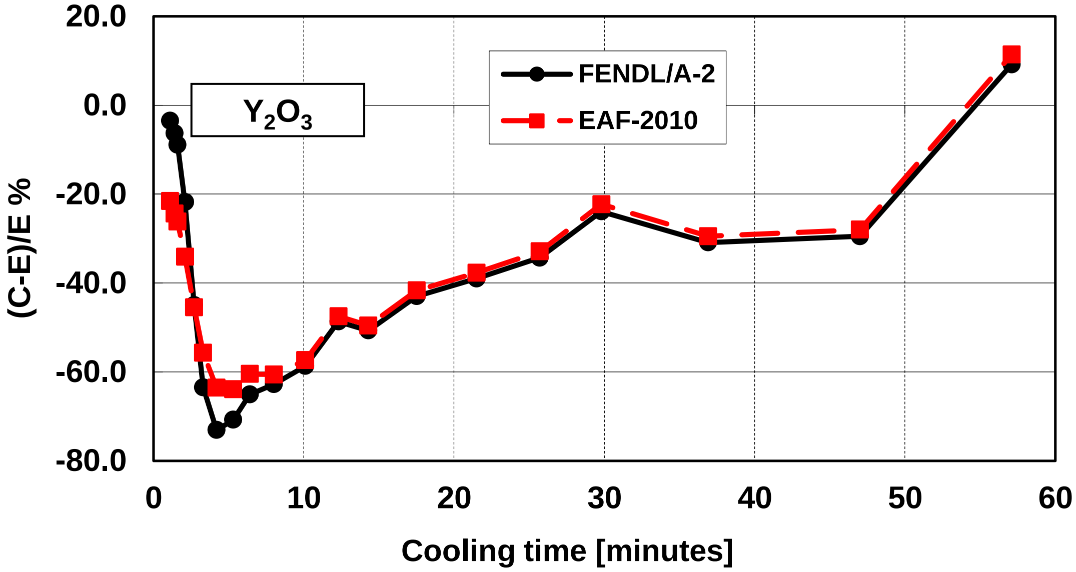

Figure 57 – Decay heat vs. cooling time of Yttrium Oxide sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

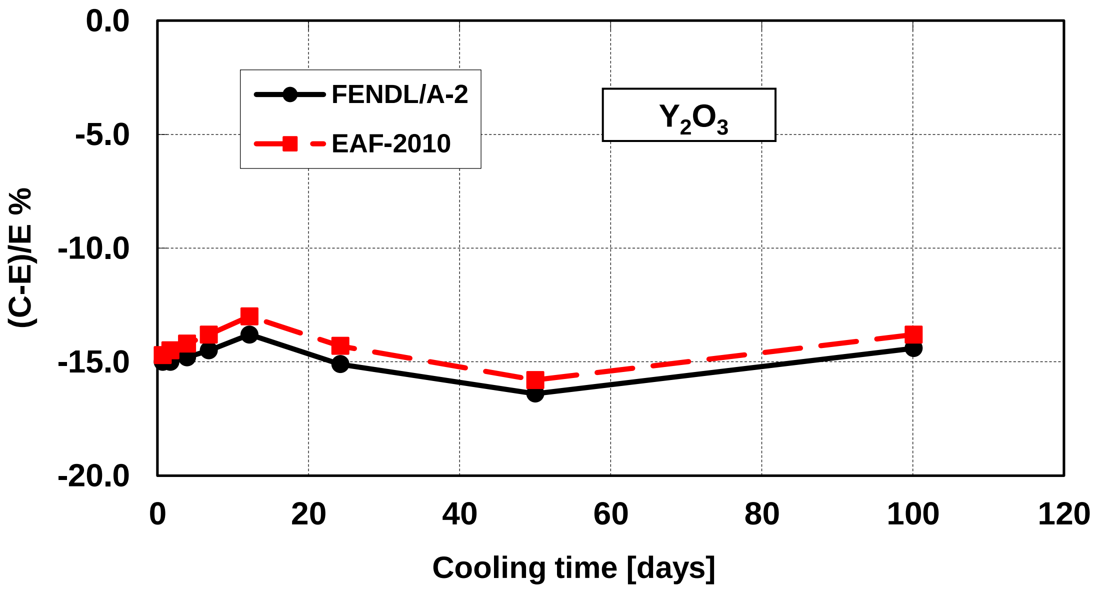

Figure 58 – Decay heat vs. cooling time of Yttrium Oxide sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

Zirconium (Zr)

Material composition : Zr 100

	EXP-5m	CALC-5m FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-5m EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
1.4 (m)	2.67E-01	2.81E-01	5.4	2.98E-01	11.4
1.6 (m)	2.59E-01	2.68E-01	3.5	2.83E-01	9.4
1.9 (m)	2.45E-01	2.57E-01	4.8	2.71E-01	10.8
2.3 (m)	2.27E-01	2.39E-01	5.3	2.52E-01	11.2
3.0 (m)	2.06E-01	2.16E-01	5.2	2.28E-01	11.0
3.6 (m)	1.84E-01	1.97E-01	6.6	2.07E-01	12.4
4.4 (m)	1.62E-01	1.72E-01	5.7	1.81E-01	11.3
5.6 (m)	1.38E-01	1.45E-01	5.3	1.52E-01	10.6
6.7 (m)	1.15E-01	1.23E-01	6.4	1.28E-01	11.5
8.3 (m)	9.11E-02	9.65E-02	5.9	1.01E-01	10.3
10.4 (m)	6.82E-02	7.15E-02	4.9	7.40E-02	8.5
12.5 (m)	5.05E-02	5.42E-02	7.2	5.56E-02	10.0
14.6 (m)	3.92E-02	4.18E-02	6.6	4.24E-02	8.3
17.7 (m)	2.82E-02	2.92E-02	3.7	2.92E-02	3.7
21.8 (m)	1.96E-02	1.99E-02	1.3	1.94E-02	-0.9
26.0 (m)	1.47E-02	1.48E-02	0.7	1.43E-02	-3.0
30.1 (m)	1.17E-02	1.20E-02	2.8	1.15E-02	-1.8
37.2 (m)	9.75E-03	9.61E-03	-1.5	9.18E-03	-5.9
47.3 (m)	8.17E-03	8.14E-03	-0.3	7.90E-03	-3.3
57.4 (m)	7.79E-03	7.39E-03	-5.2	7.29E-03	-6.4

	EXP-7h	CALC-7h FENDL/A-2 FENDL/D-2	(C-E)/E %	CALC-7h EAF-2010 JEFF-3.1.1	(C-E)/E %
Cooling Time	μW/g	μW/g		μW/g	
0.6 (d)	3.02E-01	2.97E-01	-1.4	3.02E-01	0.2
1.3 (d)	2.57E-01	2.50E-01	-3.0	2.54E-01	-1.4
2.9 (d)	1.85E-01	1.78E-01	-4.3	1.81E-01	-2.6
6.9 (d)	8.12E-02	7.66E-02	-5.6	7.79E-02	-4.1
12.9 (d)	2.39E-02	2.24E-02	-6.2	2.27E-02	-4.7
23.9 (d)	3.77E-03	3.54E-03	-6.1	3.60E-03	-4.6
49.7 (d)	1.53E-03	1.43E-03	-6.3	1.45E-03	-5.0
99.9 (d)	1.09E-03	1.04E-03	-4.2	1.05E-03	-3.2

Table 32 – Zirconium decay heat calculation-experiment comparison
(5 minutes and 7 hours irradiation)

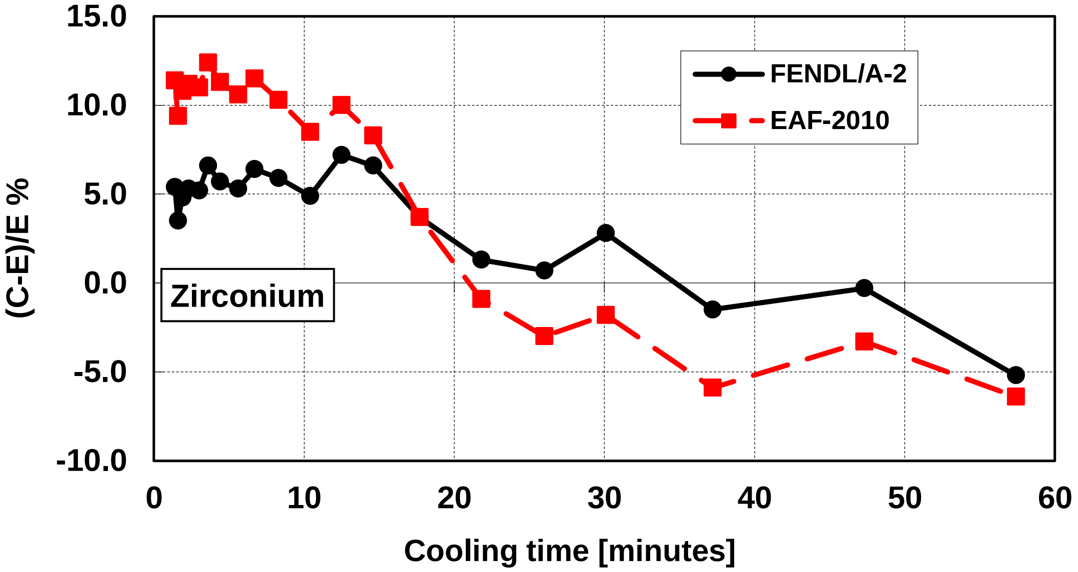

Figure 59 – Decay heat vs. cooling time of Zirconium sample irradiated for 5 min. Comparison of calculation with experiment (C-E)/E %.

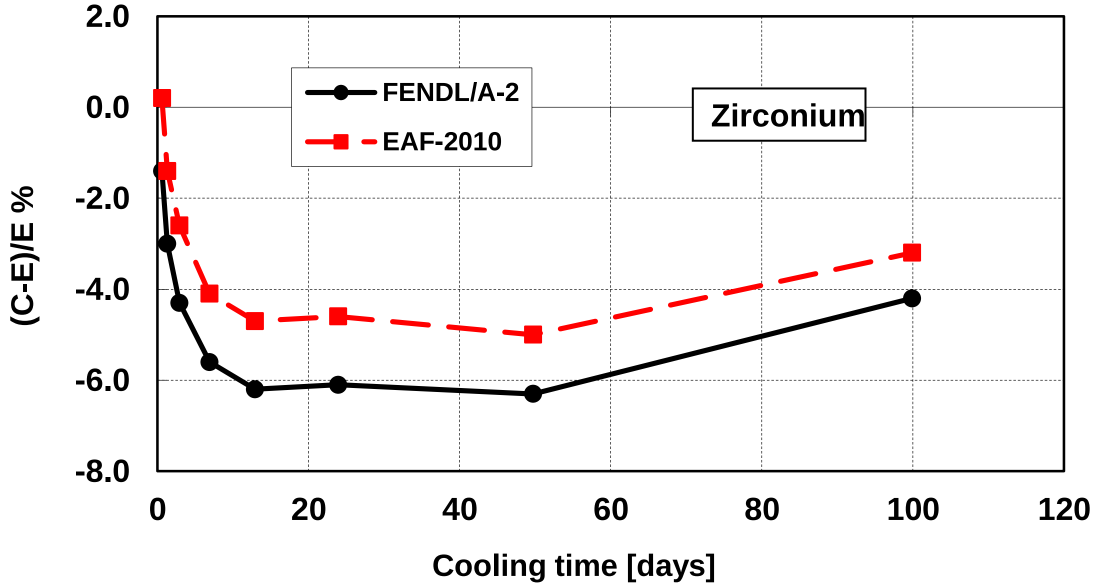

Figure 60 – Decay heat vs. cooling time of Zirconium sample irradiated for 7 hours. Comparison of calculation with experiment (C-E)/E %.

5 RESULTS ANALYSIS

For each one of the materials analysed, the following remarks can be outlined:
(N.B. For sake of simplicity the two ANITA calculations performed by using FENDL/A-2+FENDL/D-2 and EAF-2010+JEFF-3.1.1 libraries are referred to as FENDL/A-2 and EAF-2010, respectively)

- **<u>Aluminum</u>**

  The agreement between the experimental data and both the calculations FENDL/A-2 and EAF-2010 is very good for the 5 minutes irradiation. For the 7 hours irradiation the (C-E)/E values decrease rapidly after 7 days of cooling time, for both the calculations, because of impurities in the aluminum sample not considered in the calculations, as Mn, Fe, Si, Cu, Zn. As reported by the experimental group in Ref.[21], the ^{54}Mn nuclide produced by the ^{56}Fe(n,p)^{54}Mn and ^{55}Mn(n,2n)^{54}Mn reactions mainly contribute to the measured decay heat after 10 days.

- **<u>Boron Carbide (B_4C)</u>**

  Only the experimental data for the 5 minutes irradiation were provided. The agreement for both FENDL/A-2 and EAF-2010 calculations is acceptable only in the first few minutes of cooling time. One can notice a very large underestimation of the calculations, probably due to an unspecified amount of impurity elements contained in the sample.

- **<u>Barium Carbonate ($BaCO_3$)</u>**

  The behaviour of the calculations is similar both for FENDL/A-2 and EAF-2010. The agreement between experiment and calculations is good until cooling times less than 10 minutes for the 5 minutes irradiation. After that time the comparison becomes meaningless due to the contamination by the ^{18}F activity (as outlined by experimental group).
  This contamination is effective only for the measurement of barium carbonate sample irradiated for 5 minutes. For the 7 hours irradiation the agreement is good until 4 days for both the calculations. After that time the behaviour of the calculated results is different and the EAF-2010 calculations present a lower discrepancy with respect to the experimental data.

- **<u>Bismuth (Bi)</u>**

  The calculation predictions for the 5 minutes irradiation show a different behaviour. The discrepancies are bigger in the case of EAF-2010 calculations. The discrepancies become huge for the 7 hours irradiation test. No further conclusion can be drawn because the experimental data are affected by large uncertainties.

- **Calcium Oxide (CaO)**
  For the 5 minutes irradiation the FENDL/A-2 decay heat calculations greatly overestimate the experimental ones. On the contrary the EAF-2010 predictions are about 15 to 45% smaller than the experimental data. This is due to overestimated cross sections for the reactions ^{40}Ca (n,t) ^{38}K and ^{40}Ca (n,t) $^{38m+g}$K [(a)] in the FENDL/A-2 activation library with respect to the EAF-2010 library.
  For the 7 hours irradiation the predictions of the two calculations are similar: they both underestimate the experimental decay heat data (max 24% for FENDL/A-2), even if EAF-2010 shows a slightly better trend.
  .

- **PTFE Teflon (CF_2)**
  Only the experimental data for 5 the minutes irradiation were provided. The agreement with the experimental data is very good for both the calculations.

- **Cobalt (Co)**
  For the 5 minutes irradiation the EAF-2010 predictions are better than the FENDL/A-2 ones, except for low values of cooling times (<5 m). On the whole the agreement is good. For the 7 hours irradiation, except at 0.6 days cooling time, both calculations are rather close each other and agree within 10% with the experimental data.

- **Chromium (Cr)**
  Large discrepancies between the calculations and the experimental data are found both for the 5 minutes irradiation (cooling time > 20 minutes) and the 7 hours irradiation (cooling time < 10 days).The contribution of impurities should be included after 30 minutes cooling time in the 5 minutes irradiation (Na-24 from Al) and before 5 days in the 7 hours irradiation (Na-24 from Al and Mn-56 from Fe) as outlined in a note by the experimental group.
  .

- **Copper (Cu)**
  The agreement between the experimental data and the calculations are good (within 10%) for the 5 minutes irradiation (EAF-2010 shows a slightly better agreement). For the 7 hours irradiation, both the calculations underestimate decay heat experiments for the highest cooling time values, but the discrepancies are significantly lower for EAF-2010.

- **Iron (Fe)**
  For the 5 minutes irradiation the FENDL/A-2 predictions show a better agreement with the experimental data (<5%). The EAF-2010 calculations give underestimate values up to 8.5% at

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(a) The ^{38m}K becomes (by isomeric transition) ^{38}K with a 0.95 s half-life, so only the ^{38}K production is relevant.

1.6 days cooling time. For the 7 hours irradiation the discrepancies are within about 5% after 2.9 days.

- **Inconel 600 (Inconel)**

  In the 5 minutes irradiation experiment the discrepancies between the calculations and the experimental results are between 20-30% for both the calculations, until 17.5 minutes of cooling time for EAF-2010 and until 25.7 minutes for FENDL/A-2. Above, the discrepancies become lower and after 50 minutes cooling time the two calculations give a discrepancy less than 10% with respect to the experimental results.

  For the 7 hours irradiation the FENDL/A-2 calculations show a slightly better agreement with the experimental data showing an overall discrepancy within 5% for all the cooling times. For EAF-2010 the discrepancy rises to about 8.5% at 100 days cooling time.

- **Potassium Carbonate (K_2CO_3)**

  For the 5 minutes irradiation the two calculations show an opposite behaviour, underestimation in case of FENDL/A-2 (maximum 22%) and overestimation in case of EAF-2010 (up to 30%). The discrepancies are bigger for the 7 hours irradiation, but this can be due to not reliable experimental results which are affected by high uncertainties.

- **Manganese (Mn)**

  For the 5 minutes irradiation the EAF-2010 calculations show a better trend with respect to the experimental data than FENDL/A-2 ones until 22 minutes cooling time. After that value EAF-2010 results underestimate the experimental results (maximum 21%). For the 7 hours irradiation the FENDL/A-2 calculations agree within 5% with the measured data, while the EAF-2010 ones show a discrepancy up to 8.2% at 100 days cooling time.

- **Molybdenum (Mo)**

  For the 5 minutes irradiation the behaviour of both the calculations is similar, showing an overestimation with respect to the experimental results (FENDL/A-2 anyway shows lower discrepancies than EAF-2010). For the 7 hours irradiation the EAF-2010 calculations show a better agreement with the experimental data (< 16%) . The FENDL/A-2 discrepancies rise up to 44% at 100 days cooling time.

- **Sodium Carbonate (Na_2CO_3)**

  The experimental decay heat values are largely underestimated by both FENDLA-2 and EAF-2010 calculations for the 5 minutes irradiation experiment. For the 7 hours irradiation the behaviour of the two calculations is different: EAF-2010 calculations overestimate the experimental data for the first two cooling times, whereas FENDL/A-2 shows an underestimation. EAF-2010 shows an overall worse trend with respect to the FENDL/A-2 calculations.

- **Niobium (Nb)**

  For the 5 minutes irradiation the FENDL/A-2 calculations show a better agreement with the experimental data than the EAF-2010 ones for all the cooling times. For the 7 hours irradiation the behaviour is quite similar for the two calculations except for the cooling times up to 13 days where EAF-2010 shows lower discrepancies.

- **Nickel (Ni)**

  An overall better agreement with respect to the experimental data is shown by the EAF-2010 calculations than by the FENDL/A-2 ones for the 5 minutes irradiation test.

  The two calculations are both in good agreement for the 7 hours irradiation experimental data, except for the low cooling time values where the discrepancy is nearly 10%. Anyway for the cooling times between 13 and 60 days FENDL/A-2 calculations predict values lower than the experimental data and EAF-2010 higher values.

- **Nichrome (NiChro)**

  For the 5 minutes irradiation the discrepancies between experimental data and calculation results are lower for EAF-2010 calculations than for FENDL/A-2 ones. At lower cooling times all calculated results show a significant underestimation of the experimental data.

  A good agreement is found from both calculations for the 7 hours irradiation, mainly for FENDL/A-2 calculations.

- **Lead (Pb)**

  The experimental decay heat data are adequately predicted by the FENDL/A-2 calculations only for the cooling times > 10 minutes for the 5 minutes irradiation experiment. For cooling times < 10 minutes the calculations underestimate the experimental values: FENDL/A-2 calculations show a better behaviour (maximum (C-E)/E=28%) than the EAF-2010 ones that show a constant underestimation of about 30% for all the cooling times. For the 7 hours irradiation the discrepancies between experimental and calculated values are acceptable only up to 13 days, after which they rise up to nearly 100%. It has to be outlined however that the experimental values at the highest cooling times for the 7 hours irradiation experiment are affected by large uncertainties, up to 64%, so it is difficult to draw a conclusion about the calculation-experiment comparison.

- **Rhenium (Re)**

  Both the calculations predict values larger than the experimental ones for the 5 minutes irradiation experiment except for the first cooling time.

  The agreement is good for the FENDL/A-2 calculations for the 7 hours irradiation experiment.

  On the contrary the EAF-2010 calculations shown an underestimation of the experimental data over all the cooling times.

- **Sulfur (S)**

  For the 5 minutes irradiation test the agreement between calculated and experimental decay heat data is better for the EAF-2010 calculations. In fact, the (C-E)/E curve of FENDL/A-2 has a sharp peak at the cooling time of 1.6 minutes. This is probably due to a too large $^{32}S(n,t)^{30}P$ cross section.

  For the 7 hours irradiation both the calculations give good results.

- **Silicon Dioxide (SiO_2)**

  The experimental decay heat data are provided for the 5 minutes irradiation only.

  Both the calculations in general underestimate the experimental values, except for FENDL/A-2 which overestimates the experimental data in the range 20-30 days. The underestimation, more evident for EAF-2010, is probably due to the presence of unknown impurities in the sample, as outlined by the experimental group, not included in the calculations. In fact, for the 7 hours irradiation, no activity from silicon but some unknown activities probably from impurities were observed.

- **Tin Dioxide (SnO_2)**

  For the 5 minutes irradiation EAF-2010 shows a better agreement with the experimental data. For the 7 hours irradiation experiment EAF-2010 and FENDL/A-2 shows a similar trend with an underestimation of the experimental data up to 30% for cooling times < 20 days and an overestimation that rises up to 10-15% at 100 days cooling time.

- **Strontium Carbonate ($SrCO_3$)**

  Both the calculations give predictions largely lower than the experimental data for the 5 minutes irradiation and for all cooling times. It has to be noted that the EAF-2010 predictions show on the whole a better trend than the FENDL/A-2 ones.

  For the 7 hours irradiation, except for the first cooling time where both the calculations give a (C-E)/E=-52.5%, the agreement between calculated and experimental data is remarkable, mainly for FENDL/A-2.

- **Stainless Steel SS304**
  The calculations give both quite good predictions for the 5 minutes irradiation experiment, except a slight underestimation for cooling times up to 8 minutes. In the case of the 7 hours irradiation experiment, the agreement is good for FENDL/A-2 and even better for EAF-2010 calculations.

- **Stainless Steel SS316**
  For the 5 minutes irradiation both the calculations show a good agreement, (C-E)/E within 10%, with the experimental data for cooling times >10 minutes.
  In the case of the 7 hours irradiation experiment, a better agreement with the measured values is found for EAF-2010 calculations. Anyway both the calculations show a good agreement with the experimental data.

- **Tantalum (Ta)**
  The large discrepancies (80 to 100 %) shown for the 5 minutes irradiation by FENDL/A-2 calculations are strongly reduced in EAF-2010 calculations.
  The same conclusions are deduced for the 7 hours irradiation test up to 5 days cooling times. At higher cooling times comparable discrepancies are found by the two calculations.

- **Titanium (Ti)**
  The decay heat values calculated by EAF-2010 and FENDL/A-2 show a different behaviour for cooling times up to 10 days for the 5 minutes irradiation experiment. They show a similar underestimation for all the other cooling times after 10 minutes. The decay heat of titanium by both the calculations agrees within 15 % with the experimental data.
  A better agreement is found for the 7 hours irradiation history for FENDL/A-2 calculations. The overall discrepancies are within 10% for both the calculations.

- **Vanadium (V)**
  Good agreement between calculations and experimental results is found for the 5 minutes irradiation history for cooling times < 30 minutes. After 30 minutes the discrepancies gradually increase. Although the reason is not clear, it might be due to contributions from impurities (Al, Fe, Cu, etc.) in the vanadium sample. A good agreement also exists up to 24 days cooling time for the 7 hours irradiation test. For higher cooling times the big disagreement is probably due to not reliable experimental data.

- **Yttrium Oxide (Y_2O_3)**

  Both the calculations give predictions lower than the experimental values for both the irradiation tests and for nearly all the cooling times. For the 5 minutes irradiation history both the calculations show underestimated values up to nearly 75%. For the 7 hours the agreement is within 16%.

- **Zirconium (Zr)**

  A good agreement between calculations and experimental values is shown by both the calculations for the two different irradiation tests and for all cooling times, mainly for FENDL/A-2 calculations regarding the 5 minutes irradiation data and EAF-2010 for the 7 hours irradiation data.

6 CONCLUSION

The results of the validation of the updated decay data libraries used by the ANITA-4M activation code have been presented and discussed in the present report.

Activation calculations have been performed via ANITA-4M code using the updated decay data libraries based on the JEFF-3.1.1 Radioactive Decay Data Library and the EAF-2010 activation cross section library of the EASY-2010 code package (referred to as EAF-2010 calculations).

The calculation results have been compared with the experimental decay heat data related to 32 material samples irradiated in the 14 MeV neutron flux of the Fusion Neutronics Source (FNS), JAERI (now JAEA), Tokai, Japan, namely : Al, B_4C, $BaCO_3$, Bi, CaO_3, CF_2, Co, Cr, Cu, Fe, Inconel, K_2CO_3, Mn, Mo, Na_2CO_3, Nb, Ni, NiCr, Pb, Re, S, SiO_2, SnO_2, SrCO3, SS304, SS316, Ta, Ti, V, Y_2O_3, Zr.

The results of these calculations have been compared also with the calculated values obtained by using the original libraries of the ANITA-2000 code package i.e. decay data libraries based on FENDL/D-2 and the activation cross section library FENDL/A-2 (referred to as FENDL/A-2 calculations).

From the analysis of the results the first conclusion that can be derived is that the knowledge of the sample impurities content is mandatory in order to improve calculation consistency with the experimental data. If those levels of impurities are not known then the code predictions cannot be accurate, and so the comparison will be inconclusive at the cooling times when impurities are proven to be important.

Both not reliable activation cross sections and decay data can be responsible of the observed discrepancies between calculations and experimental data, showing that also the most recent evaluations need further improvements.

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