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Executive Summary

The calculation of activation inventories is a key input to virtually all aspects of the operation, safety and environmental assessment of nuclear plants. For the licensing of such devices, regulatory authorities will require proof that the calculations for structural materials and fuel inventories, and calculations to which these quantities are the inputs, are either correct or conservative. An important aspect of activation-transmutation is decay heat power.

In power plants decay power arises after shutdown from the energy released in the decay of the products of neutron interaction by α, γ and β emissions. Computation of the decay power is performed by sophisticated computer codes which solve the large number of coupled differential equations governing the generation and decay chains for the many nuclides involved. They rely on a large volume of nuclear data that includes both neutron activation-transmutation cross sections and radioactive decay data.

Validation of decay power computational predictions by means of direct comparison with integral data and measurement of sample structural materials under high energy relevant neutron spectra generates confidence in the values calculated. It also permits an assessment of the adequacy of the methods and of the nuclear data, and indicates any inaccuracy or omission that may have led to erroneous results.

No experimental data on decay power existed for most fission reactor materials other than reactor fuel, or for materials under high energy irradiation conditions typical of fusion, until a series of experiments were performed using the Fusion Neutron Source FNS facility at the Japan Atomic Energy Agency JAEA. Many elements and some alloy micro-samples were irradiated in a simulated D-T neutron field for times up to 7 hours and the resulting decay power generated was measured for cooling times of up to a year or more. Using the highly sensitive Whole Energy Absorption Spectrometer (WEAS) method, both β and γ emission decay energies were measured at selected cooling times as early as a few tens of seconds after the irradiation ended. The experimental measurements were then compared with simulations by the inventory code FISPACT-II using different nuclear data libraries: TENDL-2013, JEFF-3.2, ENDF/B-VII.1 and JENDL-4.0. This is, to our knowledge, the most detailed comparison of this type that has been undertaken.

Overall the results of this particular validation exercise indicate that the calculational methods and nuclear databases, with some notable exceptions and variability, generally allow predictions, with quantifiable margins, of the decay power of the tested materials against cooling time. This exercise tested the specific production pathways and at the same time the decay data associated with the nuclides that dominate the decay heat. Note that the decay characteristic of the predominant isotopes is independent of the production route: be it fission, fusion or transmutation in general.

Contents

1 Introduction

Safety and Environmental (S&E) impact issues have acquired increasing importance for the development of power plants. As part of future programmes and especially in connection with engineering feasibility studies, S&E and R&D analyses require a sound and reliable database for the neutron-induced primary and secondary responses. The words primary and secondary define two very different types of response: the former relates to neutronic and gamma-ray time independent responses when the plant is in operation, while the latter refers to time dependent responses which are important after shutdown. In power plants, decay heat will arise after shutdown from the energy released in the decay of the products of particle interactions.

The calculation of activation inventories is an important input to virtually all aspects of S&E analysis. For licensing, the regulatory authorities will require proof of either the correctness or conservatism of the calculations of activation-transmutation and of calculations which use activation-transmutation as input. The radioactive inventory and residual decay power generation depend on the specific design of the plant and its components, its geometrical configuration and material choices, as well as the given irradiation conditions: power, operational scenario, and neutron source distribution. It is essential to include in the plant development properly performed activation inventory calculations that are consistent with the overall plant design. An important aspect of activation is residual decay power. The residual decay power, in the event of a postulated accident in which cooling is lost, might induce structural damage in certain plant components. Temperature transients may promote gas-generating chemical reactions and, in plants of high power density, may promote the mobilisation of activation, transmutation or fission products.

There is thus a strong motivation to limit accidental temperature transients and to ensure that the design and material-choices provide for removal of decay heat, preferably by passive means. Safety studies assess the efficiency of the design in this regard using computer models which require, as a starting point, an accurate assessment of the decay heat levels in the plant. Computation of the decay power is performed by sophisticated computer codes which solve the large number of coupled differential equations which govern the generation and decay chains for the many nuclides involved. They rely on a large volume of nuclear data, both neutron activation-transmutation cross sections and radioactive decay data.

Validation of decay power predictions from such codes by means of direct comparison with integral data measurements of sample structural materials under neutron spectra allow confidence to be given to the decay power values calculated. It also permits an assessment of the adequacy of the methods and nuclear data, and indicates any inaccuracy or omission that may have led to erroneous code predictions. Safety authorities world-wide tend to request experimental validation results that can be used to assess the adequacy of the safety features. It is clear that certain safety margins can be derived from such a validation exercise, if relevant to plant operation, materials and design, and applied as bounding conditions in S&E analyses.

Little experimental data exists for structural material samples irradiated under relevant neutron spectra and even when data does exist the measured quantities are either specific activity and/or γ spectroscopy. In particular, no experimental data on decay power has previously existed for fission plant structural materials and for materials under high energy irradiation conditions (i.e. fusion). It was to fill this gap that a series of experiments were performed using the Fusion Neutron Source (FNS) facility at the Japan Atomic Energy Agency JAEA [1, 2, 3] . Material samples were irradiated in a simulated D-T neutron field and the resulting decay power was measured for cooling times of up to thirteen months. Using the highly sensitive Whole Energy Absorption Spectrometer (WEAS) method, both β and γ emission decay energies were measured at selected cooling times and, quite impressively, as soon as a few tens of seconds after the end of irradiation.

2 EXPERIMENTAL SET-UP

2.1 FNS assembly

14 MeV neutrons are generated by a 2 mA deuteron beam impinging on a stationary tritium-bearing titanium target. The total neutron flux at the sample location, for this experiment, is in the range of 1.0×10^{10} [n cm^{-2} s^{-1}], the same order of magnitude as in the first wall of the Joint European Torus (JET) fusion experiment when operating with D-T plasma. However, the irradiation time at the FNS were of 5 minutes and 7 hours in comparison with the few seconds flat burn achieved during the DTE1 JET fusion campaign. The DTE1 campaign culminated in a single 16MW fusion shot. As a point of reference the total flux in a power plant is typically expected to be in the region of 10^{13} or 10^{15} [n cm^{-2} s^{-1}], three to five orders of magnitude higher than in JET or FNS, and also for much longer irradiation times.

Thin samples, 25x25 mm^2 in area, and typically 10 μm thick, have been used, either as metallic foil or powder sandwiched between tape. Use of a thin sample minimises the self-absorption of β rays emitted in the sample itself and allows their measurement. A total of 74 different materials have been used across the different phases of the experiment.

The decay energy in each irradiated sample was measured in the Whole Energy Absorption Spectrometer (WEAS), which comprises two large bismuth-germanate BGO scintillators in a geometric arrangement, provides almost 100 % detection efficiency for both β and γ-rays (see Figure 1). Correction factors need to be applied for γ-ray efficiency and for β and electron energy loss in the sample itself (less than 15% generally), and for other effects such as the decay heat due to the plastic tape used for the powder samples. The overall experimental uncertainty totals between 6 to 10% in most cases, although it rises to higher levels at particular cooling time for certain samples. The

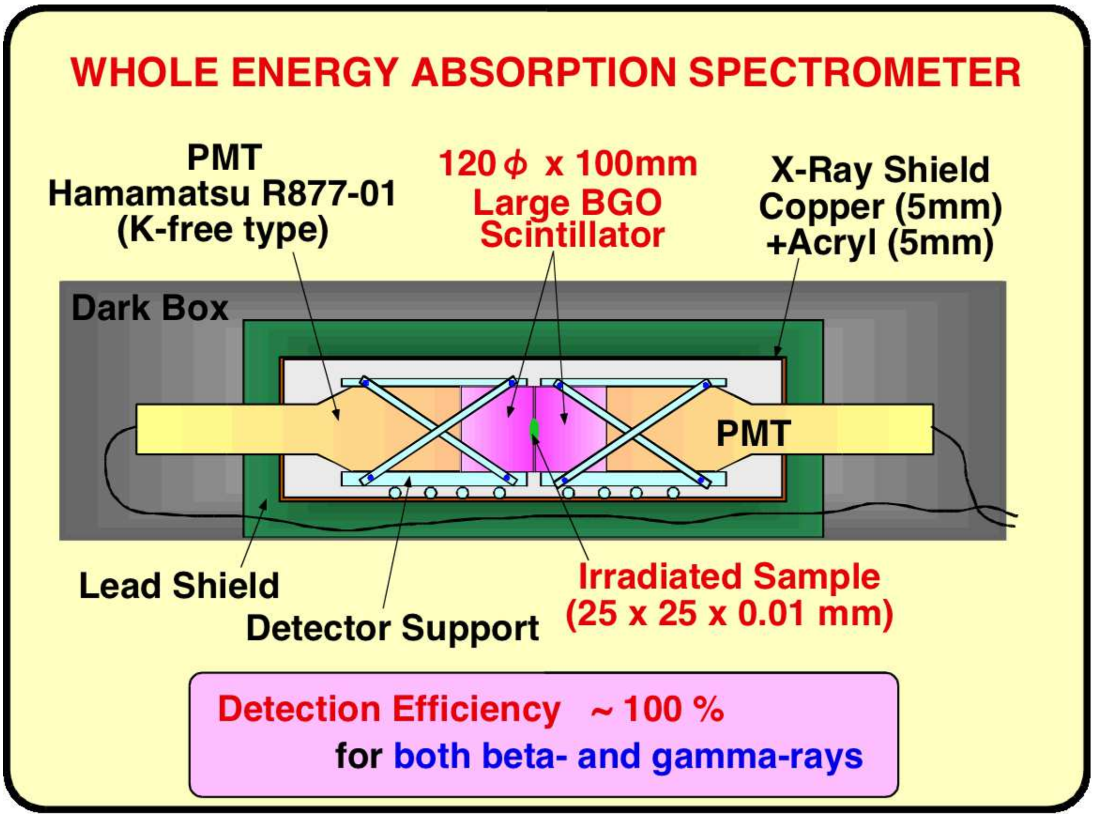


Figure 1: Whole Energy Absorption Spectrometer WEAS set-up

WEAS provides high sensitivity, down to powers less than 1 pW, which is valuable for measurement of some nuclides with long half-lives. It also has a wide dynamic range: measurements of up to a few mW have been achieved in the experiments.

2.2 Irradiation conditions

Three types of irradiation have been performed in order to extract the maximum information possible from such experiments. First, a 5 minute irradiation rapidly followed by a time dependent series of decay power measurements from tens of seconds up to one hour of cooling was used. Such prompt measurements are made possible by the use of a small sample rapidly transported from the irradiation zone to the measurement areas by means of pneumatic tubes. This particular type of measurement allows very short half-life nuclides to be detected and measured. Second, a 7 hour irradiation was performed for some of the samples, followed by a more relaxed time-dependent series of decay power measurements spanning from half a day up to a year of cooling. And third, in order to broaden the scope of the study and enlarge the materials database, the number of studied materials was increased from 32 to 74, covering many more elements of interest, but with published results only on the 5 minute irradiation experiments.

In the 5 minute irradiation experiments, three different positions were used: positions 1, 2, 3; while only one sample position, 7, was used for the 7 hour irradiations. The experimental set-ups in for each position are depicted in Figure 2. Different neutron spectra, in the 175 Vitamin-J group structure, were calculated using the Monte Carlo code MCNP [3] with a geometrical configuration corresponding to the different assembly positions, and are plotted in Figure 3. Slight spectral differences exist between position 1, 2 and 3; however the neutron flux profiles indicate a marked 14 MeV fusion peak and very few neutrons at energies lower than one MeV. The flux profile corresponding to position 7 is sufficiently shifted from the others to be treated separately. It is clear from Figure 3 and the fact the calculated standard deviation is large (typically greater than 20% [3]) for the energy groups below 100 eV, that few reaction rates can be well characterised at these energies. This means that if the energies below 100 eV are important in the production pathways of a measured radionuclide, no clear conclusion should be drawn from the comparison. Note that a nominal 0.5 to 1% standard deviation convergence criteria for reaction rates in all the neutron energy bins was not achieved in the Monte Carlo simulation, although the standard deviation of the total fluxes was below a few percent. This highlights the fact that in Monte Carlo simulations the total-flux standard deviation is not a good indicator of the quality of the neutron flux spectra, particularly in their low energy tails.

Originally in 1996, 32 relevant materials were irradiated at JAEA/FNS, for 5 minutes and 7 hours, and decay heat values measured over a wide range of cooling times: from a few tens of seconds up to 400 days, and compared to predictions with previous activation databases [4, 5]. These results are referred to as FNS-96 in this report. Additionally in 1998-99, 74 samples - one for each of naturally occurring elements, but excluding very light element and noble gases - were prepared for a new measurement campaign in the same assembly. The experimental results are referred to in this report as FNS-00, having been released officially in 2000.

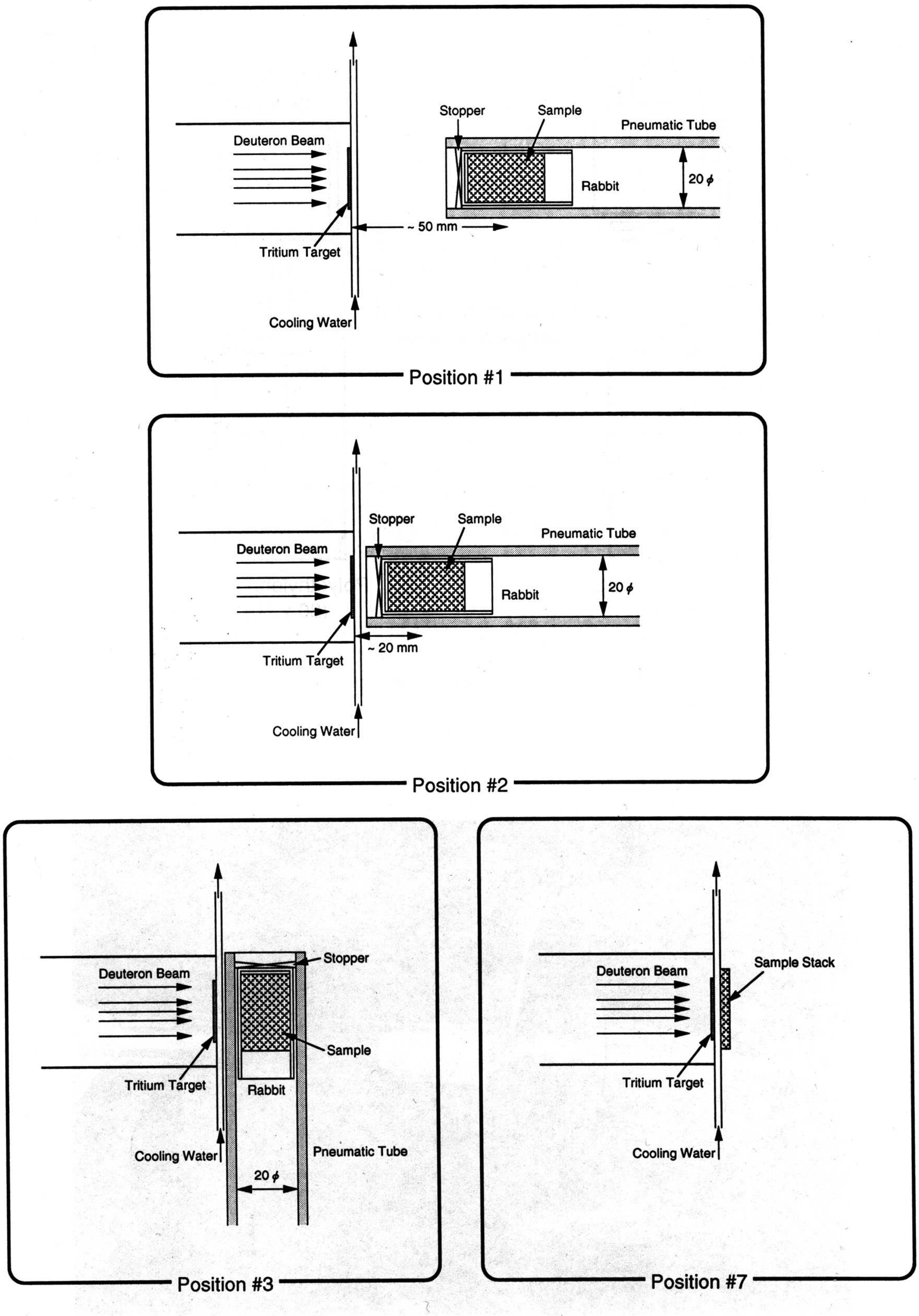


Figure 2: JAEA FNS four set up assemblies

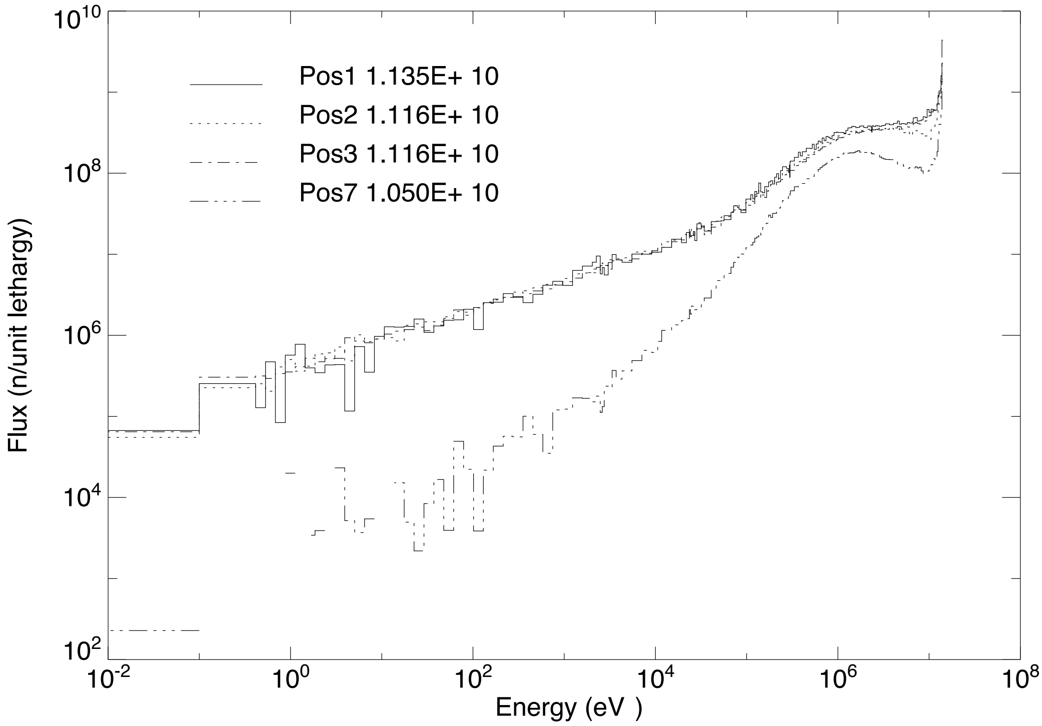


Figure 3: FNS Neutron spectra, neutron fluence monitored by ^{27}Al(n,α)^{24}Na

2.3 Material data

For each of the material samples, the percentage elemental weight has been supplied by JAEA. These tend to correspond to the theoretical weight distribution calculated from the compound or material fractions of the major isotopes. No impurity levels have been given and thus no isotopes other than the major ones have been used in the input data of the calculation scheme. The lack of real chemical analysis of the irradiated samples, although not thought to be important at the preparatory stage of this validation exercise, will be shown to be a drawback for certain materials that seem to have contained a specified (by the manufacturer), but un-quantified, amount of impurities. If those levels of impurities are not known then the code predictions cannot be accurate, and so the comparison will be inconclusive at times when impurities are proven to be important. Table 1 gives a complete list of the irradiated samples and their experimental form.

Z	Element	Form	Z	Element	Form
9	Fluorine	CF_2	46	Palladium	Metallic Foil
11	Sodium	Na_2CO_3	47	Silver	Metallic Foil
12	Magnesium	MgO	48	Cadmium	Metallic Foil
13	Aluminium	Metallic Foil	49	Indium	Metallic Foil
14	Silicon	Metallic Powder	50	Tin	SnO_2
15	Phosphorus	P_3N_5	51	Antimony	Metallic Powder
16	Sulphur	Powder	52	Tellurium	TeO_2
17	Chlorine	$C_2H_2Cl_2$	53	Iodine	IC_6H_4OH
19	Potassium	K_2CO_3	55	Caesium	Cs_2O_3
20	Calcium	CaO	56	Barium	$BaCO_3$
21	Scandium	Sc_2O_3	57	Lanthanum	La_2O_3
22	Titanium	Metallic Foil	58	Cerium	CeO_2
23	Vanadium	Metallic Foil	59	Praseodymium	Pr_6O_{11}
24	Chromium	Metallic Powder	60	Neodymium	Nd_2O_3
25	Manganese	Metallic Powder	62	Samarium	Sm_2O_3
26	Iron	Metallic Foil	63	Europium	Eu_2O_3
Alloy	SS304	Metallic Foil	64	Gadolinium	Gd_2O_3
Alloy	SS316	Metallic Foil	65	Terbium	Tb_4O_7
27	Cobalt	Metallic Foil	66	Dysprosium	Dy_2O_3
Alloy	Inconel-600	Metallic Foil	67	Holmium	Ho_2O_3
28	Nickel	Metallic Foil	68	Erbium	Er_2O_3
Alloy	Nickel-chrome	Metallic Foil	69	Thulium	Tm_2O_3
29	Copper	Metallic Foil	70	Ytterbium	Yb_2O_3
30	Zinc	Metallic Foil	71	Lutetium	Lu_2O_3
31	Gallium	Ga_2O_3	72	Hafnium	Metallic Powder
32	Germanium	GeO_2	73	Tantalum	Metallic Foil
33	Arsenic	As_2O_3	74	Tungsten	Metallic Foil
34	Selenium	Metallic Powder	75	Rhenium	Metallic Powder
35	Bromine	BrC_6H_4COOH	76	Osmium	Metallic Powder
37	Rubidium	Rb_2CO_3	77	Iridium	Metallic Powder
38	Strontium	$SrCO_3$	78	Platinum	Metallic Foil
39	Yttrium	Y_2O_3	79	Gold	Metallic Foil
40	Zirconium	Metallic Foil	80	Mercury	HgO
41	Niobium	Metallic Foil	81	Thallium	Tl_2O
42	Molybdenum	Metallic Foil	82	Lead	Metallic Foil
44	Ruthenium	Metallic Powder	83	Bismuth	Metallic Powder
45	Rhodium	Metallic Powder			

Table 1: Irradiated sample materials

3 CODE AND LIBRARIES

The European Activation System, EASY-II [6], has been used to perform this validation exercise. Four, quite-different, major cross section databases have been accessed using the FISPACT-II code [7]: TENDL-2013 [8], ENDF/B-VII.1 [9], JEFF-3.2 [10] and JENDL-4.0 [11]. TENDL-2013 is the only one of the libraries that includes a full set of exploitable covariances. In addition to cross-sections the other basic quantities required by an inventory code are information on the decay properties (such as half-life or decay scheme) of all the nuclides considered. These data are available in a handful of evaluated decay data libraries. FISPACT-II is able to read the data directly in ENDF-6 format; it requires no pre-processing to be done. The now well verified and validated eaf_dec_2010 library based primarily on the JEFF-3.1.1 and JEF-2.2 radioactive decay data libraries, with additional data from the latest UK evaluations, UKPADD6.10, contain 2233 nuclides. However, to handle the extension in incident particle type, energy range, and number of targets, many more are needed. A new 3873-nuclide decay library dec_2012 has been assembled from eaf_dec_2010 complemented with all of JEFF-3.1.1 and a handful of ENDF/B-VII.1 decay files. This new decay library was used in all the simulations, see Reference [12] for more details.

In order not to bias the experimental spectral data, the groupwise libraries used in the calculation scheme all correspond to a 709 group structure [7] collapsed using a 1 over E micro flux weighting function.

These calculations required the collapse of the nuclear data libraries for each flux at positions 1, 2, 3 and 7. The well validated FISPACT-II features that allow a determination of the dominant radionuclides, and analysis of the pathways of their formation, have been used and are reflected in the detailed comparison analysis.

Also, and for the third time [13, 14], the method used in TENDL libraries to assess the calculation uncertainties from the unique Total Monte Carlo (TMC) method has been related to either the E/C results or the experimental uncertainties. This provides a unique opportunity to assess the adequacy and reliability of the covariance data generated using the Total Monte Carlo TMC method implemented in the TALYS T6 system.

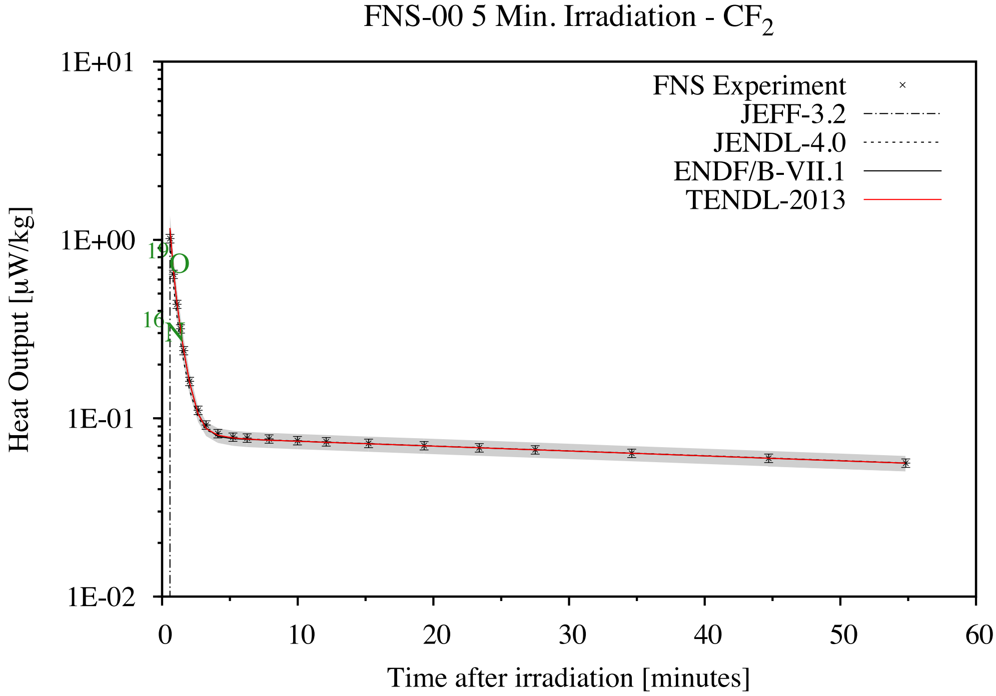
4 COMPARISON OF THE RESULTS

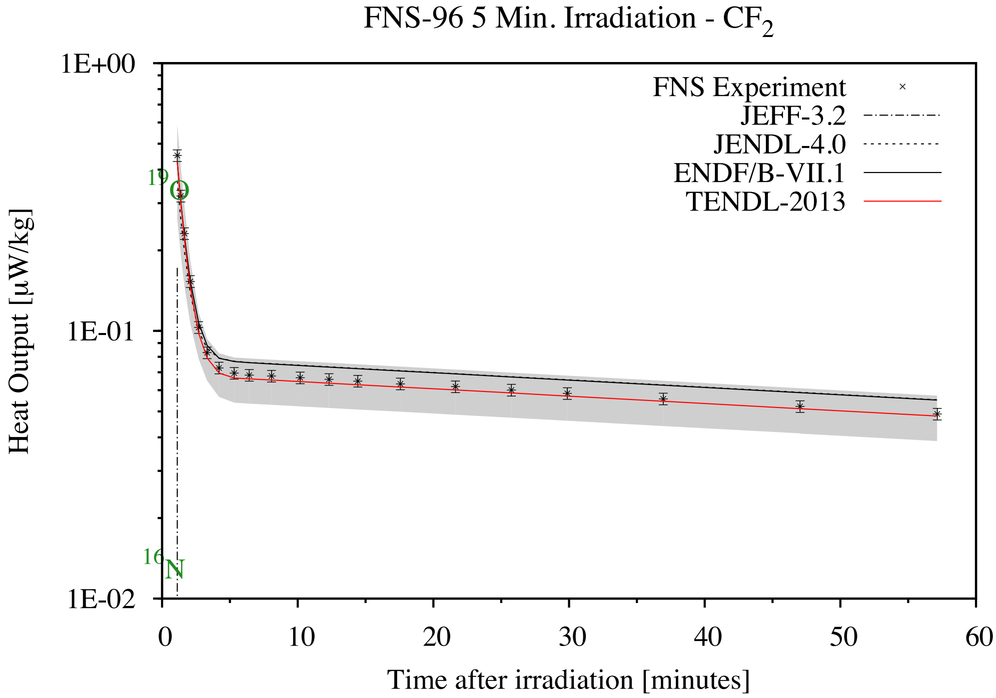
For each material sample and irradiation condition, FISPACT-II, combined with the &TENDL-2013, ENDF/B-VII.1, JEFF-3.2 and JENDL-4.0, calculations have been performed. Tabular and graphical comparisons of the results are presented. On the graphs FNS experimental measurements are also plotted and include the uncertainties as vertical lines, while the grey shadow area corresponds to the calculation uncertainty derived from TENDL-2013. The 5 minute irradiation results are presented first followed by those for the 7 hour irradiations. Care needs to be taken when interpreting the graphs, particularly in view of the log-linear scales. Such plots allow a direct visual interpretation of nuclide half-life at times when one isotope is clearly dominant. A departure from equivalence in the decay profile between experiment and calculation would indicate a mismatch in terms of half-life in one or more of the important nuclides. Graphs corresponding to the 5-minute irradiations of the year 2000 campaign are given first, followed by the results of the year 1996 experiments, where they exist. A table (for the 2000 5-minute or 1996 7-hour experiments only) give more information, such as the calculation uncertainties, and allows a more precise interpretation of the comparison. This is followed by, for each irradiation experiment, the list of the dominant radionuclides that contribute at a level of more than 0.5% to the total decay power at all cooling times. Their production pathways, calculated by FISPACT-II, are also here, including the percentage contribution of each route, if more than one exists. All these quantities allow a judgement to be made on whether the experimental result is able to validate the calculational method for the production paths and decay data. The judgement is shown in the E/C column. The half-life of each dominant radionuclide, and thus the timescale at which they are predominant, is also presented. Following this, another graph is given (again, only for the 2000 5-minute or 1996 7-hour experiments), showing the calculated decay heat as a function of time with the predominant radionuclides, added on the graphs with their isotopic name at their heat output level at shutdown on the ordinate and half live on the abscissa. Such plotting, on a log-log scale allows one to immediately comprehend the relative contribution of different nuclides to the total heat output as a function of time.

Careful consideration needs to be given when analysing a experimental data such as that produced from FNS. The fact is that the measured quantities may, or may not, be directly related to the pathways of production of a particular radionuclide. There is only a strong possibility, not a certainty, that, firstly the major radionuclides measured are the one predicted by the code, and secondly that their amount has been properly calculated before their respective decay power is derived. Although improbable, one may envisage a 20% under prediction in terms of atomic amount of a nuclide, balanced by a 20% over prediction through the decay data scheme. This would lead to a perfect E/C value. Such possibilities of error compensation, though unlikely, may well exist at a certain level and so make the interpretation of the results more difficult. However, such difficult-to-detect scenarios are made less probable when the experimental results are analysed by different activation codes, cross section and decay data [3], and are used with other comparison methods such as C/E values for the cross sections themselves.

There follows in the rest of the report a presentation, as described above, of the analysis for each of the 74 materials samples that have been irradiated.

Fluorine

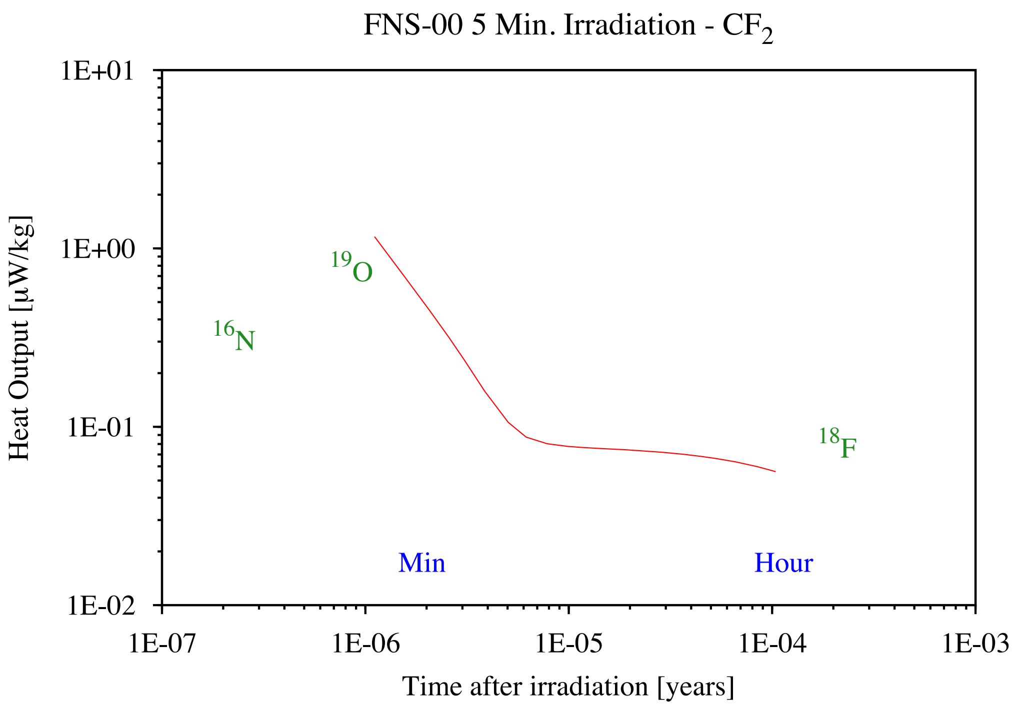




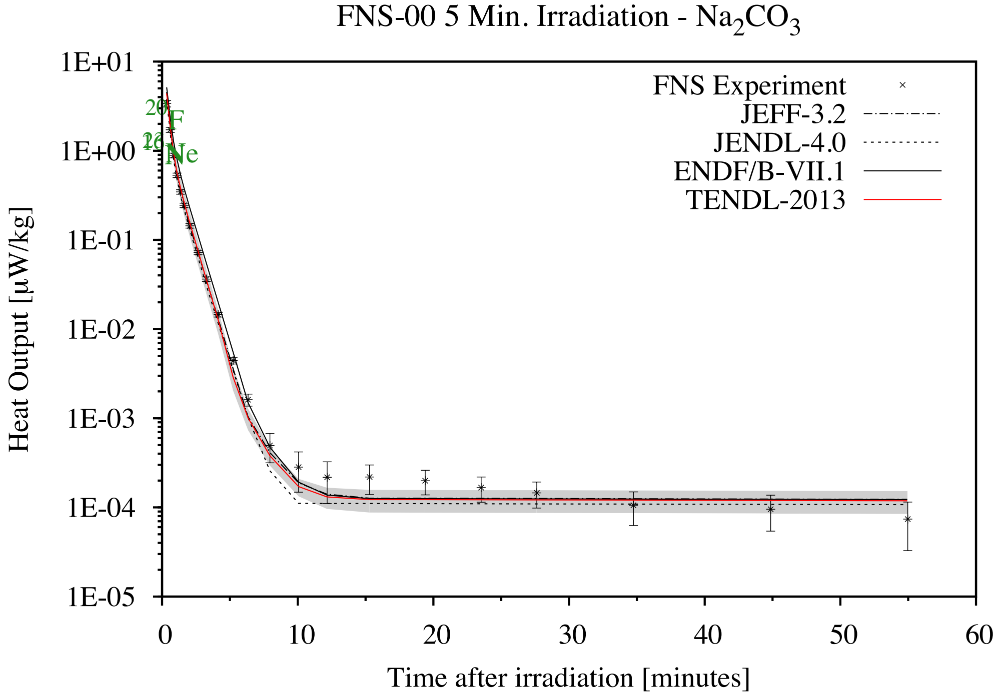
For Fluorine, the agreement looks excellent for both samples and irradiation batches at all times for TENDL-2013, and after 3 minutes cooling for all others libraries except JEFF-3.2. The variation between the two experimental data sets clearly demonstrates that experiments do not always lead to the same measurements, even when carried out in the same assembly set-up. However, the F18 route of production uncertainty of 10% accounts for such experimental fluctuation.

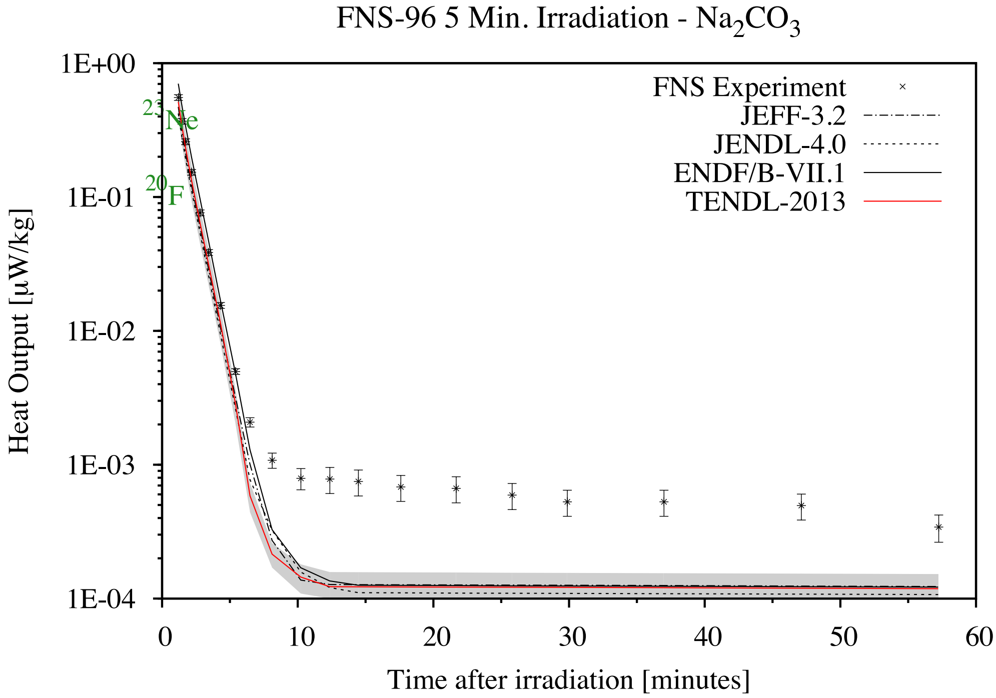
Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	1.02E+00 +/-5%	1.16E+00 +/-18%	0.87	0.88	0.88	1.07
0.83	6.42$E-$01 +/-5%	6.76$E-$01 +/-20%	0.95	0.95	0.00	1.15
1.10	4.36$E-$01 +/-5%	4.41$E-$01 +/-20%	0.99	0.99	0.00	1.17
1.35	3.17$E-$01 +/-5%	3.19$E-$01 +/-19%	1.00	1.00	0.00	1.17
1.60	2.40$E-$01 +/-5%	2.40$E-$01 +/-17%	1.00	1.01	0.00	1.16
2.03	1.61$E-$01 +/-5%	1.58$E-$01 +/-14%	1.02	1.02	0.00	1.12
2.65	1.11$E-$01 +/-5%	1.06$E-$01 +/-10%	1.05	1.04	0.00	1.09
3.25	9.17$E-$02 +/-5%	8.74$E-$02 +/-9%	1.05	1.04	0.00	1.06
4.12	8.21$E-$02 +/-5%	8.03$E-$02 +/-9%	1.02	1.04	0.00	1.02
5.22	7.84$E-$02 +/-5%	7.75$E-$02 +/-10%	1.01	1.02	0.00	1.01
6.27	7.74$E-$02 +/-5%	7.64$E-$02 +/-10%	1.01	1.02	0.00	1.01
7.88	7.66$E-$02 +/-5%	7.54$E-$02 +/-10%	1.02	1.02	0.00	1.01
9.98	7.50$E-$02 +/-5%	7.43$E-$02 +/-10%	1.01	1.01	0.00	1.01
12.10	7.38$E-$02 +/-5%	7.33$E-$02 +/-10%	1.01	1.01	0.00	1.00
15.22	7.23$E-$02 +/-5%	7.19$E-$02 +/-10%	1.01	1.01	0.00	1.00
19.32	7.02$E-$02 +/-5%	7.01$E-$02 +/-10%	1.00	1.00	0.00	1.00
23.38	6.83$E-$02 +/-5%	6.83$E-$02 +/-10%	1.00	1.00	0.00	1.00
27.50	6.65$E-$02 +/-5%	6.65$E-$02 +/-10%	1.00	1.00	0.00	1.00
34.62	6.36$E-$02 +/-5%	6.36$E-$02 +/-10%	1.00	1.00	0.00	1.00
44.72	5.97$E-$02 +/-5%	5.97$E-$02 +/-10%	1.00	1.00	0.00	1.00
54.82	5.60$E-$02 +/-5%	5.60$E-$02 +/-10%	1.00	1.00	0.00	1.00

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
O19	F19(n,p)O19	26.9s	100.0	0.99	5%
F18	F19(n,2n)F18	1.82h	100.0	1.00	5%



Sodium

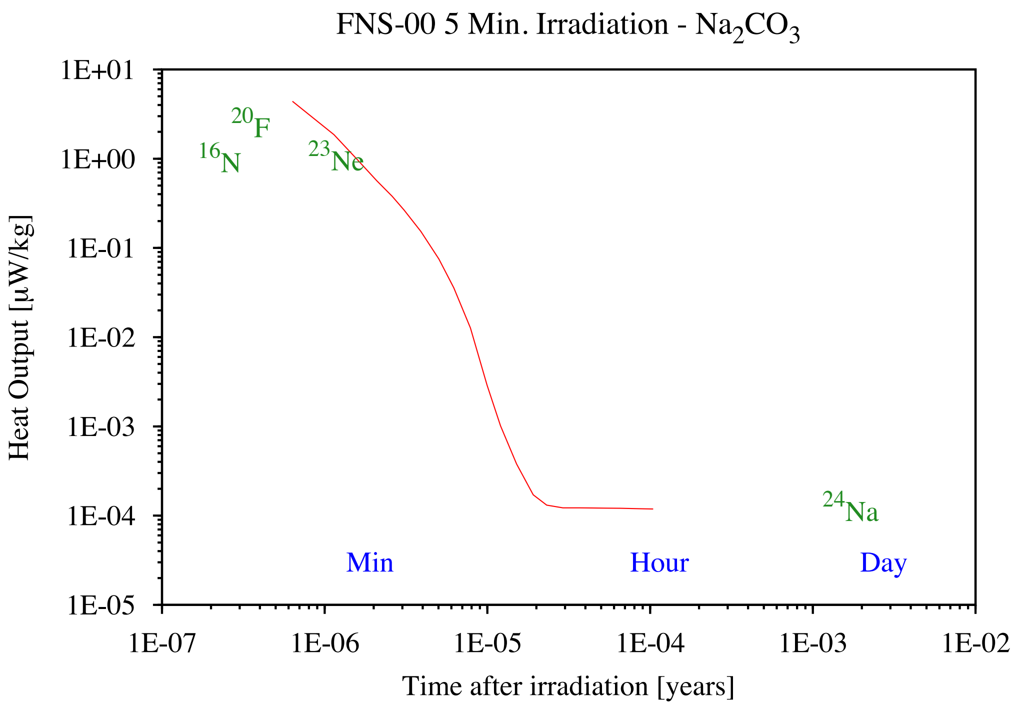


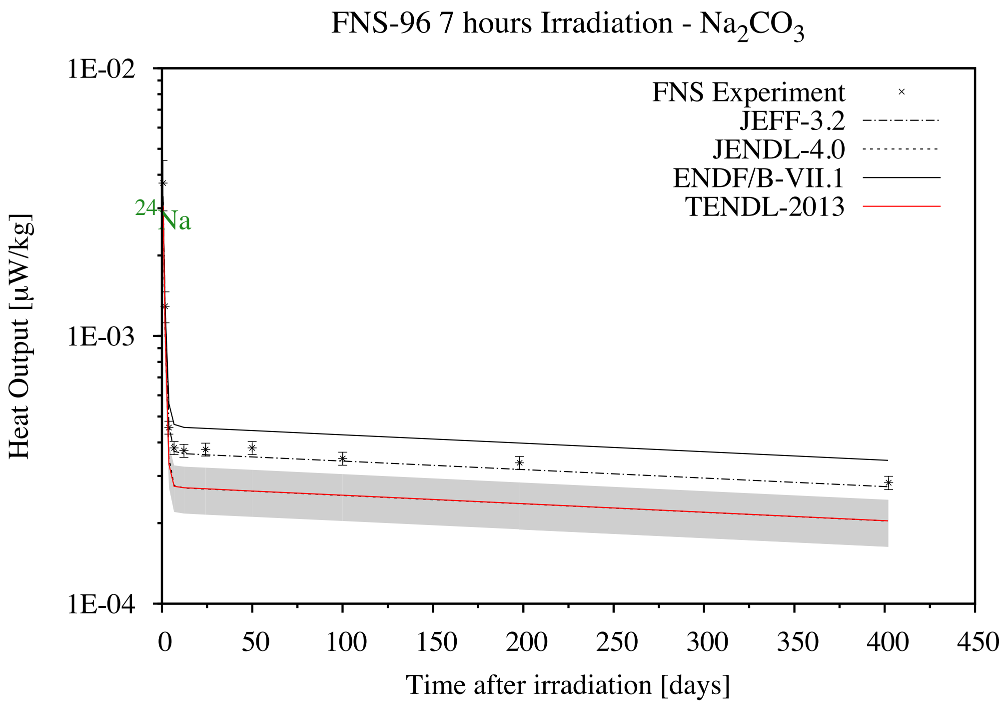


For Sodium, the two experimental measurements do not exhibit the same decay heat level, particularly in the plateau. Many factors could have influenced the experimental set-up and the presence of impurities in the sample is plausible. High experimental uncertainties accompany the latest 2000 experiment but the time dependence shape is definitely there. The TENDL-2013 Na23 capture cross section well represents the 2000 experiment and its associated uncertainty.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.33	3.38E+00 +/-8%	4.40E+00 +/-18%	0.77	0.66	0.74	0.90
0.60	1.72E+00 +/-7%	1.86E+00 +/-19%	0.92	0.74	0.91	1.10
0.85	8.86$E-$01 +/-6%	9.41$E-$01 +/-21%	0.94	0.70	0.95	1.11
1.10	5.30$E-$01 +/-6%	5.66$E-$01 +/-24%	0.94	0.66	0.96	1.10
1.37	3.45$E-$01 +/-6%	3.79$E-$01 +/-27%	0.91	0.65	1.00	1.11
1.62	2.44$E-$01 +/-6%	2.66$E-$01 +/-28%	0.92	0.64	1.00	1.11
2.05	1.44$E-$01 +/-6%	1.53$E-$01 +/-30%	0.94	0.64	1.03	1.12
2.65	7.22$E-$02 +/-6%	7.52$E-$02 +/-31%	0.96	0.65	1.00	1.14
3.27	3.63$E-$02 +/-6%	3.56$E-$02 +/-31%	1.02	0.67	1.03	1.18
4.13	1.45$E-$02 +/-6%	1.27$E-$02 +/-30%	1.15	0.73	1.11	1.25
5.23	4.44$E-$03 +/-9%	2.90$E-$03 +/-29%	1.53	0.80	1.23	1.28
6.33	1.61$E-$03 +/-15%	1.01$E-$03 +/-27%	1.59	1.07	1.55	1.58
7.95	4.94$E-$04 +/-36%	3.80$E-$04 +/-23%	1.30	1.04	1.20	1.93
10.07	2.83$E-$04 +/-48%	1.71$E-$04 +/-22%	1.66	1.47	1.50	2.55
12.17	2.18$E-$04 +/-49%	1.31$E-$04 +/-27%	1.66	1.58	1.55	1.97
15.30	2.19$E-$04 +/-37%	1.22$E-$04 +/-28%	1.79	1.74	1.72	1.98
19.40	1.99$E-$04 +/-31%	1.22$E-$04 +/-28%	1.63	1.59	1.57	1.81
23.52	1.67$E-$04 +/-31%	1.22$E-$04 +/-28%	1.37	1.34	1.32	1.52
27.62	1.46$E-$04 +/-33%	1.21$E-$04 +/-28%	1.20	1.17	1.16	1.33
34.75	1.06$E-$04 +/-41%	1.21$E-$04 +/-28%	0.88	0.86	0.85	0.97
44.87	9.55$E-$05 +/-43%	1.20$E-$04 +/-28%	0.80	0.78	0.77	0.88
54.97	7.39$E-$05 +/-56%	1.19$E-$04 +/-28%	0.62	0.61	0.60	0.69

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ne23	Na23(n,p)Ne23	37.2s	100.0	0.94	6%
Na24	Na23(n,γ)Na24	14.9h	100.0	0.88	41%
	Na23(n,γ)Na24m		0.0	0.00	%

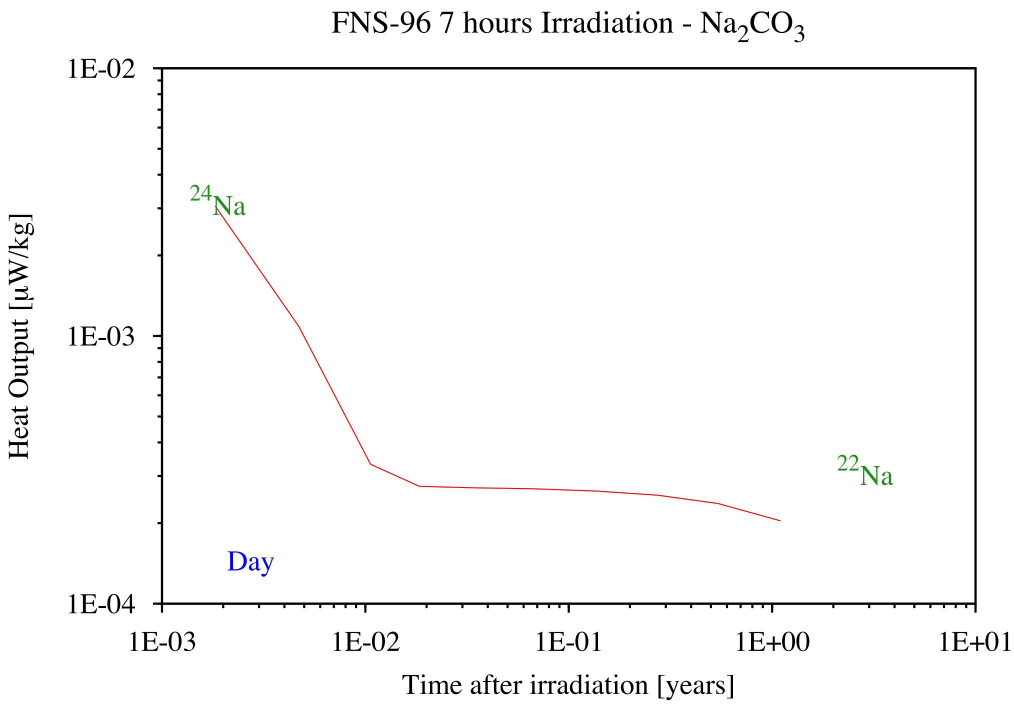




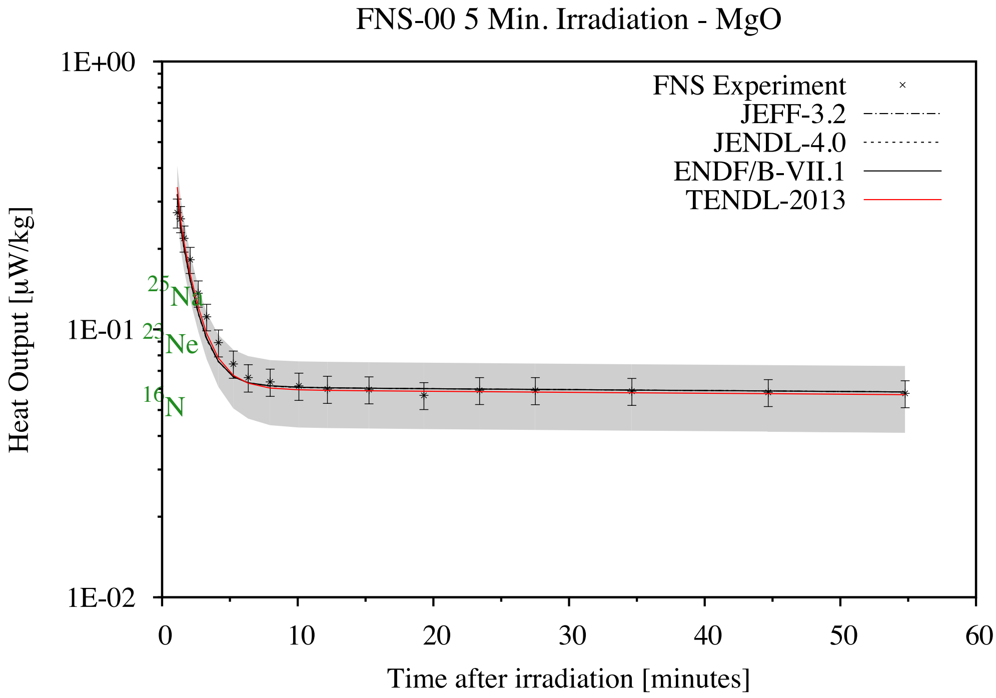
In this case the heat arising from Na22 seems to be under predicted by around 40% by TENDL-2013 and JENDL-4.0, over-predicted by 20% for ENDF/B-VII.1, but spot on with JEFF-3.2. Otherwise, there could be a contribution from unknown impurities that have not been taken into account in the simulation.

Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.67	$3.73E{-}03$ +/-21%	$3.06E{-}03$ +/-39%	1.22	1.18	1.12	1.37
1.72	$1.29E{-}03$ +/-13%	$1.08E{-}03$ +/-33%	1.19	0.99	0.99	1.23
3.87	$4.55E{-}04$ +/-6%	$3.32E{-}04$ +/-18%	1.37	0.81	0.98	1.30
6.74	$3.82E{-}04$ +/-6%	$2.74E{-}04$ +/-20%	1.39	0.82	1.03	1.38
12.19	$3.73E{-}04$ +/-6%	$2.71E{-}04$ +/-20%	1.38	0.82	1.03	1.38
24.20	$3.77E{-}04$ +/-6%	$2.69E{-}04$ +/-20%	1.40	0.83	1.05	1.41
49.95	$3.82E{-}04$ +/-6%	$2.64E{-}04$ +/-20%	1.45	0.86	1.08	1.45
100.08	$3.49E{-}04$ +/-6%	$2.54E{-}04$ +/-20%	1.37	0.82	1.02	1.37
197.95	$3.36E{-}04$ +/-6%	$2.37E{-}04$ +/-20%	1.42	0.84	1.06	1.42
402.16	$2.83E{-}04$ +/-6%	$2.04E{-}04$ +/-20%	1.39	0.83	1.03	1.39

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Na24	Na23(n,γ)Na24	14.9h	99.9	1.19	13%
Na22	Na23(n,2n)Na22	2.6y	100.0	1.42	6%


FNS-96 7 hours Irradiation - Na2CO3
Heat Output [µW/kg]
1E-02
1E-03
1E-04
24Na
22Na
Day
1E-03
1E-02
1E-01
1E+00
1E+01
Time after irradiation [years]

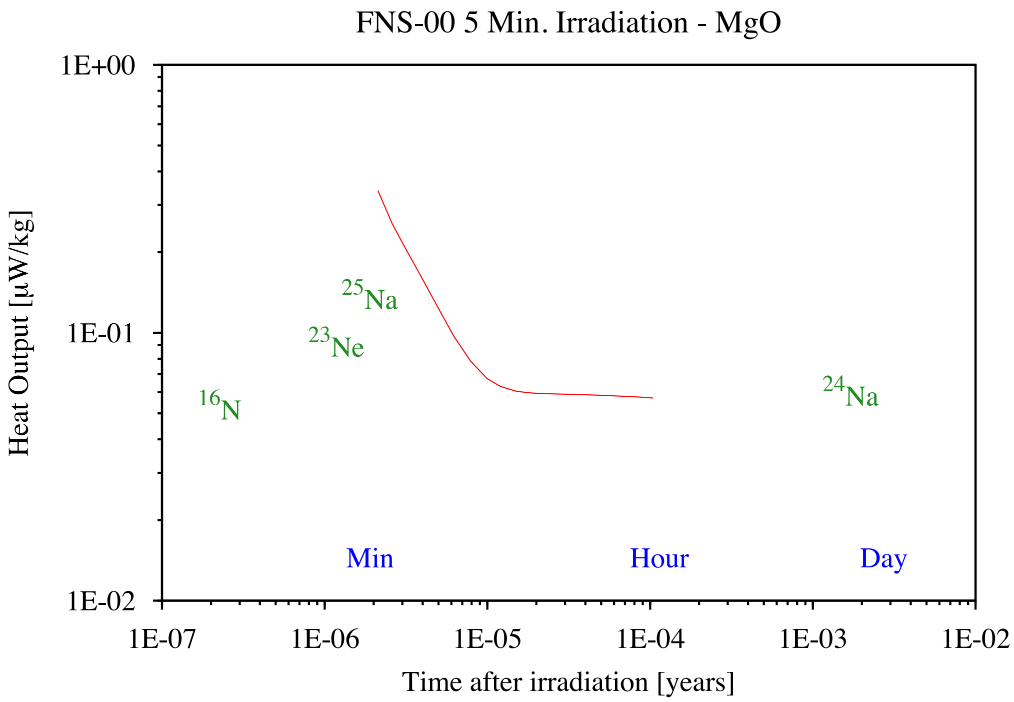
Magnesium



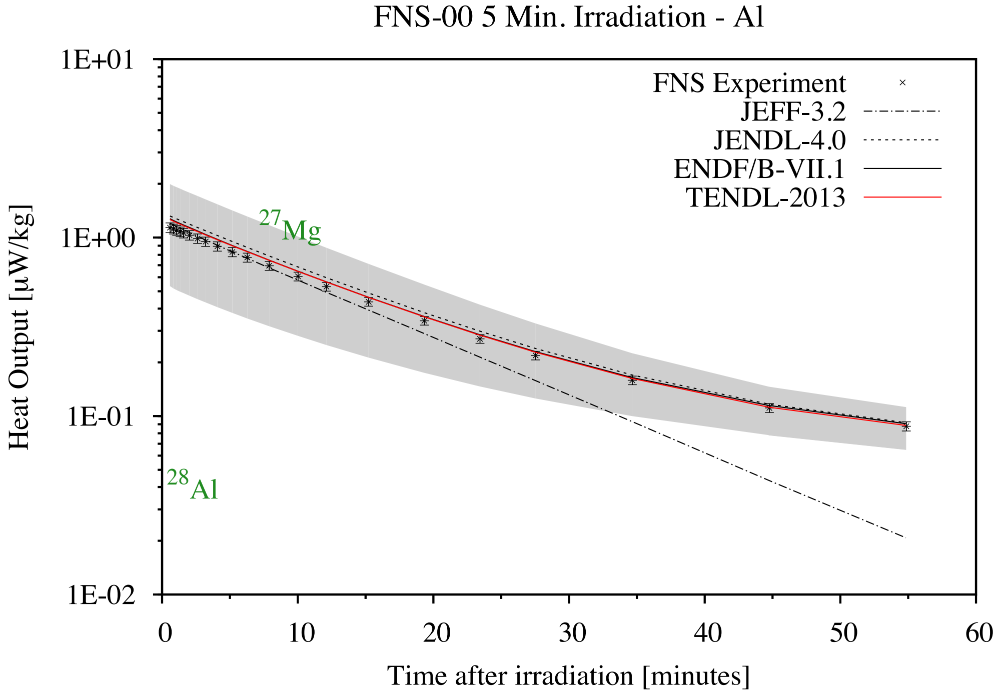
For Magnesium, there is excellent agreement at all cooling times except for JENDL-4.0. Na24 production reaction-rates are well predicted, although note that the Na24m isomer is not produced in any of the libraries.

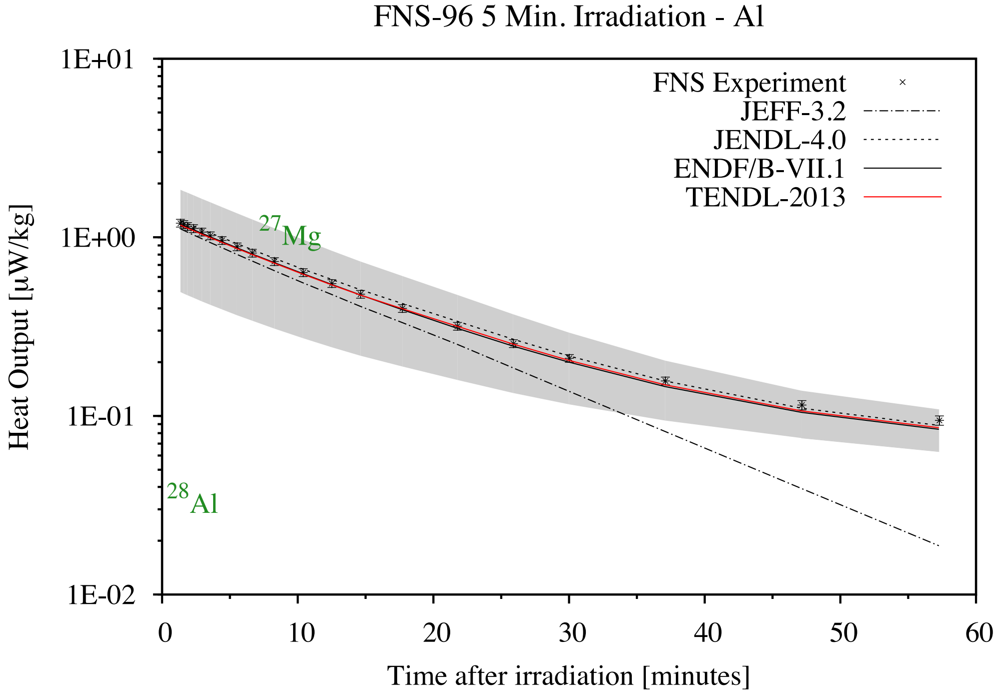
Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
1.12	$2.73E{-}01$ +/-12%	$3.40E{-}01$ +/-20%	0.80	0.85	0.85	0.86
1.37	$2.59E{-}01$ +/-11%	$2.55E{-}01$ +/-22%	1.01	1.07	1.07	1.07
1.62	$2.19E{-}01$ +/-11%	$2.11E{-}01$ +/-21%	1.04	1.08	1.08	1.09
2.07	$1.82E{-}01$ +/-11%	$1.61E{-}01$ +/-20%	1.13	1.18	1.18	1.19
2.67	$1.36E{-}01$ +/-11%	$1.21E{-}01$ +/-19%	1.12	1.18	1.18	1.19
3.28	$1.11E{-}01$ +/-11%	$9.67E{-}02$ +/-20%	1.15	1.20	1.21	1.21
4.15	$8.93E{-}02$ +/-12%	$7.83E{-}02$ +/-22%	1.14	1.17	1.18	1.18
5.25	$7.43E{-}02$ +/-12%	$6.74E{-}02$ +/-25%	1.10	1.12	1.11	1.12
6.35	$6.61E{-}02$ +/-12%	$6.30E{-}02$ +/-26%	1.05	1.05	1.05	1.05
7.97	$6.37E{-}02$ +/-12%	$6.04E{-}02$ +/-27%	1.05	1.03	1.03	1.04
10.08	$6.15E{-}02$ +/-12%	$5.95E{-}02$ +/-28%	1.03	1.01	1.01	1.01
12.18	$5.99E{-}02$ +/-12%	$5.92E{-}02$ +/-28%	1.01	0.99	0.99	0.99
15.25	$5.96E{-}02$ +/-12%	$5.90E{-}02$ +/-28%	1.01	0.99	0.99	0.99
19.30	$5.67E{-}02$ +/-12%	$5.88E{-}02$ +/-28%	0.97	0.94	0.94	0.94
23.40	$5.92E{-}02$ +/-12%	$5.86E{-}02$ +/-28%	1.01	0.99	0.99	0.99
27.52	$5.92E{-}02$ +/-12%	$5.84E{-}02$ +/-28%	1.01	0.99	0.99	0.99
34.63	$5.88E{-}02$ +/-12%	$5.80E{-}02$ +/-28%	1.01	0.99	0.99	0.99
44.68	$5.82E{-}02$ +/-12%	$5.76E{-}02$ +/-28%	1.01	0.99	0.99	0.99
54.78	$5.77E{-}02$ +/-12%	$5.71E{-}02$ +/-28%	1.01	0.99	0.99	0.99

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ne23	Mg26(n,α)Ne23	37.2s	100.0	1.01	11%
Na25	Mg25(n,p)Na25	59.6s	96.3	1.13	11%
	Mg26(n,d+np)Na25		3.7	1.13	11%
Na24	Mg24(n,p)Na24	14.9h	98.7	1.01	12%
	Mg25(n,d+np)Na24		1.3	1.01	12%



Aluminium

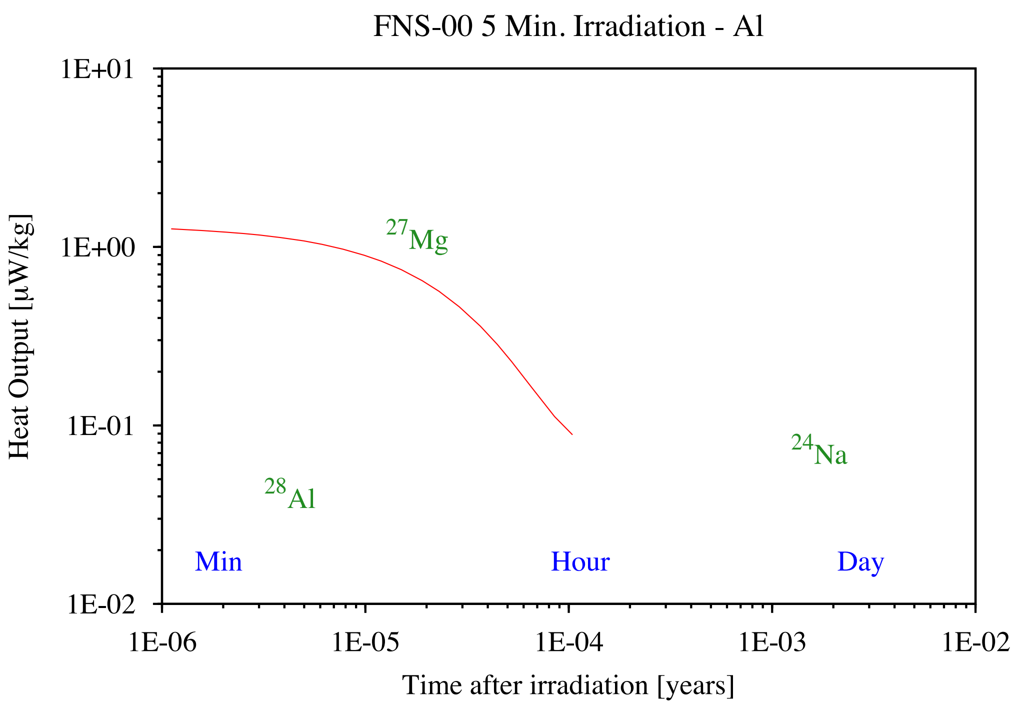


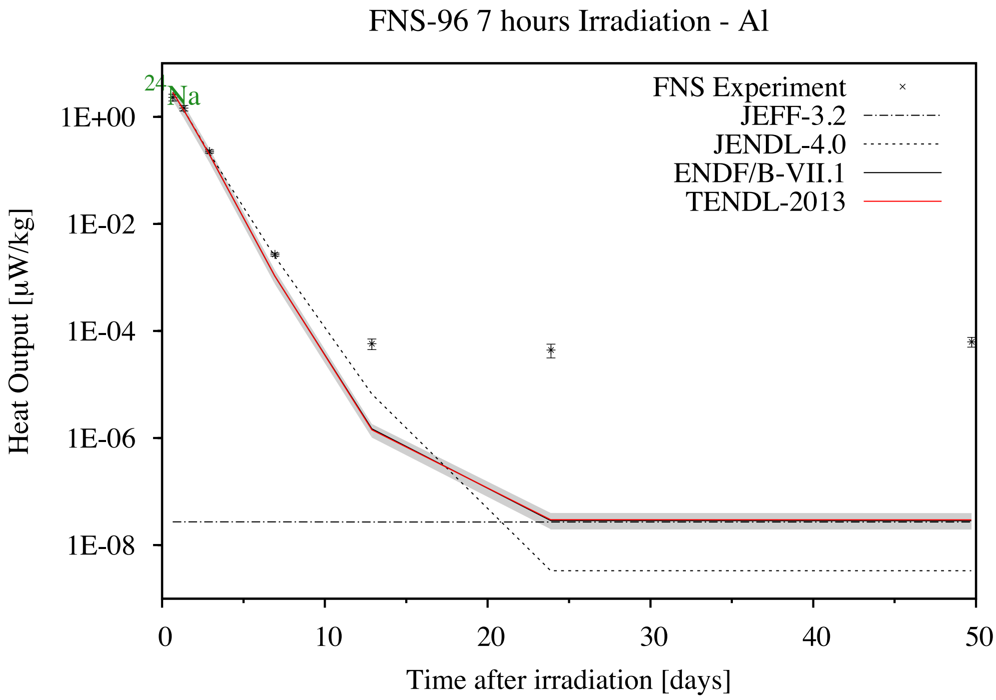


For Aluminum, an excellent agreement can be seen, for both batches, for the production route of the Mg27 radionuclide. TENDL variance seems to be large and should benefit from experimental inputs.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	1.14E+00 +/-6%	1.26E+00 +/-58%	0.90	0.89	0.95	0.86
0.83	1.12E+00 +/-6%	1.24E+00 +/-58%	0.91	0.90	0.95	0.86
1.08	1.10E+00 +/-6%	1.21E+00 +/-58%	0.91	0.90	0.95	0.86
1.33	1.08E+00 +/-6%	1.19E+00 +/-58%	0.91	0.90	0.96	0.86
1.58	1.06E+00 +/-6%	1.17E+00 +/-58%	0.91	0.90	0.96	0.86
2.02	1.03E+00 +/-6%	1.13E+00 +/-58%	0.91	0.91	0.97	0.87
2.62	9.88$E-$01 +/-6%	1.08E+00 +/-58%	0.91	0.91	0.97	0.87
3.22	9.49$E-$01 +/-6%	1.03E+00 +/-58%	0.92	0.91	0.98	0.87
4.08	8.93$E-$01 +/-6%	9.72$E-$01 +/-58%	0.92	0.91	0.99	0.87
5.18	8.31$E-$01 +/-6%	8.99$E-$01 +/-58%	0.92	0.92	1.00	0.87
6.28	7.73$E-$01 +/-6%	8.33$E-$01 +/-58%	0.93	0.93	1.01	0.88
7.90	6.95$E-$01 +/-6%	7.46$E-$01 +/-57%	0.93	0.93	1.03	0.88
10.02	6.06$E-$01 +/-6%	6.47$E-$01 +/-57%	0.94	0.93	1.05	0.88
12.12	5.30$E-$01 +/-6%	5.64$E-$01 +/-56%	0.94	0.94	1.07	0.89
15.23	4.37$E-$01 +/-6%	4.62$E-$01 +/-54%	0.94	0.94	1.11	0.89
19.33	3.42$E-$01 +/-6%	3.60$E-$01 +/-51%	0.95	0.95	1.18	0.90
23.43	2.71$E-$01 +/-6%	2.84$E-$01 +/-48%	0.95	0.95	1.26	0.90
27.53	2.18$E-$01 +/-6%	2.28$E-$01 +/-45%	0.96	0.95	1.38	0.91
34.67	1.59$E-$01 +/-6%	1.62$E-$01 +/-38%	0.98	0.96	1.70	0.93
44.77	1.11$E-$01 +/-6%	1.12$E-$01 +/-30%	0.99	0.97	2.55	0.95
54.87	8.76$E-$02 +/-6%	8.86$E-$02 +/-27%	0.99	0.97	4.21	0.95

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Mg27	Al27(n,p)Mg27	9.4m	100.0	0.94	6%

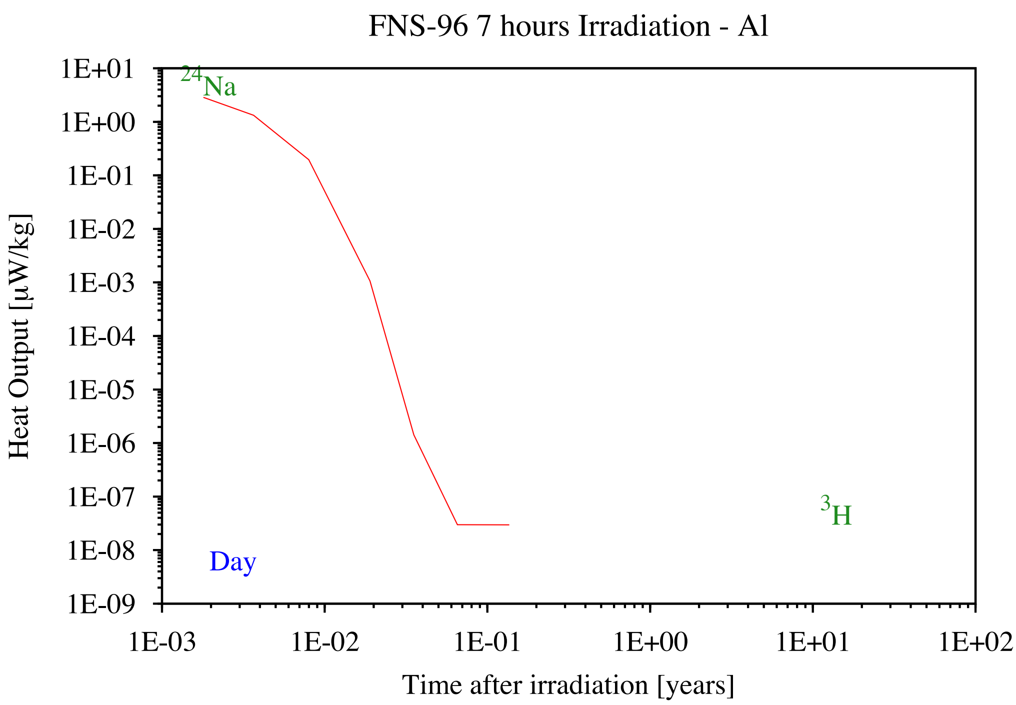




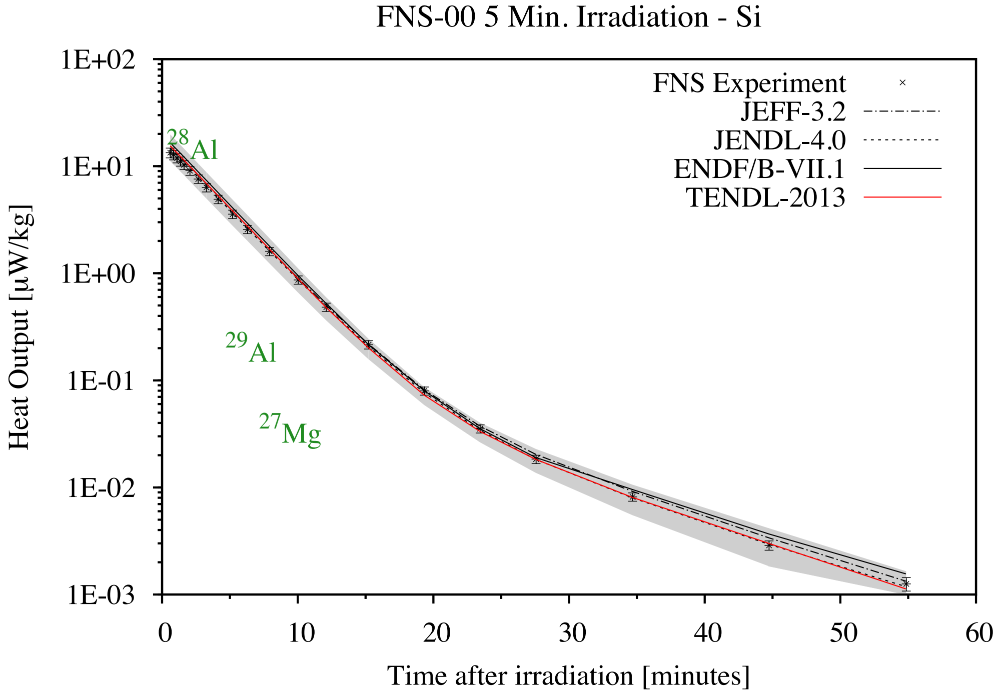
The rather good agreement but for JEFF-3.2, up to 3 days of cooling, does not persist at longer times. This may be due to unaccounted levels of impurities in the sample – indeed, thousands of ppm of Mn and Fe are enough to generate such levels of heat. It could also be due to a severe underestimation in the production of H3 or Al26.

Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.66	2.31E+00 +/-14%	2.87E+00 +/-29%	0.81	0.81	85036517.85	0.80
1.34	1.46E+00 +/-12%	1.32E+00 +/-29%	1.10	1.10	53567483.98	1.09
2.92	2.25$E-$01 +/-7%	1.96$E-$01 +/-29%	1.15	1.15	8278310.31	1.10
6.93	2.68$E-$03 +/-7%	1.07$E-$03 +/-29%	2.51	2.53	98936.57	1.09
12.89	5.78$E-$05 +/-22%	1.43$E-$06 +/-29%	40.54	38.91	2132.87	8.69
23.89	4.40$E-$05 +/-29%	2.98$E-$08 +/-34%	1477.25	1531.56	1627.03	13239.06
49.74	6.28$E-$05 +/-20%	2.97$E-$08 +/-34%	2113.23	2191.11	2328.24	18869.57

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Na24	Al27(n,α)Na24	14.9h	100.0	1.10	12%
	Al27(n,α)Na24m	0.02s	0.0	1.10	12%


FNS-96 7 hours Irradiation - Al
Heat Output [µW/kg]
Time after irradiation [years]
1E+01
1E+00
1E-01
1E-02
1E-03
1E-04
1E-05
1E-06
1E-07
1E-08
1E-09
1E-03
1E-02
1E-01
1E+00
1E+01
1E+02
24Na
3H
Day

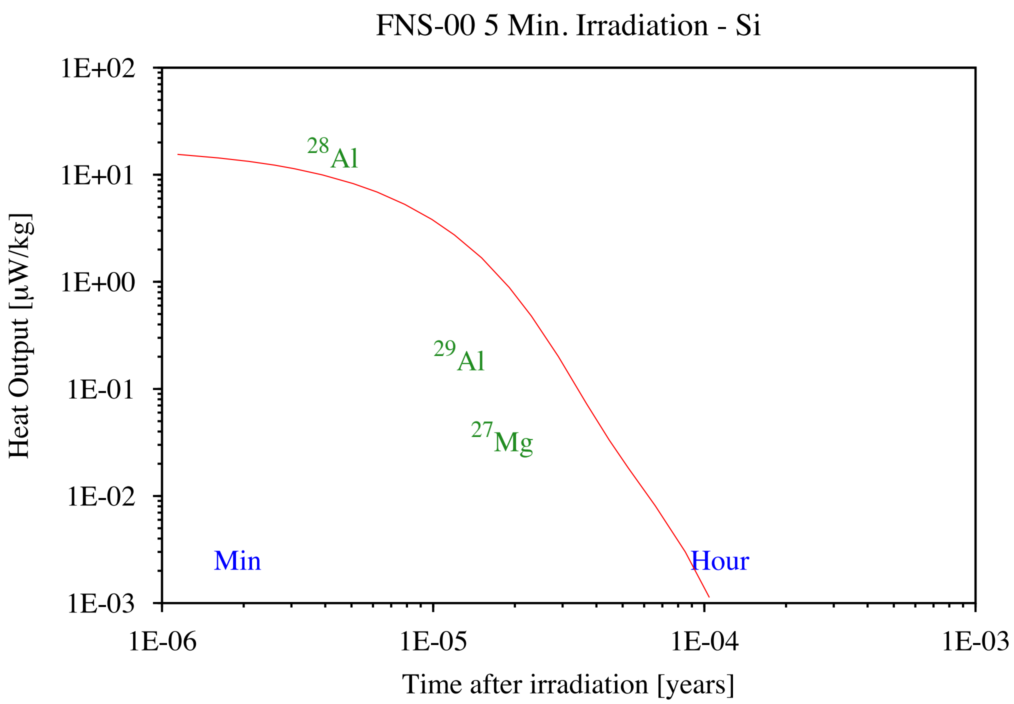
Silicon



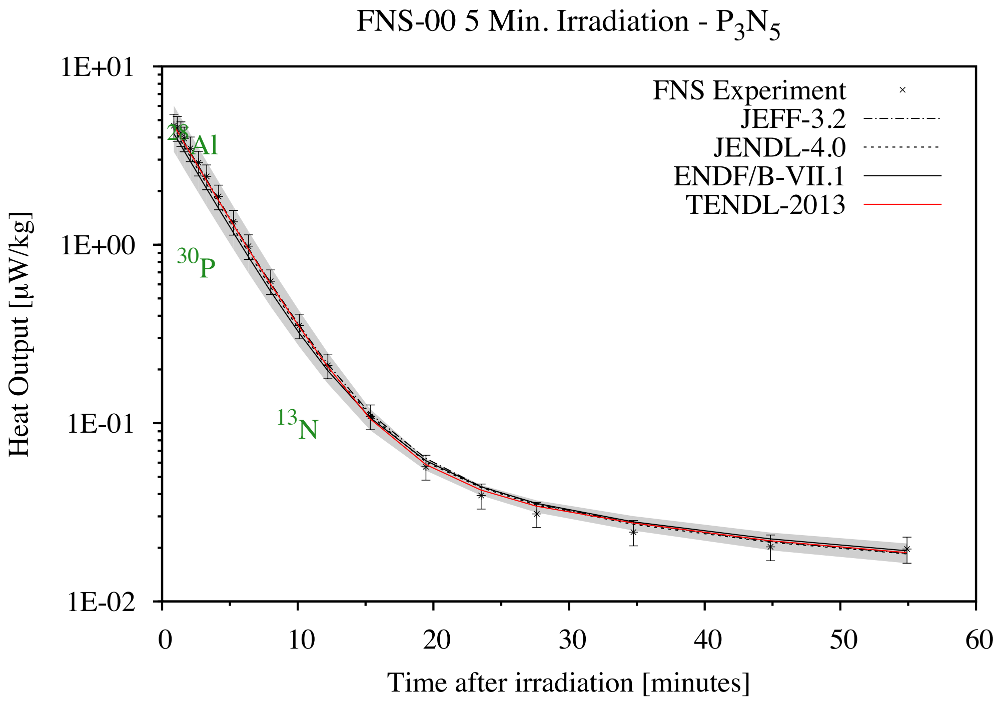
For Silicon, the first irradiated sample in 1996 (results not shown) was made of silicon oxide that certainly did contain some unaccounted level of impurities, causing an under prediction in the simulation. The second experiment contained solely pure silicon as powder and the decay heat is predicted with a much better agreement with TENDL-2013.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	1.33E+01 +/-10%	1.55E+01 +/-28%	0.86	0.80	0.86	0.91
0.85	1.28E+01 +/-10%	1.44E+01 +/-28%	0.89	0.83	0.89	0.93
1.10	1.19E+01 +/-10%	1.33E+01 +/-28%	0.89	0.84	0.90	0.94
1.37	1.11E+01 +/-10%	1.23E+01 +/-28%	0.90	0.84	0.91	0.95
1.62	1.03E+01 +/-10%	1.14E+01 +/-28%	0.90	0.84	0.91	0.95
2.05	9.08E+00 +/-10%	9.99E+00 +/-28%	0.91	0.85	0.91	0.96
2.67	7.59E+00 +/-9%	8.27E+00 +/-28%	0.92	0.86	0.92	0.97
3.27	6.34E+00 +/-9%	6.89E+00 +/-28%	0.92	0.86	0.92	0.97
4.13	4.91E+00 +/-9%	5.29E+00 +/-27%	0.93	0.87	0.93	0.97
5.20	3.57E+00 +/-9%	3.82E+00 +/-27%	0.93	0.87	0.94	0.98
6.30	2.57E+00 +/-9%	2.74E+00 +/-27%	0.94	0.88	0.94	0.98
7.93	1.60E+00 +/-9%	1.67E+00 +/-26%	0.96	0.90	0.96	0.99
10.03	8.67E−01 +/-9%	8.84E−01 +/-26%	0.98	0.91	0.96	0.99
12.10	4.83E−01 +/-9%	4.79E−01 +/-24%	1.01	0.92	0.96	1.00
15.22	2.15E−01 +/-9%	2.01E−01 +/-22%	1.07	1.00	0.99	1.03
19.33	7.97E−02 +/-9%	7.26E−02 +/-19%	1.10	1.00	0.98	1.04
23.45	3.53E−02 +/-9%	3.33E−02 +/-21%	1.06	1.00	0.95	1.03
27.57	1.84E−02 +/-9%	1.83E−02 +/-25%	1.01	0.97	0.90	1.01
34.68	8.16E−03 +/-9%	8.08E−03 +/-32%	1.01	0.85	0.89	1.02
44.75	2.88E−03 +/-10%	3.00E−03 +/-39%	0.96	0.78	0.85	0.98
54.87	1.26E−03 +/-14%	1.13E−03 +/-47%	1.12	0.81	0.94	1.06

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Al28	Si28(n,p)Al28	2.2m	100.0	0.91	10%
Al29	Si29(n,p)Al29	6.5m	95.8	0.96	9%
	Si30(n,d+np)Al29		3.9	0.96	9%
Mg27	Si30(n,α)Mg27	9.4m	100.0	0.98	9%



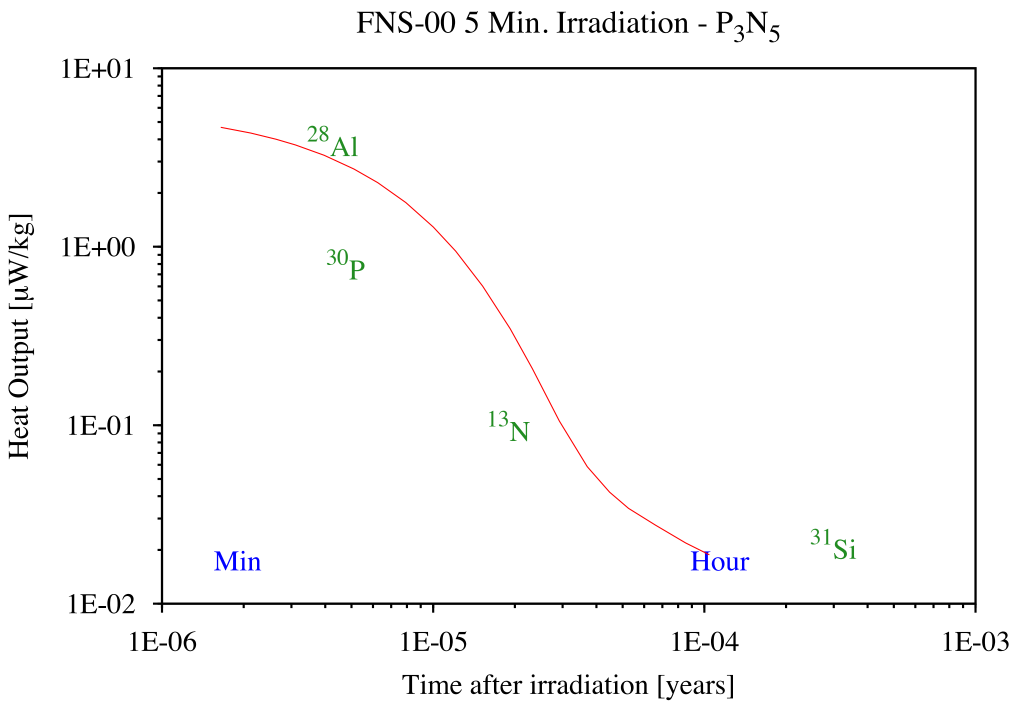
Phosphorus



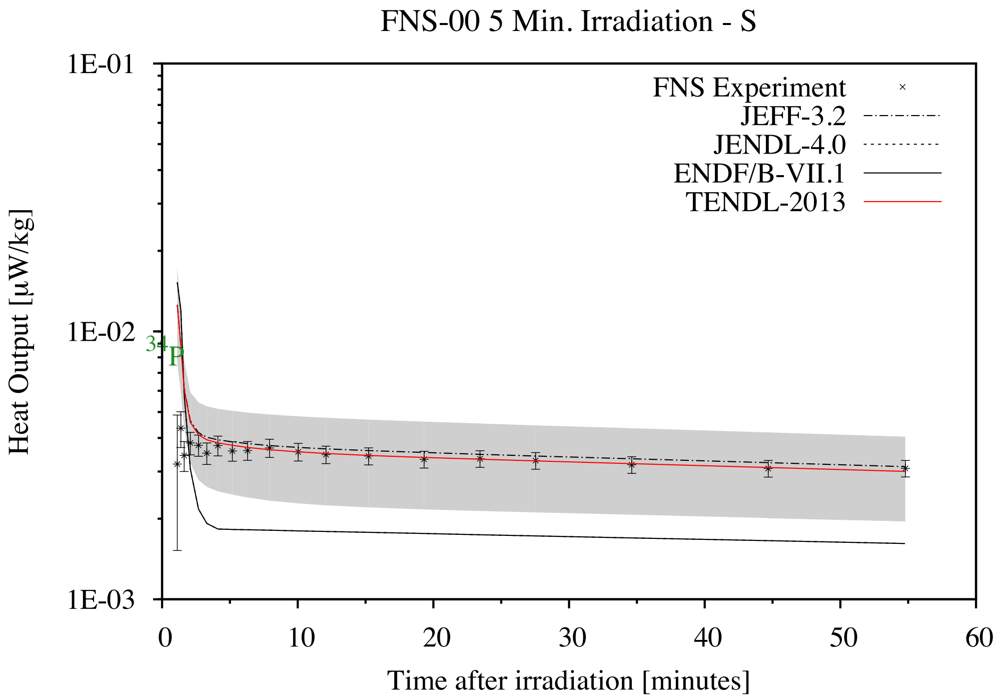
For Phosphorus, there is good agreement with the decay heat predictions for this nitrate sample, with the predictions well within a suspiciously uniform experimental uncertainty of 16%.

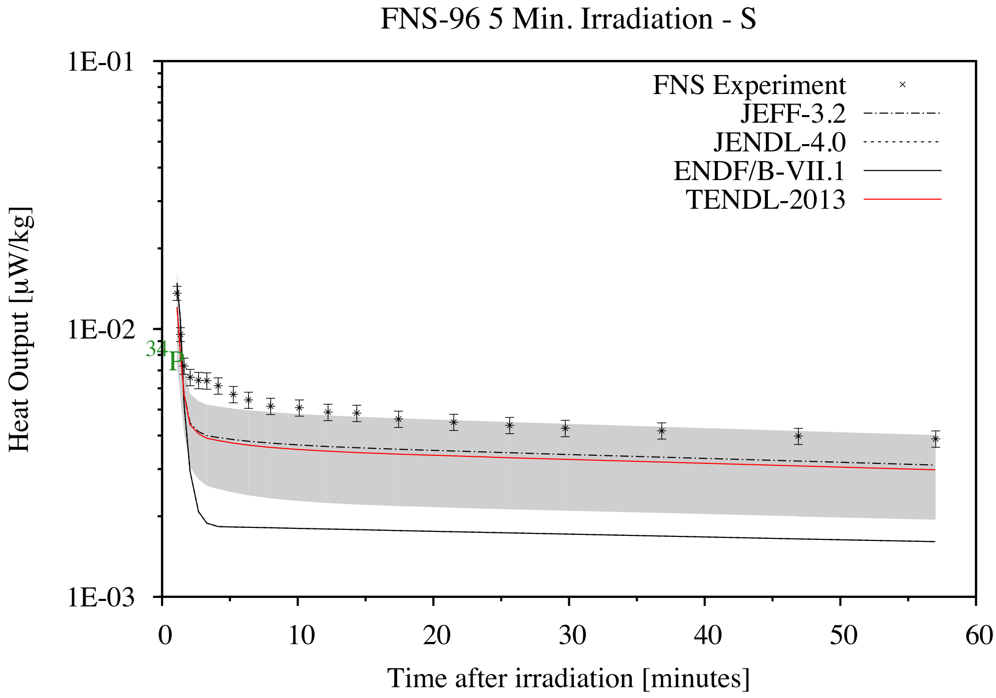
Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.87	4.65E+00 +/-16%	4.67E+00 +/-29%	1.00	1.11	0.99	1.04
1.12	4.52E+00 +/-16%	4.34E+00 +/-29%	1.04	1.16	1.03	1.09
1.38	4.22E+00 +/-16%	4.01E+00 +/-29%	1.05	1.17	1.04	1.10
1.63	3.94E+00 +/-16%	3.72E+00 +/-29%	1.06	1.18	1.05	1.11
2.08	3.47E+00 +/-16%	3.25E+00 +/-29%	1.07	1.18	1.05	1.11
2.68	2.88E+00 +/-16%	2.73E+00 +/-28%	1.06	1.17	1.04	1.10
3.28	2.42E+00 +/-16%	2.29E+00 +/-28%	1.06	1.17	1.04	1.10
4.17	1.87E+00 +/-16%	1.77E+00 +/-28%	1.06	1.17	1.04	1.10
5.27	1.34E+00 +/-16%	1.29E+00 +/-27%	1.04	1.15	1.03	1.09
6.37	9.82$E-$01 +/-16%	9.44$E-$01 +/-26%	1.04	1.15	1.03	1.08
8.00	6.25$E-$01 +/-16%	6.02$E-$01 +/-25%	1.04	1.14	1.02	1.08
10.12	3.53$E-$01 +/-16%	3.48$E-$01 +/-23%	1.01	1.10	1.00	1.05
12.22	2.10$E-$01 +/-16%	2.07$E-$01 +/-20%	1.01	1.07	0.98	1.03
15.35	1.09$E-$01 +/-16%	1.06$E-$01 +/-14%	1.03	1.02	0.96	0.98
19.45	5.70$E-$02 +/-16%	5.86$E-$02 +/-8%	0.97	0.93	0.90	0.94
23.52	3.93$E-$02 +/-16%	4.21$E-$02 +/-7%	0.93	0.89	0.89	0.90
27.62	3.10$E-$02 +/-16%	3.42$E-$02 +/-8%	0.90	0.87	0.88	0.89
34.75	2.45$E-$02 +/-16%	2.76$E-$02 +/-9%	0.89	0.87	0.89	0.90
44.85	2.02$E-$02 +/-17%	2.19$E-$02 +/-11%	0.92	0.90	0.93	0.94
54.92	1.97$E-$02 +/-17%	1.88$E-$02 +/-13%	1.05	1.02	1.06	1.06

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Al28	P31(n,α)Al28	2.2m	100.0	1.06	16%
N13	N14(n,2n)N13	9.9m	100.0	1.01	16%


FNS-00 5 Min. Irradiation - P_3N_5
1E+01
1E+00
1E-01
1E-02
Heat Output [µW/kg]
1E-06
1E-05
1E-04
1E-03
Time after irradiation [years]
^{28}Al
^{30}P
^{13}N
^{31}Si
Min
Hour

Sulphur

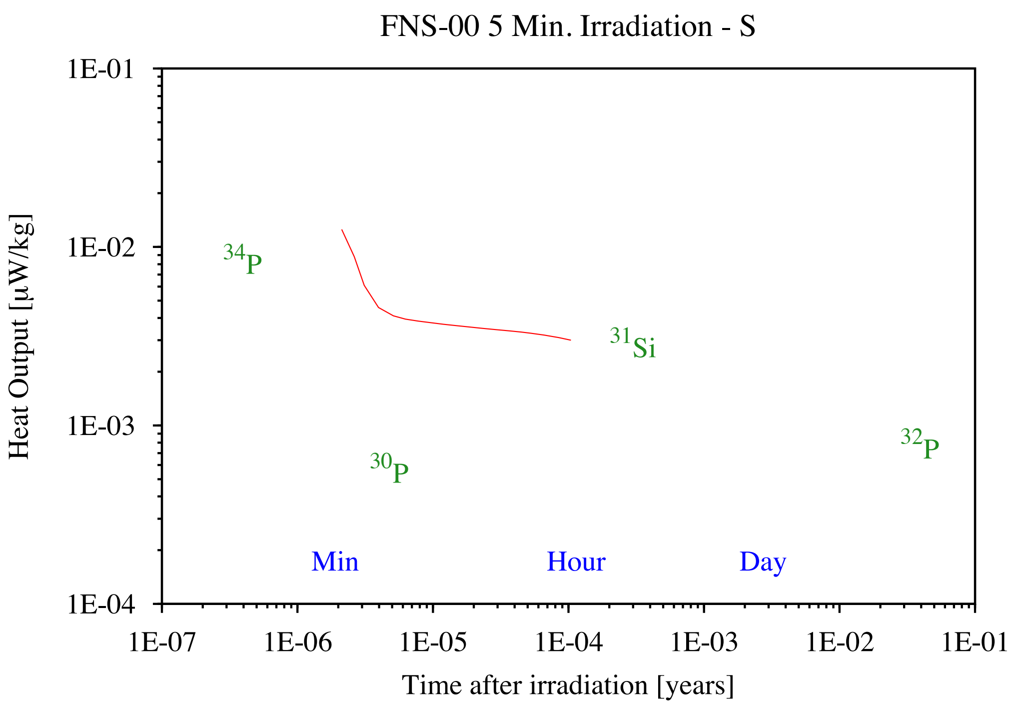


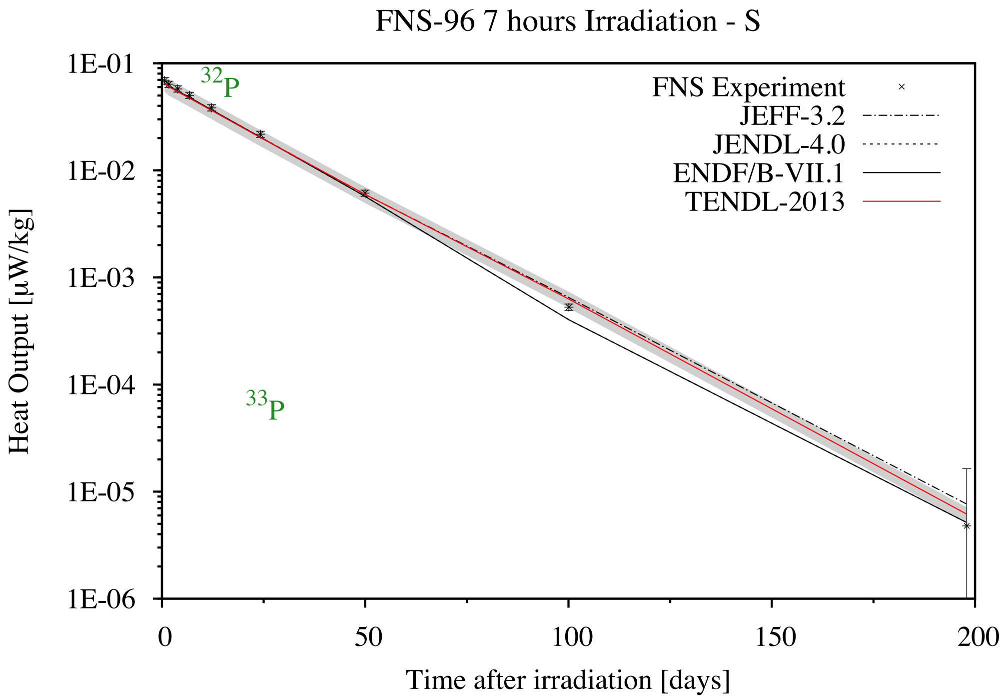


For Sulphur, it is clear that the two sets of experimental measurements do not agree, despite the fact that they should have been performed on identical sample materials. TENDL-2013 and JEFF-3.2 agree well on the most recent one. Nothing further can be extracted from such discrepant experimental results, other than an identification of the predominant isotopes.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
1.12	3.20E−03 +/-52%	1.25E−02 +/-39%	0.26	0.21	0.25	0.21
1.38	4.35E−03 +/-15%	8.80E−03 +/-33%	0.49	0.36	0.49	0.36
1.63	3.44E−03 +/-13%	6.09E−03 +/-28%	0.56	0.59	0.56	0.59
2.08	3.83E−03 +/-10%	4.58E−03 +/-30%	0.84	1.25	0.83	1.25
2.68	3.76E−03 +/-9%	4.11E−03 +/-32%	0.91	1.73	0.90	1.73
3.30	3.51E−03 +/-9%	3.94E−03 +/-33%	0.89	1.83	0.87	1.83
4.12	3.75E−03 +/-8%	3.84E−03 +/-34%	0.98	2.05	0.95	2.05
5.18	3.58E−03 +/-8%	3.76E−03 +/-35%	0.95	1.96	0.92	1.96
6.30	3.59E−03 +/-8%	3.69E−03 +/-35%	0.97	1.97	0.94	1.97
7.92	3.67E−03 +/-8%	3.62E−03 +/-35%	1.02	2.03	0.98	2.03
10.03	3.55E−03 +/-8%	3.55E−03 +/-36%	1.00	1.97	0.96	1.97
12.08	3.47E−03 +/-7%	3.50E−03 +/-36%	0.99	1.94	0.95	1.94
15.22	3.43E−03 +/-7%	3.44E−03 +/-36%	0.99	1.93	0.95	1.93
19.32	3.33E−03 +/-7%	3.39E−03 +/-36%	0.98	1.89	0.94	1.89
23.43	3.35E−03 +/-7%	3.34E−03 +/-36%	1.00	1.92	0.96	1.92
27.53	3.29E−03 +/-7%	3.29E−03 +/-36%	1.00	1.91	0.96	1.91
34.62	3.18E−03 +/-7%	3.21E−03 +/-36%	0.99	1.87	0.95	1.87
44.68	3.08E−03 +/-7%	3.10E−03 +/-35%	0.99	1.86	0.95	1.86
54.80	3.08E−03 +/-7%	3.00E−03 +/-35%	1.03	1.91	0.98	1.91

Product	**Pathways**	**$T_{1/2}$**	**Path %**	**E/C**	**ΔE%**
P34	S34(n,p)P34	12.4s	100.0	0.26	52%
Si31	S32(n,2p)Si31	2.62h	27.7	0.99	7%
	S34(n,α)Si31		72.3	0.99	7%

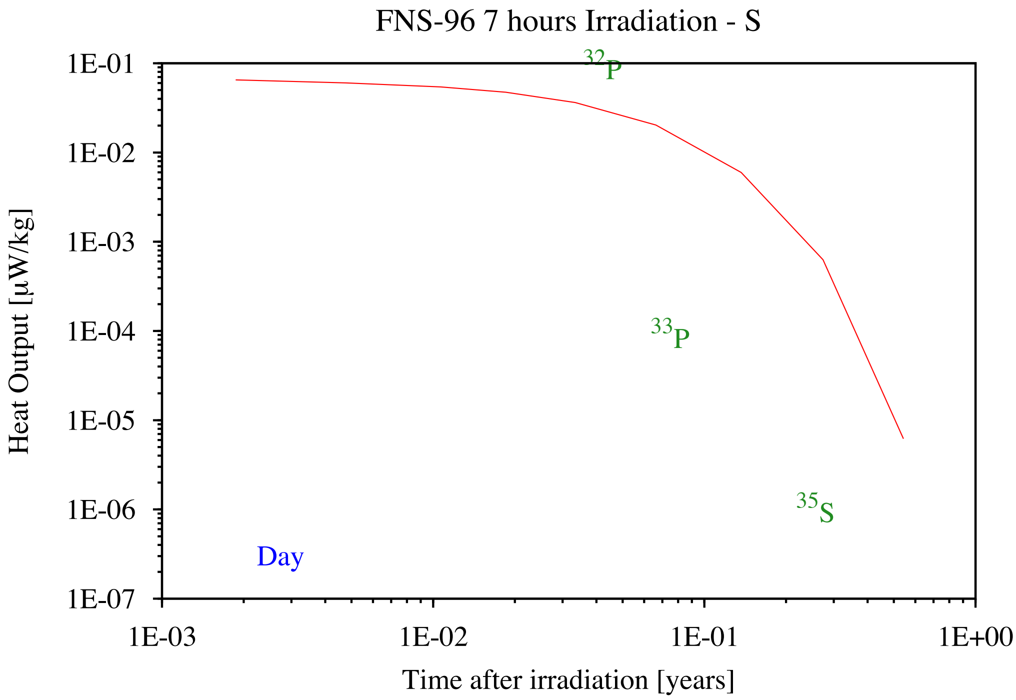




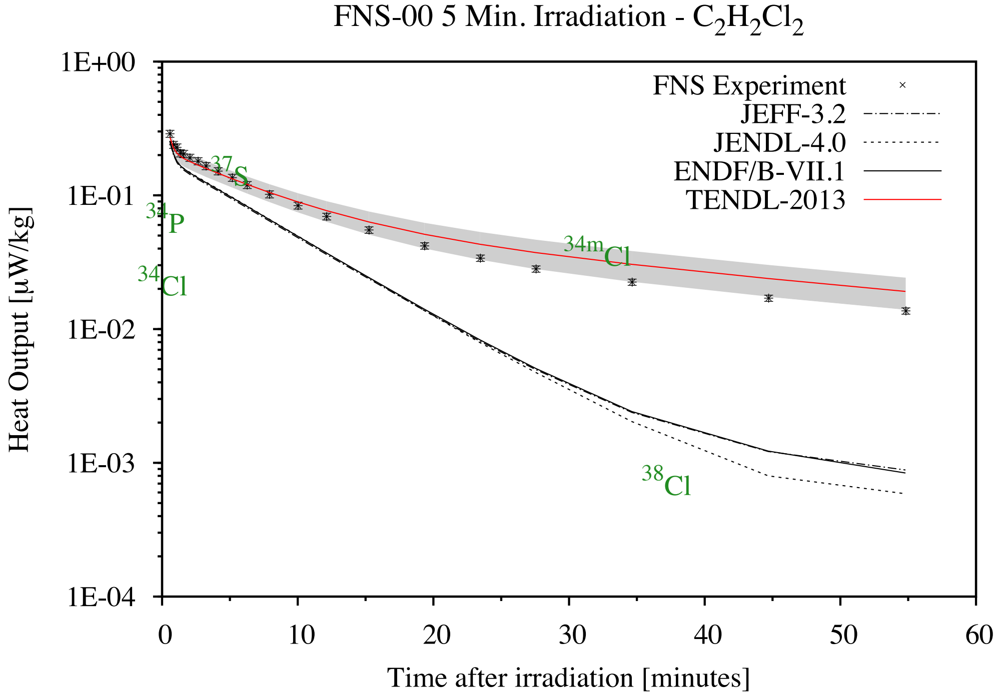
The only observation here is that the TENDL cross section uncertainty could be reviewed and halved for this unambiguous, text-book case. None of the others libraries contains covariance for this channel.

Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.68	$6.87E{-}02$ +/-7%	$6.51E{-}02$ +/-17%	1.06	1.06	1.05	1.06
1.74	$6.38E{-}02$ +/-7%	$6.02E{-}02$ +/-17%	1.06	1.05	1.06	1.05
3.89	$5.77E{-}02$ +/-7%	$5.43E{-}02$ +/-17%	1.06	1.05	1.06	1.05
6.76	$5.02E{-}02$ +/-7%	$4.73E{-}02$ +/-17%	1.06	1.05	1.06	1.05
12.20	$3.84E{-}02$ +/-7%	$3.63E{-}02$ +/-17%	1.06	1.04	1.05	1.04
24.21	$2.17E{-}02$ +/-7%	$2.03E{-}02$ +/-17%	1.07	1.06	1.07	1.06
49.96	$6.13E{-}03$ +/-7%	$5.98E{-}03$ +/-17%	1.03	1.07	1.03	1.07
100.09	$5.27E{-}04$ +/-7%	$6.28E{-}04$ +/-17%	0.84	1.31	0.81	1.31
197.94	$4.79E{-}06$ +/-242%	$6.19E{-}06$ +/-16%	0.77	0.93	0.62	0.93

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
P32	S32(n,p)P32	14.2d	99.3	1.06	7%
	S33(n,d+np)P32		0.7	1.06	7%


FNS-96 7 hours Irradiation - S
Heat Output [µW/kg]
1E-01
1E-02
1E-03
1E-04
1E-05
1E-06
1E-07
1E-03
1E-02
1E-01
1E+00
Time after irradiation [years]
32P
33P
35S
Day

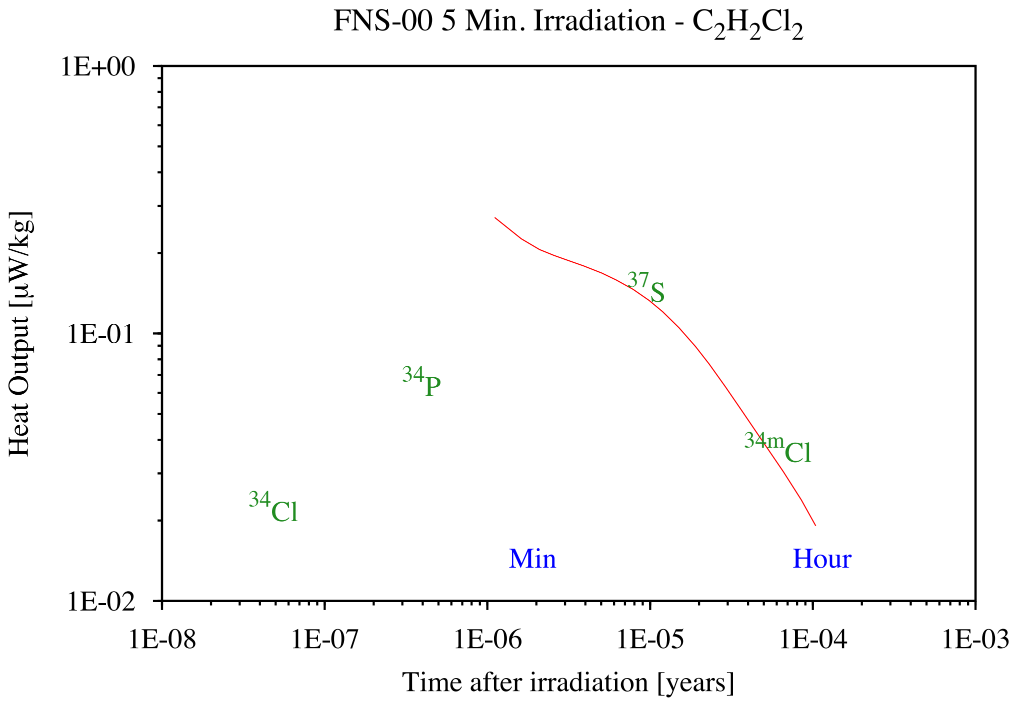
Chlorine



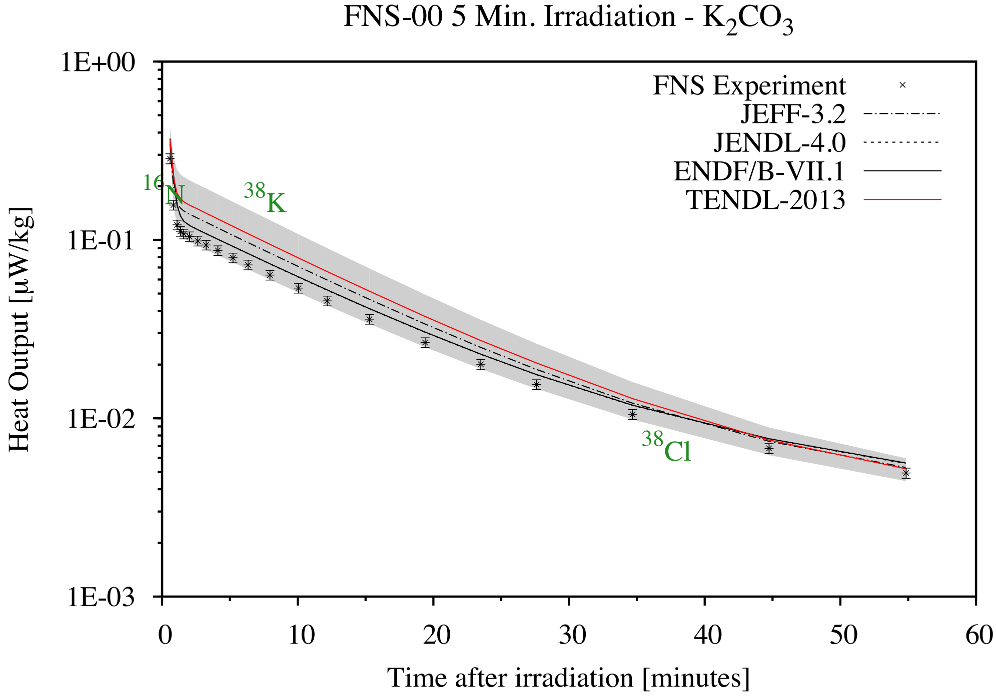
For Chlorine, a good agreement can be seen up to the point when Cl34m becomes predominant when TENDL-2013 is used. The discrepancy beyond this may be due to an incorrect branching ratio or decay heat level allocated to this short-lived metastable. None of the other libraries produce this predominant metastable.

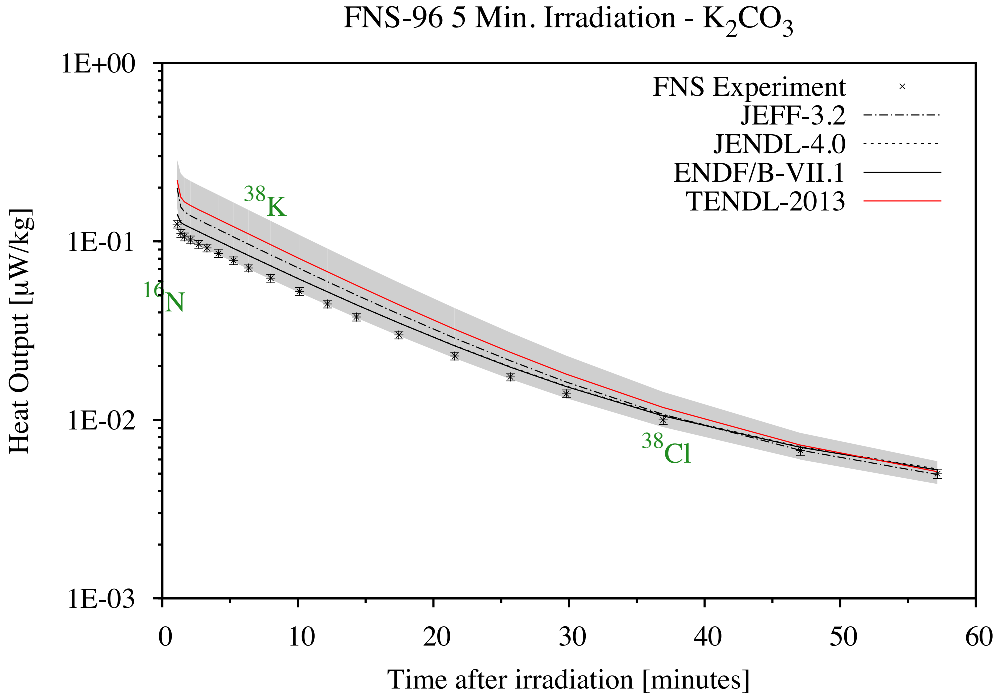
Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	$2.89E{-}01$ +/-6%	$2.71E{-}01$ +/-13%	1.06	1.14	1.16	1.16
0.85	$2.39E{-}01$ +/-6%	$2.26E{-}01$ +/-12%	1.06	1.17	1.19	1.19
1.10	$2.28E{-}01$ +/-6%	$2.06E{-}01$ +/-13%	1.11	1.27	1.30	1.28
1.35	$2.06E{-}01$ +/-6%	$1.96E{-}01$ +/-13%	1.05	1.24	1.27	1.23
1.60	$2.04E{-}01$ +/-6%	$1.89E{-}01$ +/-13%	1.08	1.29	1.32	1.28
2.05	$1.91E{-}01$ +/-6%	$1.79E{-}01$ +/-13%	1.07	1.30	1.33	1.29
2.65	$1.80E{-}01$ +/-6%	$1.68E{-}01$ +/-13%	1.07	1.33	1.37	1.32
3.25	$1.66E{-}01$ +/-6%	$1.59E{-}01$ +/-14%	1.04	1.33	1.37	1.32
4.13	$1.52E{-}01$ +/-6%	$1.46E{-}01$ +/-14%	1.04	1.37	1.41	1.36
5.18	$1.35E{-}01$ +/-6%	$1.33E{-}01$ +/-14%	1.02	1.41	1.45	1.40
6.28	$1.19E{-}01$ +/-6%	$1.21E{-}01$ +/-15%	0.99	1.45	1.48	1.44
7.92	$1.02E{-}01$ +/-6%	$1.05E{-}01$ +/-15%	0.97	1.54	1.58	1.53
10.02	$8.38E{-}02$ +/-6%	$8.92E{-}02$ +/-16%	0.94	1.70	1.74	1.69
12.13	$6.95E{-}02$ +/-6%	$7.69E{-}02$ +/-18%	0.90	1.88	1.92	1.88
15.25	$5.50E{-}02$ +/-6%	$6.33E{-}02$ +/-19%	0.87	2.26	2.32	2.28
19.35	$4.19E{-}02$ +/-6%	$5.12E{-}02$ +/-22%	0.82	2.98	3.04	3.05
23.47	$3.39E{-}02$ +/-6%	$4.31E{-}02$ +/-23%	0.79	4.09	4.18	4.28
27.57	$2.81E{-}02$ +/-5%	$3.73E{-}02$ +/-25%	0.75	5.55	5.66	5.95
34.65	$2.24E{-}02$ +/-5%	$3.04E{-}02$ +/-26%	0.74	9.28	9.42	11.03
44.72	$1.70E{-}02$ +/-5%	$2.39E{-}02$ +/-27%	0.71	13.90	13.99	21.32
54.83	$1.37E{-}02$ +/-5%	$1.91E{-}02$ +/-27%	0.71	16.28	15.45	23.28

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
P34	Cl37(n,α)P34	12.4s	99.9	1.06	6%
S37	Cl37(n,p)S37	4.9m	100.0	1.02	6%
Cl34m	Cl35(n,2n)Cl34m	32.1m	100.0	0.74	5%



Potassium

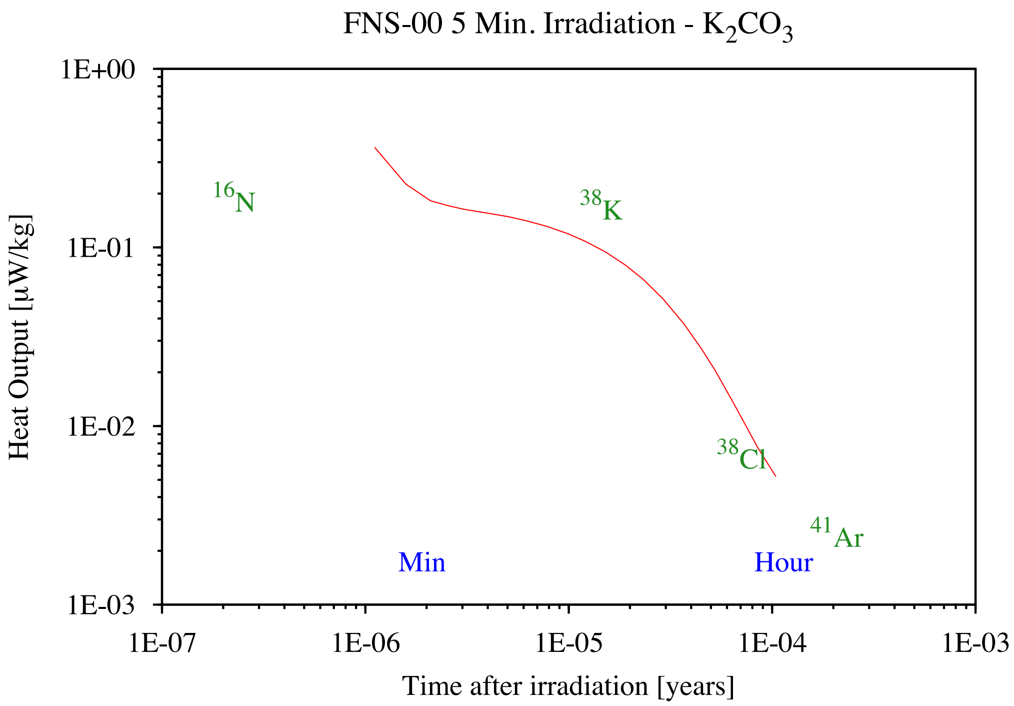


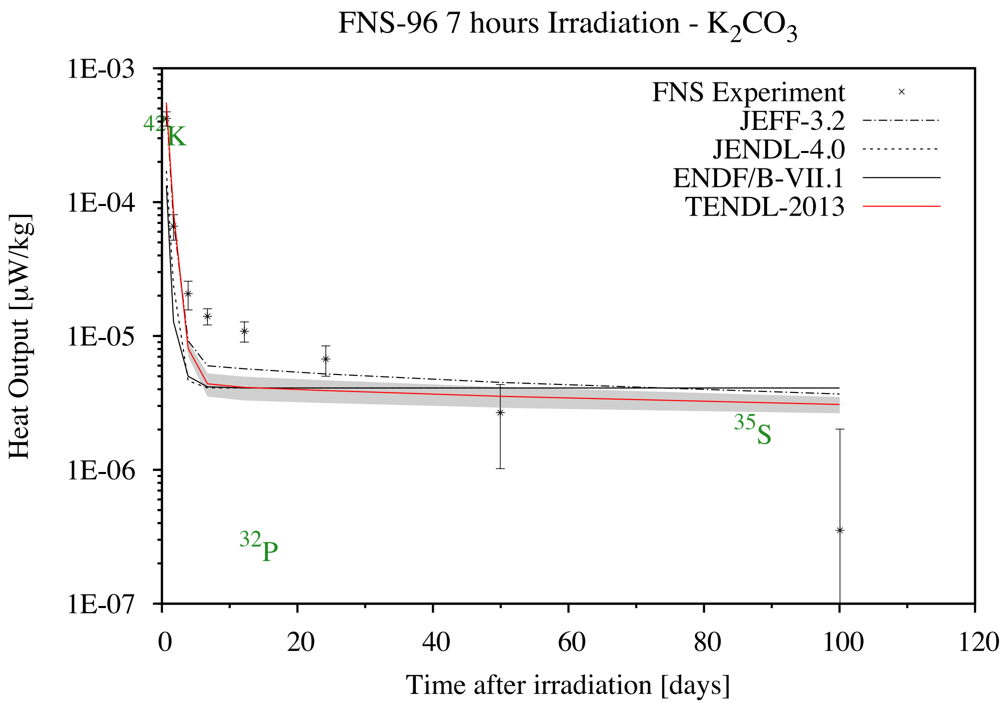


For Potassium, the extremely rapid measurements made barely 34 seconds after irradiation allow a glimpse of the N16 isotope heat, prior to the appearance of K38, and then Cl38, both of which are over-predicted by all libraries.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	2.85E−01 +/-7%	3.64E−01 +/-19%	0.78	0.77	0.83	0.80
0.83	1.57E−01 +/-6%	2.26E−01 +/-29%	0.70	0.67	0.78	0.70
1.10	1.21E−01 +/-6%	1.83E−01 +/-35%	0.66	0.77	0.75	0.78
1.35	1.12E−01 +/-6%	1.71E−01 +/-37%	0.65	0.82	0.74	0.82
1.60	1.08E−01 +/-6%	1.64E−01 +/-38%	0.66	0.85	0.74	0.85
2.03	1.04E−01 +/-6%	1.57E−01 +/-38%	0.67	0.87	0.75	0.86
2.63	9.86E−02 +/-6%	1.49E−01 +/-38%	0.66	0.86	0.74	0.86
3.25	9.36E−02 +/-6%	1.41E−01 +/-38%	0.66	0.86	0.74	0.86
4.12	8.72E−02 +/-6%	1.31E−01 +/-37%	0.67	0.86	0.75	0.87
5.22	7.94E−02 +/-6%	1.19E−01 +/-37%	0.67	0.86	0.75	0.86
6.33	7.25E−02 +/-6%	1.08E−01 +/-37%	0.67	0.86	0.75	0.86
7.95	6.35E−02 +/-6%	9.45E−02 +/-37%	0.67	0.86	0.75	0.86
10.05	5.37E−02 +/-6%	7.92E−02 +/-36%	0.68	0.87	0.76	0.87
12.17	4.55E−02 +/-6%	6.65E−02 +/-35%	0.69	0.87	0.76	0.87
15.28	3.59E−02 +/-6%	5.16E−02 +/-34%	0.70	0.87	0.77	0.87
19.38	2.66E−02 +/-6%	3.73E−02 +/-33%	0.71	0.87	0.79	0.88
23.50	2.01E−02 +/-6%	2.73E−02 +/-31%	0.73	0.88	0.80	0.88
27.60	1.55E−02 +/-6%	2.04E−02 +/-28%	0.76	0.88	0.82	0.88
34.68	1.05E−02 +/-6%	1.29E−02 +/-24%	0.81	0.89	0.86	0.89
44.75	6.77E−03 +/-6%	7.56E−03 +/-17%	0.90	0.88	0.91	0.88
54.85	4.93E−03 +/-6%	5.21E−03 +/-14%	0.95	0.88	0.93	0.88

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
N16	O16(n,p)N16	7.1s	100.0	0.78	7%
K38	K39(n,2n)K38	7.6m	100.0	0.67	6%
Cl38	K39(n,2p)Cl38	37.2m	2.9	0.81	6%
	K41(n,α)Cl38		70.3	0.81	6%
	K39(n,2p)Cl38m	0.7s	1.5	0.81	6%
	K41(n,α)Cl38m		25.7	0.81	6%

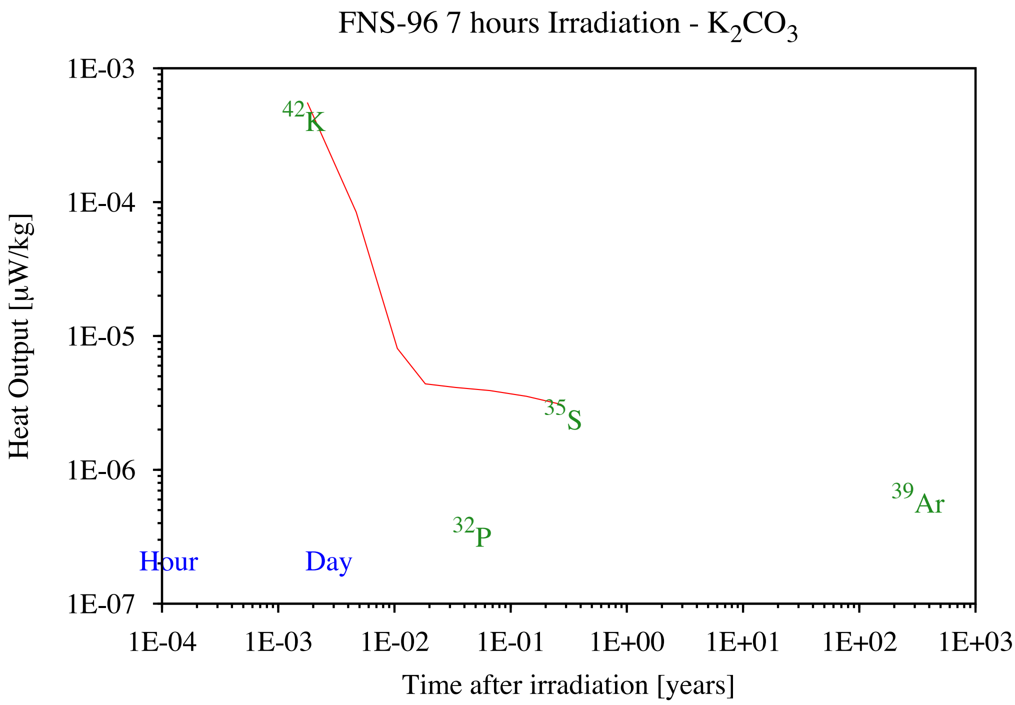




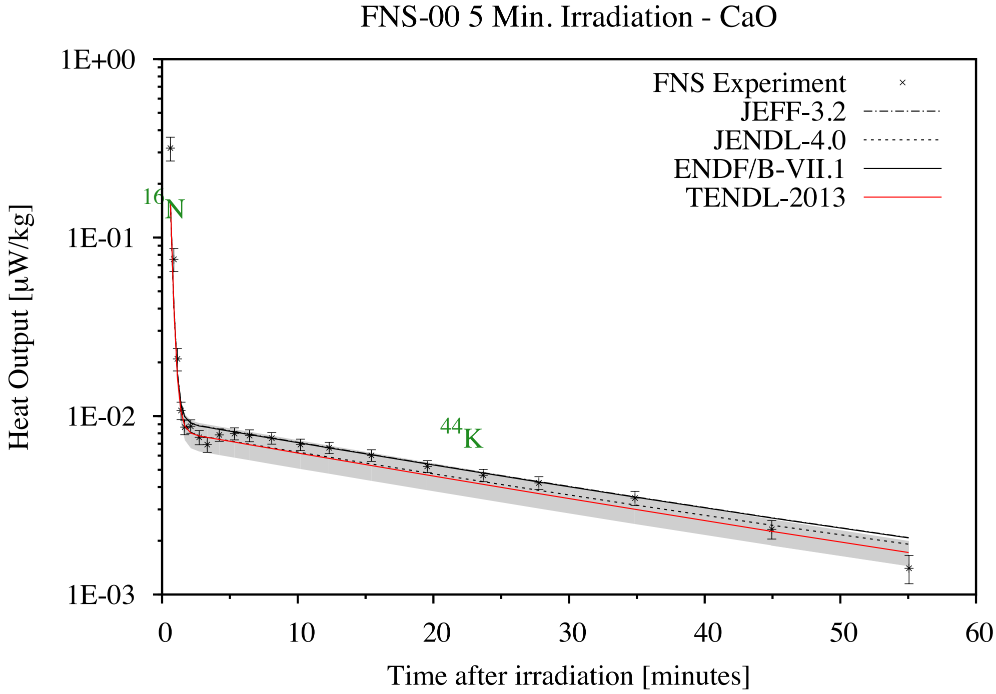
The rather high uncertainty bands on the experimental results do not allow an in-depth analysis to be undertaken. However, the decay heat profile is properly shaped.

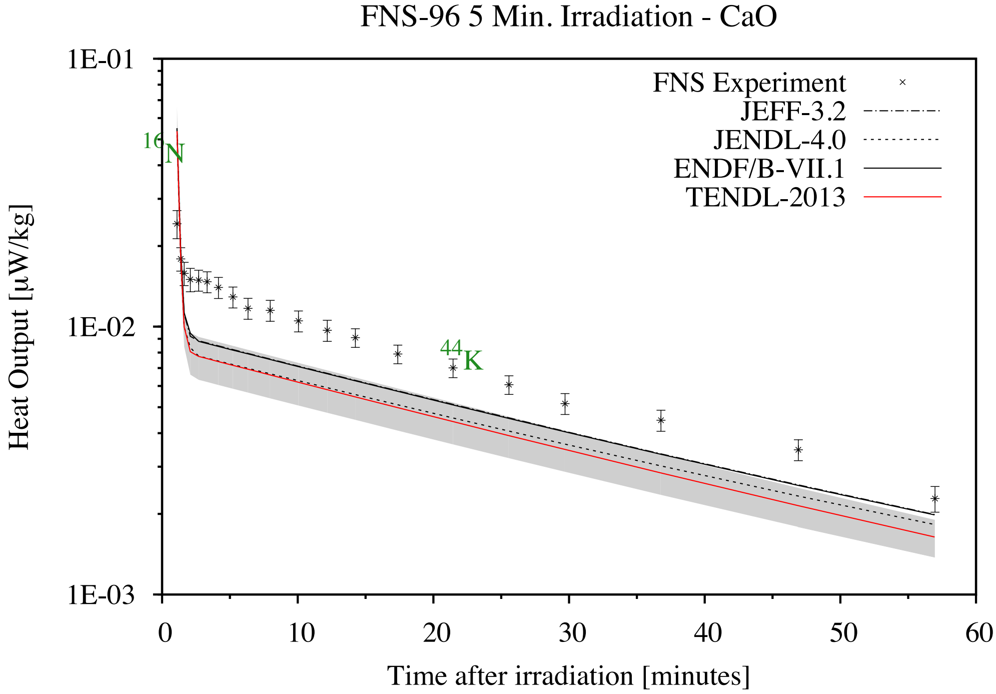
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.65	$4.21E{-}04$ +/-12%	$5.55E{-}04$ +/-10%	0.76	3.18	0.80	2.46
1.71	$6.62E{-}05$ +/-22%	$8.42E{-}05$ +/-13%	0.79	5.19	0.91	2.80
3.87	$2.07E{-}05$ +/-24%	$8.07E{-}06$ +/-13%	2.56	4.13	2.25	4.47
6.73	$1.40E{-}05$ +/-14%	$4.39E{-}06$ +/-20%	3.20	3.37	2.34	3.42
12.18	$1.09E{-}05$ +/-17%	$4.13E{-}06$ +/-20%	2.63	2.66	1.91	2.66
24.19	$6.72E{-}06$ +/-26%	$3.91E{-}06$ +/-19%	1.72	1.65	1.29	1.65
49.94	$2.68E{-}06$ +/-62%	$3.54E{-}06$ +/-18%	0.76	0.66	0.60	0.66
100.07	$3.53E{-}07$ +/-469%	$3.08E{-}06$ +/-14%	0.11	0.09	0.10	0.09

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
K42	K41(n,γ)K42	12.3h	99.9	0.79	12%
S35	K39(n,pα)S35	87.3d	100.0	0.76	62%


FNS-96 7 hours Irradiation - K_2CO_3
Heat Output [µW/kg]
1E-03
1E-04
1E-05
1E-06
1E-07
1E-04
1E-03
1E-02
1E-01
1E+00
1E+01
1E+02
1E+03
Time after irradiation [years]
^{42}K
^{35}S
^{32}P
^{39}Ar
Hour
Day

Calcium

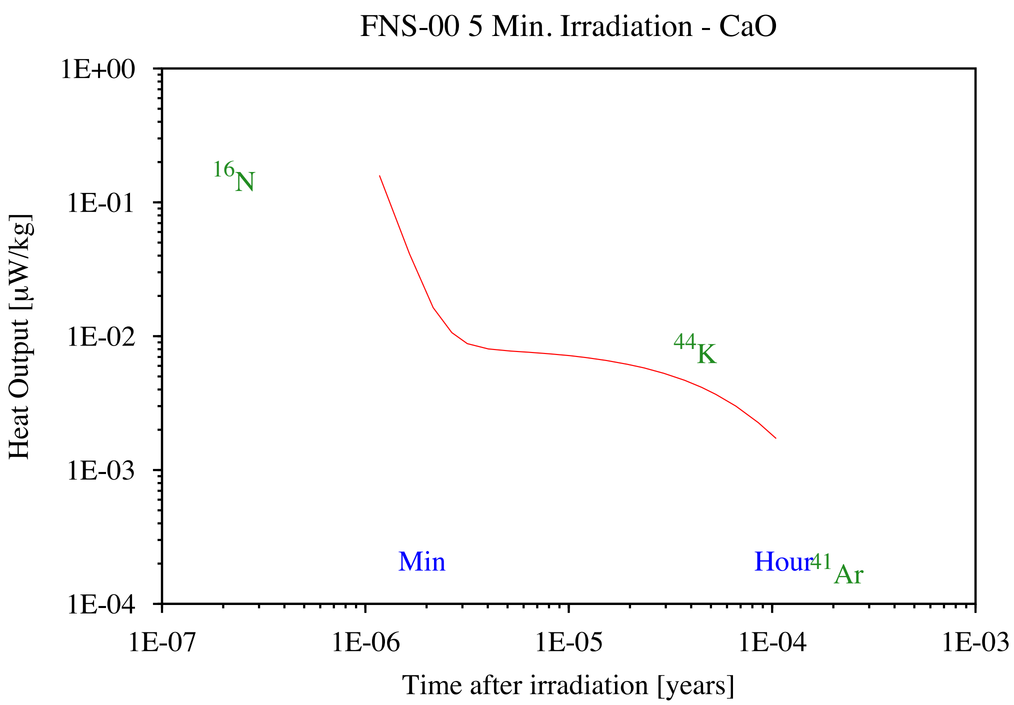


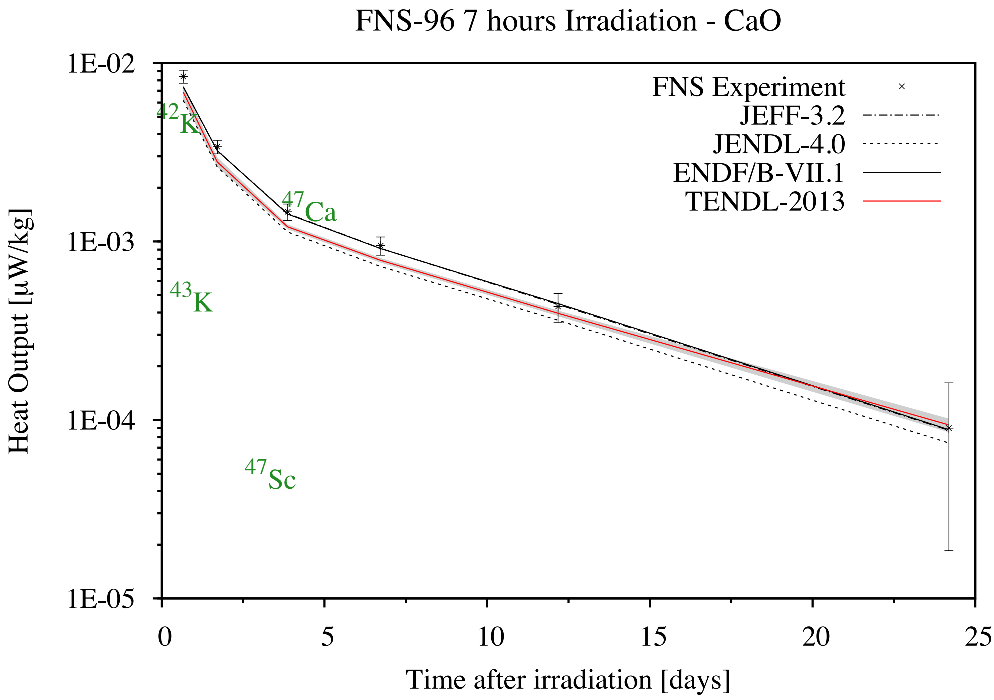


For Calcium, the latest experiment, when analysed with the either libraries seems to lead to a much better agreement, even at rather short cooling times for TENDL-2013. Discrepancies seem to exist between this and the original experiment. One explanation for this is that the CaO powder, being extremely fine, was used in extremely small amounts. Because the sample was sandwiched in-between plastic tape, its contribution needed to be subtracted from the raw measured data. In other words, the signal-to-noise ratio was high. Such a situation should have been better reflected in the otherwise low experimental uncertainties. This situation also occurs for the SrCO3, Y2O3, and SnO2 samples.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.62	$3.17E{-}01$ +/-15%	$1.59E{-}01$ +/-1%	1.99	1.99	1.98	2.09
0.87	$7.56E{-}02$ +/-15%	$4.12E{-}02$ +/-4%	1.84	1.80	1.79	1.90
1.13	$2.09E{-}02$ +/-14%	$1.63E{-}02$ +/-9%	1.28	1.24	1.19	1.19
1.40	$1.07E{-}02$ +/-11%	$1.06E{-}02$ +/-14%	1.01	0.92	0.91	0.96
1.67	$8.67E{-}03$ +/-9%	$8.79E{-}03$ +/-17%	0.99	0.87	0.87	0.96
2.12	$8.77E{-}03$ +/-9%	$8.04E{-}03$ +/-18%	1.09	0.96	0.96	1.08
2.73	$7.60E{-}03$ +/-9%	$7.73E{-}03$ +/-18%	0.98	0.86	0.86	0.98
3.33	$6.92E{-}03$ +/-9%	$7.59E{-}03$ +/-18%	0.91	0.80	0.80	0.91
4.22	$7.85E{-}03$ +/-8%	$7.39E{-}03$ +/-18%	1.06	0.93	0.93	1.06
5.33	$7.97E{-}03$ +/-8%	$7.15E{-}03$ +/-18%	1.12	0.98	0.97	1.11
6.45	$7.77E{-}03$ +/-8%	$6.91E{-}03$ +/-18%	1.13	0.99	0.98	1.12
8.08	$7.51E{-}03$ +/-7%	$6.58E{-}03$ +/-18%	1.14	1.00	1.00	1.13
10.20	$6.91E{-}03$ +/-7%	$6.17E{-}03$ +/-18%	1.12	0.98	0.97	1.11
12.32	$6.64E{-}03$ +/-7%	$5.79E{-}03$ +/-18%	1.15	1.00	1.00	1.13
15.43	$6.02E{-}03$ +/-7%	$5.28E{-}03$ +/-18%	1.14	0.99	0.99	1.12
19.55	$5.22E{-}03$ +/-8%	$4.68E{-}03$ +/-18%	1.12	0.97	0.96	1.09
23.67	$4.65E{-}03$ +/-8%	$4.15E{-}03$ +/-18%	1.12	0.97	0.97	1.08
27.78	$4.22E{-}03$ +/-8%	$3.68E{-}03$ +/-18%	1.15	0.99	0.98	1.10
34.87	$3.47E{-}03$ +/-9%	$3.00E{-}03$ +/-17%	1.16	0.99	0.98	1.09
44.95	$2.32E{-}03$ +/-12%	$2.26E{-}03$ +/-17%	1.03	0.86	0.86	0.95
55.07	$1.40E{-}03$ +/-18%	$1.72E{-}03$ +/-16%	0.82	0.68	0.67	0.73

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
K44	Ca44(n,p)K44	22.1m	100.0	1.12	8%

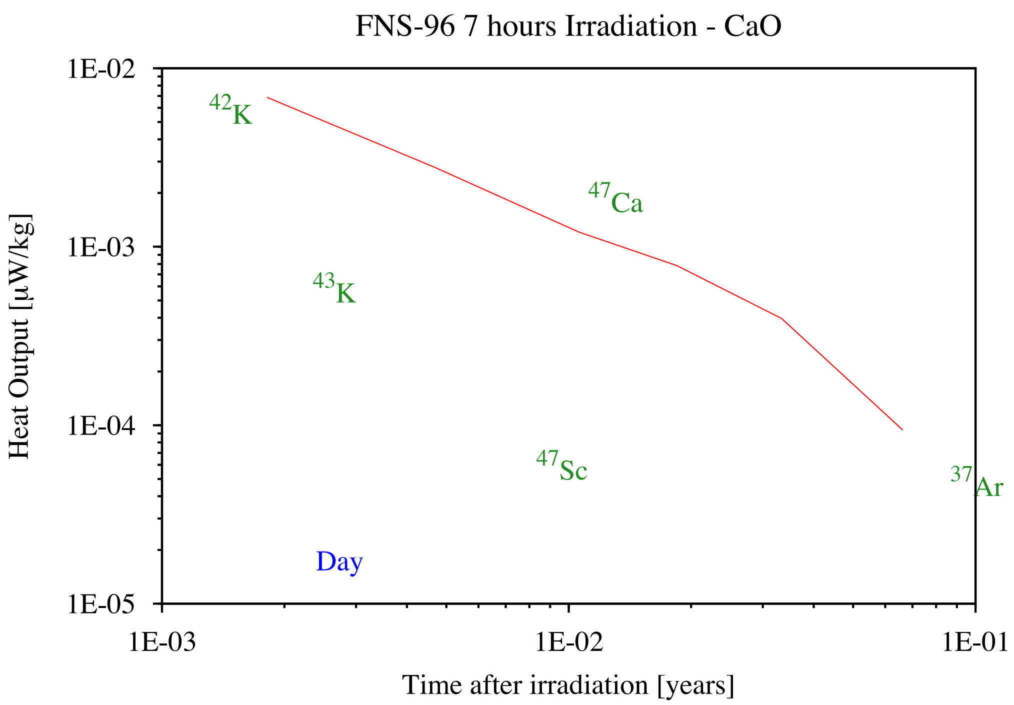




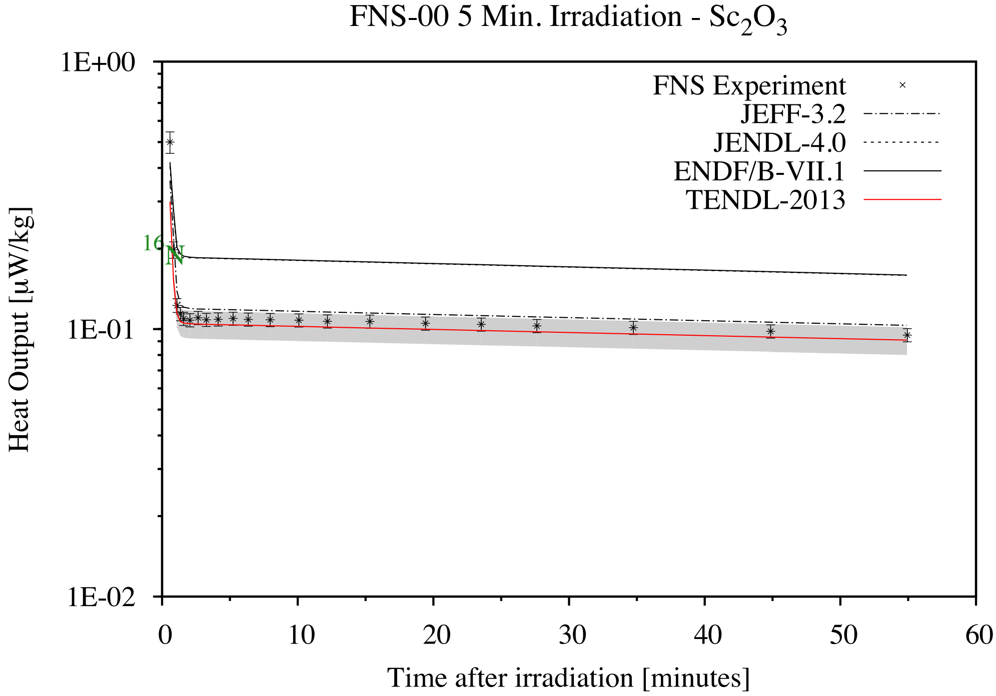
A rather good agreement exists for this element with multiple production pathways in all libraries.

Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.66	8.41$E-$03 +/-8%	6.88$E-$03 +/-9%	1.22	1.14	1.14	1.36
1.71	3.40$E-$03 +/-9%	2.79$E-$03 +/-6%	1.21	1.05	1.05	1.30
3.87	1.47$E-$03 +/-10%	1.21$E-$03 +/-3%	1.22	1.03	1.02	1.30
6.73	9.49$E-$04 +/-12%	7.84$E-$04 +/-3%	1.21	1.04	1.04	1.31
12.18	4.32$E-$04 +/-18%	3.96$E-$04 +/-3%	1.09	0.96	0.97	1.19
24.19	9.00$E-$05 +/-79%	9.40$E-$05 +/-9%	0.96	1.02	1.03	1.21

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
K42	Ca42(n,p)K42	12.3h	96.7	1.22	8%
	Ca43(n,d+np)K42		3.3	1.22	8%
Ca47	Ca48(n,2n)Ca47	4.5d	99.9	1.22	10%


FNS-96 7 hours Irradiation - CaO
1E-02
1E-03
1E-04
1E-05
Heat Output [µW/kg]
1E-03
1E-02
1E-01
Time after irradiation [years]
42K
47Ca
43K
47Sc
37Ar
Day

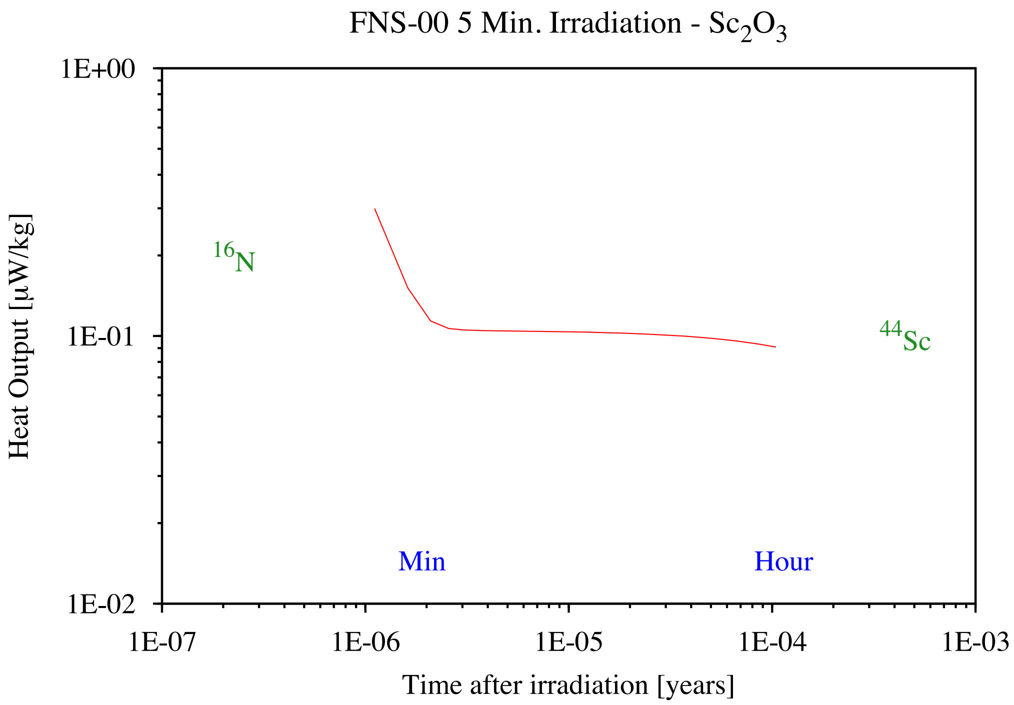
Scandium



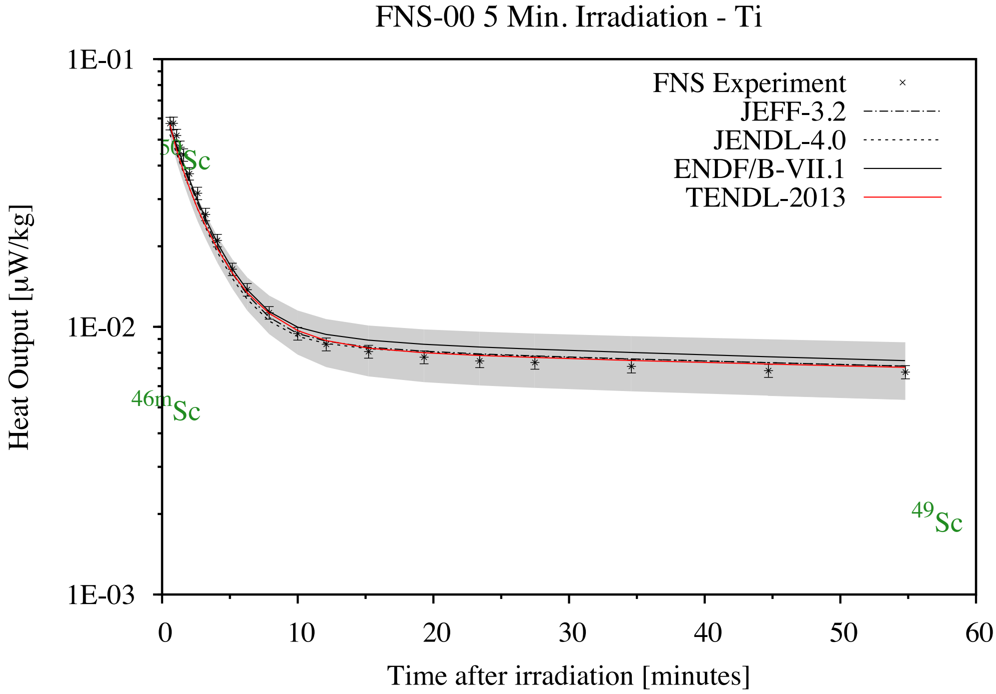
For Scandium, the above plot demonstrates an excellent agreement for the production of Sc44, where the TENDL results are always within the experimental uncertainty. TENDL-2013 variance could be reduced to reflect this experiment. ENDF/B-VII.1 and JENDL-4.0 over-predict by a factor of two.

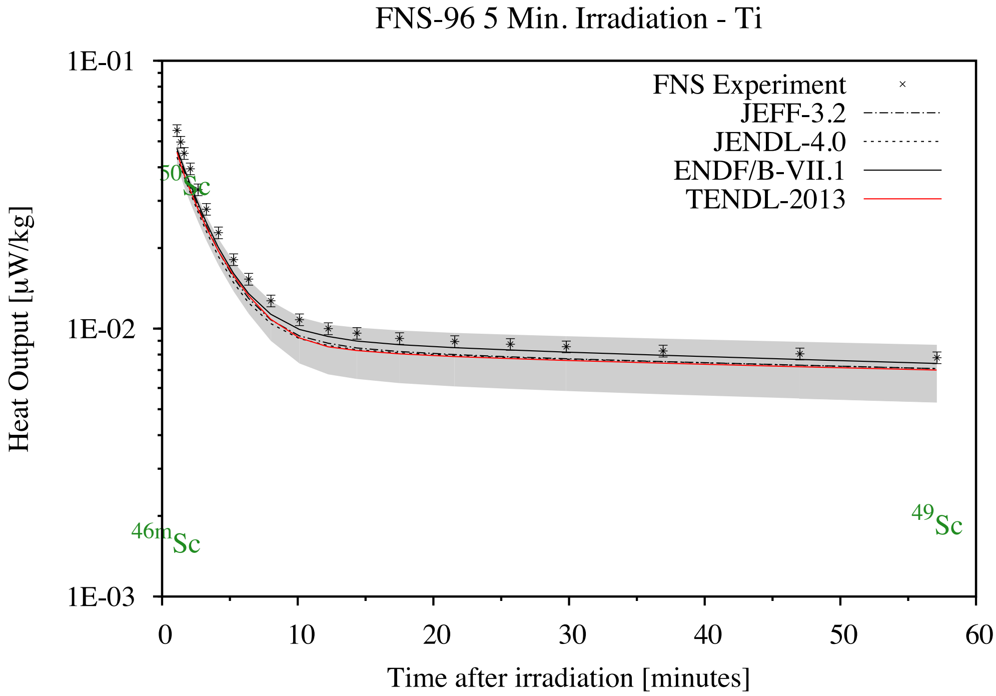
Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	5.00$E-$01 +/-9%	3.00$E-$01 +/-4%	1.67	1.19	1.39	1.23
0.85	1.98$E-$01 +/-7%	1.51$E-$01 +/-8%	1.31	0.71	0.90	0.73
1.10	1.23$E-$01 +/-6%	1.14$E-$01 +/-11%	1.08	0.61	0.89	0.62
1.35	1.14$E-$01 +/-6%	1.07$E-$01 +/-12%	1.07	0.60	0.92	0.62
1.60	1.09$E-$01 +/-6%	1.05$E-$01 +/-12%	1.04	0.58	0.91	0.59
2.05	1.08$E-$01 +/-6%	1.05$E-$01 +/-12%	1.03	0.58	0.90	0.58
2.65	1.10$E-$01 +/-6%	1.04$E-$01 +/-12%	1.06	0.60	0.93	0.60
3.27	1.08$E-$01 +/-6%	1.04$E-$01 +/-12%	1.04	0.59	0.91	0.59
4.13	1.09$E-$01 +/-6%	1.04$E-$01 +/-12%	1.05	0.59	0.92	0.59
5.23	1.10$E-$01 +/-6%	1.04$E-$01 +/-12%	1.06	0.60	0.93	0.60
6.35	1.09$E-$01 +/-6%	1.03$E-$01 +/-12%	1.05	0.59	0.92	0.60
7.97	1.08$E-$01 +/-6%	1.03$E-$01 +/-12%	1.05	0.59	0.92	0.60
10.08	1.08$E-$01 +/-6%	1.02$E-$01 +/-12%	1.05	0.60	0.93	0.60
12.18	1.07$E-$01 +/-6%	1.02$E-$01 +/-12%	1.05	0.59	0.92	0.60
15.32	1.07$E-$01 +/-6%	1.01$E-$01 +/-12%	1.06	0.60	0.93	0.60
19.42	1.05$E-$01 +/-6%	9.98$E-$02 +/-12%	1.05	0.60	0.92	0.60
23.53	1.04$E-$01 +/-6%	9.87$E-$02 +/-12%	1.05	0.60	0.93	0.60
27.63	1.03$E-$01 +/-6%	9.77$E-$02 +/-12%	1.05	0.60	0.93	0.60
34.75	1.01$E-$01 +/-6%	9.59$E-$02 +/-12%	1.06	0.60	0.93	0.60
44.87	9.81$E-$02 +/-6%	9.33$E-$02 +/-12%	1.05	0.60	0.92	0.60
54.93	9.50$E-$02 +/-6%	9.09$E-$02 +/-12%	1.04	0.60	0.92	0.60

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Sc44	Sc45(n,2n)Sc44	3.9h	100.0	1.04	6%


FNS-00 5 Min. Irradiation - Sc2O3
Heat Output [µW/kg]
1E+00
1E-01
1E-02
16N
44Sc
Min
Hour
1E-07
1E-06
1E-05
1E-04
1E-03
Time after irradiation [years]

Titanium

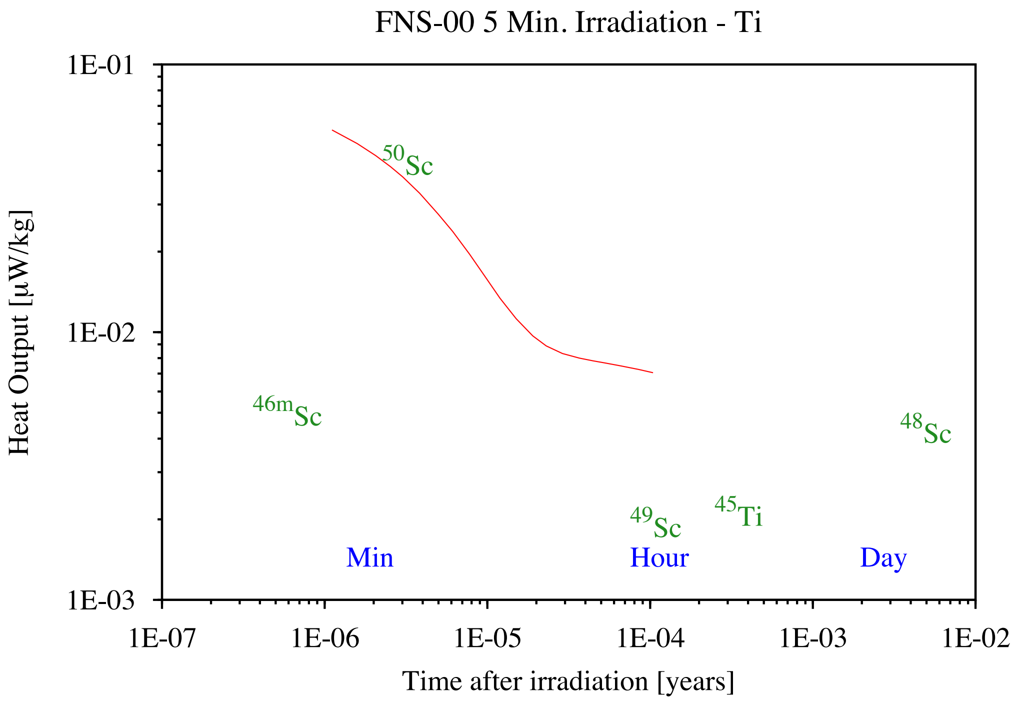


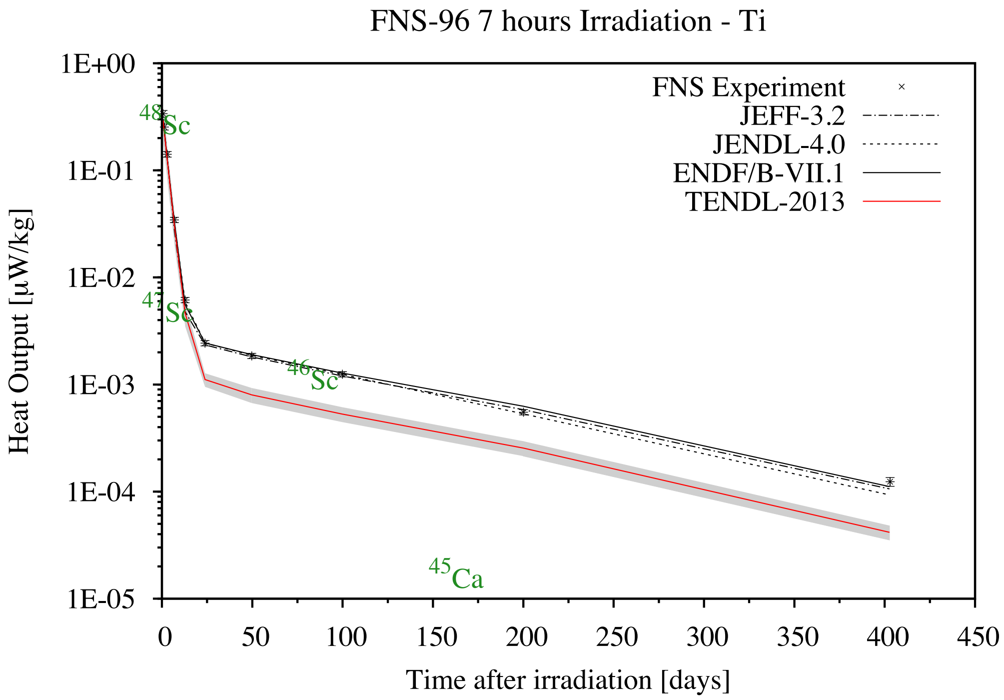


For titanium, the two 5-minute graphs exhibit some unexplained differences between the two experimental batches. The routes of production of the many isotopes involved are complex and prohibit further in-depth analyses.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	$5.75E{-}02$ +/-5%	$5.70E{-}02$ +/-9%	1.01	1.02	1.04	1.10
0.83	$5.76E{-}02$ +/-5%	$5.06E{-}02$ +/-9%	1.14	1.12	1.14	1.20
1.08	$5.19E{-}02$ +/-5%	$4.56E{-}02$ +/-10%	1.14	1.09	1.11	1.17
1.33	$4.69E{-}02$ +/-5%	$4.15E{-}02$ +/-10%	1.13	1.07	1.09	1.15
1.58	$4.39E{-}02$ +/-5%	$3.80E{-}02$ +/-10%	1.15	1.08	1.11	1.17
2.02	$3.73E{-}02$ +/-5%	$3.30E{-}02$ +/-10%	1.13	1.05	1.08	1.13
2.62	$3.15E{-}02$ +/-5%	$2.76E{-}02$ +/-10%	1.14	1.06	1.09	1.14
3.22	$2.63E{-}02$ +/-5%	$2.38E{-}02$ +/-11%	1.11	1.04	1.07	1.12
4.08	$2.10E{-}02$ +/-5%	$1.95E{-}02$ +/-11%	1.08	1.02	1.06	1.11
5.18	$1.64E{-}02$ +/-5%	$1.59E{-}02$ +/-13%	1.03	1.00	1.04	1.08
6.28	$1.38E{-}02$ +/-5%	$1.34E{-}02$ +/-14%	1.03	1.00	1.04	1.09
7.90	$1.13E{-}02$ +/-5%	$1.12E{-}02$ +/-16%	1.00	0.99	1.04	1.07
10.00	$9.43E{-}03$ +/-5%	$9.69E{-}03$ +/-19%	0.97	0.95	1.00	1.02
12.10	$8.60E{-}03$ +/-6%	$8.88E{-}03$ +/-20%	0.97	0.92	0.97	0.99
15.22	$8.08E{-}03$ +/-6%	$8.32E{-}03$ +/-22%	0.97	0.91	0.96	0.98
19.32	$7.71E{-}03$ +/-6%	$8.00E{-}03$ +/-22%	0.96	0.90	0.95	0.96
23.42	$7.45E{-}03$ +/-6%	$7.81E{-}03$ +/-23%	0.95	0.89	0.94	0.95
27.48	$7.36E{-}03$ +/-6%	$7.68E{-}03$ +/-23%	0.96	0.89	0.94	0.95
34.60	$7.12E{-}03$ +/-6%	$7.49E{-}03$ +/-23%	0.95	0.89	0.94	0.94
44.70	$6.86E{-}03$ +/-6%	$7.26E{-}03$ +/-24%	0.94	0.89	0.93	0.93
54.80	$6.77E{-}03$ +/-6%	$7.05E{-}03$ +/-24%	0.96	0.91	0.95	0.95

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Sc50	Ti50(n,p)Sc50	1.7m	61.3	1.15	5%
	Ti50(n,p)Sc50m	0.3s	40.5	1.15	5%
Sc48	Ti48(n,p)Sc48	1.8d	99.5	0.96	6%
	Ti49(n,d+np)Sc48		0.4	0.96	6%

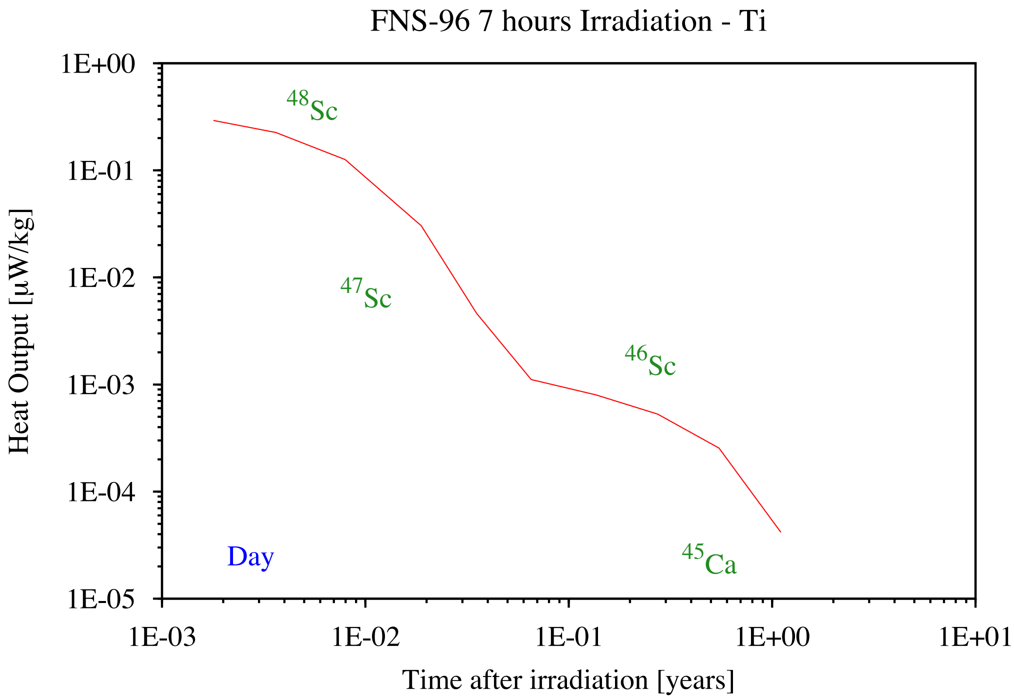




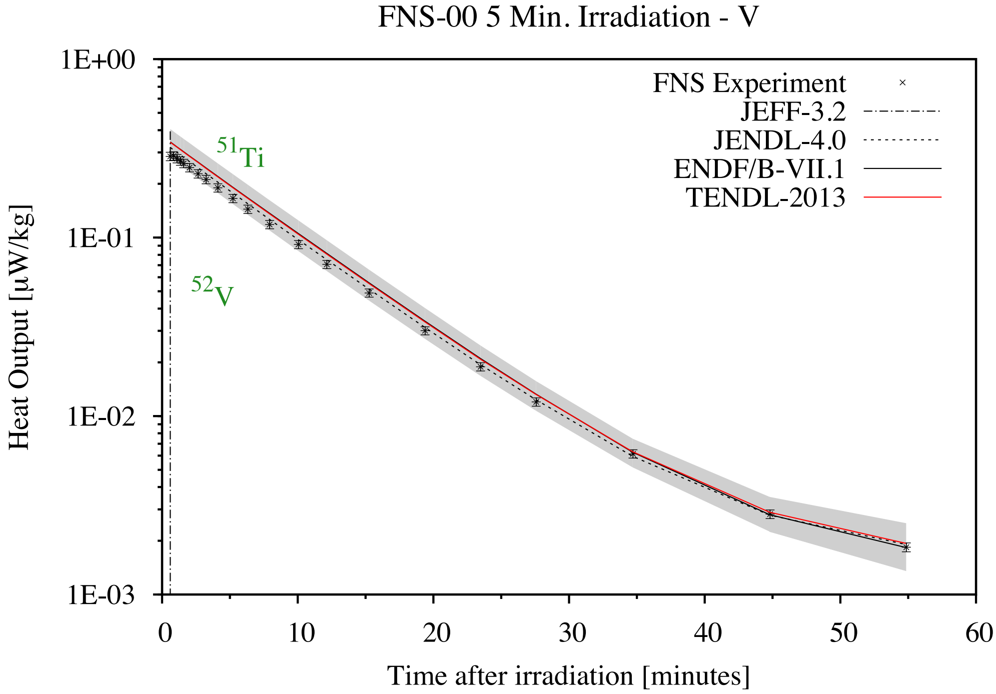
An excellent agreement exists at all cooling times, even with such complex production routes, for all libraries except TENDL-2013, which under-predicts the Sc46 production routes by about a factor 2.

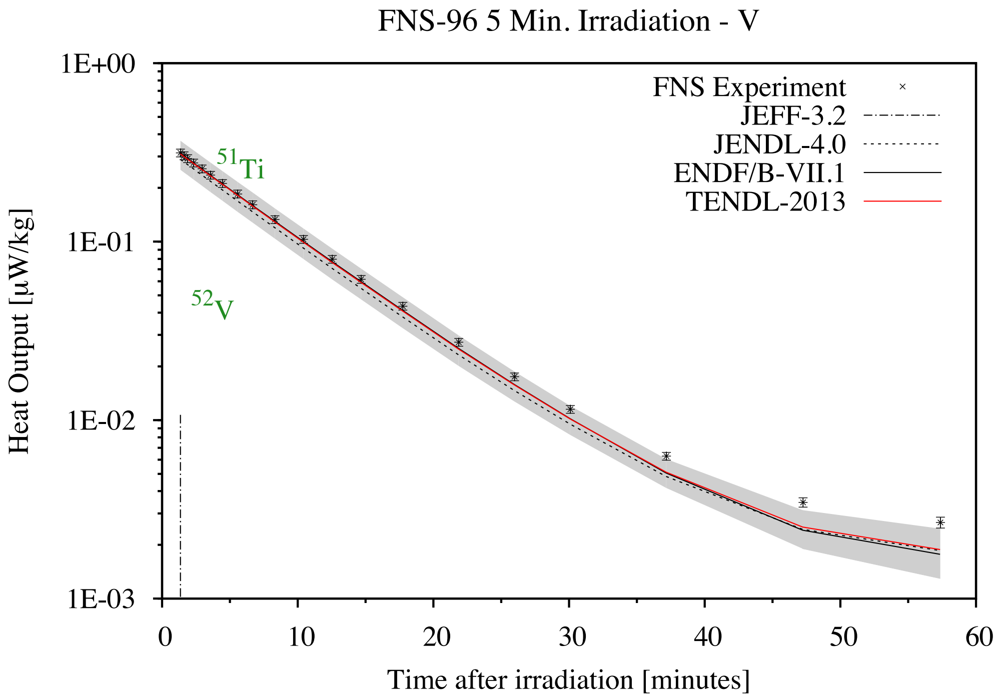
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.65	$3.38E{-}01$ +/-7%	$2.93E{-}01$ +/-34%	1.16	1.15	1.12	1.12
1.32	$2.54E{-}01$ +/-6%	$2.26E{-}01$ +/-35%	1.12	1.11	1.09	1.09
2.90	$1.41E{-}01$ +/-6%	$1.26E{-}01$ +/-34%	1.12	1.11	1.08	1.09
6.87	$3.45E{-}02$ +/-6%	$3.04E{-}02$ +/-32%	1.13	1.06	1.24	1.06
12.87	$6.16E{-}03$ +/-6%	$4.62E{-}03$ +/-24%	1.33	1.11	1.29	1.05
23.86	$2.43E{-}03$ +/-6%	$1.11E{-}03$ +/-15%	2.19	1.00	1.04	1.00
49.71	$1.85E{-}03$ +/-6%	$8.01E{-}04$ +/-16%	2.31	0.97	1.02	0.99
99.90	$1.25E{-}03$ +/-6%	$5.30E{-}04$ +/-16%	2.36	0.98	1.04	1.00
200.12	$5.51E{-}04$ +/-6%	$2.55E{-}04$ +/-16%	2.16	0.88	0.95	1.03
402.96	$1.23E{-}04$ +/-9%	$4.17E{-}05$ +/-15%	2.96	1.11	1.17	1.33

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Sc48	Ti48(n,p)Sc48	1.8d	99.7	1.12	6%
Sc46	Ti46(n,p)Sc46	83.7d	67.3	2.36	6%
	Ti47(n,d+np)Sc46		13.2	2.36	6%
	Ti46(n,p)Sc46m	18.7s	17.5	2.36	6%
	Ti47(n,d+np)Sc46m		1.9	2.36	6%


FNS-96 7 hours Irradiation - Ti
Heat Output [µW/kg]
1E+00
1E-01
1E-02
1E-03
1E-04
1E-05
1E-03
1E-02
1E-01
1E+00
1E+01
Time after irradiation [years]
48Sc
47Sc
46Sc
45Ca
Day

Vanadium

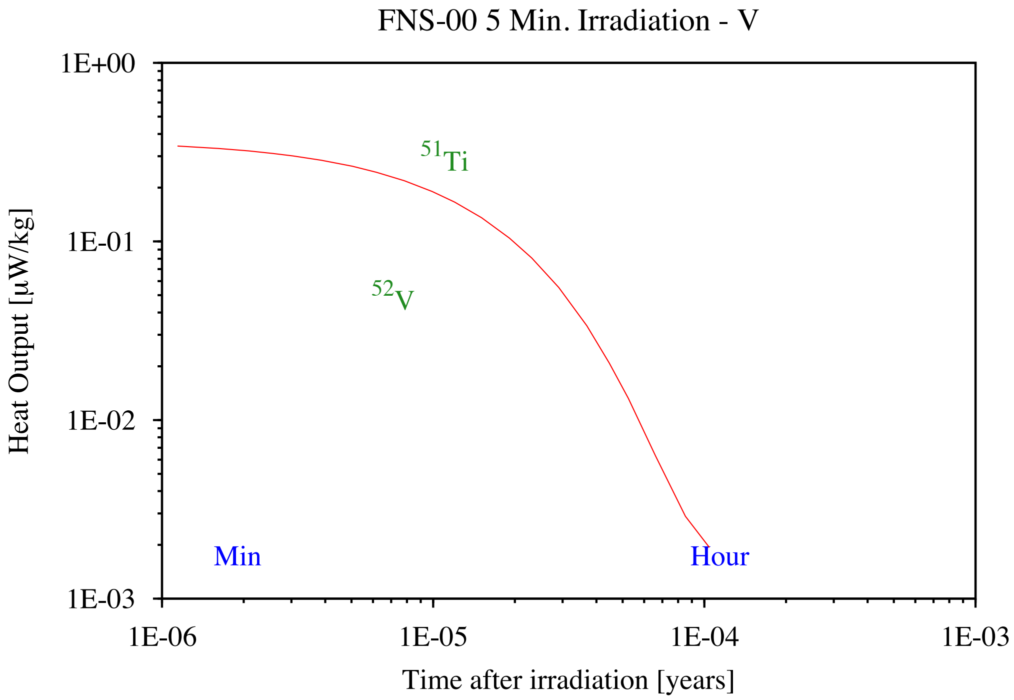


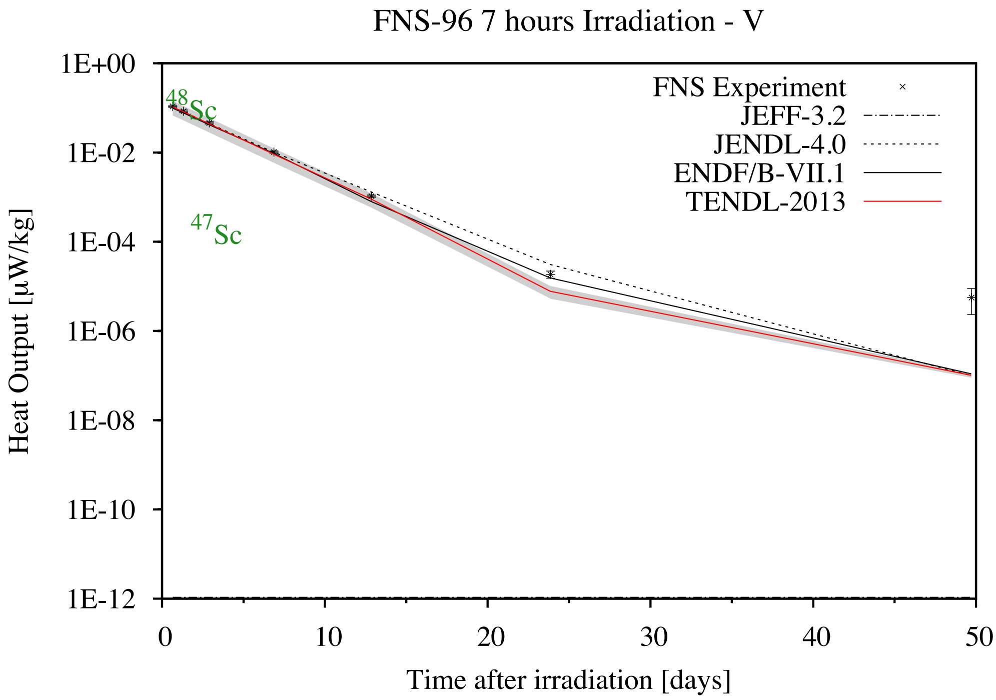


For Vanadium, the clear underestimation after 30 minutes cooling in the 1996 sample does not seem to persist in the results of the second batch. The two measured data-sets do not corroborate one another. However, TENDL-2013 shows good agreement with the experiment while JEFF-3.2 simply fails to deliver.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	$2.85E{-}01$ +/-5%	$3.42E{-}01$ +/-18%	0.83	0.83	0.72	0.89
0.85	$2.87E{-}01$ +/-5%	$3.32E{-}01$ +/-18%	0.86	0.86	0.00	0.92
1.10	$2.77E{-}01$ +/-5%	$3.21E{-}01$ +/-19%	0.86	0.86	0.00	0.92
1.35	$2.69E{-}01$ +/-5%	$3.11E{-}01$ +/-19%	0.86	0.86	0.00	0.92
1.60	$2.61E{-}01$ +/-5%	$3.01E{-}01$ +/-19%	0.86	0.86	0.00	0.93
2.03	$2.47E{-}01$ +/-5%	$2.85E{-}01$ +/-19%	0.87	0.86	0.00	0.93
2.65	$2.28E{-}01$ +/-5%	$2.63E{-}01$ +/-19%	0.86	0.86	0.00	0.93
3.25	$2.12E{-}01$ +/-5%	$2.44E{-}01$ +/-19%	0.87	0.86	0.00	0.93
4.12	$1.90E{-}01$ +/-5%	$2.19E{-}01$ +/-19%	0.87	0.86	0.00	0.93
5.22	$1.66E{-}01$ +/-5%	$1.91E{-}01$ +/-19%	0.87	0.87	0.00	0.93
6.32	$1.44E{-}01$ +/-5%	$1.66E{-}01$ +/-19%	0.87	0.86	0.00	0.93
7.93	$1.18E{-}01$ +/-5%	$1.36E{-}01$ +/-19%	0.87	0.87	0.00	0.94
10.05	$9.15E{-}02$ +/-5%	$1.04E{-}01$ +/-19%	0.88	0.87	0.00	0.94
12.15	$7.07E{-}02$ +/-5%	$8.08E{-}02$ +/-20%	0.88	0.87	0.00	0.94
15.27	$4.89E{-}02$ +/-5%	$5.53E{-}02$ +/-20%	0.88	0.88	0.00	0.95
19.38	$3.01E{-}02$ +/-5%	$3.37E{-}02$ +/-20%	0.89	0.88	0.00	0.96
23.48	$1.89E{-}02$ +/-5%	$2.08E{-}02$ +/-19%	0.91	0.90	0.00	0.97
27.58	$1.20E{-}02$ +/-5%	$1.32E{-}02$ +/-19%	0.91	0.90	0.00	0.97
34.72	$6.14E{-}03$ +/-5%	$6.31E{-}03$ +/-18%	0.97	0.98	0.00	1.03
44.82	$2.82E{-}03$ +/-6%	$2.89E{-}03$ +/-22%	0.98	1.01	0.00	1.01
54.87	$1.84E{-}03$ +/-6%	$1.93E{-}03$ +/-30%	0.95	1.00	0.00	0.97

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ti51	V51(n,p)Ti51	5.8m	99.9	0.87	5%
V52	V51(n,γ)V52	3.7m	99.9	0.87	5%
Sc48	v51(n,α)Sc48	1.8d	100.0	0.95	6%

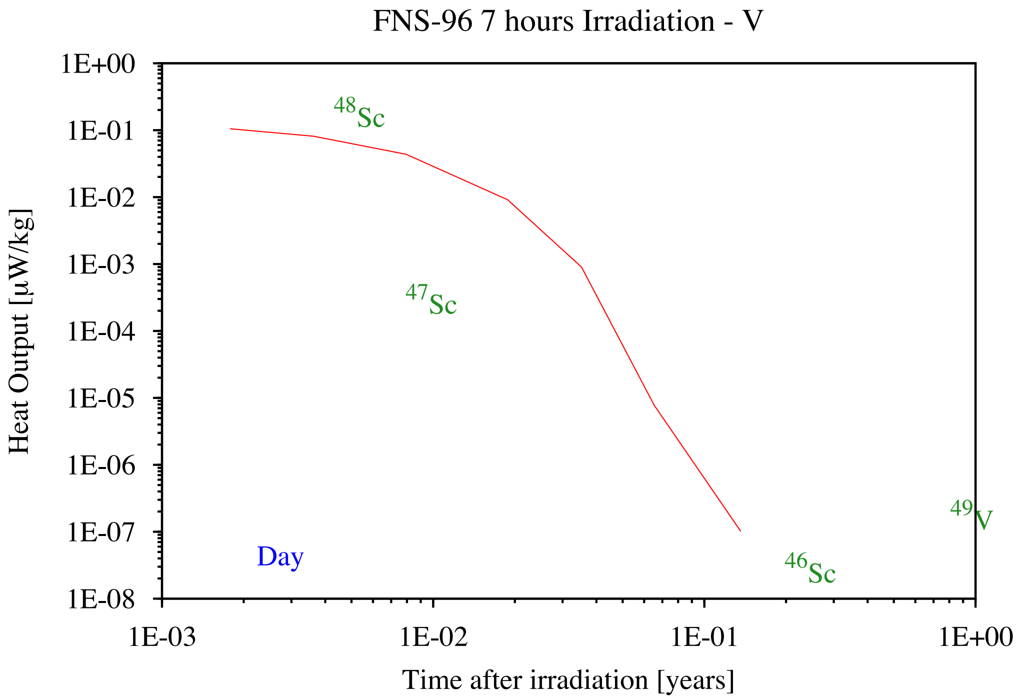




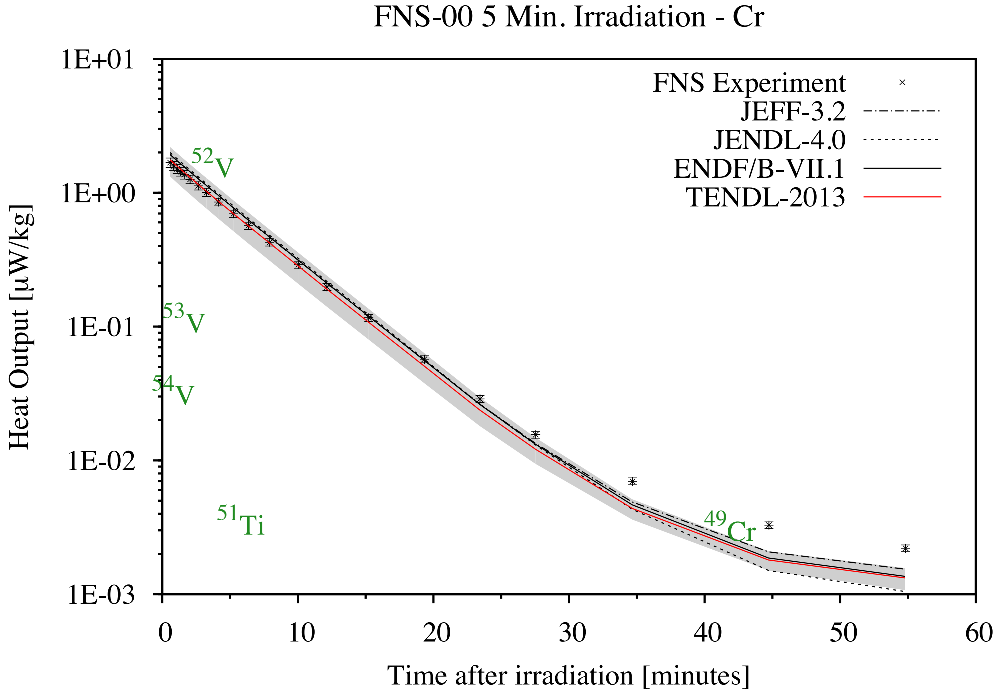
An excellent agreement can be seen, except for JEFF-3.2, at all but the last 50-day cooling step, where the experimental uncertainty is quoted as 58%.

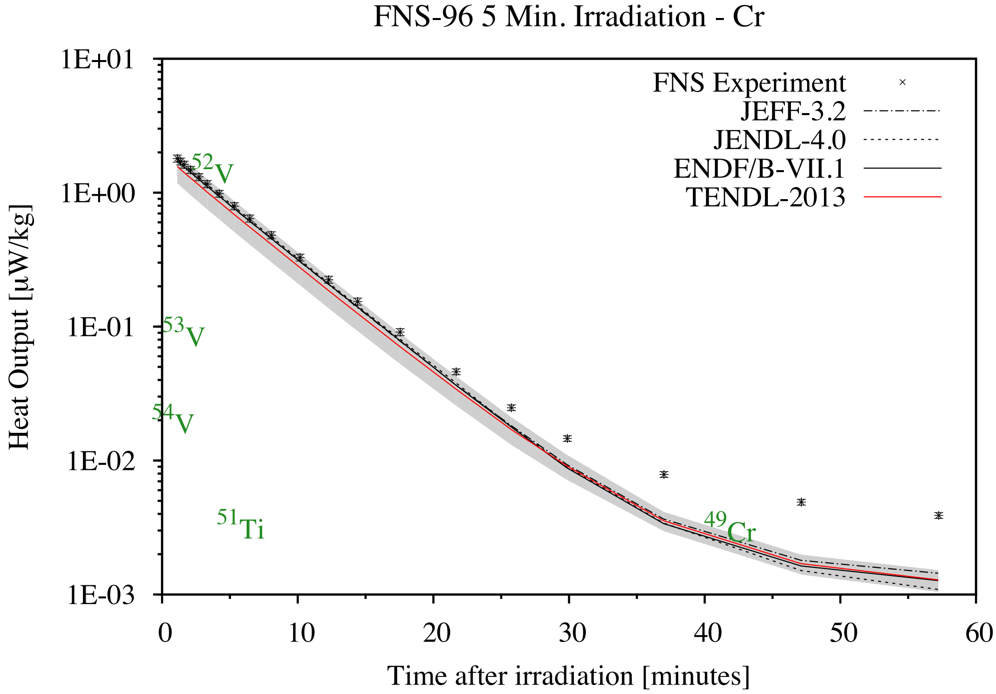
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.65	$1.08E{-}01$ +/-6%	$1.05E{-}01$ +/-36%	1.03	1.09	101013880055.37	1.03
1.32	$8.42E{-}02$ +/-6%	$8.13E{-}02$ +/-36%	1.04	1.10	78753413895.02	1.03
2.90	$4.61E{-}02$ +/-6%	$4.37E{-}02$ +/-36%	1.05	1.10	43071196079.16	1.04
6.87	$1.02E{-}02$ +/-6%	$9.15E{-}03$ +/-36%	1.12	1.07	9549552920.05	1.01
12.86	$1.06E{-}03$ +/-6%	$9.02E{-}04$ +/-35%	1.17	1.33	988626585.36	0.81
23.86	$1.86E{-}05$ +/-18%	$7.78E{-}06$ +/-31%	2.39	1.21	17378128.62	0.60
49.73	$5.62E{-}06$ +/-58%	$1.02E{-}07$ +/-10%	55.28	51.32	5258333.65	55.94

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Sc48	V51(n,α)Sc48	1.8d	100.0	1.04	6%


FNS-96 7 hours Irradiation - V
Heat Output [µW/kg]
1E+00
1E-01
1E-02
1E-03
1E-04
1E-05
1E-06
1E-07
1E-08
1E-03
1E-02
1E-01
1E+00
Time after irradiation [years]
48Sc
47Sc
46Sc
49V
Day

Chromium

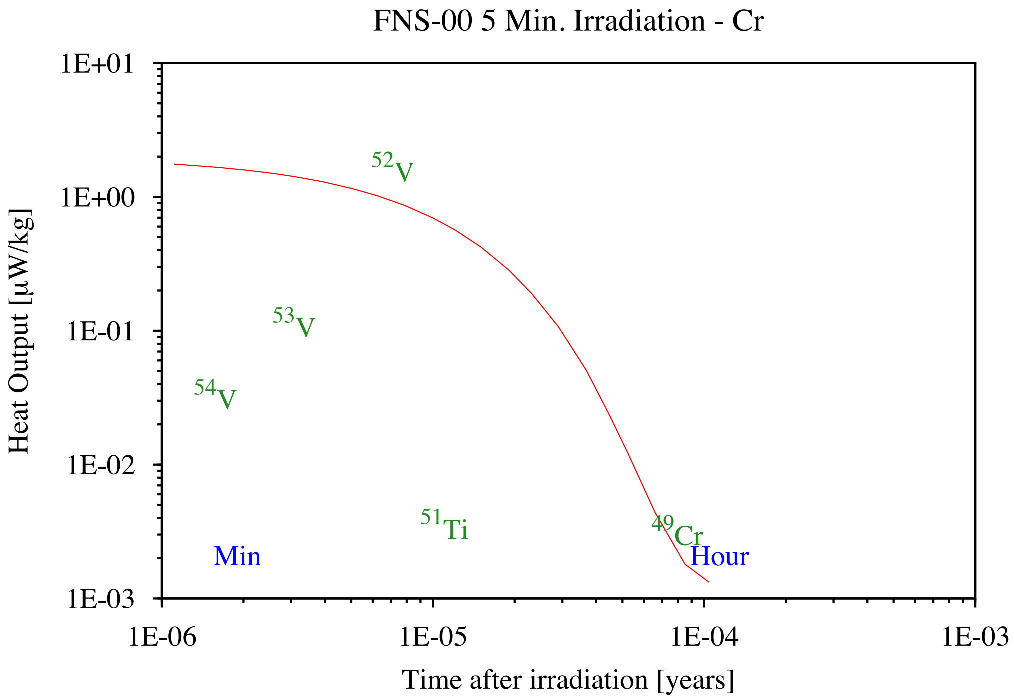


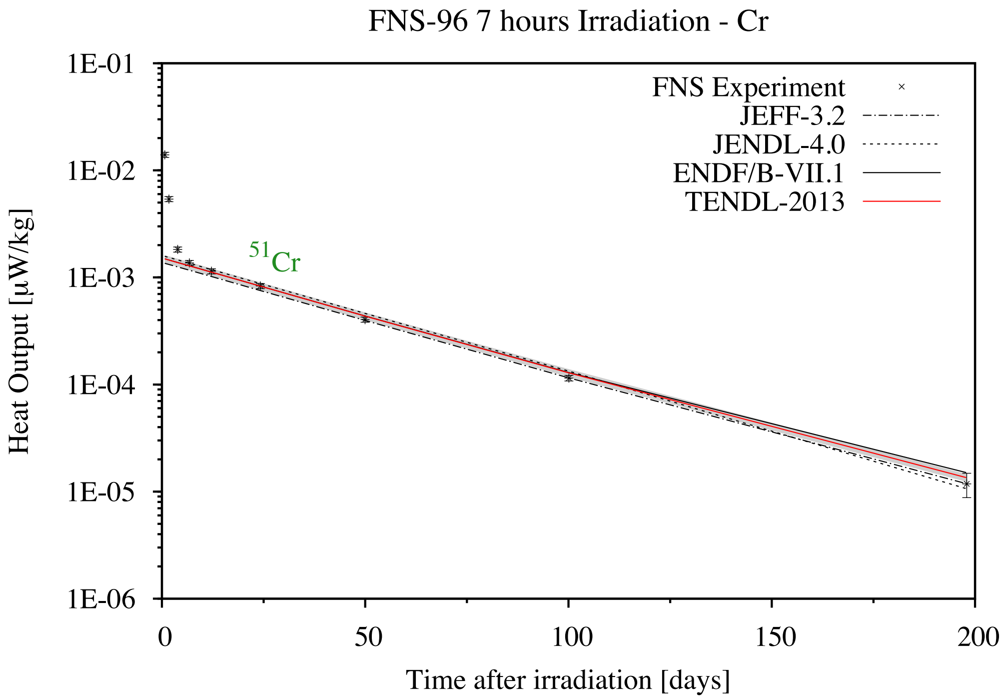


For Chromium, there is a good agreement if one allows for the fact that Al and Fe impurities could have been present in the sample at levels up to 2000 and 6000 ppm, respectively. Such levels of impurities have been measured in similar samples.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	1.68E+00 +/-8%	1.76E+00 +/-25%	0.96	0.87	0.87	0.84
0.85	1.58E+00 +/-8%	1.66E+00 +/-25%	0.95	0.87	0.87	0.84
1.10	1.51E+00 +/-8%	1.58E+00 +/-25%	0.96	0.87	0.87	0.84
1.37	1.44E+00 +/-8%	1.49E+00 +/-25%	0.96	0.88	0.88	0.85
1.62	1.37E+00 +/-7%	1.42E+00 +/-25%	0.96	0.87	0.87	0.85
2.05	1.26E+00 +/-7%	1.30E+00 +/-25%	0.97	0.88	0.88	0.85
2.65	1.13E+00 +/-7%	1.15E+00 +/-26%	0.98	0.88	0.89	0.86
3.27	1.00E+00 +/-7%	1.02E+00 +/-26%	0.98	0.89	0.89	0.86
4.13	8.53$E-$01 +/-7%	8.64$E-$01 +/-26%	0.99	0.89	0.89	0.86
5.25	6.95$E-$01 +/-6%	6.97$E-$01 +/-26%	1.00	0.90	0.90	0.87
6.35	5.67$E-$01 +/-6%	5.66$E-$01 +/-26%	1.00	0.90	0.91	0.88
7.93	4.26$E-$01 +/-6%	4.20$E-$01 +/-26%	1.02	0.92	0.92	0.89
10.03	2.90$E-$01 +/-6%	2.83$E-$01 +/-26%	1.03	0.93	0.93	0.90
12.15	1.98$E-$01 +/-6%	1.90$E-$01 +/-26%	1.04	0.94	0.94	0.91
15.23	1.16$E-$01 +/-6%	1.08$E-$01 +/-26%	1.08	0.97	0.98	0.95
19.33	5.70$E-$02 +/-6%	5.06$E-$02 +/-25%	1.13	1.02	1.02	1.00
23.43	2.88$E-$02 +/-6%	2.38$E-$02 +/-24%	1.21	1.10	1.09	1.09
27.55	1.56$E-$02 +/-6%	1.21$E-$02 +/-22%	1.29	1.18	1.16	1.19
34.68	6.98$E-$03 +/-6%	4.37$E-$03 +/-17%	1.60	1.50	1.43	1.62
44.75	3.28$E-$03 +/-6%	1.80$E-$03 +/-17%	1.82	1.76	1.58	2.18
54.82	2.21$E-$03 +/-6%	1.32$E-$03 +/-18%	1.67	1.62	1.44	2.10

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
V52	Cr52(n,p)V52	3.7m	98.1	0.98	7%
	Cr53(n,d+np)V52		1.9	0.98	7%
Cr49	Cr50(n,2n)Cr49	41.9m	100.0	1.82	6%

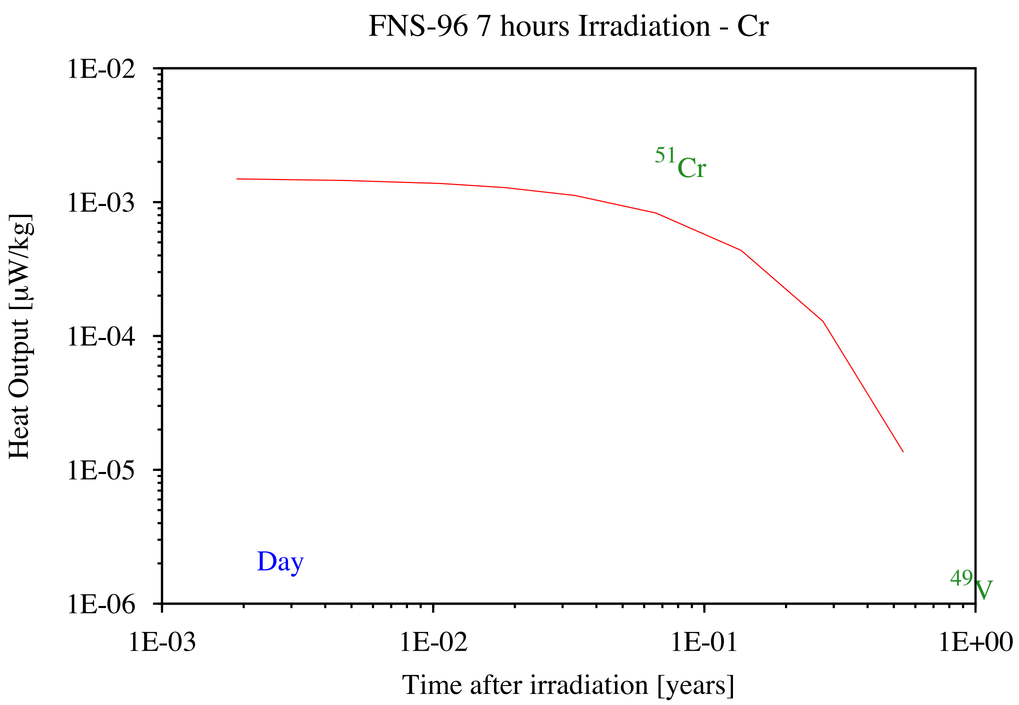




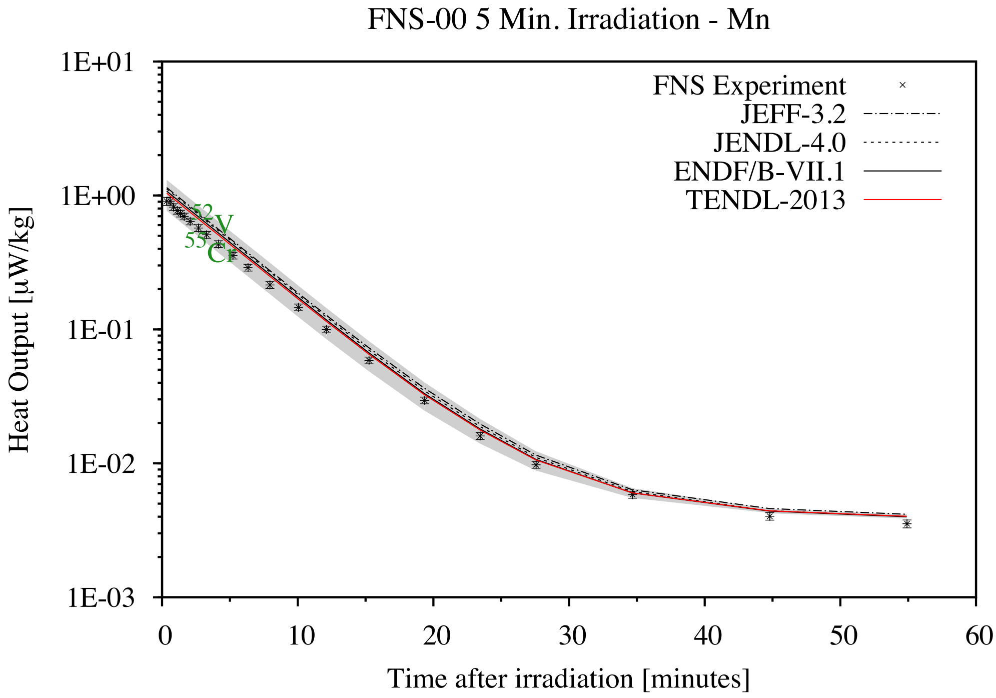
Some short-lived isotopes seem to be missing in all the simulations, almost certainly produced from impurities within the sample, but the overall agreement remains excellent.

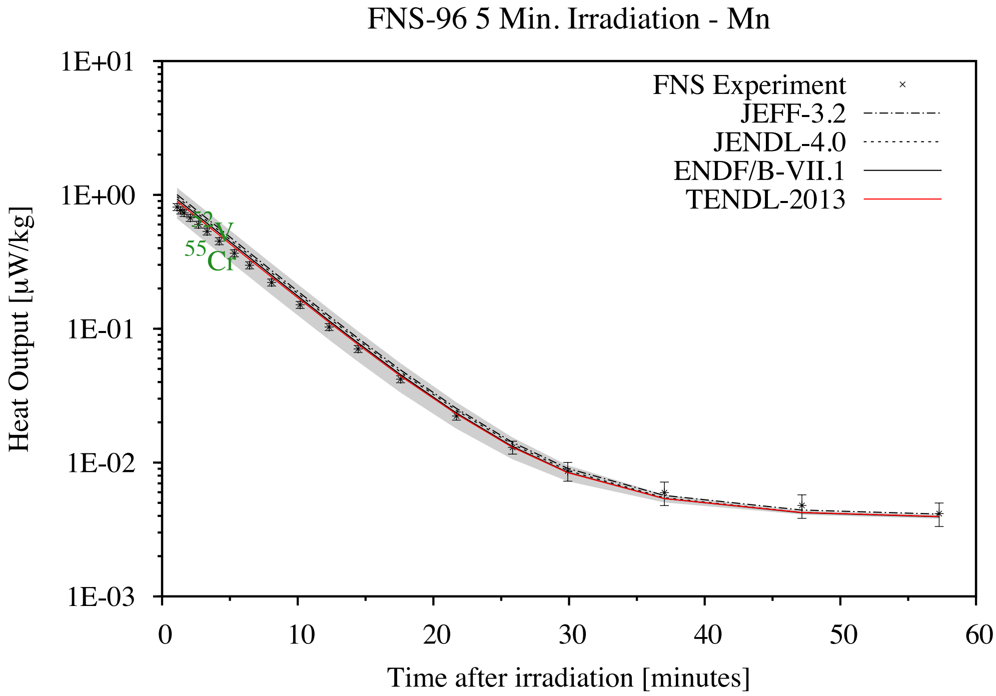
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.69	1.40$E-$02 +/-6%	1.49$E-$03 +/-8%	9.37	9.36	10.30	8.86
1.74	5.39$E-$03 +/-6%	1.45$E-$03 +/-8%	3.71	3.71	4.08	3.51
3.89	1.83$E-$03 +/-6%	1.38$E-$03 +/-8%	1.33	1.32	1.46	1.25
6.75	1.37$E-$03 +/-6%	1.28$E-$03 +/-8%	1.06	1.06	1.17	1.01
12.20	1.14$E-$03 +/-6%	1.12$E-$03 +/-8%	1.02	1.02	1.12	0.96
24.21	8.31$E-$04 +/-6%	8.29$E-$04 +/-8%	1.00	1.00	1.10	0.95
49.96	4.03$E-$04 +/-6%	4.36$E-$04 +/-8%	0.93	0.92	1.02	0.87
100.09	1.15$E-$04 +/-6%	1.29$E-$04 +/-8%	0.89	0.89	0.99	0.86
197.96	1.18$E-$05 +/-26%	1.35$E-$05 +/-8%	0.87	0.78	0.99	1.11

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Cr51	Cr52(n,2n)Cr51	27.7d	100.0	1.00	6%


FNS-96 7 hours Irradiation - Cr
1E-02
1E-03
1E-04
1E-05
1E-06
Heat Output [µW/kg]
51Cr
Day
49V
1E-03
1E-02
1E-01
1E+00
Time after irradiation [years]

Manganese

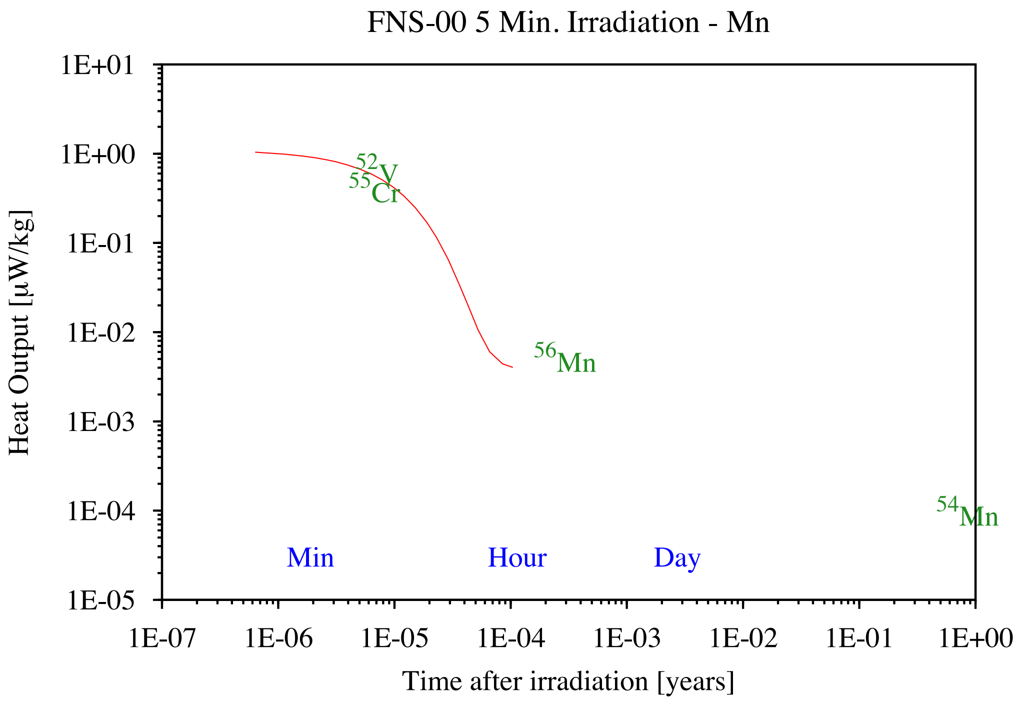


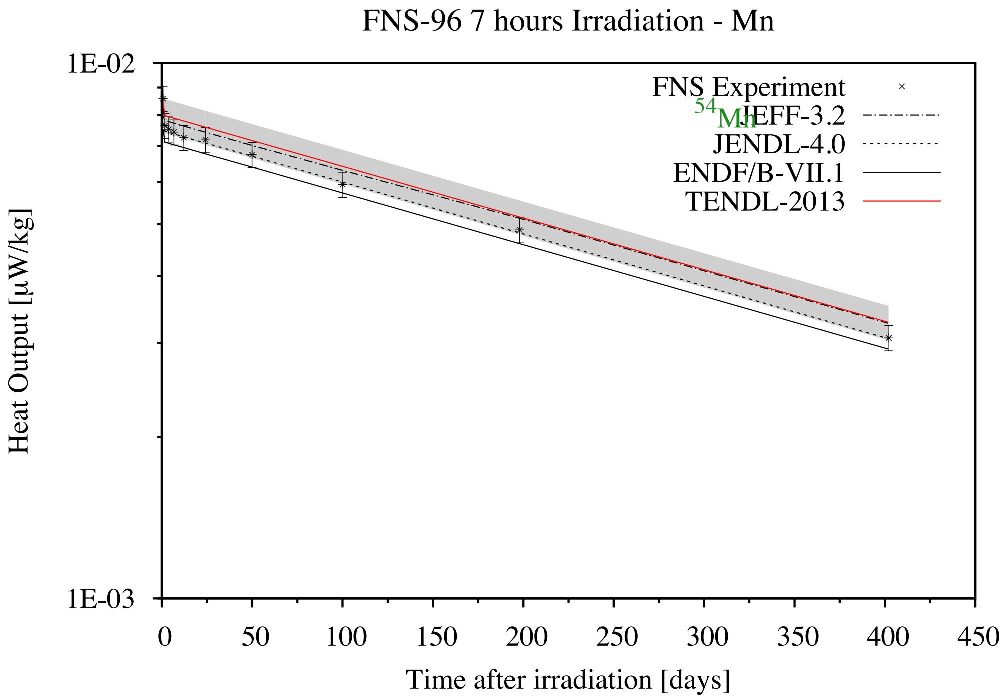


For Manganese, there is a good agreement at short cooling times for both batches with all libraries. All those libraries accurately reproduce the most recent IRDFF International Reference Dosimetry File.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.33	9.06E−01 +/-7%	1.04E+00 +/-26%	0.87	0.84	0.79	0.81
0.60	9.06E−01 +/-6%	9.88E−01 +/-26%	0.92	0.88	0.83	0.85
0.85	8.18E−01 +/-6%	9.43E−01 +/-26%	0.87	0.84	0.79	0.81
1.12	7.70E−01 +/-6%	8.97E−01 +/-26%	0.86	0.83	0.78	0.80
1.37	7.34E−01 +/-6%	8.55E−01 +/-26%	0.86	0.83	0.78	0.80
1.63	6.98E−01 +/-6%	8.14E−01 +/-26%	0.86	0.83	0.78	0.80
2.07	6.41E−01 +/-6%	7.50E−01 +/-26%	0.85	0.82	0.77	0.79
2.68	5.71E−01 +/-6%	6.68E−01 +/-26%	0.86	0.83	0.77	0.79
3.28	5.09E−01 +/-6%	5.97E−01 +/-26%	0.85	0.82	0.77	0.79
4.15	4.33E−01 +/-6%	5.07E−01 +/-26%	0.85	0.83	0.77	0.79
5.22	3.56E−01 +/-6%	4.15E−01 +/-26%	0.86	0.83	0.78	0.80
6.33	2.89E−01 +/-6%	3.37E−01 +/-26%	0.86	0.83	0.78	0.80
7.95	2.15E−01 +/-6%	2.49E−01 +/-26%	0.86	0.84	0.78	0.80
10.05	1.46E−01 +/-6%	1.68E−01 +/-26%	0.87	0.84	0.78	0.81
12.12	1.00E−01 +/-6%	1.15E−01 +/-26%	0.87	0.85	0.78	0.81
15.25	5.88E−02 +/-6%	6.53E−02 +/-25%	0.90	0.88	0.81	0.84
19.35	2.95E−02 +/-6%	3.25E−02 +/-24%	0.91	0.89	0.81	0.85
23.45	1.60E−02 +/-6%	1.78E−02 +/-21%	0.90	0.89	0.81	0.85
27.57	9.76E−03 +/-6%	1.06E−02 +/-16%	0.92	0.91	0.85	0.88
34.68	5.85E−03 +/-6%	6.02E−03 +/-8%	0.97	0.97	0.92	0.95
44.80	4.02E−03 +/-7%	4.42E−03 +/-4%	0.91	0.91	0.88	0.91
54.92	3.54E−03 +/-7%	4.02E−03 +/-3%	0.88	0.88	0.85	0.88

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
V52	Mn55(n,α)V52	3.7m	100.0	0.84	6%
Cr55	Mn55(n,p)Cr55	3.5m	100.0	0.84	6%
Mn56	Mn55(n,γ)Mn56	2.5h	100.0	0.88	7%

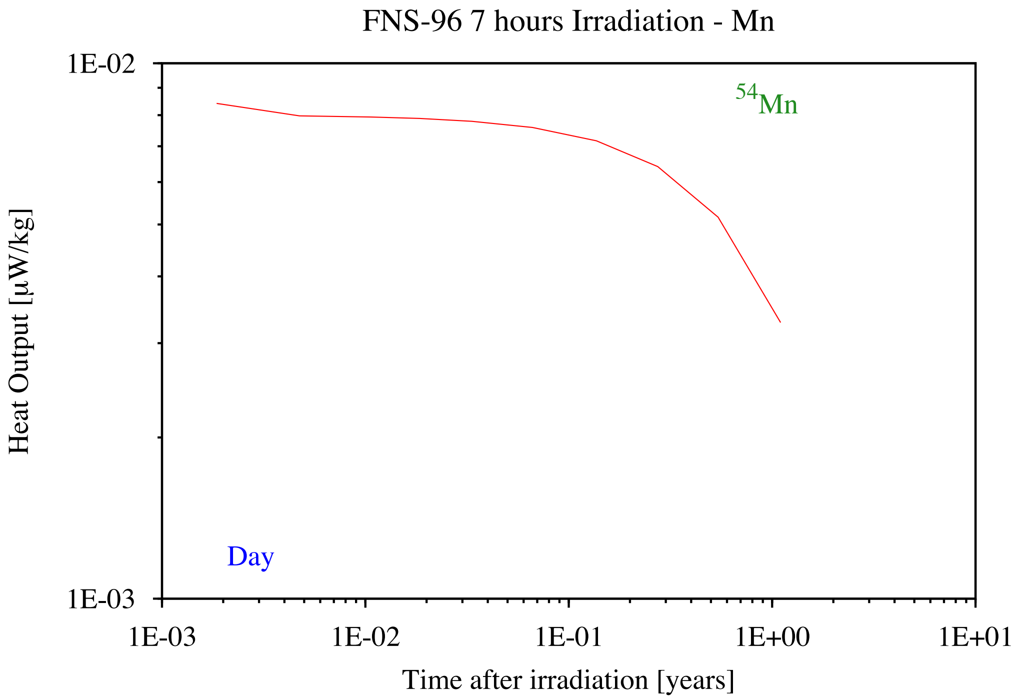




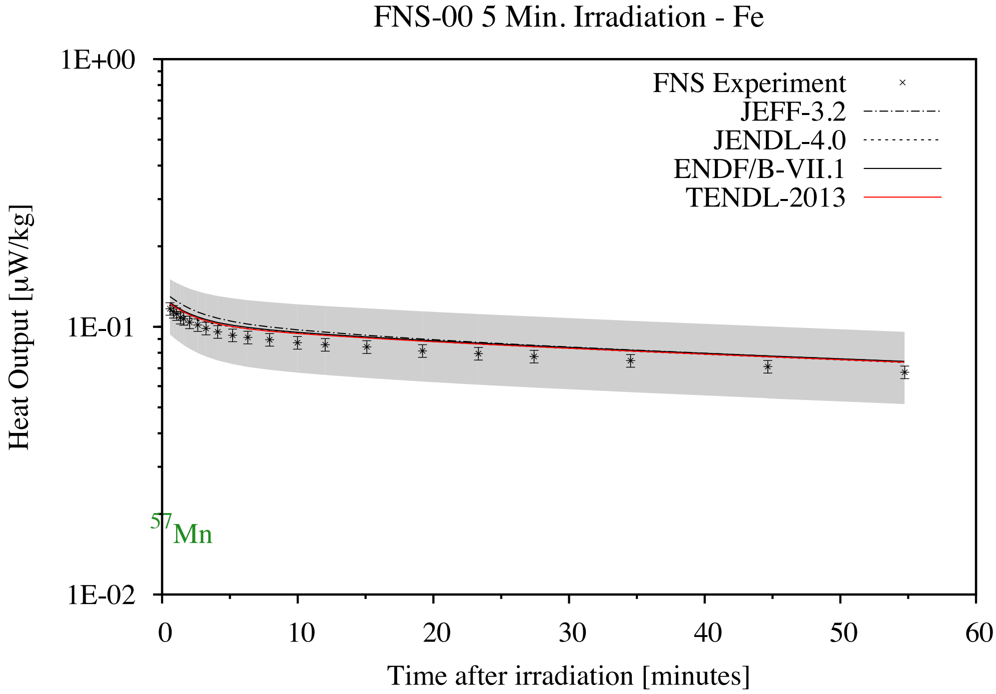
The production path of Mn54 seems to better agree with the measurement. The calculation uncertainty derived from TENDL-2013 covariance well reflect the dispersion.

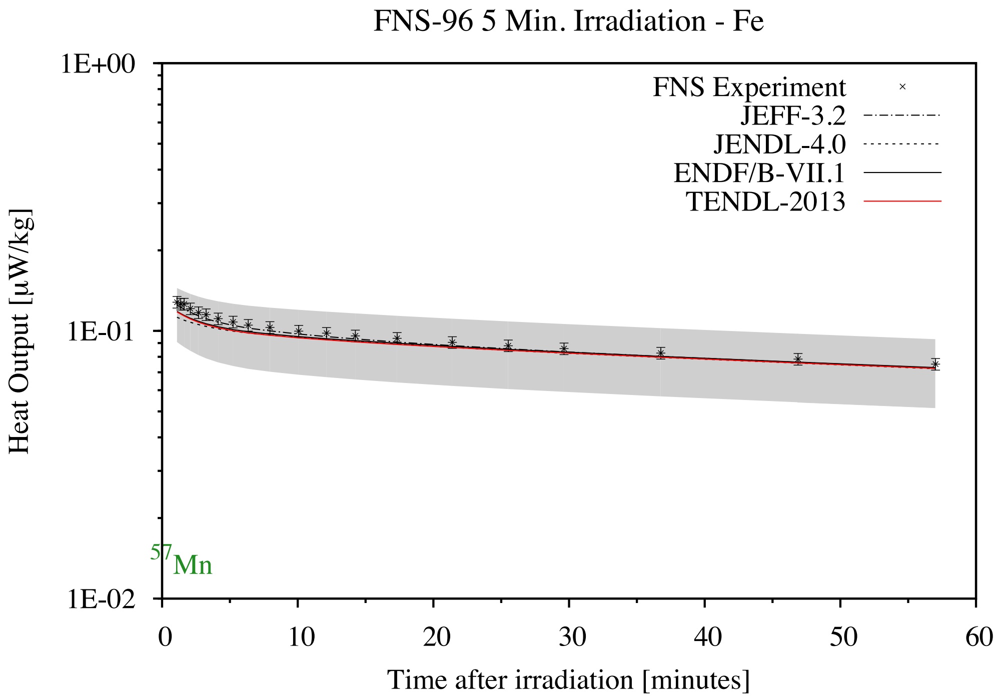
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.68	8.58E−03 +/-5%	8.41E−03 +/-7%	1.02	1.14	1.04	1.08
1.73	7.64E−03 +/-5%	7.98E−03 +/-7%	0.96	1.07	0.98	1.02
3.89	7.52E−03 +/-5%	7.94E−03 +/-7%	0.95	1.06	0.97	1.01
6.75	7.43E−03 +/-5%	7.89E−03 +/-7%	0.94	1.06	0.96	1.01
12.20	7.25E−03 +/-5%	7.79E−03 +/-7%	0.93	1.04	0.95	1.00
24.21	7.19E−03 +/-5%	7.59E−03 +/-7%	0.95	1.06	0.97	1.01
49.96	6.74E−03 +/-5%	7.17E−03 +/-7%	0.94	1.06	0.96	1.01
100.10	5.93E−03 +/-5%	6.41E−03 +/-7%	0.92	1.04	0.94	0.99
197.97	4.88E−03 +/-5%	5.16E−03 +/-7%	0.95	1.06	0.95	1.01
402.18	3.07E−03 +/-5%	3.28E−03 +/-7%	0.94	1.05	0.94	1.00

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Mn54	Mn55(n,2n)Mn54	312d	100.0	0.94	5%


FNS-96 7 hours Irradiation - Mn
1E-02
1E-03
Heat Output [µW/kg]
54Mn
Day
1E-03
1E-02
1E-01
1E+00
1E+01
Time after irradiation [years]

Iron

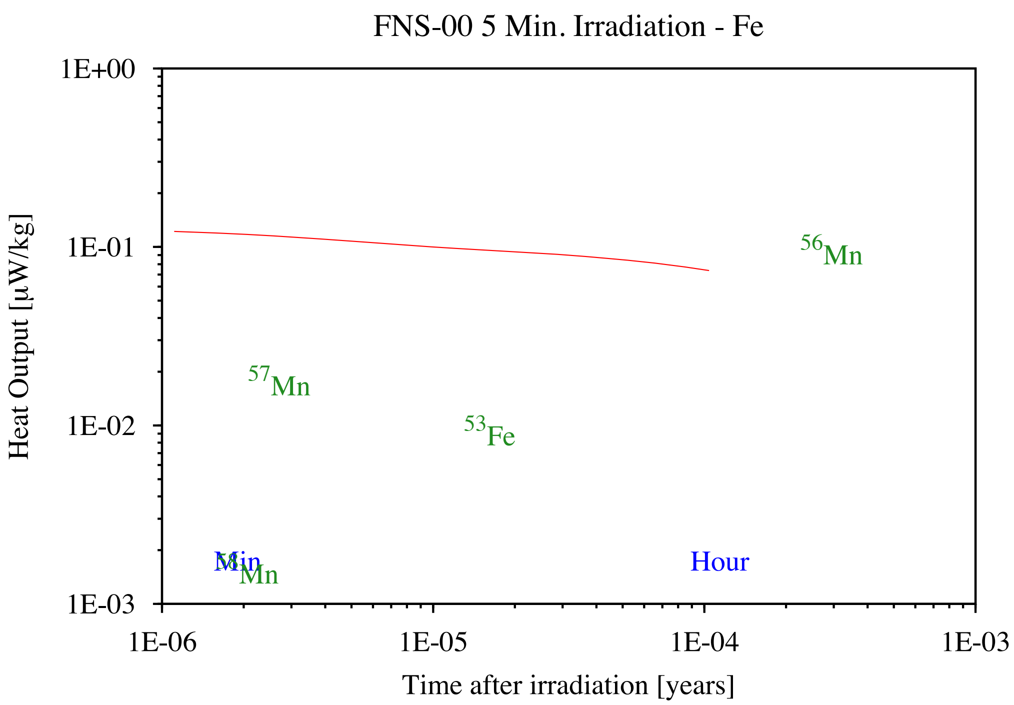


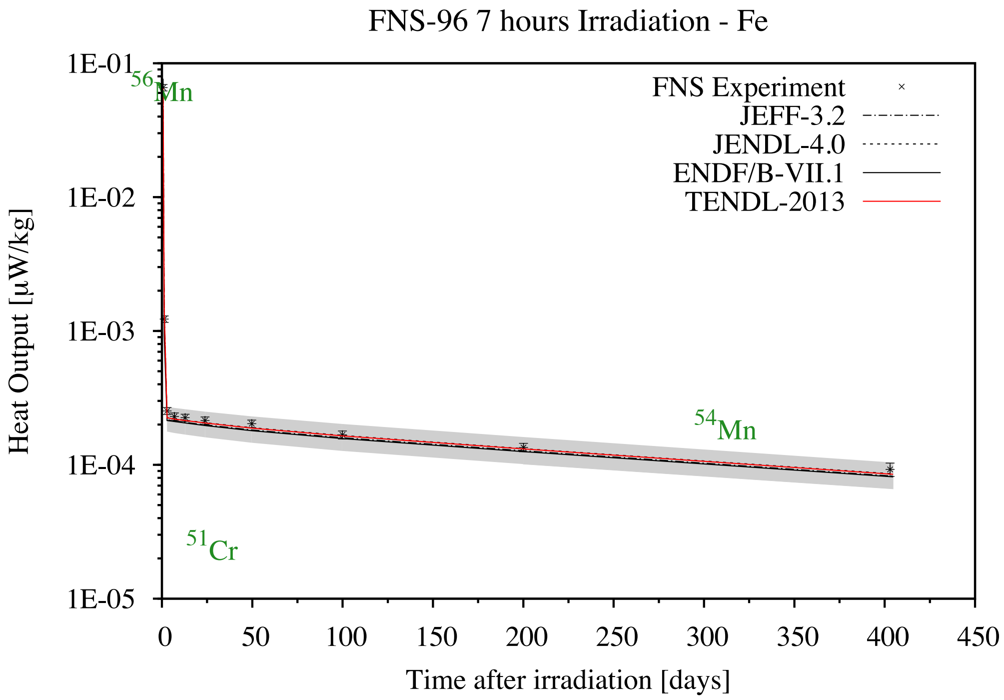


For Iron, the experimental decay results differ in the two batches and are positioned just above and below the code predictions that remain unchanged in all but the distribution of cooling time steps. However, the experimental errors are given as a range of one standard deviation, not a limit of the error. If the error bars for the two batches of experimental data do not overlap each other, it does not directly mean that the experimental data are incorrect. TENDL-2013 variance could be reduced to 15%.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	1.17E−01 +/-5%	1.22E−01 +/-23%	0.96	0.95	0.90	1.01
0.83	1.14E−01 +/-5%	1.20E−01 +/-24%	0.95	0.94	0.90	1.00
1.08	1.12E−01 +/-5%	1.17E−01 +/-24%	0.95	0.94	0.90	0.99
1.35	1.08E−01 +/-5%	1.15E−01 +/-24%	0.94	0.93	0.89	0.98
1.60	1.07E−01 +/-5%	1.14E−01 +/-25%	0.94	0.93	0.89	0.98
2.03	1.04E−01 +/-5%	1.11E−01 +/-25%	0.94	0.93	0.89	0.96
2.63	1.02E−01 +/-5%	1.08E−01 +/-26%	0.94	0.93	0.89	0.96
3.23	9.87E−02 +/-5%	1.05E−01 +/-26%	0.94	0.93	0.89	0.95
4.10	9.58E−02 +/-5%	1.03E−01 +/-27%	0.93	0.92	0.89	0.94
5.20	9.30E−02 +/-5%	1.00E−01 +/-28%	0.93	0.92	0.89	0.93
6.32	9.13E−02 +/-5%	9.83E−02 +/-28%	0.93	0.92	0.89	0.93
7.93	8.96E−02 +/-5%	9.63E−02 +/-28%	0.93	0.92	0.90	0.93
9.98	8.73E−02 +/-5%	9.44E−02 +/-29%	0.92	0.91	0.90	0.92
12.03	8.58E−02 +/-5%	9.28E−02 +/-29%	0.92	0.91	0.90	0.92
15.10	8.41E−02 +/-5%	9.08E−02 +/-29%	0.93	0.92	0.90	0.92
19.20	8.13E−02 +/-5%	8.84E−02 +/-29%	0.92	0.91	0.90	0.92
23.32	7.94E−02 +/-5%	8.62E−02 +/-30%	0.92	0.91	0.91	0.92
27.42	7.75E−02 +/-5%	8.42E−02 +/-30%	0.92	0.91	0.91	0.92
34.53	7.47E−02 +/-5%	8.12E−02 +/-30%	0.92	0.91	0.91	0.92
44.65	7.10E−02 +/-5%	7.73E−02 +/-30%	0.92	0.91	0.91	0.92
54.75	6.77E−02 +/-5%	7.37E−02 +/-30%	0.92	0.91	0.91	0.92

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Mn56	Fe56(n,p)Mn56	2.5h	99.6	0.92	5%

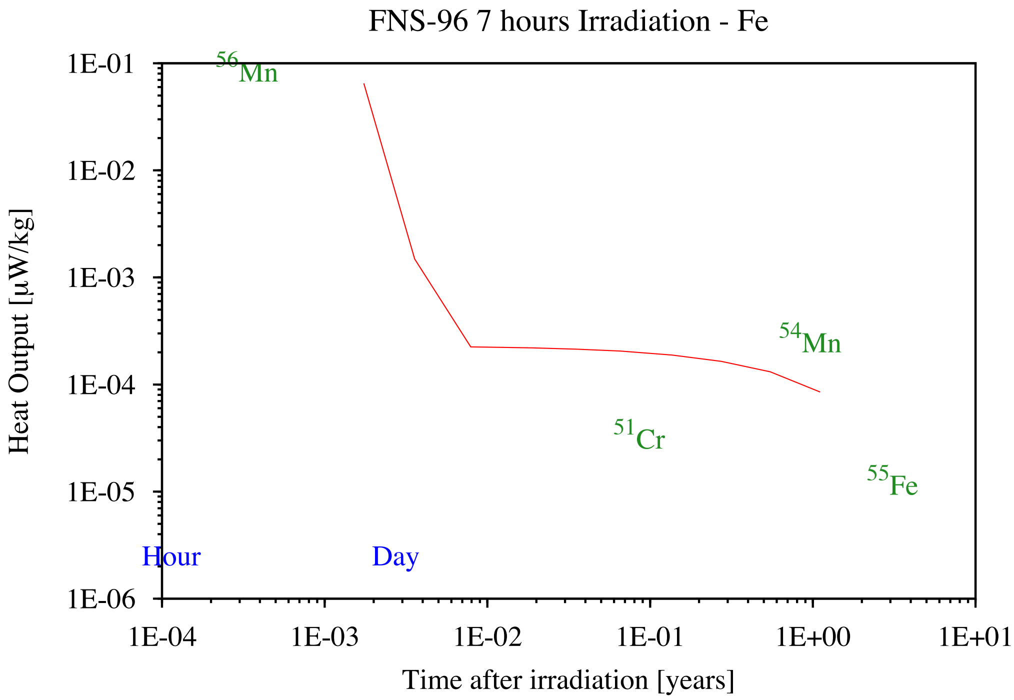




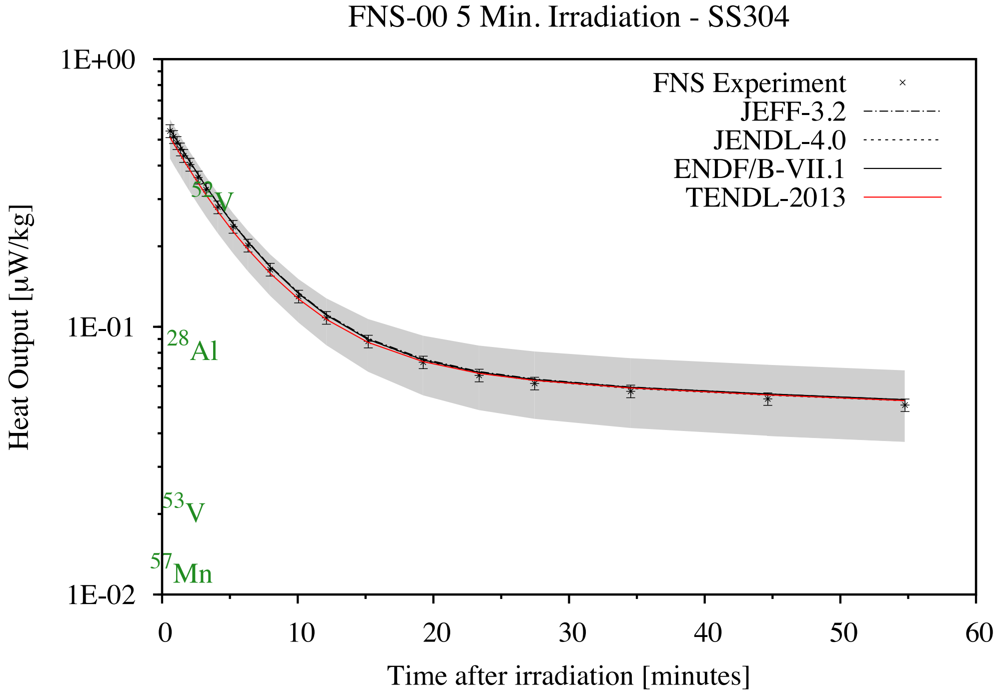
The above picture shows excellent agreements, well within the experimental uncertainty bands.

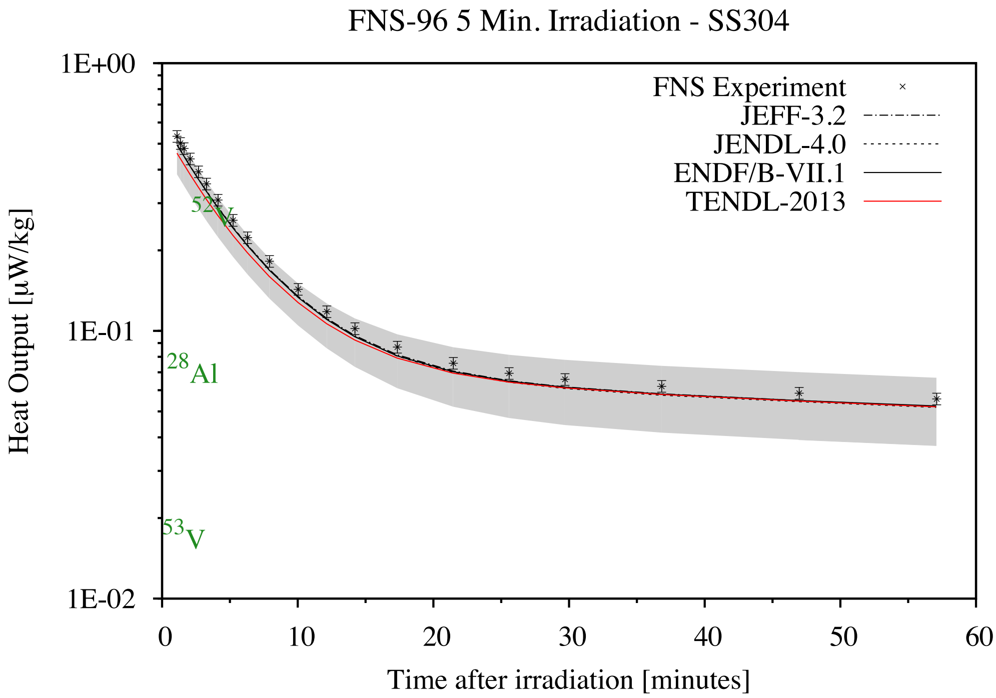
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.63	$6.58E{-}02$ +/-5%	$6.49E{-}02$ +/-37%	1.01	1.64	0.86	1.12
1.30	$1.23E{-}03$ +/-5%	$1.49E{-}03$ +/-31%	0.83	1.34	0.78	0.93
2.88	$2.53E{-}04$ +/-6%	$2.24E{-}04$ +/-21%	1.13	1.18	1.17	1.12
6.89	$2.30E{-}04$ +/-6%	$2.20E{-}04$ +/-21%	1.05	1.09	1.08	1.04
12.88	$2.25E{-}04$ +/-6%	$2.14E{-}04$ +/-21%	1.05	1.10	1.08	1.04
23.89	$2.14E{-}04$ +/-6%	$2.05E{-}04$ +/-22%	1.04	1.09	1.08	1.04
49.72	$2.03E{-}04$ +/-6%	$1.88E{-}04$ +/-22%	1.08	1.13	1.11	1.07
99.91	$1.67E{-}04$ +/-7%	$1.64E{-}04$ +/-23%	1.02	1.07	1.05	1.01
200.13	$1.35E{-}04$ +/-7%	$1.31E{-}04$ +/-23%	1.03	1.08	1.06	1.02
402.95	$9.24E{-}05$ +/-11%	$8.51E{-}05$ +/-22%	1.09	1.14	1.12	1.08

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Mn56	Fe56(n,p)Mn56	2.5d	98.8	1.13	5%
Mn54	Fe54(n,p)Mn54	312d	99.9	1.09	11%


FNS-96 7 hours Irradiation - Fe
Heat Output [µW/kg]
Time after irradiation [years]
56Mn
54Mn
51Cr
55Fe
Hour
Day
1E-01
1E-02
1E-03
1E-04
1E-05
1E-06
1E-04
1E-03
1E-02
1E-01
1E+00
1E+01

SS304

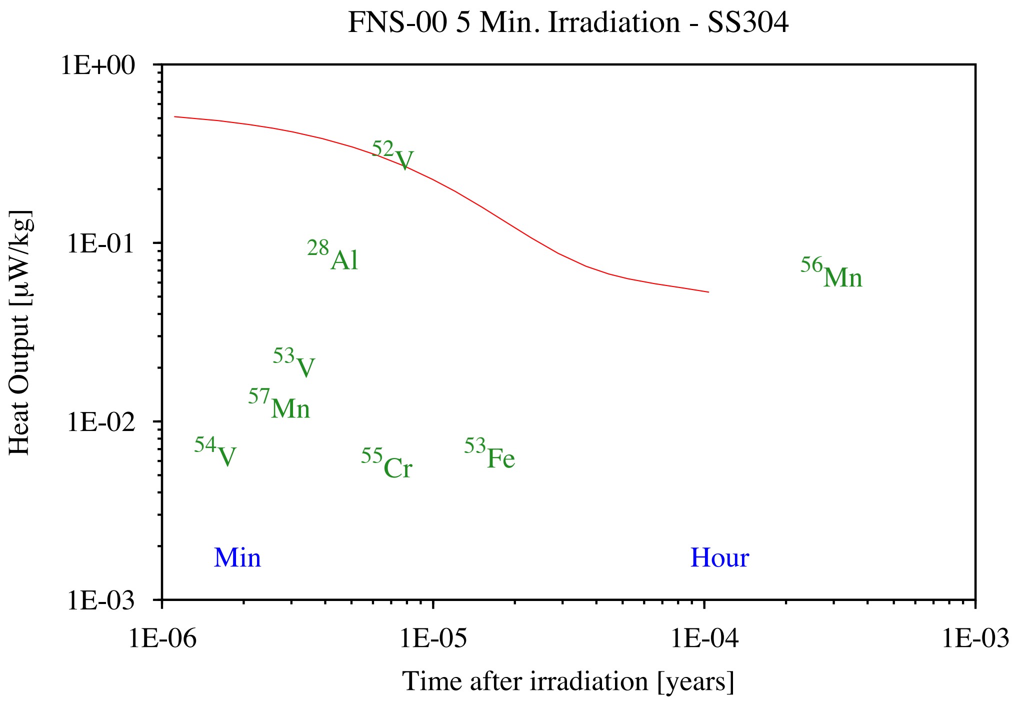


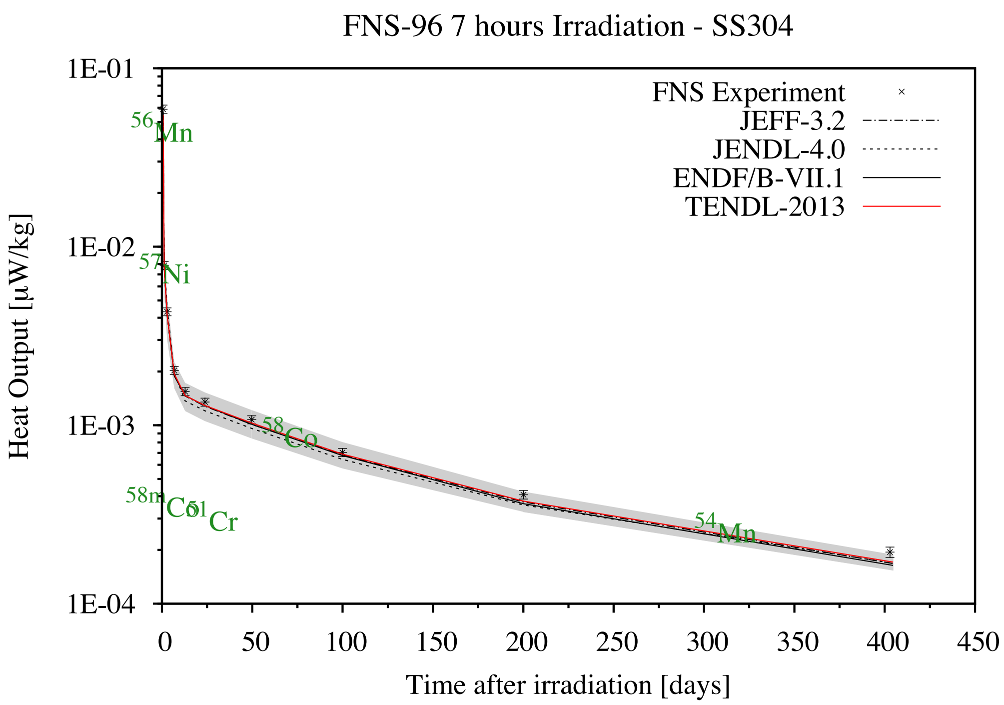


For SS-304, remarkable agreements between experiment and predictions exist for this steel for cooling times up to 1 hour.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	5.39E−01 +/-6%	5.10E−01 +/-17%	1.06	0.98	0.98	0.99
0.85	5.12E−01 +/-6%	4.84E−01 +/-17%	1.06	0.98	0.99	0.99
1.10	4.86E−01 +/-6%	4.61E−01 +/-17%	1.06	0.98	0.98	0.98
1.35	4.60E−01 +/-6%	4.39E−01 +/-17%	1.05	0.97	0.97	0.98
1.60	4.35E−01 +/-6%	4.19E−01 +/-17%	1.04	0.97	0.97	0.97
2.05	4.04E−01 +/-6%	3.85E−01 +/-17%	1.05	0.98	0.98	0.98
2.65	3.61E−01 +/-6%	3.45E−01 +/-17%	1.05	0.97	0.97	0.97
3.25	3.25E−01 +/-6%	3.11E−01 +/-17%	1.05	0.97	0.97	0.97
4.12	2.80E−01 +/-6%	2.69E−01 +/-17%	1.04	0.97	0.97	0.97
5.23	2.37E−01 +/-5%	2.27E−01 +/-17%	1.04	0.98	0.97	0.97
6.33	2.01E−01 +/-5%	1.95E−01 +/-17%	1.03	0.97	0.97	0.97
7.97	1.64E−01 +/-5%	1.59E−01 +/-18%	1.03	0.98	0.97	0.97
10.07	1.30E−01 +/-5%	1.27E−01 +/-19%	1.02	0.98	0.97	0.97
12.12	1.08E−01 +/-5%	1.07E−01 +/-20%	1.01	0.98	0.97	0.97
15.20	8.82E−02 +/-5%	8.74E−02 +/-22%	1.01	0.98	0.97	0.98
19.25	7.37E−02 +/-5%	7.41E−02 +/-25%	1.00	0.98	0.97	0.98
23.37	6.59E−02 +/-5%	6.70E−02 +/-27%	0.98	0.97	0.97	0.98
27.47	6.15E−02 +/-5%	6.31E−02 +/-28%	0.97	0.97	0.96	0.98
34.55	5.74E−02 +/-5%	5.91E−02 +/-29%	0.97	0.97	0.96	0.98
44.65	5.38E−02 +/-5%	5.57E−02 +/-30%	0.97	0.96	0.96	0.97
54.77	5.10E−02 +/-5%	5.30E−02 +/-30%	0.96	0.95	0.95	0.96

Product	**Pathways**	**$T_{1/2}$**	**Path %**	**E/C**	**ΔE%**
V52	Cr52(n,p)V52	3.7m	94.5	1.05	6%
	Cr53(n,d+np)V52		1.9	1.05	6%
	Mn55(n,α)V52		2.9	1.05	6%
Mn56	Fe56(n,p)Mn56	2.5h	99.3	0.96	5%

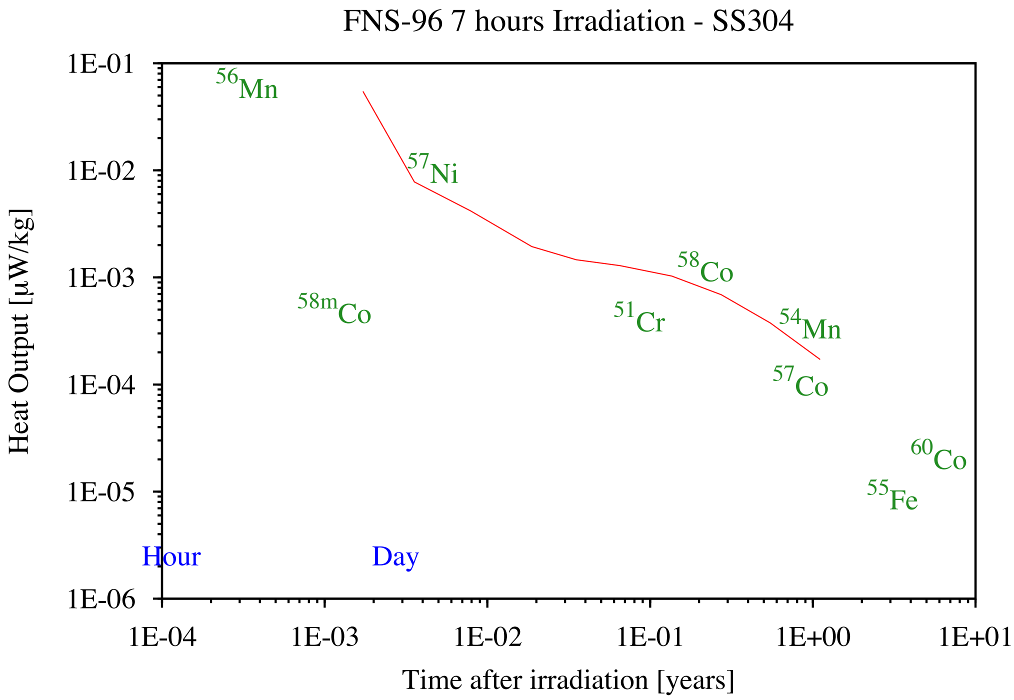




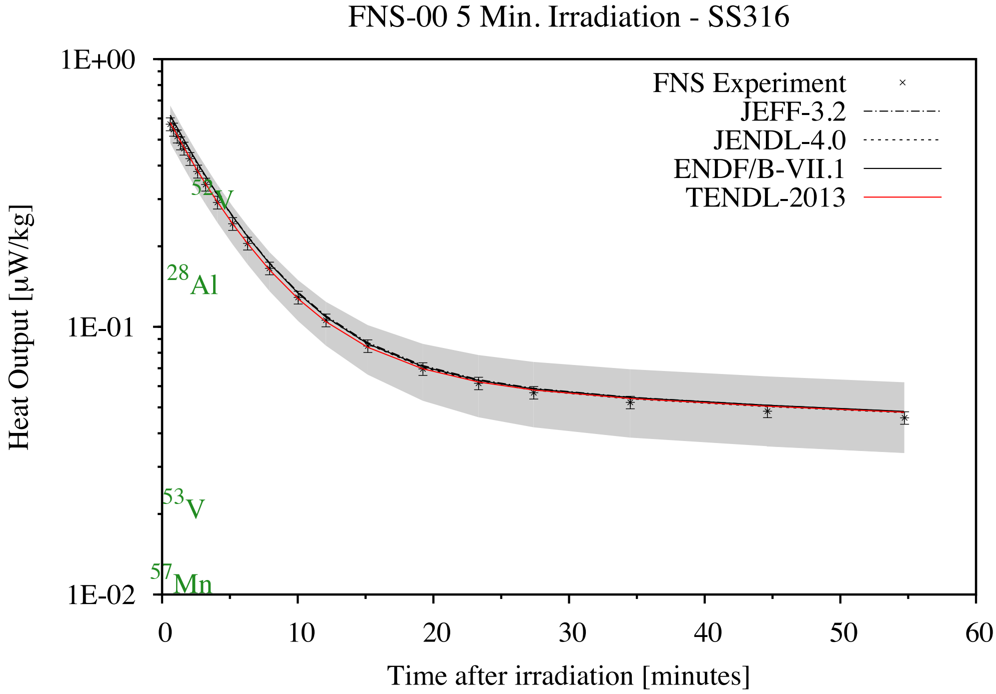
From the above graph one sees a very clean and well defined agreement.

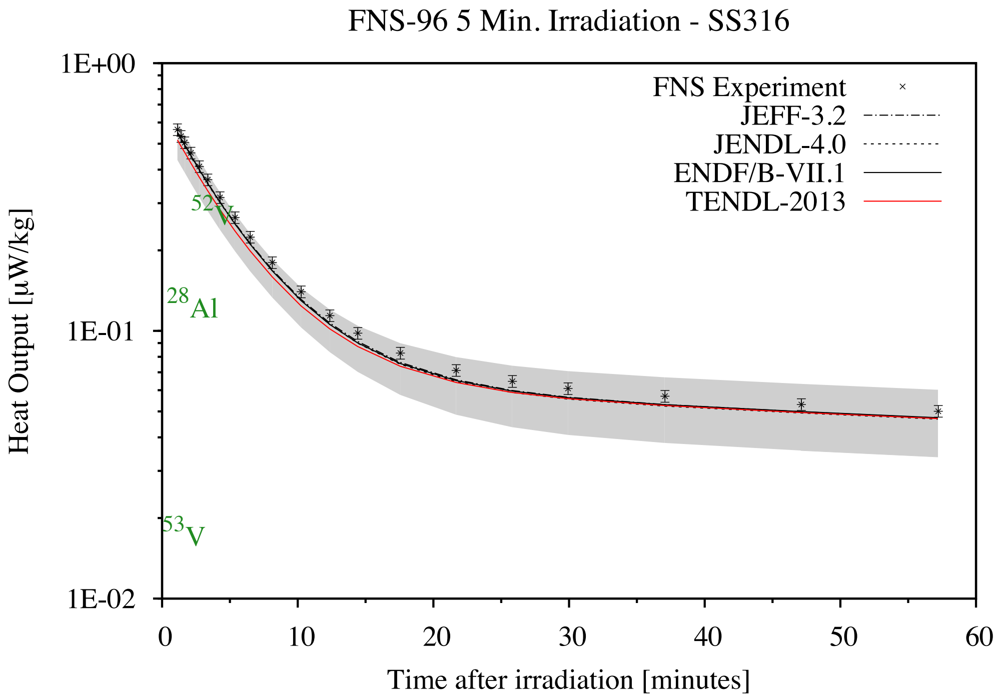
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.63	5.90E−02 +/-6%	5.47E−02 +/-31%	1.08	1.03	1.03	1.09
1.30	7.85E−03 +/-5%	7.78E−03 +/-30%	1.01	1.03	1.04	0.92
2.88	4.32E−03 +/-5%	4.18E−03 +/-27%	1.03	1.02	1.04	0.95
6.85	2.02E−03 +/-5%	1.94E−03 +/-17%	1.04	1.07	1.06	1.03
12.84	1.54E−03 +/-5%	1.46E−03 +/-18%	1.05	1.05	1.06	1.13
23.84	1.35E−03 +/-5%	1.29E−03 +/-18%	1.04	1.05	1.06	1.12
49.69	1.07E−03 +/-5%	1.03E−03 +/-18%	1.04	1.06	1.06	1.12
99.88	7.03E−04 +/-5%	6.89E−04 +/-17%	1.02	1.04	1.03	1.09
200.10	4.08E−04 +/-5%	3.76E−04 +/-13%	1.08	1.12	1.10	1.14
402.93	1.94E−04 +/-7%	1.71E−04 +/-10%	1.14	1.19	1.16	1.15

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ni57	Ni58(n,2n)Ni57	1.4d	100.0	1.01	5%
Co58	Ni58(n,p)Co58	70.8d	91.6	1.04	5%
	Ni58(n,p)Co58m		8.4	1.04	5%
Mn54	Mn55(n,2n)Mn54	312d	48.5	1.14	7%
	Fe54(n,p)Mn54		51.4	1.14	7%


FNS-96 7 hours Irradiation - SS304
Heat Output [µW/kg]
Time after irradiation [years]
1E-01
1E-02
1E-03
1E-04
1E-05
1E-06
1E-04
1E-03
1E-02
1E-01
1E+00
1E+01
56Mn
57Ni
58Co
58mCo
51Cr
54Mn
57Co
60Co
55Fe
Hour
Day

SS316

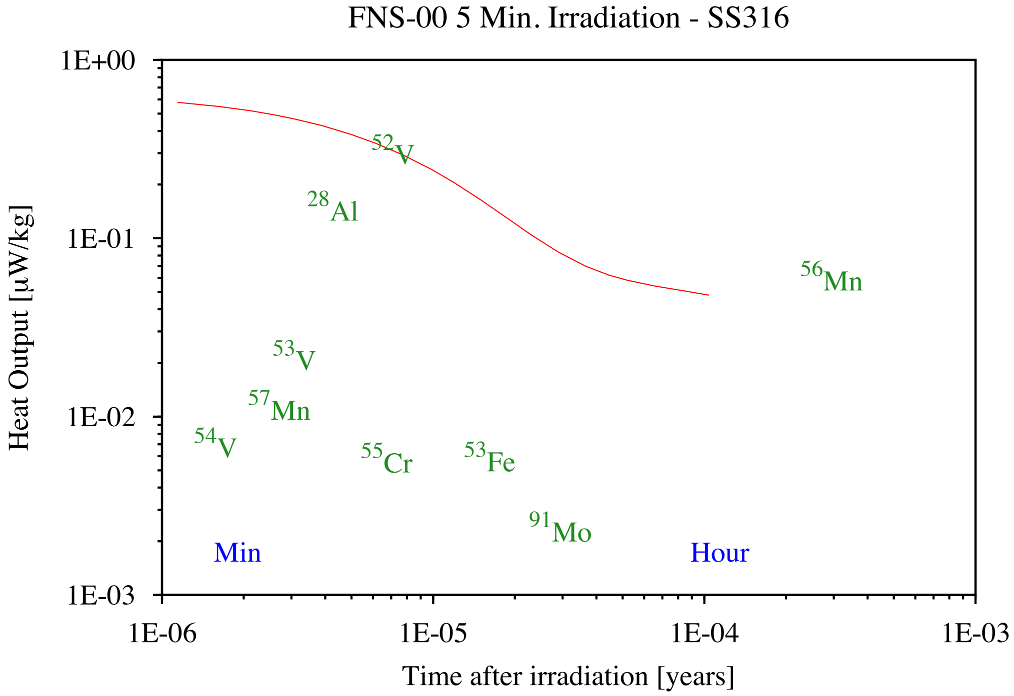


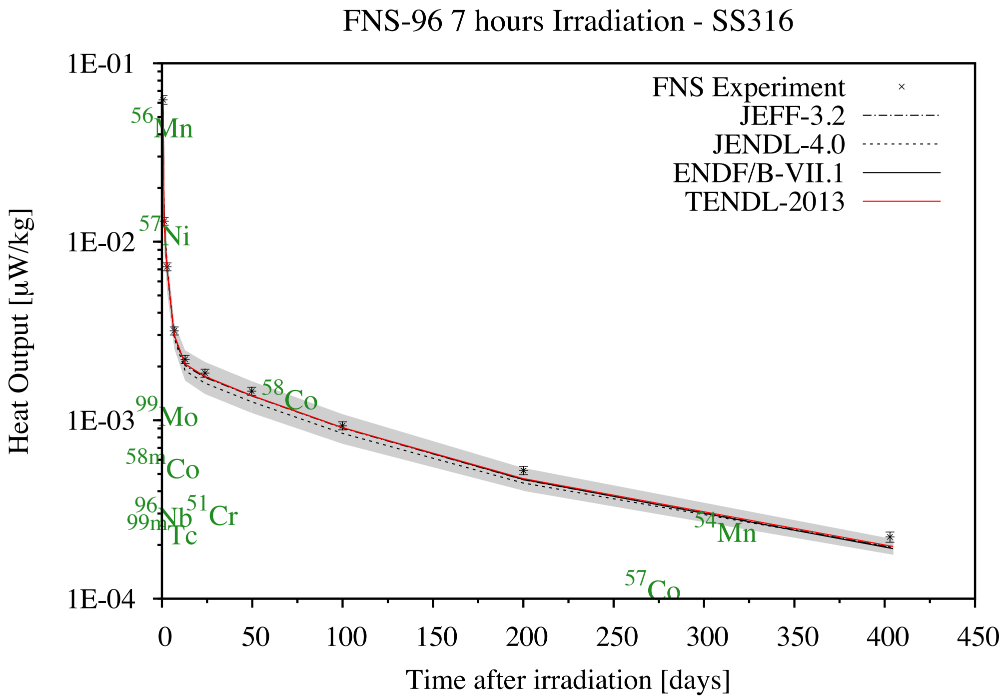


For SS-316, remarkable agreements between experiment and predictions exist for this type of stainless steel for cooling times up to 1 hour.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	5.72E−01 +/-6%	5.78E−01 +/-16%	0.99	0.93	0.93	0.94
0.85	5.46E−01 +/-6%	5.48E−01 +/-16%	1.00	0.93	0.93	0.95
1.12	5.15E−01 +/-6%	5.19E−01 +/-16%	0.99	0.93	0.93	0.94
1.37	4.85E−01 +/-6%	4.92E−01 +/-16%	0.99	0.92	0.92	0.94
1.62	4.64E−01 +/-6%	4.67E−01 +/-16%	0.99	0.93	0.93	0.94
2.05	4.24E−01 +/-6%	4.28E−01 +/-16%	0.99	0.93	0.93	0.94
2.62	3.80E−01 +/-6%	3.83E−01 +/-16%	0.99	0.93	0.93	0.94
3.22	3.40E−01 +/-6%	3.42E−01 +/-16%	1.00	0.93	0.93	0.94
4.08	2.91E−01 +/-6%	2.92E−01 +/-16%	1.00	0.93	0.93	0.94
5.20	2.43E−01 +/-5%	2.43E−01 +/-16%	1.00	0.94	0.93	0.94
6.30	2.05E−01 +/-5%	2.05E−01 +/-16%	1.00	0.94	0.94	0.94
7.92	1.65E−01 +/-5%	1.63E−01 +/-17%	1.01	0.96	0.95	0.96
10.03	1.29E−01 +/-5%	1.27E−01 +/-17%	1.01	0.96	0.96	0.96
12.08	1.06E−01 +/-5%	1.05E−01 +/-19%	1.01	0.97	0.96	0.97
15.17	8.48E−02 +/-5%	8.39E−02 +/-21%	1.01	0.98	0.97	0.98
19.23	6.96E−02 +/-5%	6.97E−02 +/-24%	1.00	0.98	0.97	0.99
23.33	6.15E−02 +/-5%	6.22E−02 +/-26%	0.99	0.98	0.97	0.99
27.40	5.68E−02 +/-5%	5.80E−02 +/-27%	0.98	0.97	0.96	0.98
34.52	5.22E−02 +/-5%	5.40E−02 +/-29%	0.97	0.96	0.96	0.97
44.63	4.84E−02 +/-5%	5.05E−02 +/-29%	0.96	0.95	0.95	0.96
54.73	4.57E−02 +/-5%	4.79E−02 +/-29%	0.95	0.95	0.95	0.96

Product	**Pathways**	**$T_{1/2}$**	**Path %**	**E/C**	**ΔE%**
V52	Cr52(n,p)V52	3.7m	94.5	0.99	6%
	Cr53(n,d)V52		1.9	0.99	6%
	Mn55(n,α)V52		2.9	0.99	6%
Mn56	Fe56(n,p)Mn56	2.5h	99.2	0.95	5%

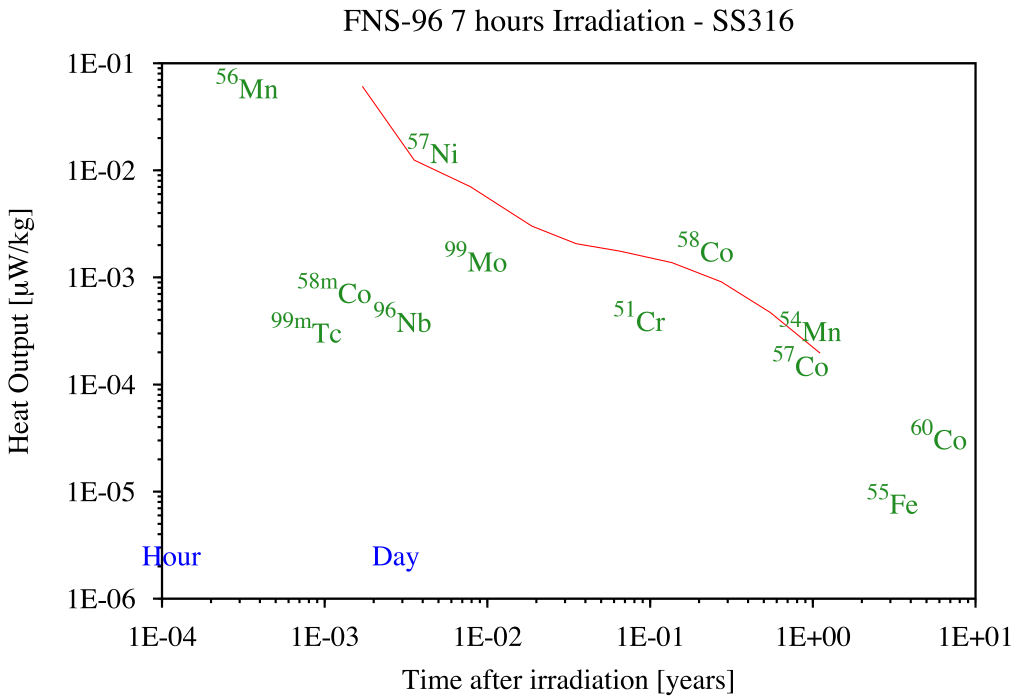




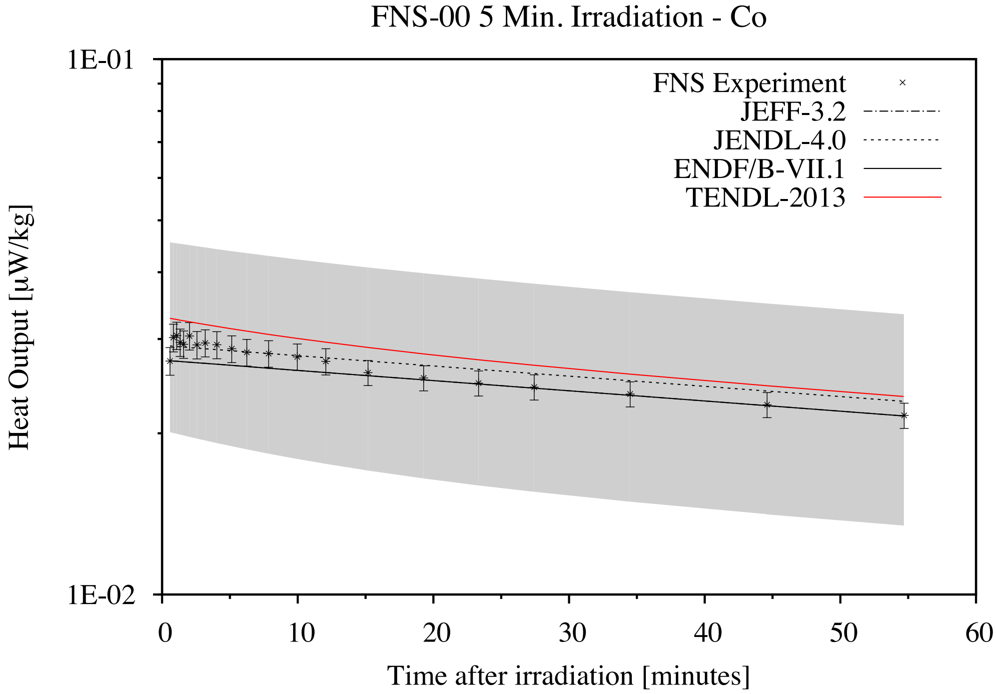
Although numerous radionuclides are present, a well characterised agreement exists, nearly within the uncertainties, up to an amazing 400 days cooling.

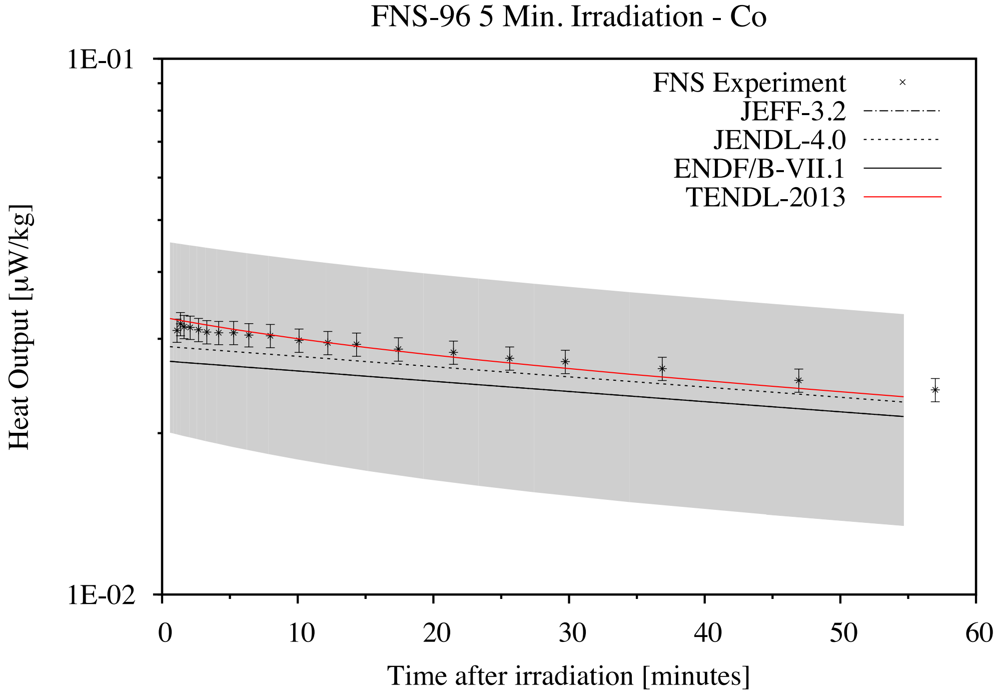
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.62	6.24$E-$02 +/-6%	6.09$E-$02 +/-28%	1.03	1.01	1.13	1.17
1.30	1.30$E-$02 +/-5%	1.25$E-$02 +/-28%	1.05	1.03	1.08	0.95
2.88	7.24$E-$03 +/-5%	7.01$E-$03 +/-25%	1.03	1.04	1.05	0.96
6.85	3.17$E-$03 +/-5%	3.02$E-$03 +/-17%	1.05	1.06	1.07	1.10
12.84	2.19$E-$03 +/-5%	2.06$E-$03 +/-19%	1.06	1.06	1.08	1.16
23.83	1.84$E-$03 +/-5%	1.76$E-$03 +/-20%	1.04	1.05	1.06	1.14
49.69	1.45$E-$03 +/-5%	1.38$E-$03 +/-20%	1.06	1.06	1.06	1.15
99.88	9.31$E-$04 +/-5%	9.10$E-$04 +/-19%	1.02	1.02	1.03	1.10
200.10	5.23$E-$04 +/-5%	4.71$E-$04 +/-15%	1.11	1.12	1.13	1.18
402.93	2.22$E-$04 +/-7%	1.96$E-$04 +/-10%	1.13	1.16	1.15	1.15

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ni57	Ni58(n,2n)Ni57	1.4d	100.0	1.05	5%
Co58	Ni58(n,p)Co58	70.8d	91.6	1.03	5%
	Ni58(n,p)Co58m		8.4	1.03	5%
Mn54	Mn55(n,2n)Mn54	312d	48.5	1.13	7%
	Fe54(n,p)Mn54		51.4	1.13	7%


FNS-96 7 hours Irradiation - SS316
Heat Output [µW/kg]
Time after irradiation [years]
1E-01
1E-02
1E-03
1E-04
1E-05
1E-06
1E-04
1E-03
1E-02
1E-01
1E+00
1E+01
56Mn
57Ni
99Mo
58Co
58mCo
96Nb
99mTc
51Cr
54Mn
57Co
60Co
55Fe
Hour
Day

Cobalt

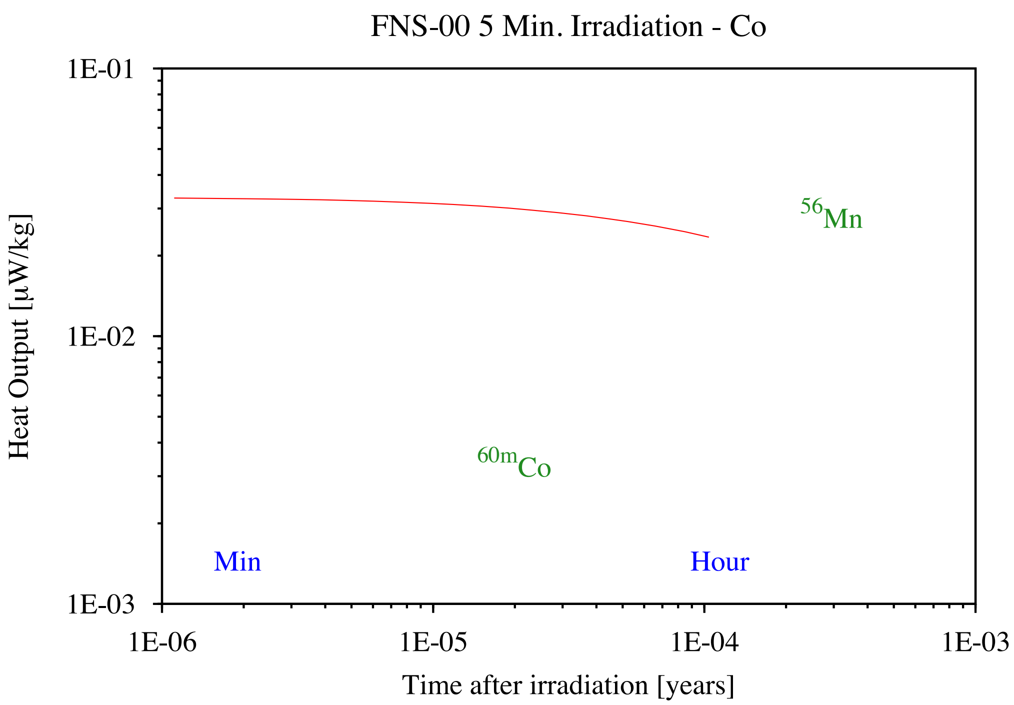


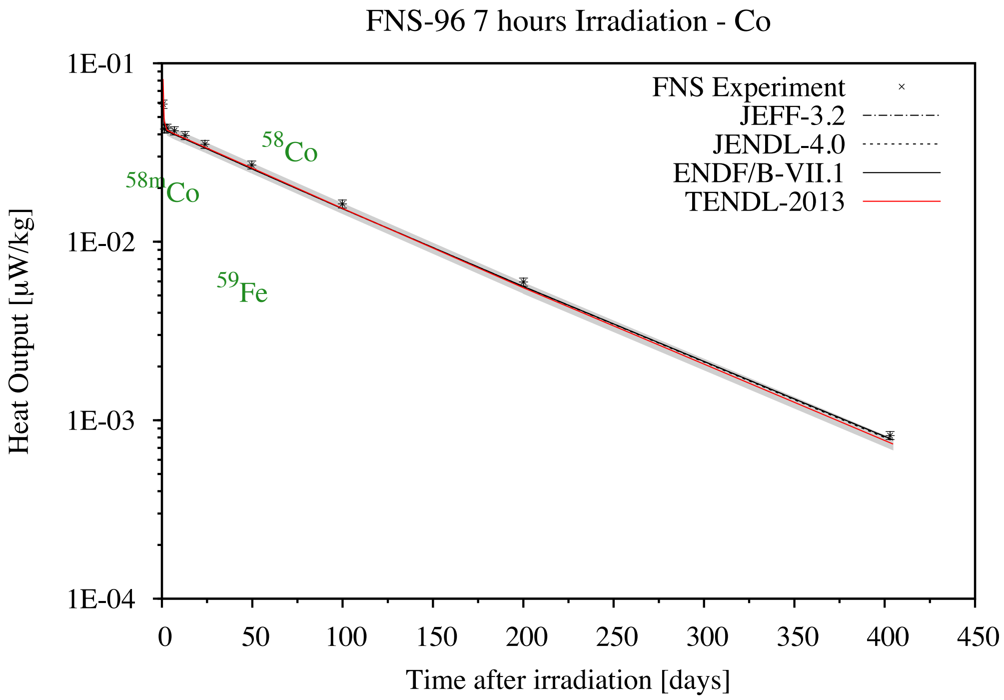


For Cobalt, the two batches of measured experimental data sets are different. The differences lie outside of the quoted experimental uncertainty. However, the code predictions stay, for both batches, within the large quoted calculational uncertainties. TENDL-2013 variance could be reduced to 20%, halved.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	2.73E−02 +/-6%	3.28E−02 +/-39%	0.83	1.00	1.00	0.94
0.83	3.02E−02 +/-6%	3.27E−02 +/-39%	0.92	1.11	1.11	1.04
1.08	3.05E−02 +/-6%	3.26E−02 +/-39%	0.93	1.12	1.12	1.05
1.33	2.96E−02 +/-6%	3.25E−02 +/-39%	0.91	1.09	1.09	1.02
1.58	2.93E−02 +/-6%	3.25E−02 +/-39%	0.90	1.08	1.08	1.01
2.02	3.04E−02 +/-6%	3.23E−02 +/-39%	0.94	1.12	1.12	1.05
2.57	2.93E−02 +/-6%	3.21E−02 +/-39%	0.91	1.08	1.08	1.01
3.18	2.95E−02 +/-6%	3.19E−02 +/-39%	0.92	1.09	1.09	1.03
4.03	2.93E−02 +/-6%	3.17E−02 +/-39%	0.92	1.09	1.09	1.02
5.13	2.88E−02 +/-6%	3.14E−02 +/-40%	0.92	1.07	1.07	1.01
6.25	2.83E−02 +/-6%	3.10E−02 +/-40%	0.91	1.06	1.06	1.00
7.85	2.82E−02 +/-6%	3.06E−02 +/-40%	0.92	1.06	1.06	1.00
9.97	2.78E−02 +/-6%	3.01E−02 +/-40%	0.92	1.06	1.06	0.99
12.07	2.72E−02 +/-6%	2.96E−02 +/-41%	0.92	1.05	1.05	0.98
15.18	2.60E−02 +/-5%	2.89E−02 +/-41%	0.90	1.01	1.01	0.95
19.28	2.54E−02 +/-5%	2.81E−02 +/-41%	0.90	1.01	1.01	0.95
23.33	2.48E−02 +/-5%	2.75E−02 +/-42%	0.90	1.00	1.00	0.94
27.43	2.44E−02 +/-5%	2.68E−02 +/-42%	0.91	1.00	1.00	0.94
34.50	2.37E−02 +/-5%	2.58E−02 +/-42%	0.92	1.01	1.01	0.94
44.60	2.26E−02 +/-5%	2.46E−02 +/-42%	0.92	1.00	1.00	0.94
54.70	2.16E−02 +/-5%	2.34E−02 +/-43%	0.92	1.00	1.00	0.94

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Mn56	Co59(n,α)Mn56	2.5h	100.0	0.92	5%

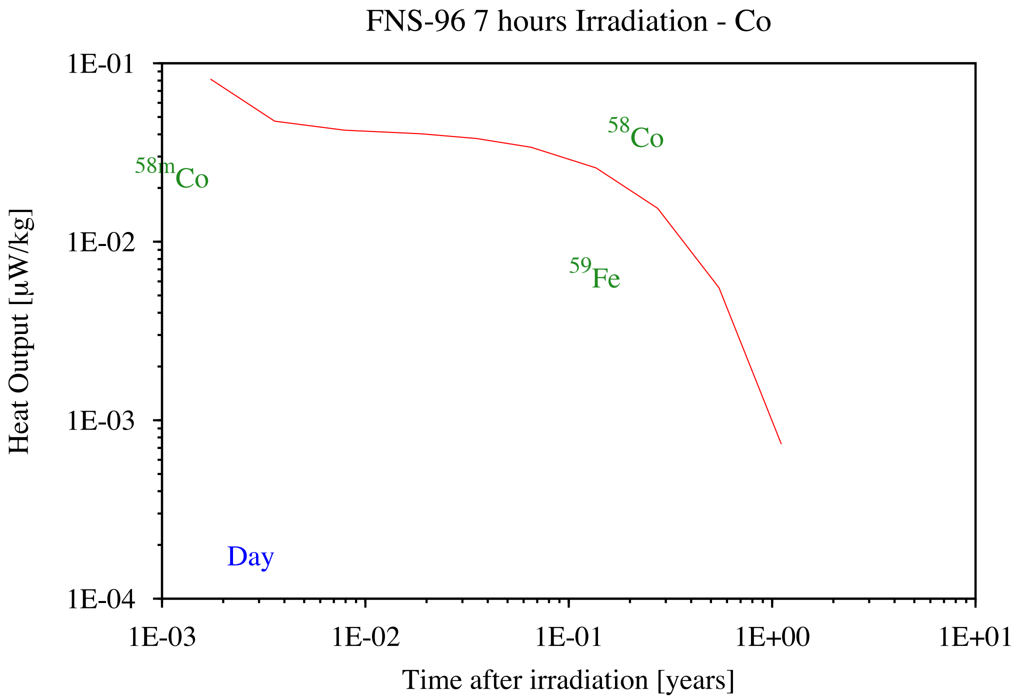




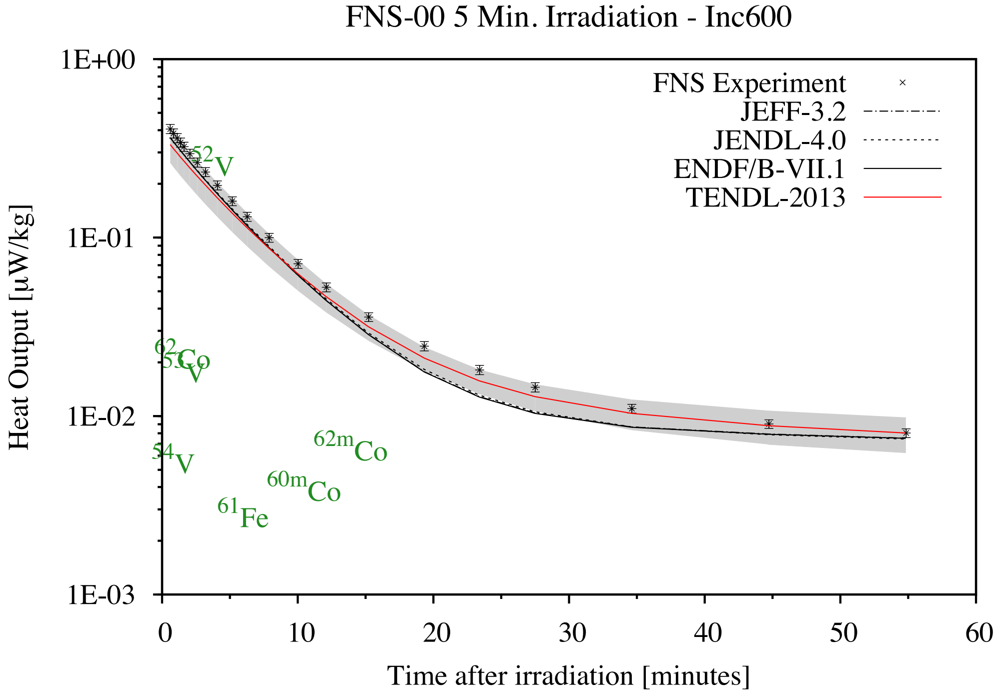
Good agreement, within the experimental uncertainty bands.

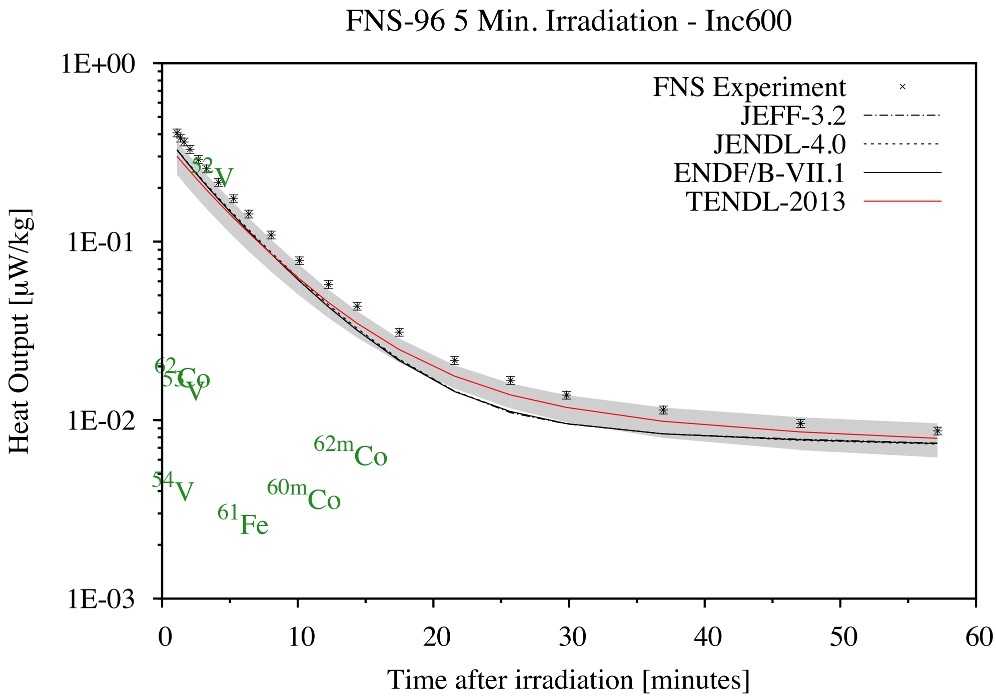
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.63	5.90E−02 +/-5%	8.16E−02 +/-13%	0.72	0.97	0.97	0.95
1.31	4.28E−02 +/-5%	4.74E−02 +/-6%	0.90	1.00	1.00	1.00
2.89	4.33E−02 +/-5%	4.22E−02 +/-7%	1.03	1.04	1.04	1.04
6.86	4.19E−02 +/-5%	4.03E−02 +/-7%	1.04	1.05	1.05	1.05
12.85	3.94E−02 +/-5%	3.79E−02 +/-7%	1.04	1.05	1.05	1.05
23.84	3.52E−02 +/-5%	3.39E−02 +/-7%	1.04	1.05	1.05	1.05
49.70	2.69E−02 +/-5%	2.59E−02 +/-7%	1.04	1.05	1.05	1.05
99.89	1.63E−02 +/-5%	1.54E−02 +/-7%	1.06	1.06	1.06	1.06
200.11	5.95E−03 +/-5%	5.53E−03 +/-7%	1.08	1.06	1.06	1.06
402.95	8.21E−04 +/-5%	7.35E−04 +/-7%	1.12	1.06	1.06	1.07

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Co58m	Co59(n,2n)Co58m	8.9h	99.7	0.72	5%
Co58	Co59(n,2n)Co58	70.8d	86.2	1.06	5%
	Co59(n,2n)Co58m	8.9h	13.8	1.06	5%


FNS-96 7 hours Irradiation - Co
Heat Output [µW/kg]
1E-01
1E-02
1E-03
1E-04
1E-03
1E-02
1E-01
1E+00
1E+01
Time after irradiation [years]
58mCo
58Co
59Fe
Day

Inconel-600

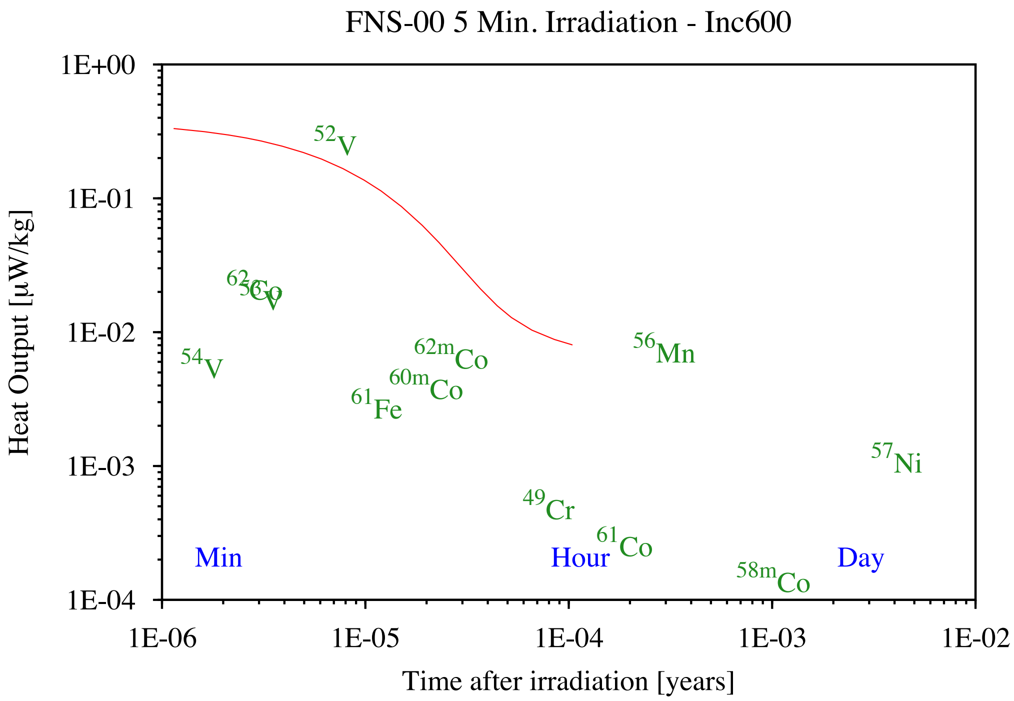


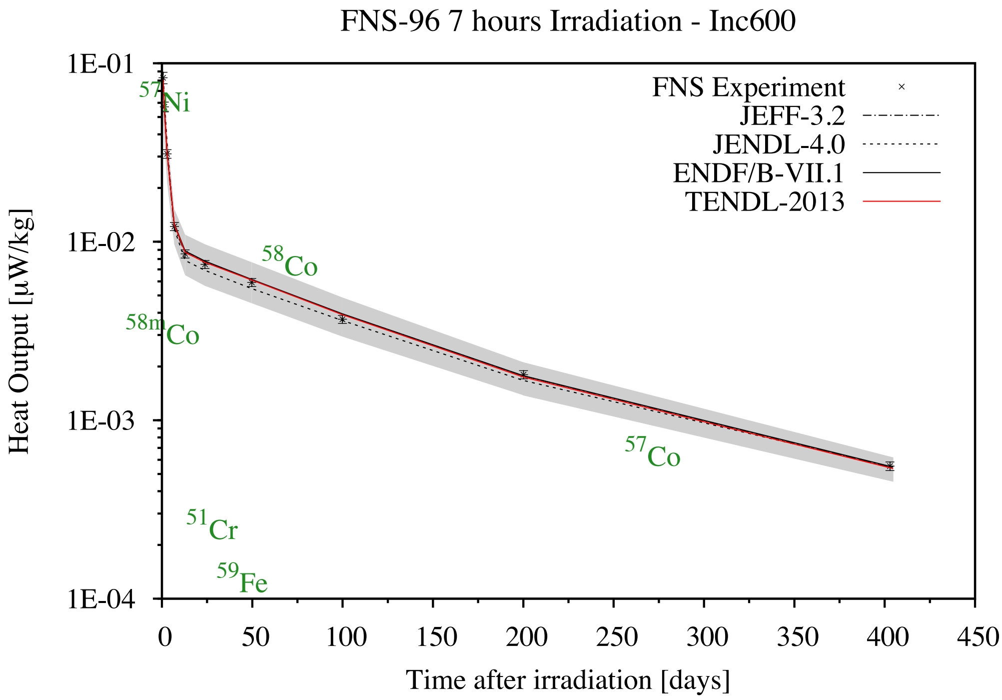


For Inconel, an interesting parallel can be drawn there when V-52 is dominant up to 30 minutes cooling time. It is produced through multiple channels from Cr-52, Cr-53 and Mn-55 and here seems to be under predicted by around 20% in TENDL-2013. This trend is corroborated in the pathways arising from Cr isotopes, although in the pure Cr graphs the under-prediction is less significant.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	4.06E−01 +/-6%	3.32E−01 +/-21%	1.22	1.12	1.12	1.12
0.85	3.84E−01 +/-6%	3.15E−01 +/-21%	1.22	1.12	1.12	1.12
1.12	3.61E−01 +/-6%	2.97E−01 +/-21%	1.22	1.12	1.11	1.11
1.37	3.41E−01 +/-6%	2.82E−01 +/-22%	1.21	1.11	1.11	1.11
1.62	3.23E−01 +/-6%	2.68E−01 +/-22%	1.21	1.11	1.11	1.11
2.05	2.95E−01 +/-6%	2.45E−01 +/-22%	1.20	1.12	1.12	1.11
2.60	2.64E−01 +/-6%	2.20E−01 +/-22%	1.20	1.12	1.12	1.11
3.20	2.33E−01 +/-6%	1.96E−01 +/-22%	1.19	1.12	1.12	1.10
4.08	1.96E−01 +/-6%	1.67E−01 +/-22%	1.18	1.12	1.12	1.10
5.18	1.60E−01 +/-6%	1.37E−01 +/-22%	1.17	1.12	1.12	1.11
6.28	1.31E−01 +/-6%	1.13E−01 +/-21%	1.16	1.12	1.12	1.11
7.90	9.98E−02 +/-6%	8.68E−02 +/-21%	1.15	1.14	1.14	1.12
10.02	7.14E−02 +/-6%	6.27E−02 +/-20%	1.14	1.16	1.16	1.14
12.12	5.27E−02 +/-6%	4.66E−02 +/-18%	1.13	1.19	1.19	1.16
15.23	3.59E−02 +/-6%	3.16E−02 +/-17%	1.13	1.26	1.25	1.23
19.33	2.47E−02 +/-6%	2.11E−02 +/-15%	1.17	1.40	1.39	1.35
23.40	1.81E−02 +/-6%	1.57E−02 +/-16%	1.15	1.42	1.41	1.39
27.50	1.45E−02 +/-6%	1.28E−02 +/-17%	1.13	1.40	1.39	1.37
34.63	1.10E−02 +/-6%	1.04E−02 +/-20%	1.06	1.27	1.27	1.27
44.73	9.03E−03 +/-6%	8.82E−03 +/-21%	1.02	1.14	1.14	1.15
54.85	8.03E−03 +/-6%	8.03E−03 +/-22%	1.00	1.07	1.07	1.08

Product	**Pathways**	**$T_{1/2}$**	**Path %**	**E/C**	**ΔE%**
V52	Cr52(n,p)V52	3.7m	97.1	1.19	6%
	Cr53(n,d+np)V52		1.9	1.19	6%
	Mn55(n,α)V52		0.9	1.19	6%
Mn56	Fe56(n,p)Mn56	2.5h	98.9	1.00	6%

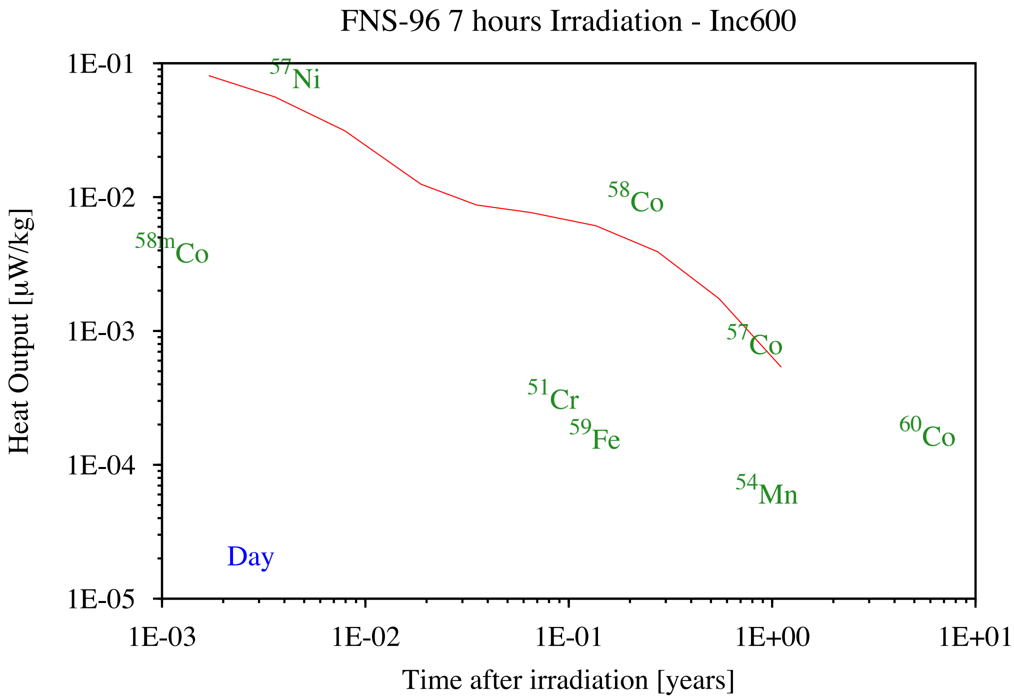




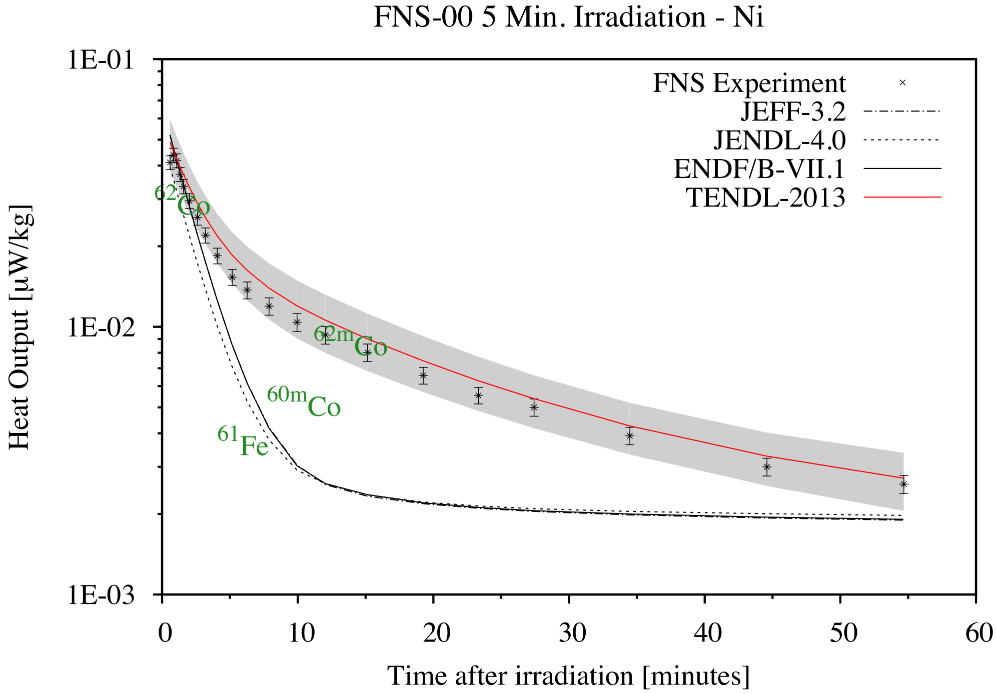
For this Inconel 600 alloy, one sees clean agreements between measurement and simulations.

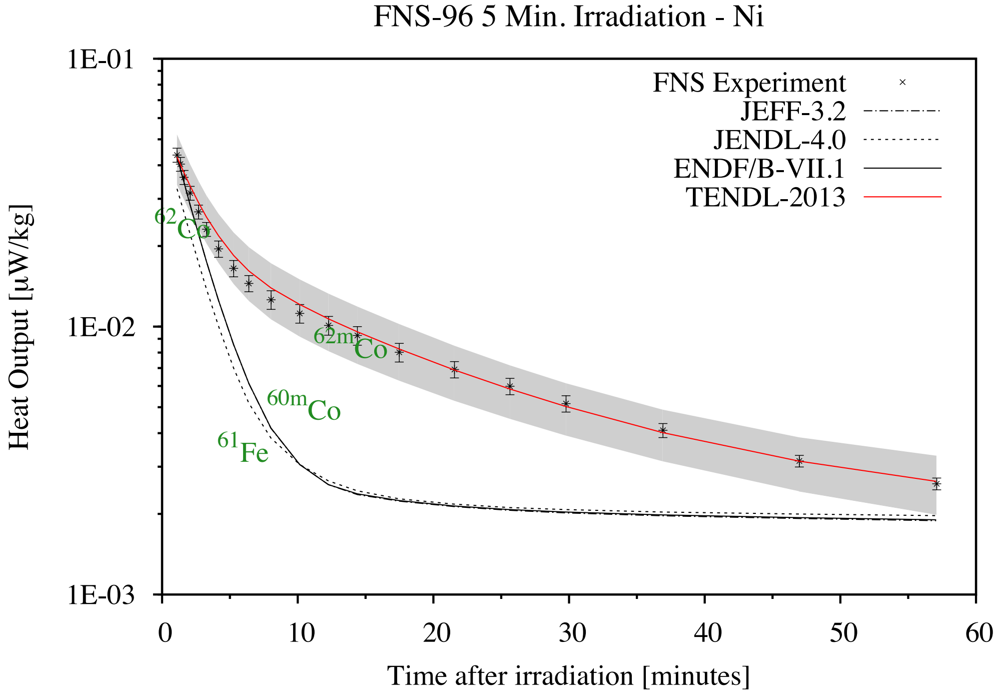
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.62	8.29E−02 +/-7%	8.08E−02 +/-34%	1.03	1.05	1.06	0.93
1.31	5.70E−02 +/-6%	5.60E−02 +/-35%	1.02	1.02	1.03	0.90
2.89	3.11E−02 +/-6%	3.13E−02 +/-31%	0.99	0.98	0.99	0.88
6.86	1.22E−02 +/-5%	1.25E−02 +/-22%	0.98	0.96	1.02	1.03
12.86	8.55E−03 +/-5%	8.72E−03 +/-26%	0.98	0.96	0.98	1.09
23.84	7.47E−03 +/-5%	7.67E−03 +/-26%	0.97	0.96	0.97	1.08
49.69	5.92E−03 +/-5%	6.10E−03 +/-26%	0.97	0.96	0.97	1.08
99.88	3.68E−03 +/-5%	3.91E−03 +/-25%	0.94	0.93	0.93	1.02
200.11	1.80E−03 +/-5%	1.75E−03 +/-21%	1.03	1.01	1.02	1.08
402.94	5.53E−04 +/-6%	5.36E−04 +/-15%	1.03	1.01	1.02	1.01

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ni57	Ni58(n,2n)Ni57	1.4d	100.0	1.02	6%
Co58	Ni58(n,p)Co58	70.8d	91.6	0.94	5%
	Ni58(n,p)Co58m		8.4	0.94	5%
Co57	Ni58(n,d+np)Co57	271d	99.6	1.03	5%


FNS-96 7 hours Irradiation - Inc600
Heat Output [µW/kg]
1E-01
1E-02
1E-03
1E-04
1E-05
1E-03
1E-02
1E-01
1E+00
1E+01
Time after irradiation [years]
57Ni
58Co
58mCo
57Co
51Cr
59Fe
60Co
54Mn
Day

Nickel

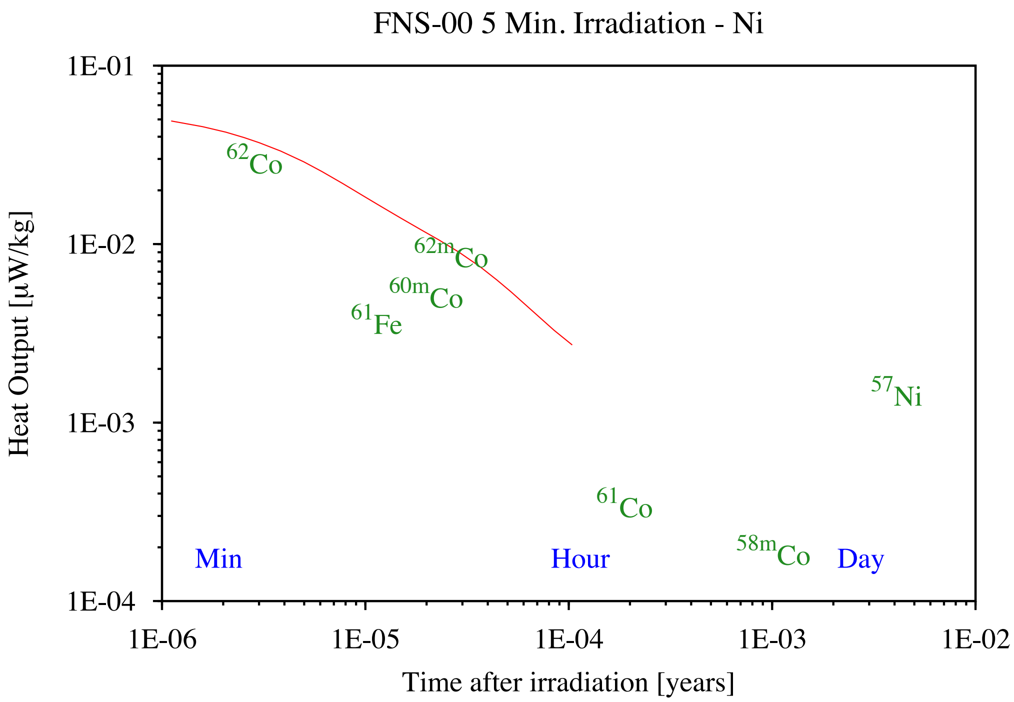


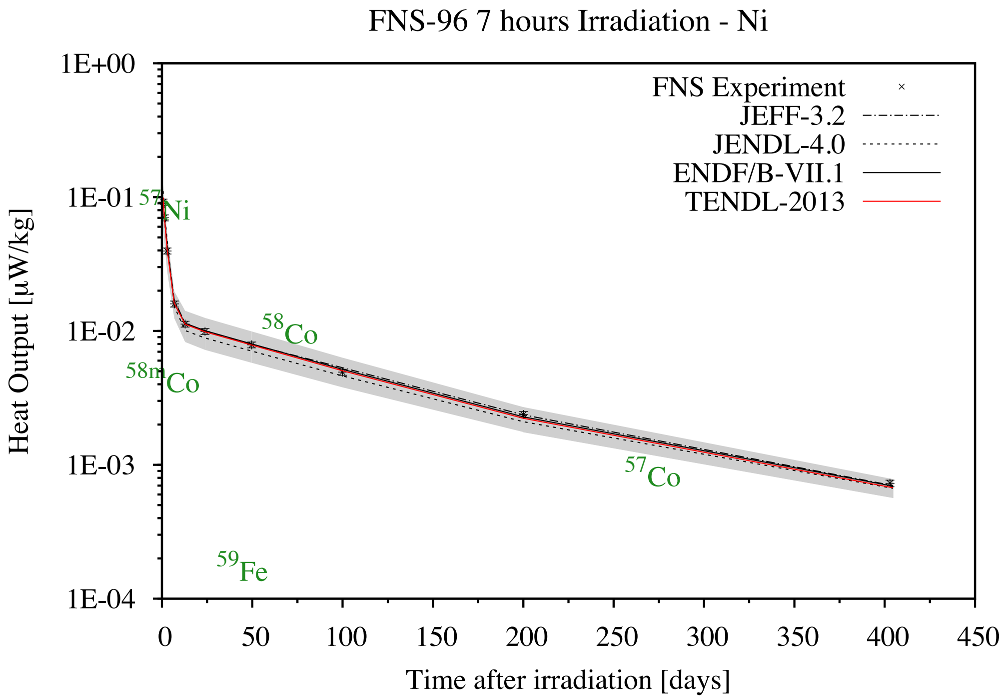


For Nickel, the two sets of experimental measurements differ. However, the code predictions stay within 10% of the measurements at all cooling times for TENDL-2013. All the others libraries lack isomer production pathways.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	4.11E−02 +/-6%	4.90E−02 +/-22%	0.84	0.79	0.79	1.04
0.83	4.38E−02 +/-6%	4.55E−02 +/-22%	0.96	0.94	0.94	1.23
1.08	4.18E−02 +/-6%	4.24E−02 +/-21%	0.99	1.00	1.00	1.30
1.33	3.71E−02 +/-6%	3.95E−02 +/-21%	0.94	0.99	0.99	1.29
1.58	3.35E−02 +/-6%	3.70E−02 +/-21%	0.90	0.99	0.99	1.29
2.02	2.95E−02 +/-6%	3.32E−02 +/-20%	0.89	1.05	1.05	1.35
2.62	2.56E−02 +/-6%	2.89E−02 +/-20%	0.89	1.17	1.17	1.49
3.22	2.20E−02 +/-7%	2.55E−02 +/-20%	0.86	1.27	1.27	1.60
4.07	1.84E−02 +/-7%	2.19E−02 +/-21%	0.84	1.46	1.46	1.82
5.17	1.53E−02 +/-7%	1.86E−02 +/-22%	0.83	1.79	1.79	2.16
6.27	1.37E−02 +/-7%	1.63E−02 +/-23%	0.84	2.22	2.22	2.60
7.88	1.19E−02 +/-7%	1.39E−02 +/-24%	0.86	2.85	2.84	3.15
9.95	1.04E−02 +/-8%	1.20E−02 +/-24%	0.87	3.44	3.42	3.57
12.05	9.32E−03 +/-8%	1.06E−02 +/-24%	0.88	3.59	3.62	3.59
15.15	8.02E−03 +/-7%	9.02E−03 +/-24%	0.89	3.40	3.44	3.40
19.25	6.58E−03 +/-7%	7.47E−03 +/-24%	0.88	2.99	3.01	2.97
23.32	5.54E−03 +/-7%	6.29E−03 +/-23%	0.88	2.62	2.64	2.59
27.42	5.00E−03 +/-7%	5.39E−03 +/-22%	0.93	2.43	2.45	2.39
34.48	3.92E−03 +/-8%	4.27E−03 +/-22%	0.92	1.96	1.97	1.92
44.58	3.00E−03 +/-8%	3.29E−03 +/-23%	0.91	1.54	1.55	1.50
54.68	2.58E−03 +/-8%	2.72E−03 +/-24%	0.95	1.35	1.36	1.31

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Co62	Ni62(n,p)Co62	1.5m	99.8	0.90	6%
Co62m	Ni62(n,p)Co62m	13.9m	100.0	0.89	7%

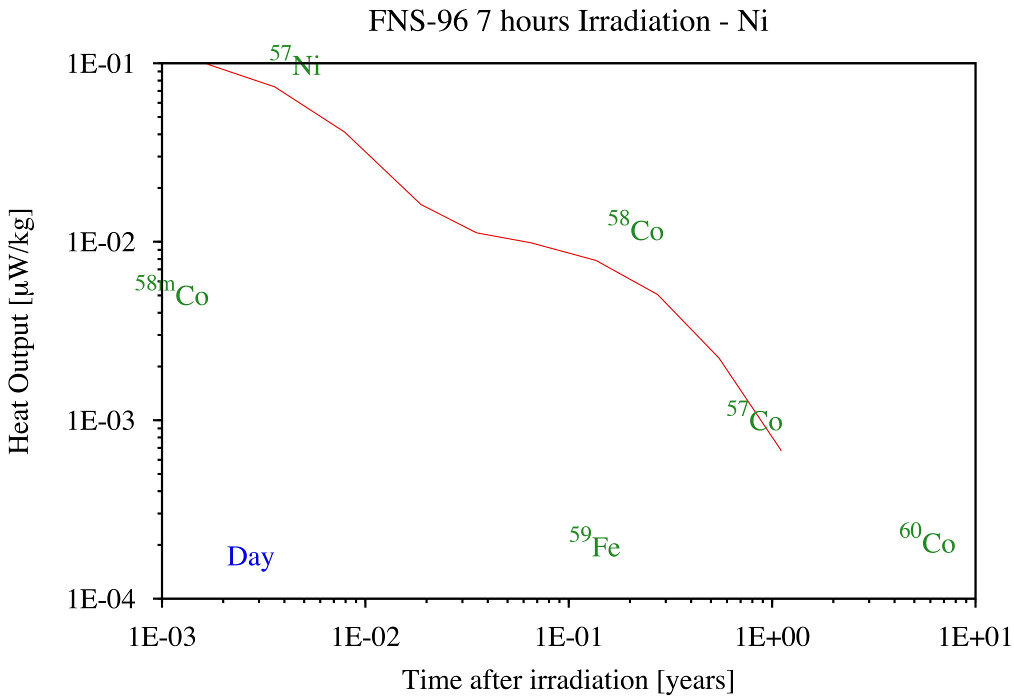




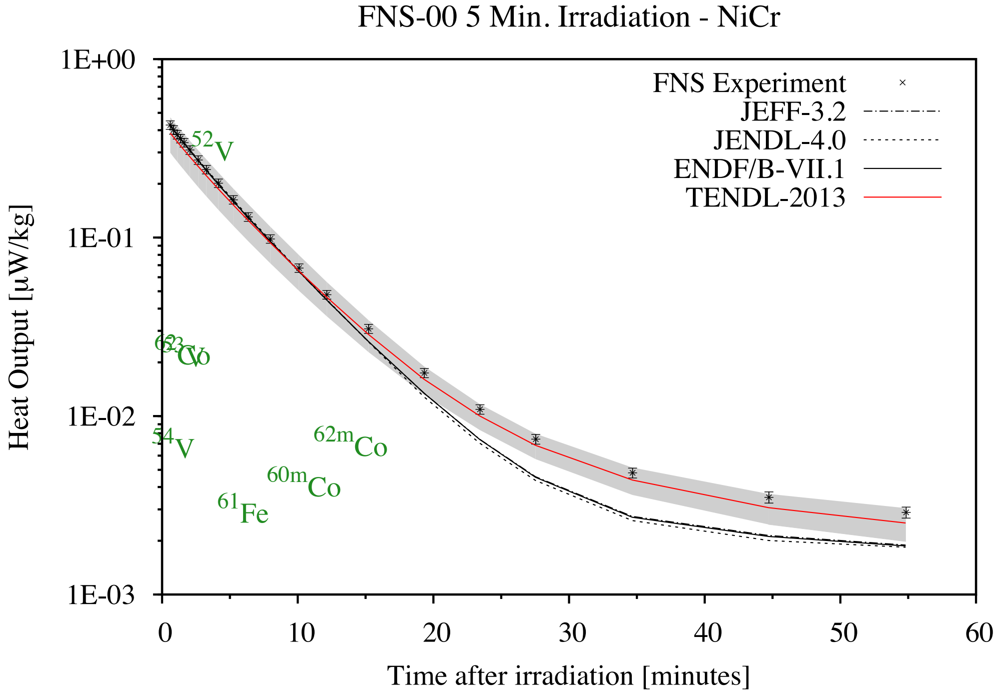
An excellent agreement exists with all databases.

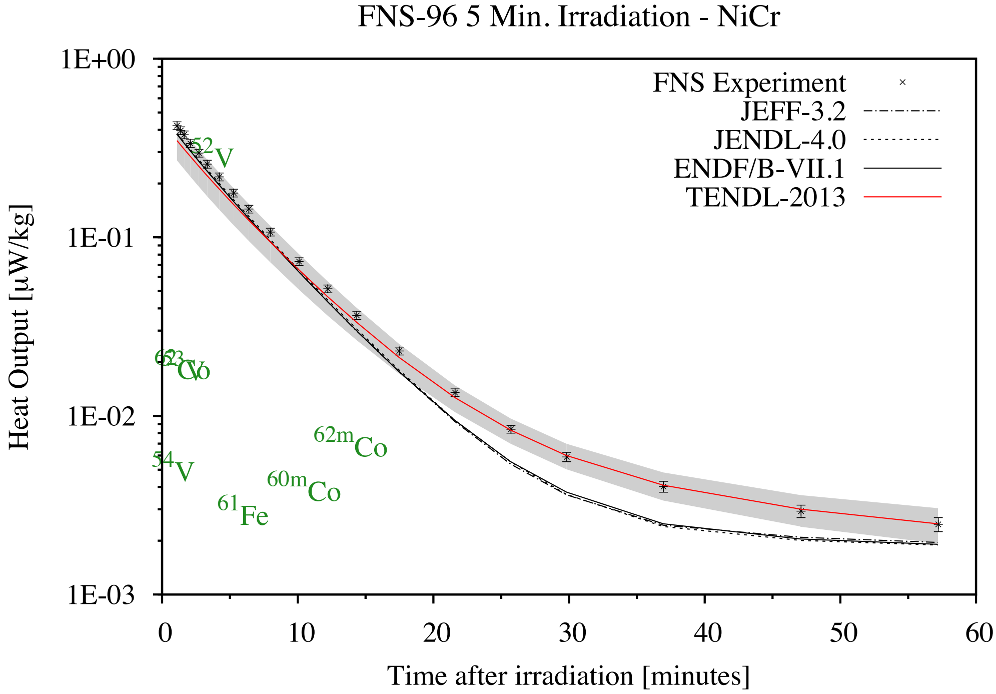
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	9.17E−02 +/-5%	9.96E−02 +/-36%	0.92	0.95	0.95	0.83
1.31	7.01E−02 +/-5%	7.37E−02 +/-36%	0.95	0.96	0.97	0.85
2.89	3.96E−02 +/-5%	4.11E−02 +/-31%	0.96	0.90	0.91	0.83
6.86	1.59E−02 +/-5%	1.61E−02 +/-23%	0.99	1.00	0.93	1.04
12.85	1.13E−02 +/-5%	1.12E−02 +/-26%	1.00	0.99	0.99	1.12
23.85	9.92E−03 +/-5%	9.86E−03 +/-27%	1.01	0.99	1.00	1.12
49.70	7.87E−03 +/-5%	7.86E−03 +/-26%	1.00	0.98	0.99	1.11
99.89	4.92E−03 +/-5%	5.05E−03 +/-25%	0.97	0.95	0.92	1.07
200.11	2.37E−03 +/-5%	2.23E−03 +/-21%	1.06	1.04	1.00	1.13
402.94	7.27E−04 +/-6%	6.74E−04 +/-16%	1.08	1.05	1.04	1.09

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ni57	Ni58(n,2n)Ni57	1.4d	100.0	0.92	5%
Co58	Ni58(n,p)Co58	70.8d	91.6	0.97	5%
	Ni58(n,p)Co58m	8.9h	8.4	0.97	5%
Co57	Ni58(n,d+np)Co57	271d	99.6	1.08	5%


FNS-96 7 hours Irradiation - Ni
Heat Output [µW/kg]
Time after irradiation [years]
1E-01
1E-02
1E-03
1E-04
1E-03
1E-02
1E-01
1E+00
1E+01
57Ni
58Co
58mCo
57Co
59Fe
60Co
Day

Nickel-chrome

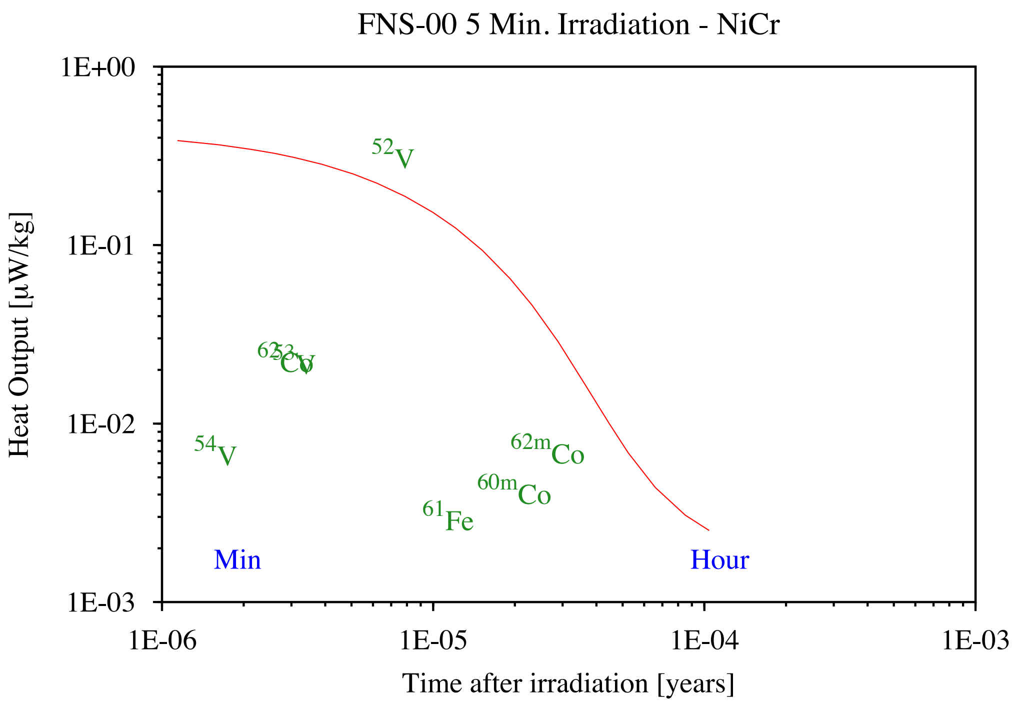


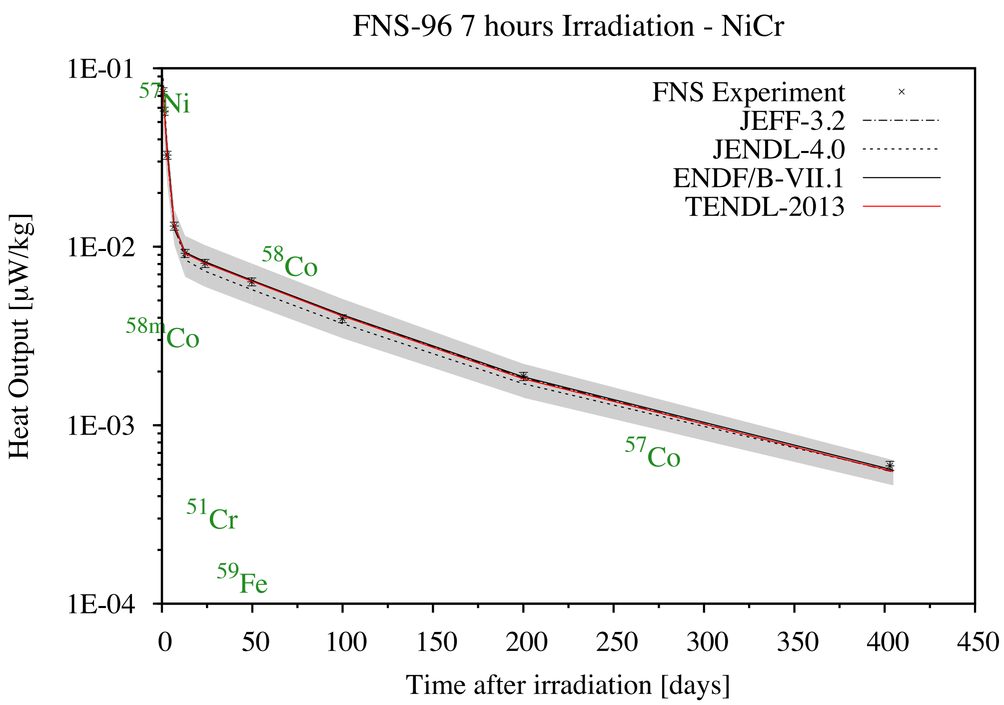


For Ni-Cr, the first 15 minutes of cooling time are dominated by the Cr isotope produced V-52 and the trend is the same (slight under-prediction) as seen in the Cr alloys. Here again the lack of isomeric states production pathways lead the other libraries to under-predict.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	$4.27E{-}01$ +/-5%	$3.85E{-}01$ +/-22%	1.11	1.01	1.01	1.01
0.85	$4.01E{-}01$ +/-5%	$3.65E{-}01$ +/-23%	1.10	1.00	1.00	1.00
1.12	$3.77E{-}01$ +/-5%	$3.44E{-}01$ +/-23%	1.10	1.00	1.00	1.00
1.37	$3.59E{-}01$ +/-5%	$3.27E{-}01$ +/-23%	1.10	1.01	1.01	1.00
1.62	$3.40E{-}01$ +/-5%	$3.10E{-}01$ +/-23%	1.10	1.01	1.01	1.00
2.05	$3.10E{-}01$ +/-5%	$2.83E{-}01$ +/-23%	1.09	1.01	1.01	1.00
2.67	$2.72E{-}01$ +/-5%	$2.50E{-}01$ +/-23%	1.09	1.01	1.01	1.00
3.27	$2.40E{-}01$ +/-5%	$2.22E{-}01$ +/-23%	1.08	1.01	1.01	1.00
4.15	$2.02E{-}01$ +/-5%	$1.87E{-}01$ +/-24%	1.08	1.01	1.02	1.00
5.25	$1.63E{-}01$ +/-5%	$1.53E{-}01$ +/-24%	1.07	1.02	1.02	1.00
6.35	$1.31E{-}01$ +/-5%	$1.25E{-}01$ +/-23%	1.05	1.01	1.01	0.99
7.98	$9.83E{-}02$ +/-5%	$9.34E{-}02$ +/-23%	1.05	1.03	1.03	1.02
10.10	$6.75E{-}02$ +/-5%	$6.50E{-}02$ +/-23%	1.04	1.05	1.05	1.04
12.15	$4.78E{-}02$ +/-5%	$4.62E{-}02$ +/-22%	1.03	1.07	1.08	1.06
15.22	$3.08E{-}02$ +/-6%	$2.87E{-}02$ +/-20%	1.08	1.18	1.18	1.19
19.33	$1.74E{-}02$ +/-6%	$1.60E{-}02$ +/-18%	1.09	1.30	1.30	1.36
23.43	$1.09E{-}02$ +/-6%	$1.00E{-}02$ +/-17%	1.09	1.48	1.47	1.55
27.55	$7.42E{-}03$ +/-6%	$6.85E{-}03$ +/-16%	1.08	1.63	1.62	1.70
34.68	$4.80E{-}03$ +/-6%	$4.38E{-}03$ +/-17%	1.10	1.77	1.75	1.85
44.73	$3.50E{-}03$ +/-7%	$3.07E{-}03$ +/-19%	1.14	1.66	1.64	1.75
54.85	$2.88E{-}03$ +/-7%	$2.52E{-}03$ +/-21%	1.15	1.54	1.52	1.57

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
V52	Cr52(n,p)V52	3.7m	98.1	1.08	5%
	Cr53(n,d+np)V52		1.9	1.08	5%
Co60m	Ni60(n,p)Co60m	10.4m	98.9	1.04	5%
	Ni61(n,d)Co60m		1.1	1.04	5%
Co62m	Ni62(n,p)Co62m	13.9m	100.0	1.08	6%

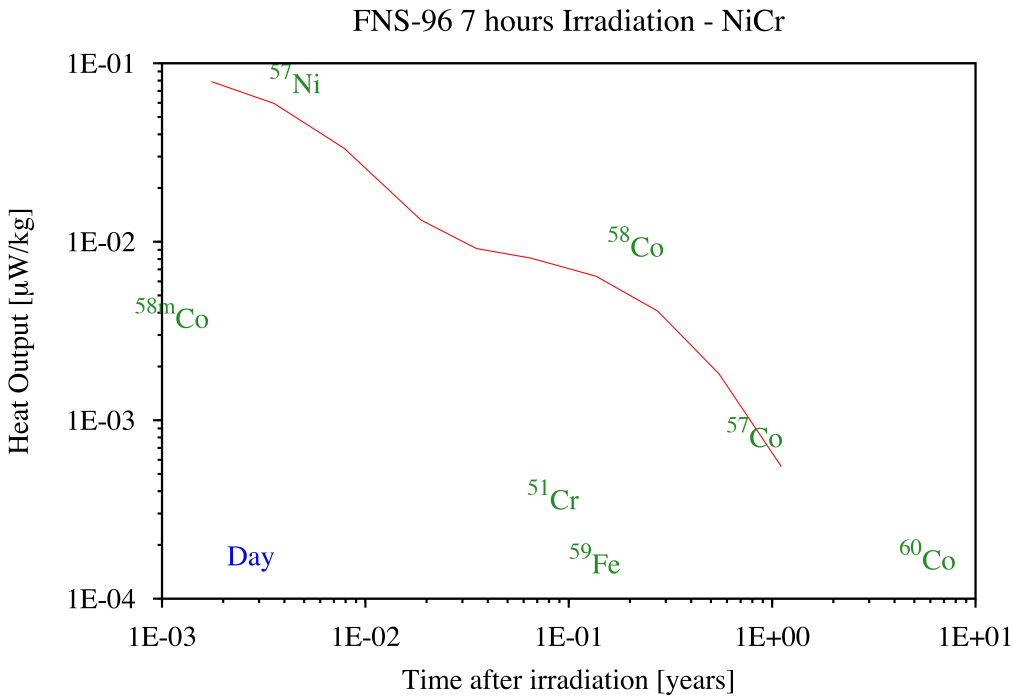




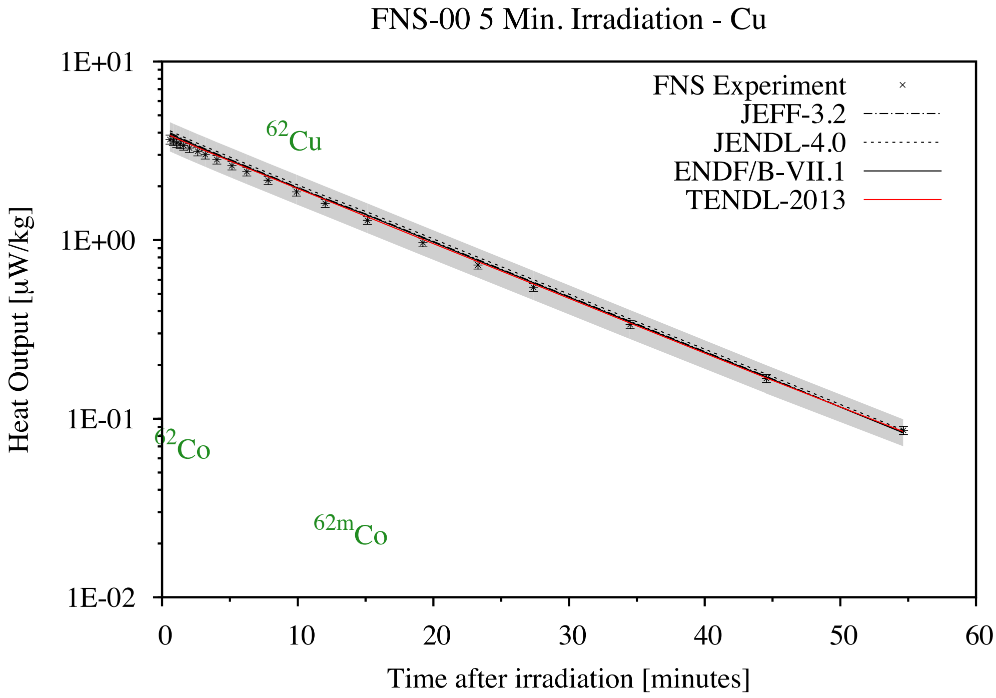
Here also clean agreements exist between measurements and predictions.

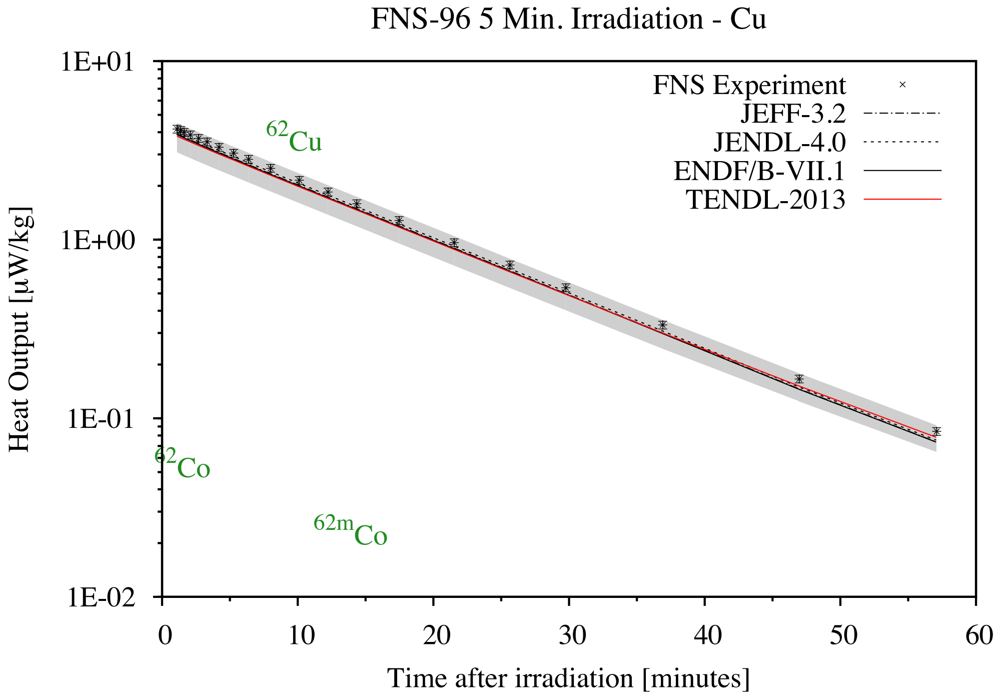
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.64	7.40E−02 +/-5%	7.89E−02 +/-36%	0.94	0.96	0.97	0.84
1.30	5.75E−02 +/-5%	5.95E−02 +/-35%	0.97	0.97	0.98	0.86
2.88	3.26E−02 +/-5%	3.33E−02 +/-31%	0.98	0.91	0.98	0.89
6.85	1.31E−02 +/-5%	1.32E−02 +/-22%	0.99	0.98	1.04	0.98
12.85	9.18E−03 +/-5%	9.16E−03 +/-26%	1.00	0.99	1.00	1.08
23.85	8.07E−03 +/-5%	8.09E−03 +/-26%	1.00	0.98	0.99	1.11
49.70	6.36E−03 +/-5%	6.41E−03 +/-26%	0.99	0.98	0.99	1.11
99.89	3.96E−03 +/-5%	4.09E−03 +/-25%	0.97	0.95	0.96	1.07
200.12	1.88E−03 +/-5%	1.82E−03 +/-21%	1.03	1.01	1.02	1.10
402.94	5.92E−04 +/-6%	5.50E−04 +/-16%	1.08	1.06	1.08	1.07

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ni57	Ni58(n,2n)Ni57	1.4d	100.0	0.97	5%
Co58	Ni58(n,p)Co58	70.8d	91.6	0.97	5%
	Ni58(n,p)Co58m		8.4	0.97	5%
Co57	Ni58(n,d+np)Co57	271d	99.6	1.08	6%


FNS-96 7 hours Irradiation - NiCr
Heat Output [µW/kg]
1E-01
1E-02
1E-03
1E-04
1E-03
1E-02
1E-01
1E+00
1E+01
Time after irradiation [years]
57Ni
58Co
58mCo
57Co
51Cr
59Fe
60Co
Day

Copper

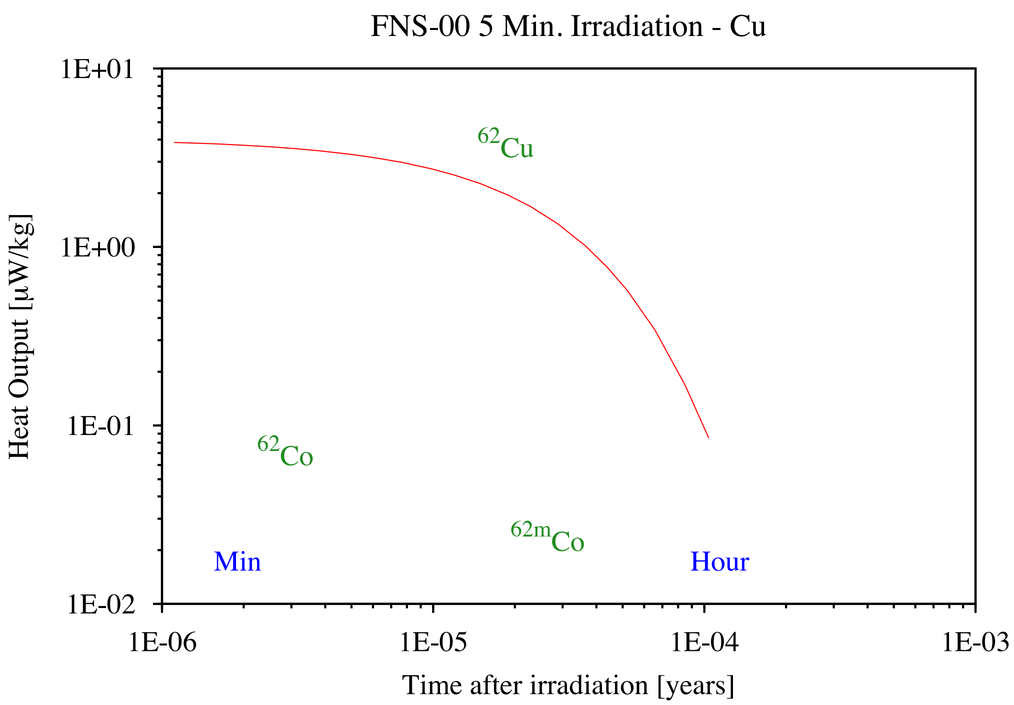


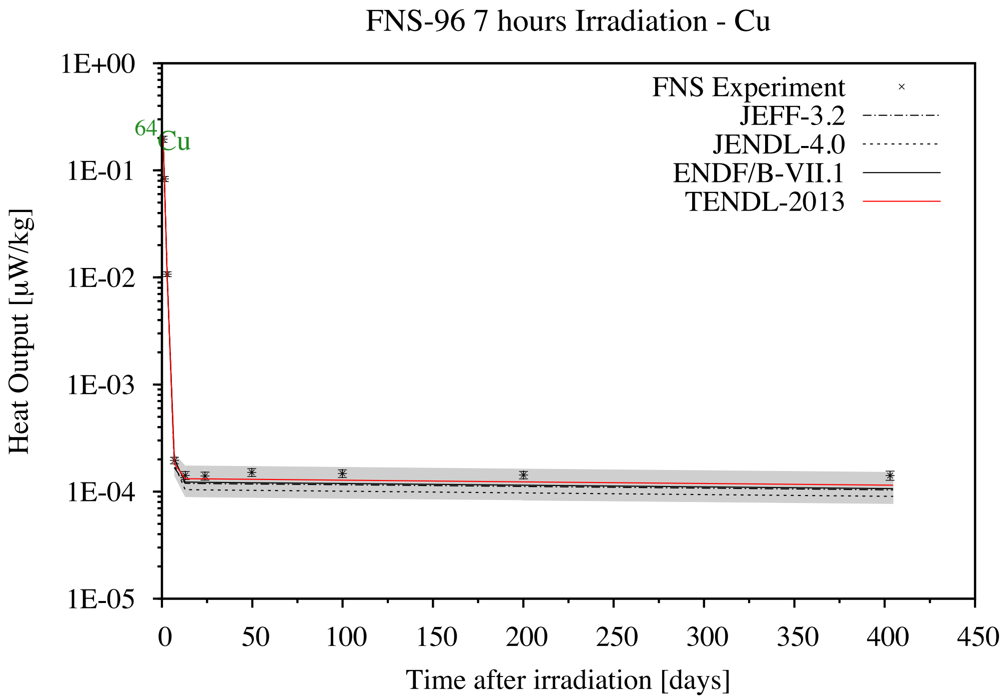


For Copper, a good agreement can be seen for both sample runs. However, the rather uniform measurements could be used to question the quoted 6% experimental uncertainty in face of the fact that the two batches seem to differ by more that this 6% value.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	$3.66E{+}00$ +/-6%	$3.85E{+}00$ +/-19%	0.95	0.93	0.92	0.89
0.83	$3.59E{+}00$ +/-6%	$3.78E{+}00$ +/-19%	0.95	0.93	0.92	0.90
1.08	$3.50E{+}00$ +/-6%	$3.71E{+}00$ +/-19%	0.94	0.93	0.91	0.89
1.33	$3.45E{+}00$ +/-6%	$3.64E{+}00$ +/-19%	0.95	0.93	0.92	0.90
1.60	$3.38E{+}00$ +/-6%	$3.56E{+}00$ +/-19%	0.95	0.93	0.92	0.90
2.02	$3.28E{+}00$ +/-6%	$3.45E{+}00$ +/-19%	0.95	0.93	0.92	0.90
2.63	$3.14E{+}00$ +/-6%	$3.30E{+}00$ +/-19%	0.95	0.94	0.93	0.90
3.18	$3.01E{+}00$ +/-6%	$3.17E{+}00$ +/-19%	0.95	0.94	0.93	0.90
4.03	$2.82E{+}00$ +/-6%	$2.98E{+}00$ +/-19%	0.95	0.94	0.93	0.90
5.15	$2.61E{+}00$ +/-5%	$2.75E{+}00$ +/-19%	0.95	0.94	0.93	0.90
6.25	$2.42E{+}00$ +/-5%	$2.54E{+}00$ +/-19%	0.95	0.94	0.93	0.91
7.82	$2.16E{+}00$ +/-5%	$2.27E{+}00$ +/-19%	0.95	0.94	0.94	0.91
9.92	$1.86E{+}00$ +/-5%	$1.95E{+}00$ +/-19%	0.95	0.95	0.94	0.91
12.02	$1.61E{+}00$ +/-5%	$1.68E{+}00$ +/-19%	0.95	0.95	0.94	0.91
15.13	$1.29E{+}00$ +/-5%	$1.35E{+}00$ +/-19%	0.96	0.94	0.93	0.90
19.23	$9.68E{-}01$ +/-5%	$1.01E{+}00$ +/-19%	0.96	0.94	0.93	0.90
23.28	$7.26E{-}01$ +/-5%	$7.58E{-}01$ +/-19%	0.96	0.94	0.93	0.90
27.38	$5.44E{-}01$ +/-5%	$5.68E{-}01$ +/-19%	0.96	0.94	0.94	0.91
34.50	$3.37E{-}01$ +/-5%	$3.43E{-}01$ +/-18%	0.98	0.96	0.96	0.93
44.55	$1.68E{-}01$ +/-5%	$1.69E{-}01$ +/-18%	0.99	0.98	0.97	0.94
54.65	$8.60E{-}02$ +/-5%	$8.49E{-}02$ +/-17%	1.01	1.03	1.02	1.00

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	$\mathbf{\Delta E\%}$
Cu62	Cu63(n,2n)Cu62	9.7m	100.0	0.95	5%

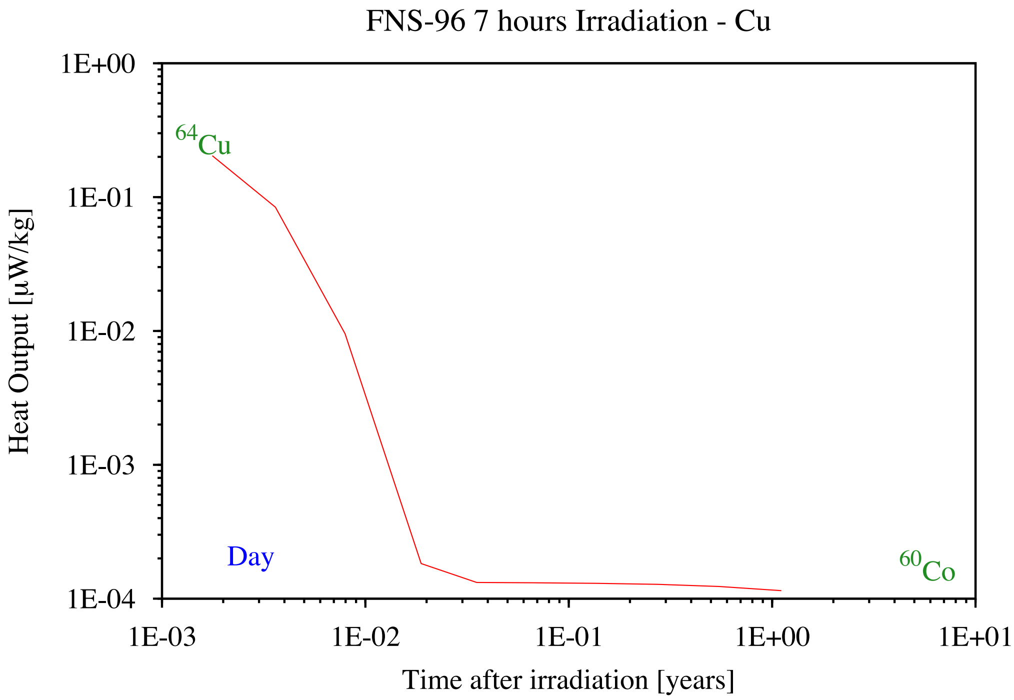




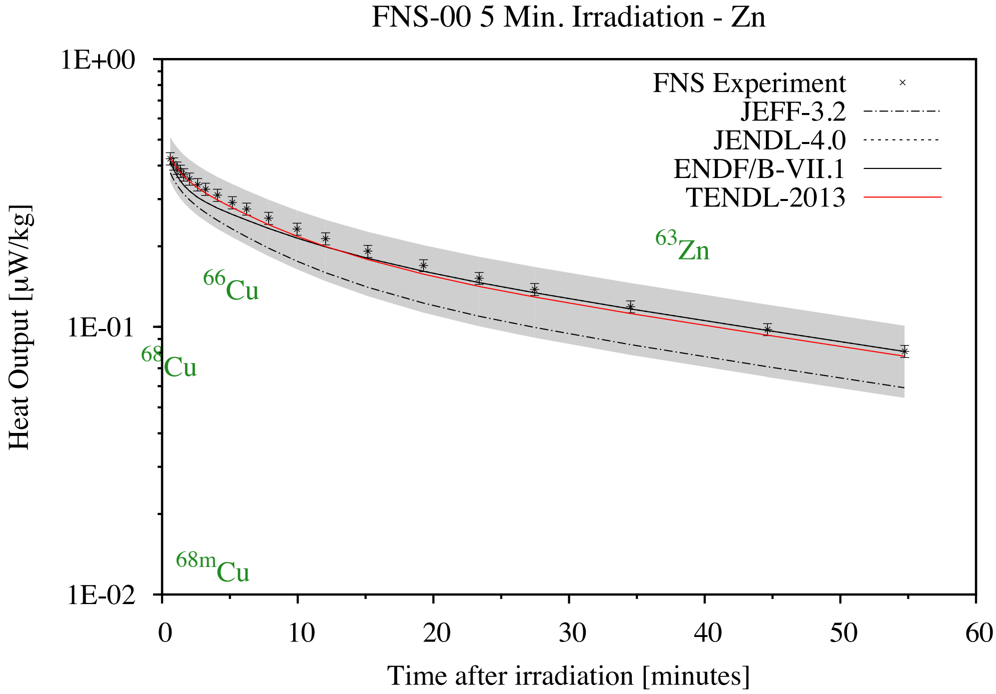
The above graph shows a good agreement, often within the experimental uncertainty. The TENDL-2013 uncertainty could be halved.

Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.65	$1.95E{-}01$ +/-7%	$2.04E{-}01$ +/-7%	0.96	0.94	0.95	0.97
1.32	$8.31E{-}02$ +/-6%	$8.41E{-}02$ +/-7%	0.99	0.97	0.98	1.00
2.90	$1.07E{-}02$ +/-5%	$9.55E{-}03$ +/-7%	1.12	1.06	1.09	1.03
6.87	$1.96E{-}04$ +/-7%	$1.83E{-}04$ +/-24%	1.07	0.98	1.17	1.10
12.89	$1.42E{-}04$ +/-9%	$1.32E{-}04$ +/-33%	1.07	1.15	1.19	1.36
23.90	$1.40E{-}04$ +/-9%	$1.31E{-}04$ +/-33%	1.06	1.14	1.18	1.35
49.72	$1.51E{-}04$ +/-8%	$1.30E{-}04$ +/-33%	1.16	1.25	1.28	1.47
99.92	$1.48E{-}04$ +/-8%	$1.28E{-}04$ +/-33%	1.15	1.24	1.27	1.46
200.14	$1.43E{-}04$ +/-8%	$1.23E{-}04$ +/-33%	1.16	1.25	1.28	1.47
402.97	$1.41E{-}04$ +/-10%	$1.15E{-}04$ +/-33%	1.23	1.33	1.36	1.56

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Cu64	Cu65(n,2n)Cu64	12.7h	99.2	0.96	7%
	Cu63(n,g)Cu64		0.7	0.96	7%
Co60	Cu63(n,α)Co60m	10.4m	55.3	1.23	10%
	Cu63(n,α)Co60	5.2y	44.7	1.23	10%


FNS-96 7 hours Irradiation - Cu
1E+00
1E-01
1E-02
1E-03
1E-04
Heat Output [µW/kg]
64Cu
Day
60Co
1E-03
1E-02
1E-01
1E+00
1E+01
Time after irradiation [years]

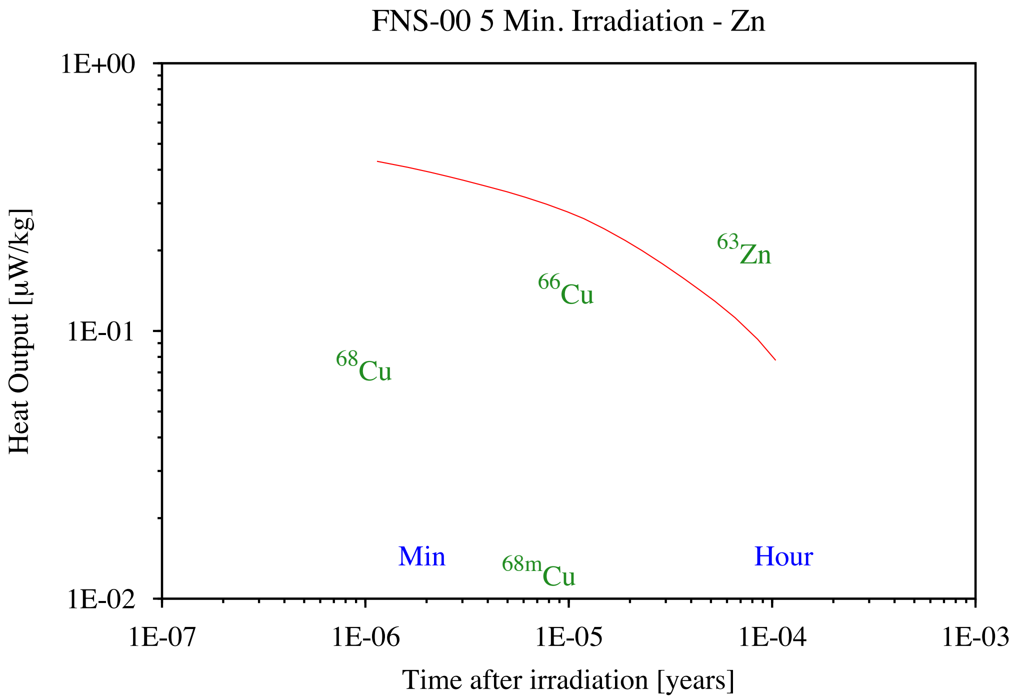
Zinc

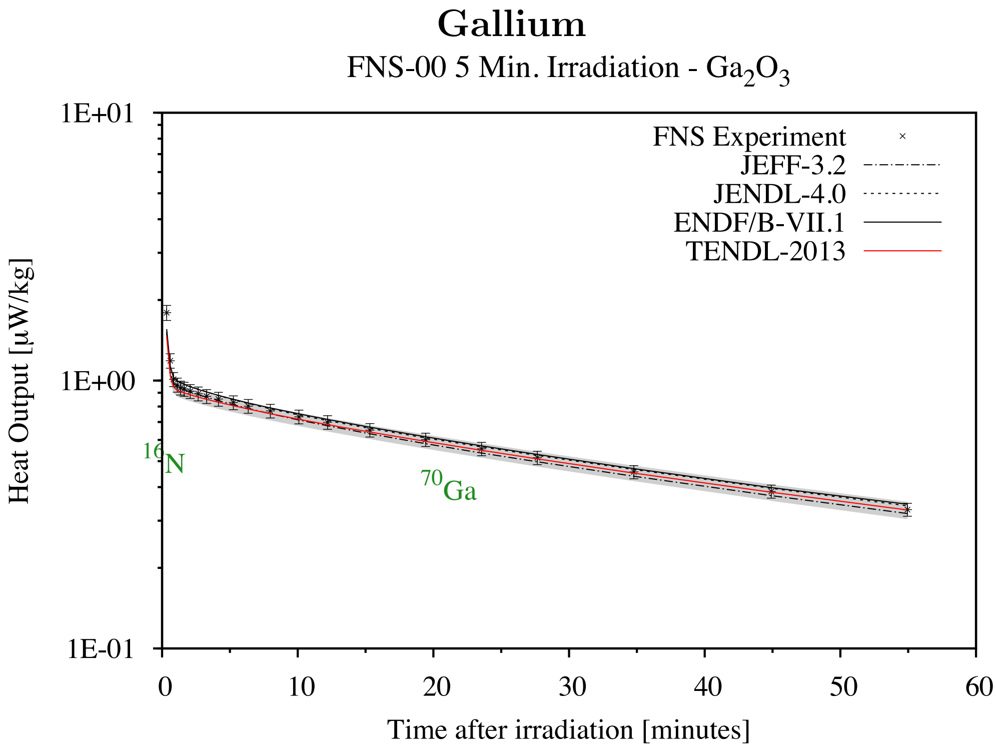


For Zinc, in the above graph a remarkable agreement can be seen, with all libraries except for JEFF-3.2, confirming again, if needed, the importance of this V&V process.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	4.25E−01 +/-5%	4.30E−01 +/-19%	0.99	1.02	1.13	1.02
0.85	4.06E−01 +/-5%	4.09E−01 +/-19%	0.99	1.05	1.14	1.05
1.10	3.92E−01 +/-5%	3.91E−01 +/-20%	1.00	1.07	1.16	1.07
1.35	3.81E−01 +/-5%	3.77E−01 +/-20%	1.01	1.09	1.17	1.09
1.60	3.70E−01 +/-5%	3.65E−01 +/-20%	1.01	1.09	1.18	1.09
2.02	3.57E−01 +/-5%	3.49E−01 +/-21%	1.02	1.11	1.20	1.11
2.62	3.40E−01 +/-5%	3.31E−01 +/-21%	1.03	1.11	1.21	1.11
3.22	3.27E−01 +/-5%	3.16E−01 +/-22%	1.03	1.12	1.23	1.12
4.08	3.10E−01 +/-5%	2.98E−01 +/-22%	1.04	1.12	1.24	1.12
5.18	2.91E−01 +/-5%	2.79E−01 +/-23%	1.04	1.11	1.25	1.11
6.23	2.76E−01 +/-5%	2.63E−01 +/-23%	1.05	1.10	1.27	1.10
7.85	2.55E−01 +/-5%	2.41E−01 +/-24%	1.06	1.09	1.29	1.09
9.95	2.32E−01 +/-5%	2.18E−01 +/-25%	1.06	1.08	1.32	1.08
12.05	2.13E−01 +/-5%	2.00E−01 +/-26%	1.07	1.07	1.34	1.07
15.17	1.92E−01 +/-5%	1.78E−01 +/-27%	1.07	1.06	1.36	1.06
19.27	1.69E−01 +/-5%	1.57E−01 +/-28%	1.08	1.05	1.38	1.05
23.37	1.52E−01 +/-5%	1.42E−01 +/-29%	1.07	1.04	1.38	1.04
27.47	1.38E−01 +/-5%	1.29E−01 +/-30%	1.07	1.03	1.39	1.03
34.53	1.19E−01 +/-5%	1.12E−01 +/-30%	1.06	1.02	1.39	1.02
44.63	9.77E−02 +/-5%	9.31E−02 +/-30%	1.05	1.01	1.38	1.01
54.75	8.10E−02 +/-5%	7.77E−02 +/-30%	1.04	1.00	1.37	1.00

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Zn63	Zn64(n,2n)Zn63	38.4m	100.0	1.06	5%

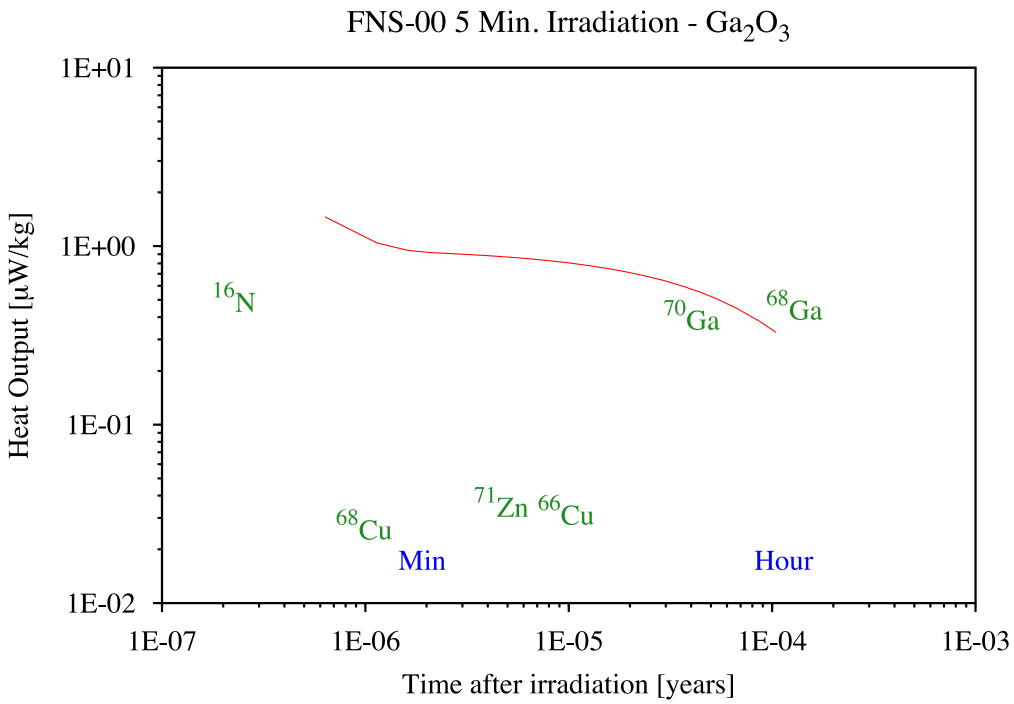

FNS-00 5 Min. Irradiation - Zn
Heat Output [µW/kg]
1E+00
1E-01
1E-02
1E-07
1E-06
1E-05
1E-04
1E-03
Time after irradiation [years]
63Zn
66Cu
68Cu
Min
68mCu
Hour

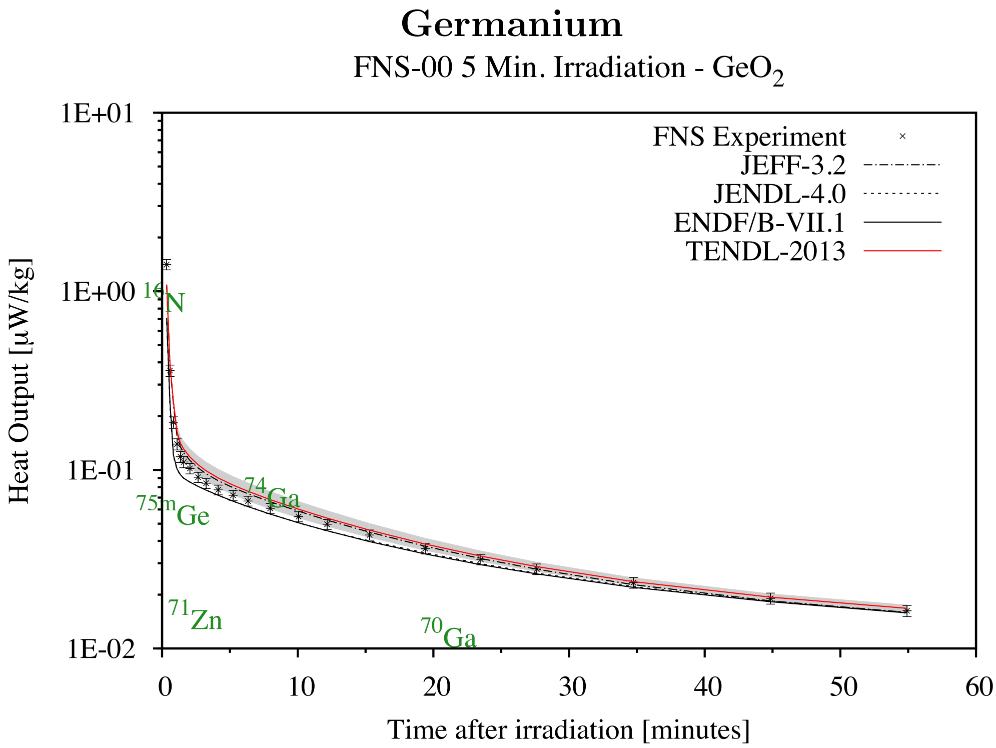


For Gallium, a remarkable agreement can be seen particularly when the TENDL-2013 data library is used.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.33	$1.79E{+}00$ +/-6%	$1.46E{+}00$ +/-3%	1.23	1.15	1.20	1.18
0.60	$1.19E{+}00$ +/-6%	$1.04E{+}00$ +/-5%	1.14	1.05	1.10	1.05
0.85	$1.01E{+}00$ +/-6%	$9.47E{-}01$ +/-5%	1.07	0.98	1.03	0.98
1.12	$9.63E{-}01$ +/-6%	$9.19E{-}01$ +/-5%	1.05	0.97	1.02	0.97
1.37	$9.39E{-}01$ +/-6%	$9.09E{-}01$ +/-5%	1.03	0.96	1.00	0.95
1.63	$9.29E{-}01$ +/-6%	$8.99E{-}01$ +/-5%	1.03	0.96	1.01	0.96
2.07	$9.12E{-}01$ +/-6%	$8.85E{-}01$ +/-5%	1.03	0.96	1.01	0.96
2.67	$8.92E{-}01$ +/-6%	$8.68E{-}01$ +/-5%	1.03	0.96	1.01	0.96
3.28	$8.73E{-}01$ +/-6%	$8.51E{-}01$ +/-5%	1.03	0.96	1.01	0.96
4.15	$8.53E{-}01$ +/-6%	$8.30E{-}01$ +/-5%	1.03	0.97	1.01	0.97
5.25	$8.28E{-}01$ +/-6%	$8.06E{-}01$ +/-6%	1.03	0.97	1.02	0.98
6.35	$8.02E{-}01$ +/-6%	$7.83E{-}01$ +/-6%	1.02	0.97	1.02	0.98
7.98	$7.70E{-}01$ +/-6%	$7.53E{-}01$ +/-6%	1.02	0.97	1.02	0.98
10.08	$7.33E{-}01$ +/-6%	$7.17E{-}01$ +/-6%	1.02	0.98	1.03	0.98
12.20	$6.99E{-}01$ +/-6%	$6.85E{-}01$ +/-6%	1.02	0.98	1.03	0.99
15.32	$6.53E{-}01$ +/-6%	$6.43E{-}01$ +/-6%	1.02	0.98	1.03	0.98
19.43	$6.02E{-}01$ +/-6%	$5.93E{-}01$ +/-6%	1.01	0.98	1.04	0.98
23.55	$5.56E{-}01$ +/-6%	$5.49E{-}01$ +/-6%	1.01	0.97	1.04	0.98
27.67	$5.15E{-}01$ +/-6%	$5.10E{-}01$ +/-6%	1.01	0.97	1.04	0.98
34.78	$4.56E{-}01$ +/-6%	$4.51E{-}01$ +/-7%	1.01	0.97	1.04	0.98
44.90	$3.85E{-}01$ +/-6%	$3.83E{-}01$ +/-7%	1.01	0.97	1.04	0.97
54.95	$3.30E{-}01$ +/-6%	$3.29E{-}01$ +/-7%	1.00	0.95	1.03	0.97

Product	Pathways	$T_{1/2}$	Path %	E/C	ΔE%
N16	O16(n,p)N16	7.1s	99.9	1.23	6%
Ga70	Ga69(n,γ)Ga70	21.1m	1.2	1.01	6%
	Ga71(n,2n)Ga70		98.8	1.01	6%
Ga68	Ga69(n,2n)Ga68	1.1h	100.0	1.00	6%

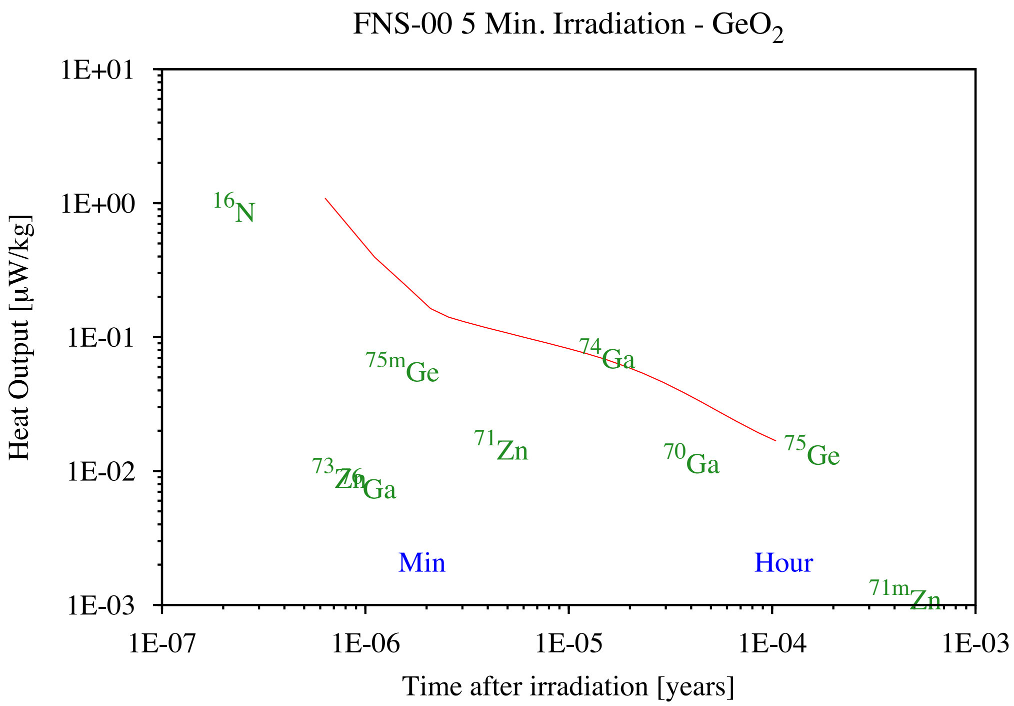


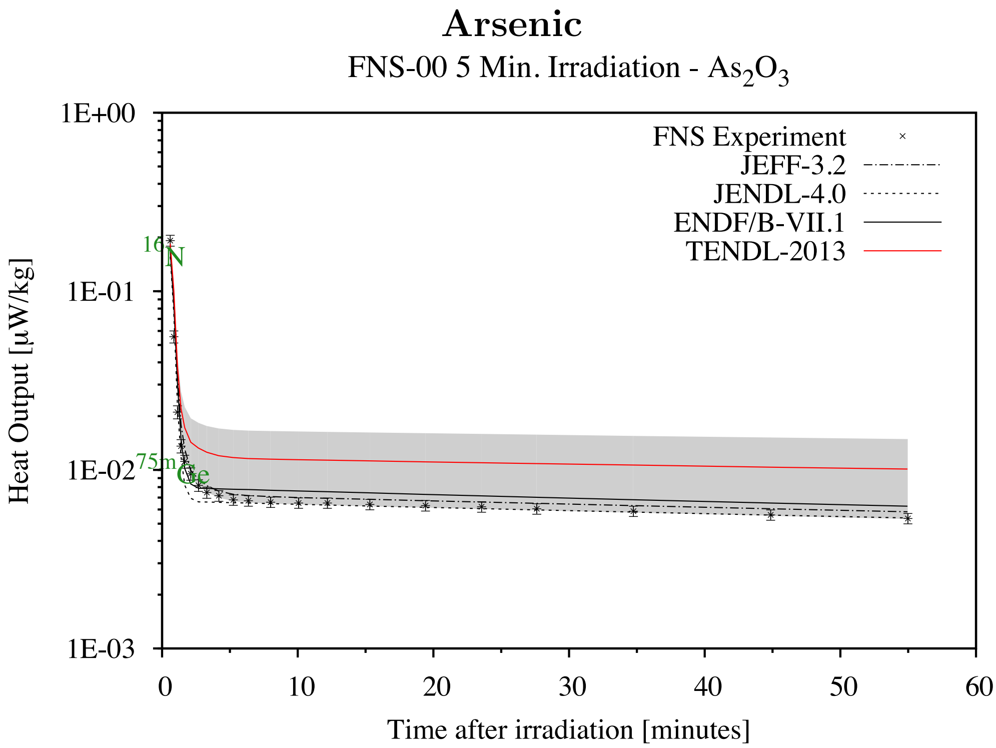


For Germanium, it is clear that the changes made in the TENDL-2013 data on the complex routes of production of the Ge75 and Ga74 isotopes have improved the predictions.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.33	$1.41E{+}00$ +/-7%	$1.09E{+}00$ +/-2%	1.29	1.99	1.31	2.09
0.58	$3.60E{-}01$ +/-7%	$3.96E{-}01$ +/-4%	0.91	1.52	0.94	1.57
0.83	$1.84E{-}01$ +/-7%	$2.42E{-}01$ +/-7%	0.76	1.52	0.79	1.54
1.10	$1.39E{-}01$ +/-7%	$1.63E{-}01$ +/-10%	0.85	1.38	0.90	1.39
1.35	$1.18E{-}01$ +/-7%	$1.41E{-}01$ +/-11%	0.84	1.26	0.88	1.26
1.60	$1.11E{-}01$ +/-7%	$1.31E{-}01$ +/-11%	0.85	1.23	0.89	1.23
2.05	$1.02E{-}01$ +/-7%	$1.18E{-}01$ +/-12%	0.86	1.19	0.90	1.19
2.65	$9.09E{-}02$ +/-7%	$1.07E{-}01$ +/-12%	0.85	1.12	0.89	1.12
3.25	$8.42E{-}02$ +/-6%	$9.89E{-}02$ +/-12%	0.85	1.09	0.88	1.09
4.13	$7.73E{-}02$ +/-6%	$9.02E{-}02$ +/-12%	0.86	1.07	0.89	1.07
5.23	$7.21E{-}02$ +/-6%	$8.22E{-}02$ +/-12%	0.88	1.08	0.91	1.08
6.33	$6.69E{-}02$ +/-6%	$7.58E{-}02$ +/-12%	0.88	1.07	0.91	1.07
7.97	$6.09E{-}02$ +/-6%	$6.82E{-}02$ +/-12%	0.89	1.08	0.92	1.08
10.07	$5.47E{-}02$ +/-6%	$6.02E{-}02$ +/-11%	0.91	1.08	0.93	1.08
12.17	$4.96E{-}02$ +/-6%	$5.37E{-}02$ +/-10%	0.92	1.09	0.95	1.09
15.30	$4.32E{-}02$ +/-7%	$4.60E{-}02$ +/-9%	0.94	1.09	0.96	1.08
19.40	$3.62E{-}02$ +/-7%	$3.84E{-}02$ +/-8%	0.94	1.07	0.97	1.05
23.50	$3.15E{-}02$ +/-7%	$3.29E{-}02$ +/-7%	0.96	1.07	0.99	1.06
27.62	$2.78E{-}02$ +/-7%	$2.87E{-}02$ +/-6%	0.97	1.06	1.00	1.05
34.75	$2.34E{-}02$ +/-7%	$2.37E{-}02$ +/-5%	0.99	1.06	1.03	1.05
44.85	$1.91E{-}02$ +/-7%	$1.94E{-}02$ +/-5%	0.98	1.04	1.03	1.04
54.92	$1.63E{-}02$ +/-7%	$1.68E{-}02$ +/-5%	0.97	1.03	1.02	1.02

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ge75m	Ge76(n,2n)Ge75m	47.7s	98.4	0.76	7%
	Ge76(n,g)Ge75m		0.5	0.76	7%
Ga74	Ge74(n,p)Ga74	8.1m	71.8	0.89	6%
	Ge74(n,p)Ga74m	9.5s	28.1	0.89	6%
Ge75	Ge76(n,2n)Ge75	1.3h	40.1	0.97	7%
	Ge76(n,2n)Ge75m	47.7s	59.2	0.97	7%
	Ge76(n,g)Ge75		0.6	0.97	7%

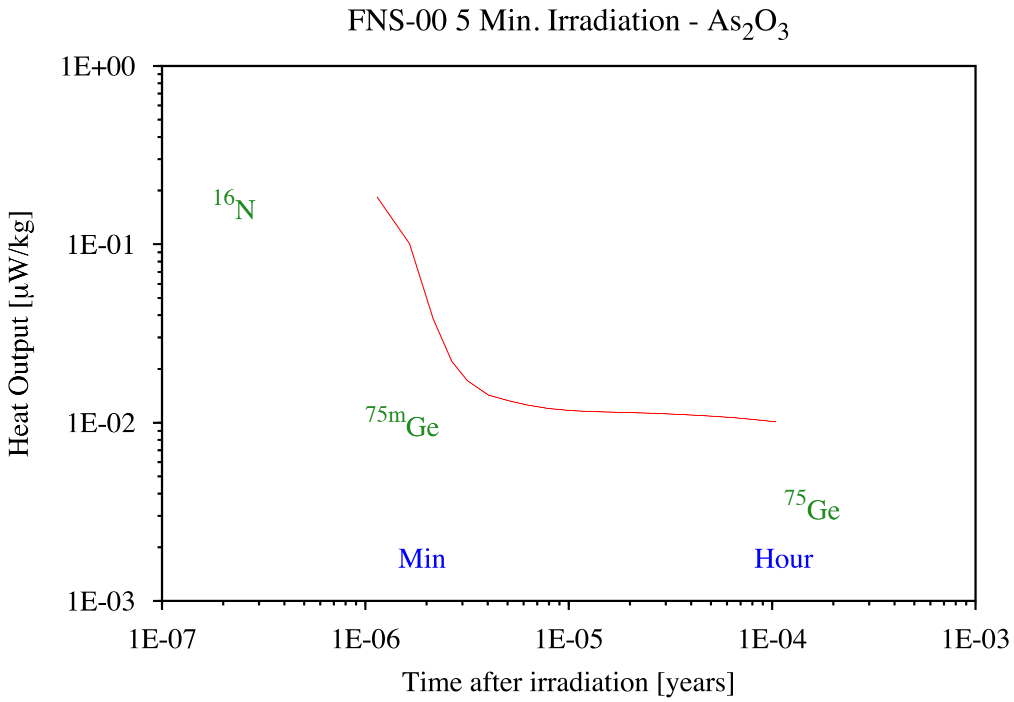




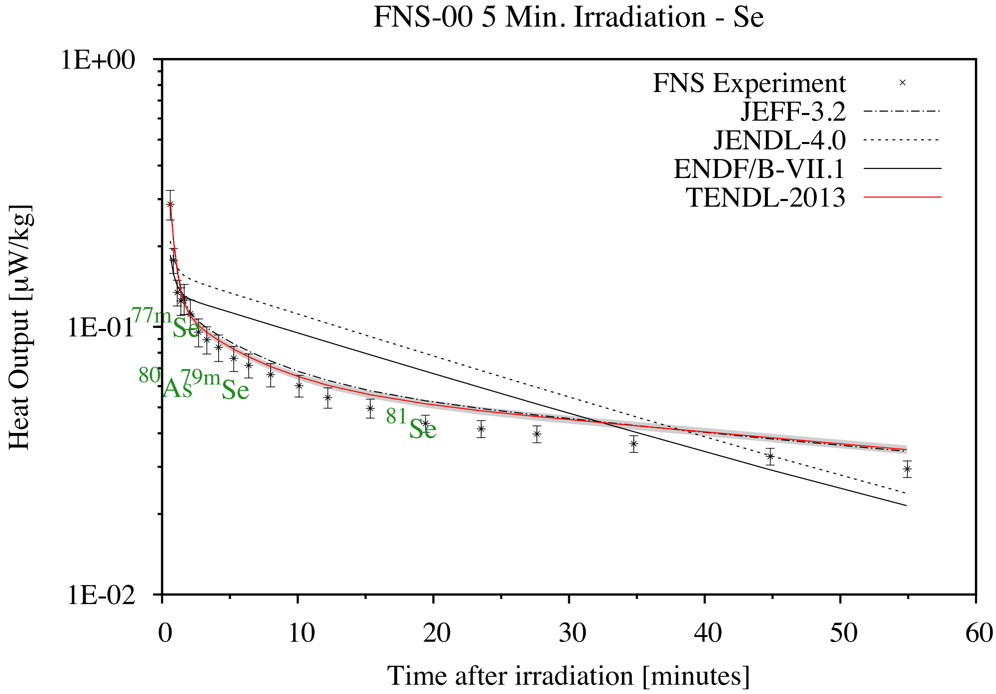
For Arsenic, the same isotope as for the germanium decay heat, Ge75, dominates, but this time produced through different paths. JENDL-4.0 leads to significantly better results than TENDL-2013, although on the edge of the uncertainty band.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	1.92E−01 +/-7%	1.84E−01 +/-3%	1.04	1.15	1.08	1.23
0.87	5.56E−02 +/-8%	1.01E−01 +/-6%	0.55	0.67	0.59	0.74
1.13	2.11E−02 +/-8%	3.82E−02 +/-15%	0.55	0.68	0.63	0.92
1.40	1.36E−02 +/-9%	2.20E−02 +/-25%	0.62	0.91	0.76	1.15
1.67	1.12E−02 +/-8%	1.72E−02 +/-31%	0.65	1.10	0.85	1.36
2.12	9.50E−03 +/-8%	1.43E−02 +/-36%	0.67	1.14	0.96	1.37
2.68	8.19E−03 +/-8%	1.32E−02 +/-38%	0.62	1.04	0.92	1.24
3.30	7.47E−03 +/-7%	1.25E−02 +/-40%	0.60	0.95	0.92	1.13
4.18	7.16E−03 +/-7%	1.20E−02 +/-42%	0.60	0.91	0.94	1.09
5.25	6.79E−03 +/-7%	1.17E−02 +/-43%	0.58	0.87	0.93	1.04
6.37	6.71E−03 +/-7%	1.16E−02 +/-43%	0.58	0.87	0.94	1.03
8.00	6.60E−03 +/-7%	1.15E−02 +/-44%	0.57	0.86	0.93	1.02
10.07	6.53E−03 +/-7%	1.14E−02 +/-44%	0.57	0.86	0.93	1.02
12.18	6.52E−03 +/-7%	1.13E−02 +/-44%	0.58	0.87	0.94	1.03
15.32	6.40E−03 +/-7%	1.12E−02 +/-44%	0.57	0.86	0.94	1.02
19.42	6.31E−03 +/-7%	1.11E−02 +/-45%	0.57	0.87	0.94	1.02
23.55	6.21E−03 +/-7%	1.10E−02 +/-45%	0.57	0.87	0.94	1.02
27.62	6.06E−03 +/-7%	1.08E−02 +/-45%	0.56	0.86	0.93	1.02
34.75	5.87E−03 +/-7%	1.06E−02 +/-46%	0.55	0.86	0.93	1.01
44.87	5.60E−03 +/-7%	1.04E−02 +/-47%	0.54	0.86	0.92	1.00
54.98	5.34E−03 +/-7%	1.01E−02 +/-47%	0.53	0.85	0.92	0.99

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ge75m	As75(n,p)Ge75m	47.7s	100.0	0.55	8%
Ge75	As75(n,p)Ge75	1.3h	47.3	0.53	6%
	As75(n,p)Ge75m	47.7s	52.8	0.53	6%



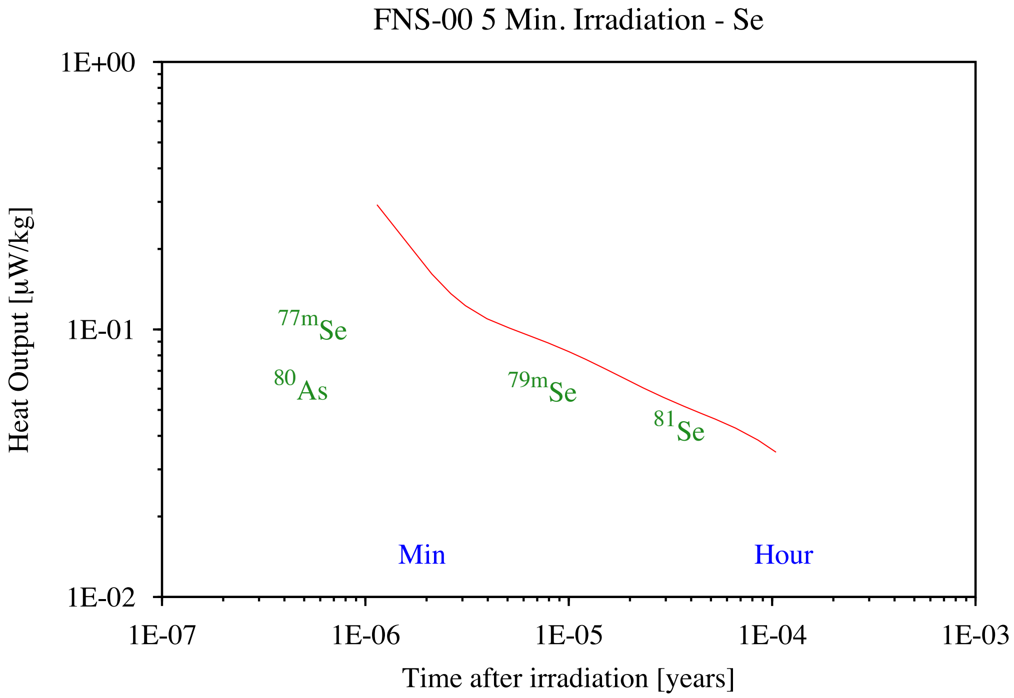
Selenium

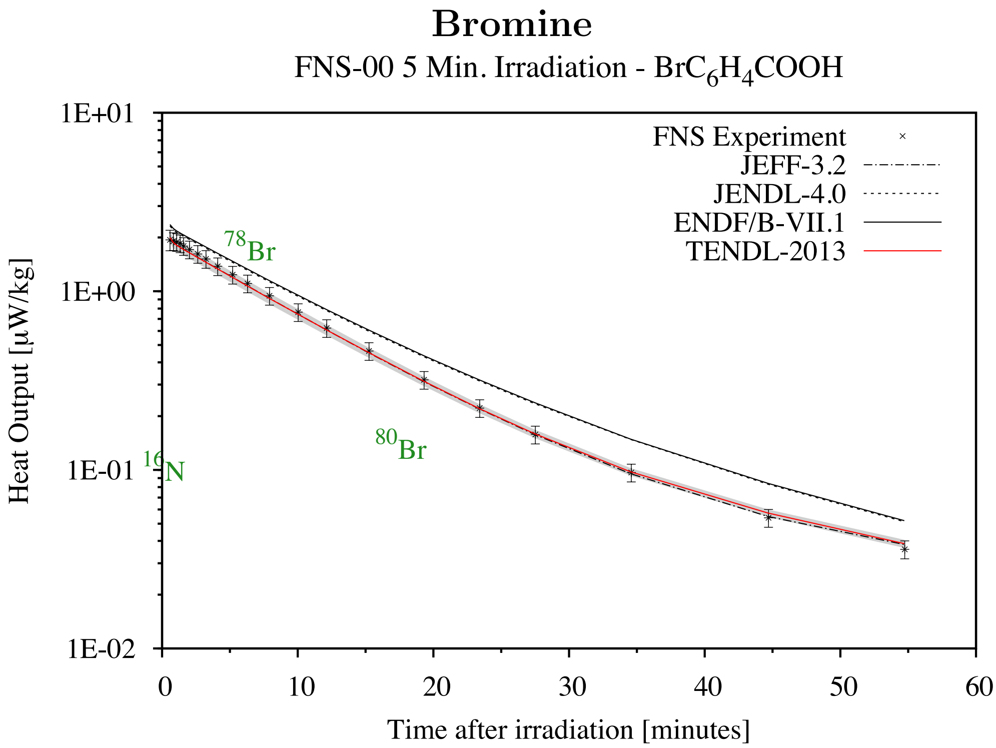


For Selenium, a complex set of pathways influence the decay heat arising from this element. The code predictions are just outside the quoted experimental uncertainties for JEFF-3.2 and TENDL-2013. Metastable isomers dominate at short cooling times.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	2.87$E-$01 +/-13%	2.93$E-$01 +/-6%	0.98	1.55	0.98	1.37
0.85	1.77$E-$01 +/-11%	2.09$E-$01 +/-4%	0.85	1.13	0.84	0.98
1.12	1.34$E-$01 +/-11%	1.61$E-$01 +/-3%	0.83	0.94	0.82	0.81
1.38	1.25$E-$01 +/-12%	1.36$E-$01 +/-3%	0.92	0.93	0.90	0.78
1.63	1.28$E-$01 +/-13%	1.23$E-$01 +/-3%	1.04	0.98	1.01	0.82
2.08	1.12$E-$01 +/-13%	1.10$E-$01 +/-3%	1.02	0.88	0.99	0.74
2.68	9.56$E-$02 +/-12%	1.01$E-$01 +/-3%	0.94	0.77	0.91	0.65
3.30	8.95$E-$02 +/-12%	9.54$E-$02 +/-3%	0.94	0.74	0.90	0.63
4.17	8.37$E-$02 +/-11%	8.91$E-$02 +/-3%	0.94	0.72	0.90	0.61
5.28	7.63$E-$02 +/-11%	8.25$E-$02 +/-3%	0.92	0.68	0.88	0.57
6.38	7.18$E-$02 +/-10%	7.73$E-$02 +/-3%	0.93	0.67	0.88	0.56
8.00	6.63$E-$02 +/-10%	7.11$E-$02 +/-3%	0.93	0.65	0.89	0.55
10.10	6.03$E-$02 +/-9%	6.50$E-$02 +/-3%	0.93	0.64	0.89	0.54
12.22	5.44$E-$02 +/-9%	6.05$E-$02 +/-3%	0.90	0.62	0.86	0.53
15.35	4.96$E-$02 +/-8%	5.57$E-$02 +/-3%	0.89	0.63	0.86	0.54
19.42	4.36$E-$02 +/-7%	5.16$E-$02 +/-3%	0.84	0.64	0.82	0.55
23.52	4.16$E-$02 +/-7%	4.86$E-$02 +/-3%	0.86	0.70	0.84	0.61
27.63	3.98$E-$02 +/-7%	4.62$E-$02 +/-3%	0.86	0.77	0.85	0.67
34.77	3.66$E-$02 +/-7%	4.28$E-$02 +/-3%	0.86	0.90	0.85	0.79
44.83	3.28$E-$02 +/-7%	3.86$E-$02 +/-4%	0.85	1.12	0.86	0.99
54.93	2.95$E-$02 +/-7%	3.48$E-$02 +/-4%	0.85	1.37	0.86	1.23

Product	**Pathways**	**$T_{1/2}$**	**Path %**	**E/C**	**ΔE%**
Se77m	Se77(n,n')Se77m	17.3s	12.4	0.98	13%
	Se78(n,2n)Se77m		86.9	0.98	13%
	Se78(n,g)Se77m		0.7	0.98	13%
Se81	Se80(n,γ)Se81	18.45m	2.4	0.84	7%
	Se82(n,2n)Se81		91.2	0.84	7%
	Se82(n,2n)Se81m	57.2m	6.3	0.84	7%

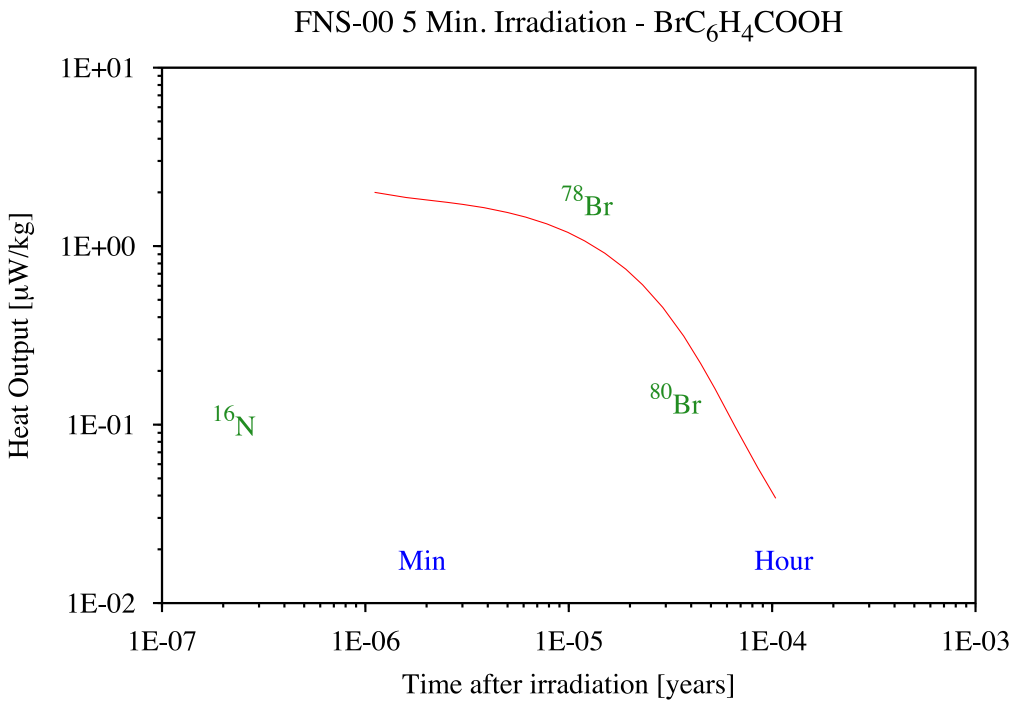


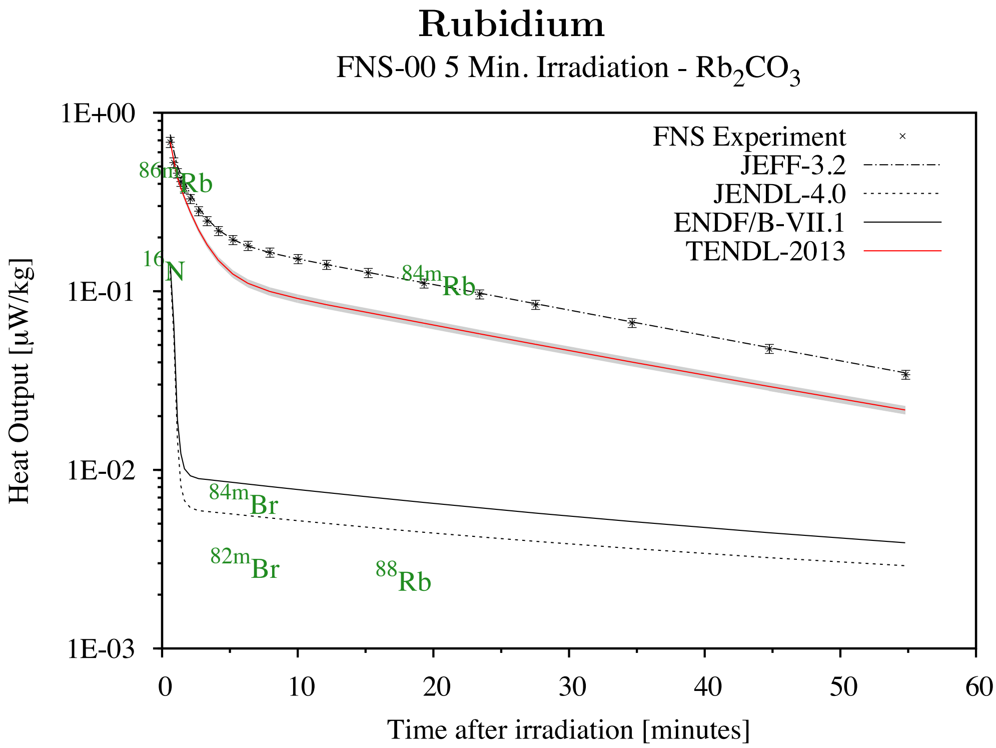


For Bromine, the above picture not only shows a near perfect match in term of experimental and calculated values for JEFF-3.2 and TENDL-2013 but also good agreement between the experimental and calculational uncertainties, even at cooling times as small as 30 seconds.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	1.94E+00 +/-13%	2.00E+00 +/-7%	0.97	0.82	0.97	0.84
0.83	1.91E+00 +/-11%	1.87E+00 +/-7%	1.02	0.85	1.01	0.87
1.08	1.89E+00 +/-11%	1.81E+00 +/-7%	1.04	0.87	1.04	0.88
1.33	1.85E+00 +/-11%	1.76E+00 +/-7%	1.05	0.88	1.05	0.89
1.58	1.79E+00 +/-11%	1.71E+00 +/-7%	1.04	0.87	1.04	0.88
2.02	1.71E+00 +/-11%	1.64E+00 +/-7%	1.04	0.86	1.04	0.88
2.63	1.62E+00 +/-11%	1.54E+00 +/-7%	1.05	0.86	1.05	0.88
3.23	1.52E+00 +/-11%	1.45E+00 +/-7%	1.04	0.86	1.04	0.87
4.10	1.38E+00 +/-11%	1.33E+00 +/-7%	1.04	0.85	1.03	0.86
5.20	1.24E+00 +/-11%	1.19E+00 +/-7%	1.04	0.84	1.04	0.85
6.30	1.11E+00 +/-11%	1.07E+00 +/-7%	1.03	0.83	1.03	0.84
7.92	9.44E−01 +/-11%	9.13E−01 +/-7%	1.03	0.82	1.03	0.83
10.03	7.64E−01 +/-11%	7.43E−01 +/-7%	1.03	0.80	1.03	0.82
12.13	6.23E−01 +/-11%	6.07E−01 +/-7%	1.02	0.79	1.03	0.80
15.25	4.63E−01 +/-11%	4.53E−01 +/-7%	1.02	0.76	1.02	0.77
19.32	3.19E−01 +/-11%	3.13E−01 +/-6%	1.02	0.73	1.02	0.74
23.42	2.22E−01 +/-11%	2.20E−01 +/-6%	1.01	0.70	1.01	0.70
27.52	1.58E−01 +/-11%	1.59E−01 +/-5%	0.99	0.66	1.00	0.67
34.58	9.66E−02 +/-11%	9.74E−02 +/-5%	0.99	0.65	1.02	0.65
44.70	5.39E−02 +/-11%	5.73E−02 +/-5%	0.94	0.64	0.98	0.65
54.75	3.59E−02 +/-11%	3.87E−02 +/-5%	0.93	0.69	0.94	0.70

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Br78	Br79(n,2n)Br78	6.46m	99.8	1.03	11%
Br80	Br79(n,γ)Br80	17.6m	7.9	1.02	11%
	Br81(n,2n)Br80		90.9	1.02	11%
	Br81(n,2n)Br80m		1.1	1.02	11%

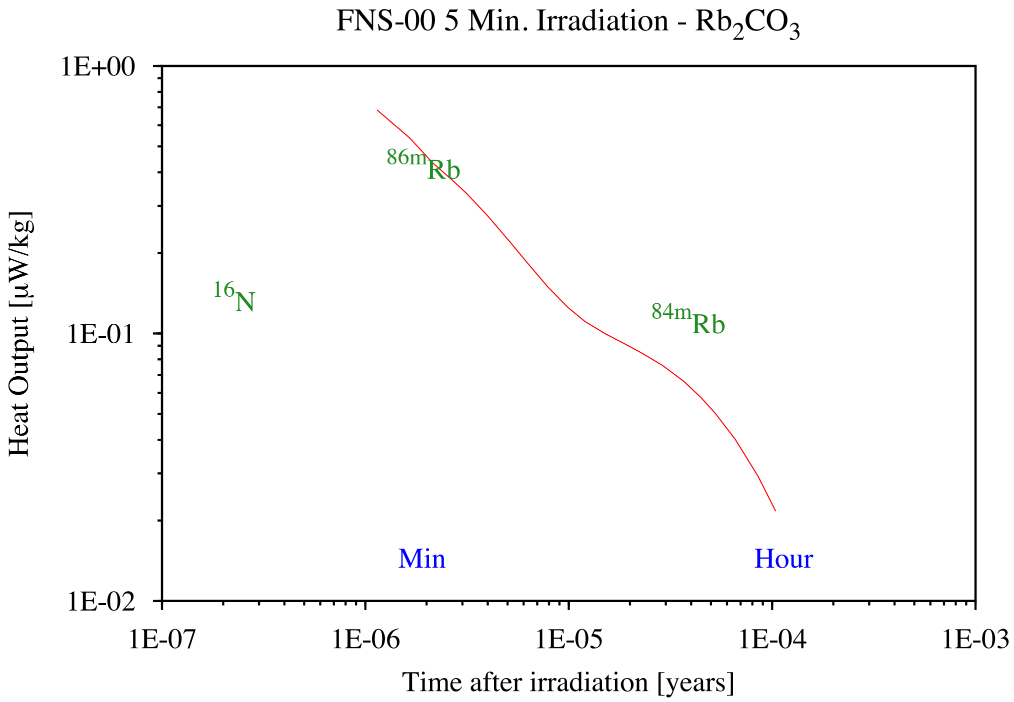




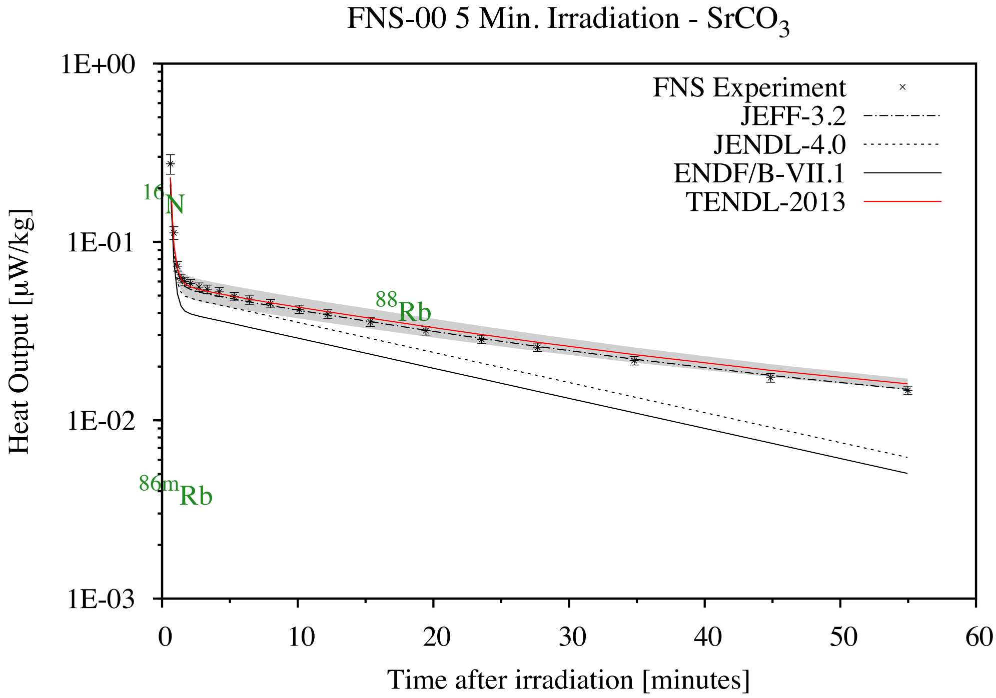
Rubidium: EAF-2010 and TENDL-2012 performed better than TENDL-2013 [13]. JEFF-3.2 generates the best agreement. The graph also shows a clean validation of the two paths leading to metastable isomers.

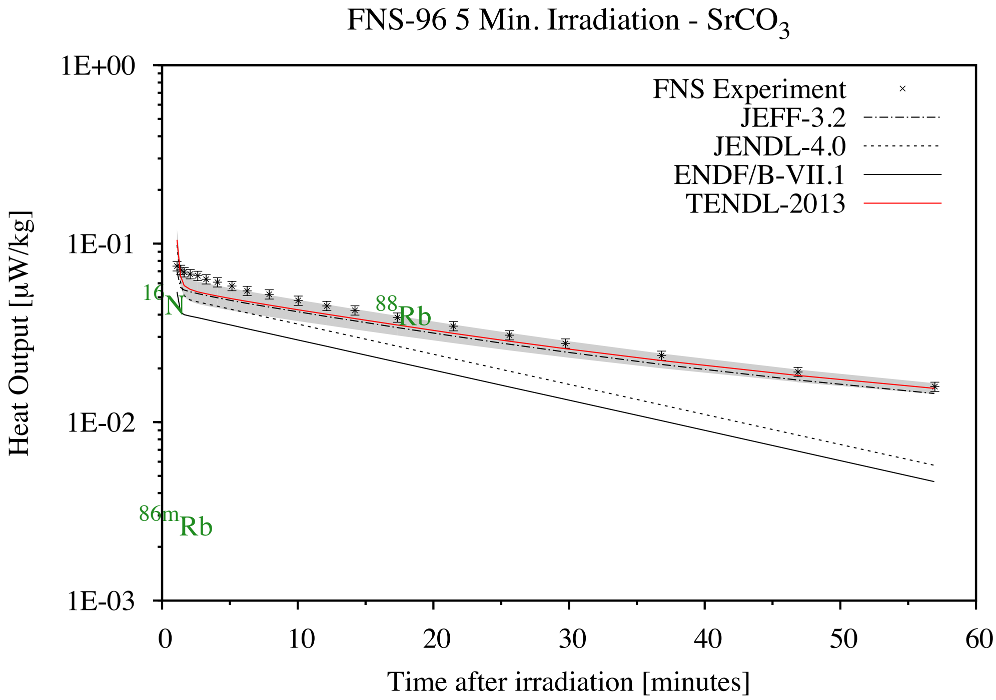
Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	6.83E−01 +/-7%	6.85E−01 +/-3%	1.00	4.81	0.91	5.24
0.87	5.26E−01 +/-6%	5.39E−01 +/-3%	0.98	8.09	0.86	9.40
1.13	4.58E−01 +/-6%	4.32E−01 +/-3%	1.06	23.94	0.91	30.95
1.38	4.11E−01 +/-6%	3.78E−01 +/-3%	1.09	33.40	0.91	50.57
1.65	3.77E−01 +/-6%	3.34E−01 +/-4%	1.13	37.18	0.93	55.99
2.08	3.29E−01 +/-6%	2.77E−01 +/-4%	1.19	35.51	0.94	53.68
2.70	2.81E−01 +/-6%	2.20E−01 +/-4%	1.28	31.44	0.96	47.48
3.32	2.47E−01 +/-6%	1.82E−01 +/-4%	1.36	28.02	0.97	42.28
4.15	2.18E−01 +/-6%	1.49E−01 +/-4%	1.46	25.08	0.99	37.81
5.22	1.94E−01 +/-6%	1.25E−01 +/-5%	1.55	22.79	0.99	34.29
6.33	1.80E−01 +/-6%	1.11E−01 +/-5%	1.62	21.62	1.01	32.48
7.95	1.65E−01 +/-6%	9.97E−02 +/-5%	1.65	20.44	1.00	30.63
10.02	1.52E−01 +/-6%	9.10E−02 +/-6%	1.67	19.54	1.00	29.18
12.13	1.41E−01 +/-6%	8.42E−02 +/-5%	1.67	18.86	1.00	28.06
15.20	1.27E−01 +/-6%	7.59E−02 +/-5%	1.67	17.96	0.99	26.58
19.32	1.11E−01 +/-6%	6.62E−02 +/-5%	1.67	16.84	0.99	24.71
23.42	9.62E−02 +/-6%	5.78E−02 +/-5%	1.67	15.70	0.99	22.84
27.53	8.40E−02 +/-6%	5.05E−02 +/-5%	1.66	14.66	0.99	21.12
34.65	6.65E−02 +/-6%	4.02E−02 +/-5%	1.66	12.95	0.99	18.36
44.77	4.76E−02 +/-6%	2.93E−02 +/-5%	1.62	10.70	0.98	14.78
54.82	3.41E−02 +/-6%	2.17E−02 +/-5%	1.58	8.73	0.98	11.74

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Rb86m	Rb85(n,γ)Rb86m	1.0m	0.7	1.06	6%
	Rb87(n,2n)Rb86m		99.3	1.06	6%
Rb84	Rb85(n,2n)Rb84m	20.4m	100.0	1.67	6%



Strontium

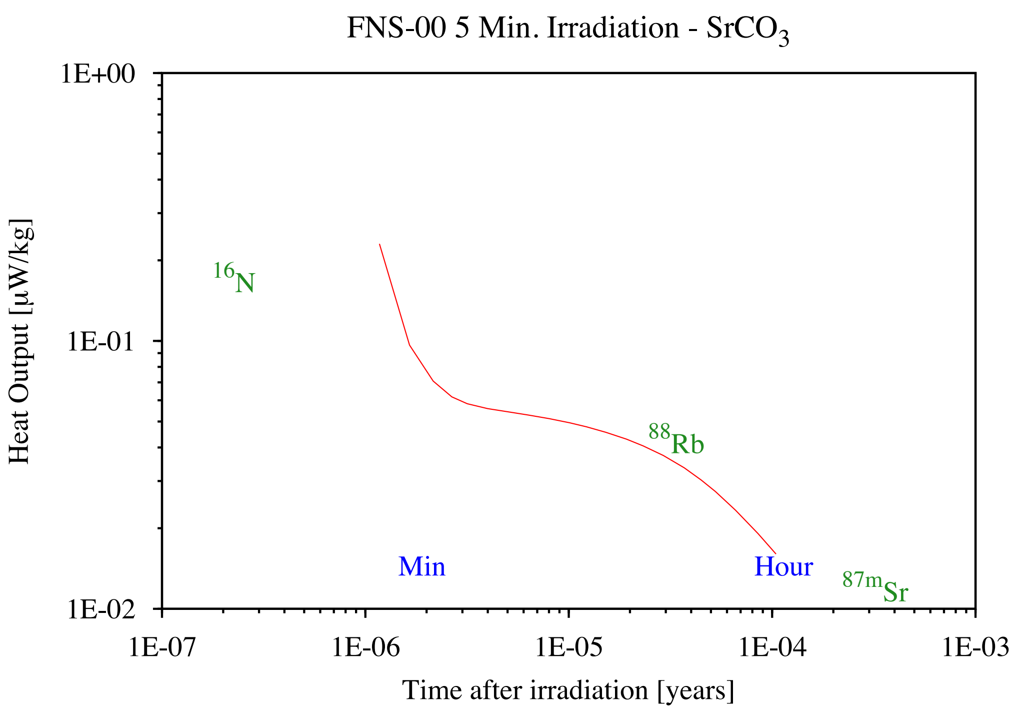


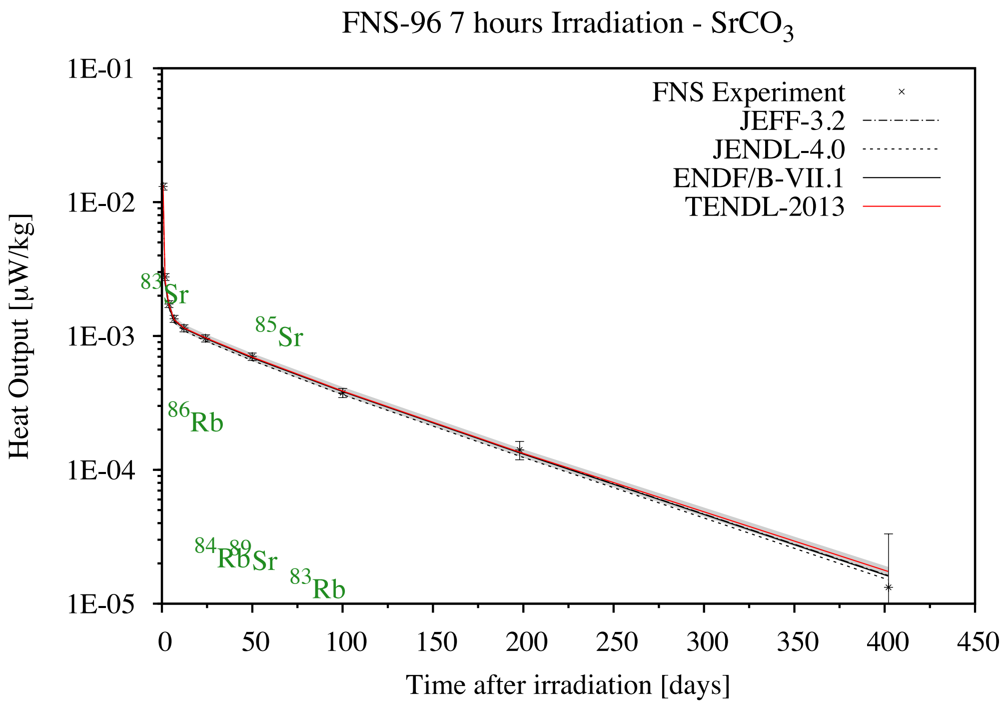


For Strontium, the two experimental measurement sets differ significantly, although both JEFF-3.2 and TENDL-2013 data libraries exhibit remarkable agreement with the both measurement sets.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.62	2.74$E-$01 +/-13%	2.30$E-$01 +/-4%	1.19	1.31	1.20	1.30
0.87	1.12$E-$01 +/-8%	9.65$E-$02 +/-9%	1.17	1.44	1.19	1.31
1.13	7.30$E-$02 +/-6%	7.08$E-$02 +/-12%	1.03	1.43	1.06	1.23
1.40	6.23$E-$02 +/-6%	6.18$E-$02 +/-13%	1.01	1.43	1.04	1.19
1.67	6.00$E-$02 +/-6%	5.83$E-$02 +/-14%	1.03	1.46	1.07	1.21
2.10	5.85$E-$02 +/-6%	5.59$E-$02 +/-14%	1.05	1.48	1.08	1.21
2.72	5.58$E-$02 +/-6%	5.42$E-$02 +/-14%	1.03	1.46	1.07	1.19
3.33	5.42$E-$02 +/-6%	5.29$E-$02 +/-14%	1.03	1.45	1.06	1.18
4.22	5.25$E-$02 +/-6%	5.12$E-$02 +/-14%	1.02	1.45	1.06	1.18
5.32	4.94$E-$02 +/-6%	4.94$E-$02 +/-14%	1.00	1.43	1.04	1.16
6.43	4.73$E-$02 +/-6%	4.78$E-$02 +/-14%	0.99	1.42	1.03	1.16
8.00	4.51$E-$02 +/-5%	4.56$E-$02 +/-14%	0.99	1.45	1.03	1.18
10.12	4.19$E-$02 +/-5%	4.30$E-$02 +/-13%	0.98	1.46	1.01	1.19
12.22	3.94$E-$02 +/-5%	4.06$E-$02 +/-13%	0.97	1.49	1.01	1.21
15.35	3.56$E-$02 +/-5%	3.73$E-$02 +/-13%	0.95	1.52	1.00	1.24
19.45	3.18$E-$02 +/-5%	3.36$E-$02 +/-12%	0.95	1.59	0.99	1.30
23.57	2.84$E-$02 +/-5%	3.03$E-$02 +/-12%	0.94	1.67	0.99	1.36
27.68	2.57$E-$02 +/-5%	2.74$E-$02 +/-11%	0.94	1.77	0.99	1.44
34.80	2.16$E-$02 +/-5%	2.33$E-$02 +/-10%	0.93	1.96	0.98	1.60
44.87	1.73$E-$02 +/-5%	1.91$E-$02 +/-8%	0.91	2.32	0.97	1.89
54.98	1.47$E-$02 +/-5%	1.60$E-$02 +/-7%	0.92	2.92	0.99	2.38

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Rb88	Sr88(n,p)Rb88	17.8m	99.9	0.95	5%

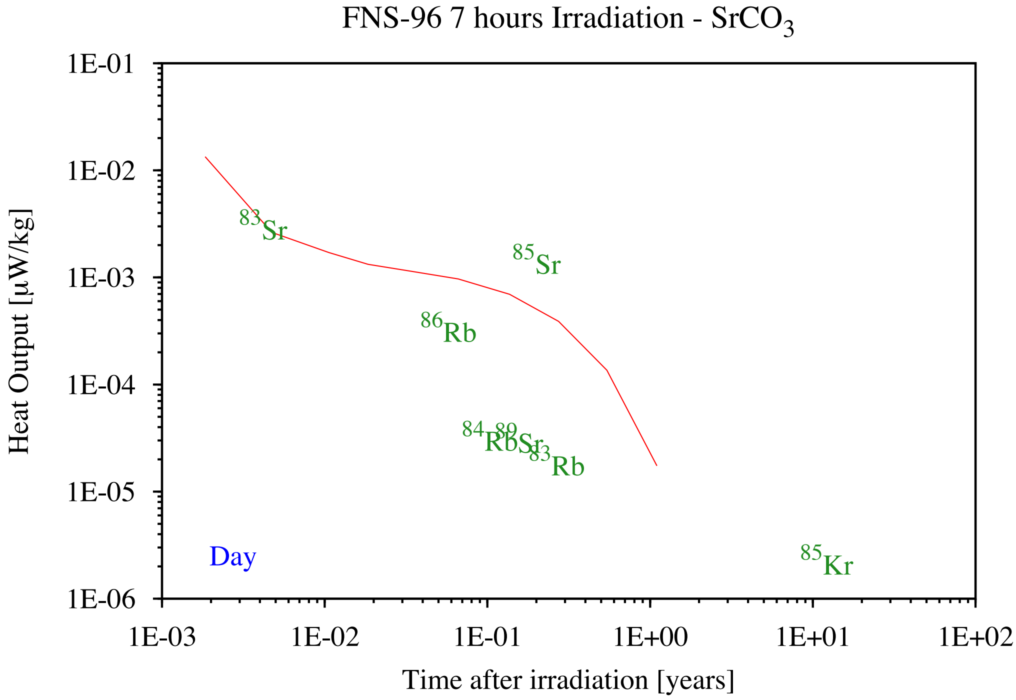




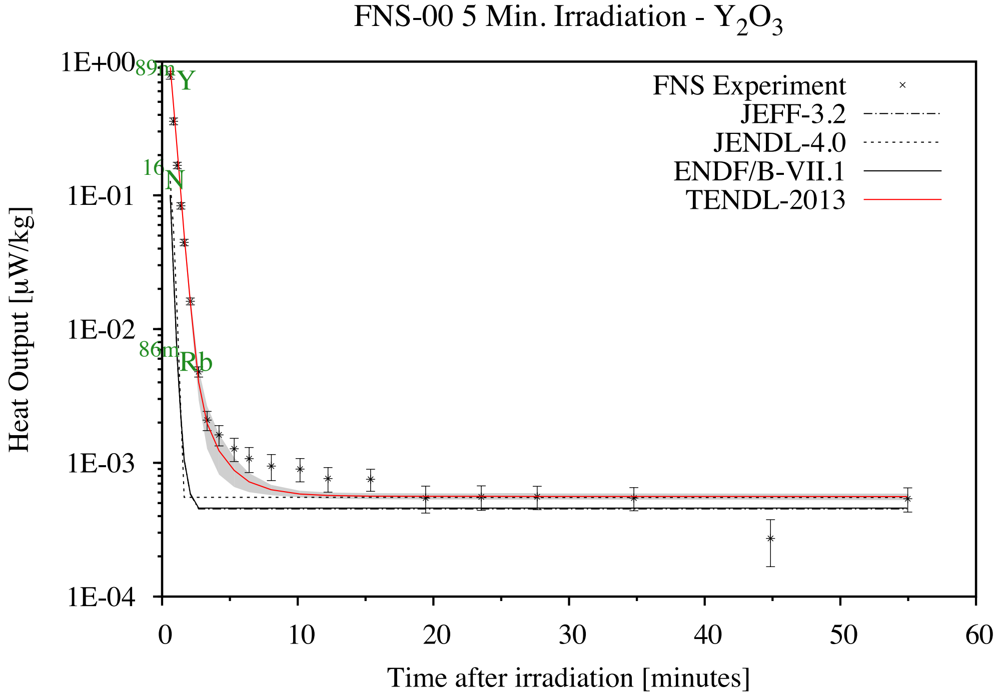
The above picture shows an unequivocal, near perfect agreement, in all cases on the heat arising from complex pathways.

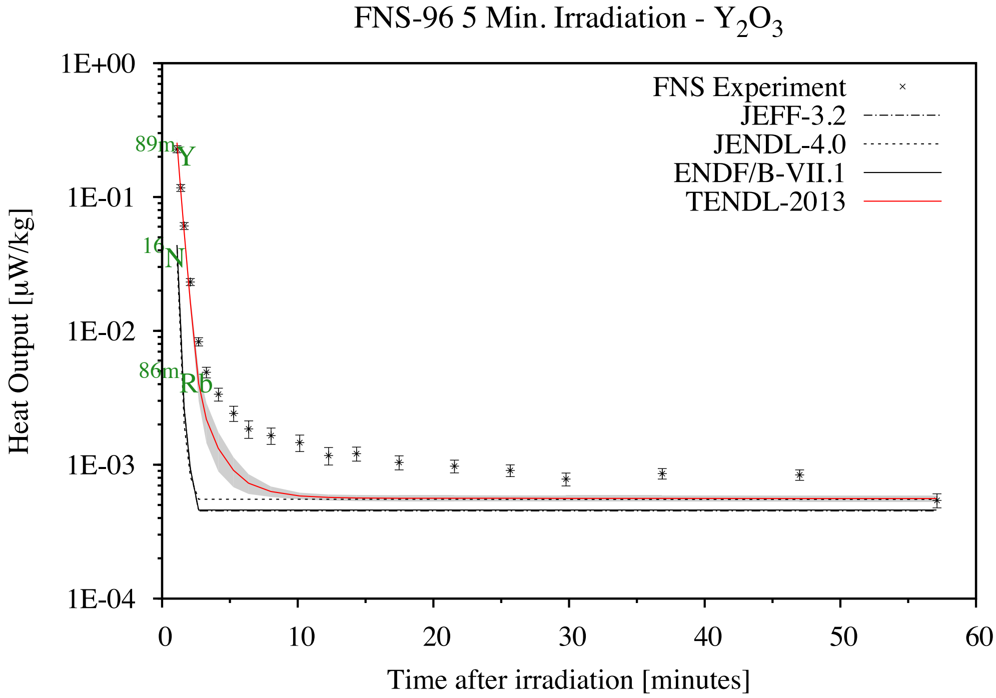
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.67	$1.31E{-}02$ +/-6%	$1.34E{-}02$ +/-6%	0.98	4.09	1.15	3.99
1.73	$2.76E{-}03$ +/-6%	$2.63E{-}03$ +/-6%	1.05	1.12	1.07	1.10
3.88	$1.73E{-}03$ +/-6%	$1.71E{-}03$ +/-5%	1.01	1.06	1.00	1.06
6.75	$1.34E{-}03$ +/-6%	$1.32E{-}03$ +/-6%	1.02	1.03	1.01	1.06
12.19	$1.14E{-}03$ +/-6%	$1.15E{-}03$ +/-6%	1.00	1.01	1.00	1.05
24.20	$9.61E{-}04$ +/-6%	$9.69E{-}04$ +/-6%	0.99	1.00	1.00	1.05
49.95	$7.01E{-}04$ +/-6%	$6.95E{-}04$ +/-7%	1.01	1.02	1.02	1.07
100.08	$3.76E{-}04$ +/-8%	$3.88E{-}04$ +/-7%	0.97	0.98	0.97	1.03
197.95	$1.41E{-}04$ +/-16%	$1.36E{-}04$ +/-7%	1.04	1.05	1.05	1.11
402.15	$1.33E{-}05$ +/-151%	$1.74E{-}05$ +/-8%	0.76	0.82	0.82	0.88

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Sr83	Sr84(n,2n)Sr83	1.3d	86.1	1.05	6%
	Sr84(n,2n)Sr83m		13.9	1.05	6%
Sr85	Sr86(n,2n)Sr85	64.8d	81.5	0.97	8%
	Sr86(n,2n)Sr85m		18.5	0.97	8%


FNS-96 7 hours Irradiation - SrCO3
Heat Output [µW/kg]
1E-01
1E-02
1E-03
1E-04
1E-05
1E-06
1E-03
1E-02
1E-01
1E+00
1E+01
1E+02
Time after irradiation [years]
83Sr
85Sr
86Rb
84Rb
89Sr
83Rb
85Kr
Day

Yttrium

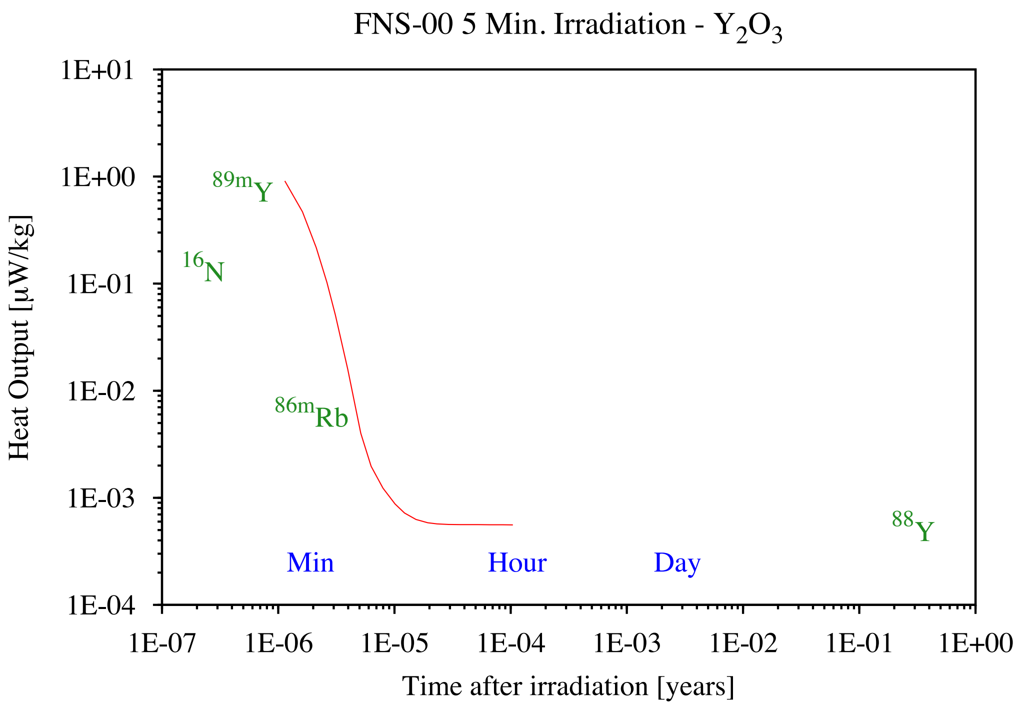


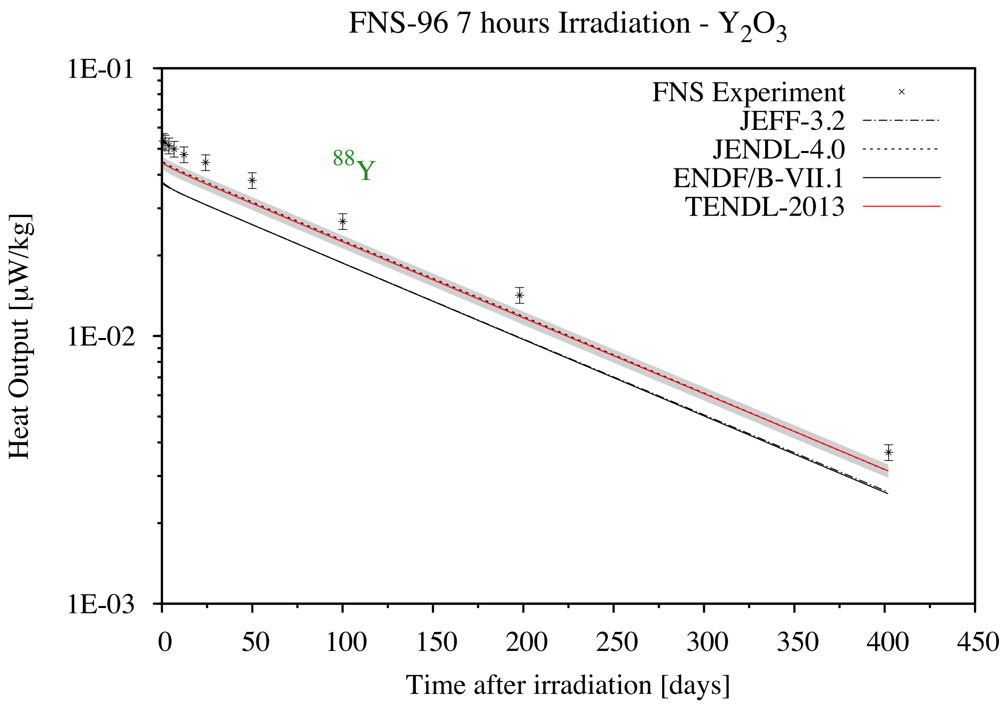


For Yttrium, here again the two experimental data sets differ significantly and the more recent one is accompanied by some rather high uncertainty levels. However, only TENDL-2013 properly predict the short lived predominant isotopes.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	7.92E−01 +/-7%	9.08E−01 +/-6%	0.87	7.88	7.88	6.18
0.85	3.58E−01 +/-6%	4.69E−01 +/-6%	0.76	13.96	13.96	6.41
1.12	1.68E−01 +/-6%	2.17E−01 +/-7%	0.77	28.39	28.34	13.55
1.38	8.35E−02 +/-6%	1.02E−01 +/-7%	0.82	37.81	37.85	35.41
1.63	4.44E−02 +/-6%	5.06E−02 +/-8%	0.88	41.98	42.19	80.59
2.08	1.61E−02 +/-6%	1.58E−02 +/-12%	1.02	27.39	27.68	29.23
2.70	4.80E−03 +/-9%	4.00E−03 +/-26%	1.20	10.46	10.61	8.70
3.32	2.08E−03 +/-16%	1.97E−03 +/-35%	1.06	4.54	4.61	3.78
4.20	1.62E−03 +/-17%	1.23E−03 +/-33%	1.32	3.53	3.58	2.93
5.32	1.27E−03 +/-20%	8.77E−04 +/-25%	1.45	2.78	2.81	2.31
6.42	1.07E−03 +/-21%	7.20E−04 +/-16%	1.49	2.34	2.37	1.95
8.05	9.46E−04 +/-22%	6.28E−04 +/-9%	1.50	2.06	2.09	1.71
10.17	8.98E−04 +/-20%	5.84E−04 +/-6%	1.54	1.96	1.99	1.63
12.23	7.62E−04 +/-21%	5.70E−04 +/-5%	1.34	1.66	1.69	1.38
15.37	7.54E−04 +/-19%	5.64E−04 +/-5%	1.34	1.64	1.67	1.37
19.43	5.45E−04 +/-23%	5.62E−04 +/-5%	0.97	1.19	1.21	0.99
23.53	5.56E−04 +/-21%	5.61E−04 +/-5%	0.99	1.21	1.23	1.01
27.65	5.57E−04 +/-20%	5.61E−04 +/-5%	0.99	1.22	1.23	1.01
34.78	5.45E−04 +/-20%	5.60E−04 +/-5%	0.97	1.19	1.21	0.99
44.85	2.72E−04 +/-38%	5.60E−04 +/-5%	0.49	0.59	0.60	0.49
54.97	5.39E−04 +/-20%	5.59E−04 +/-5%	0.96	1.18	1.19	0.98

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
N16	O16(n,p)N16	7.1s	99.9	0.87	7%
Y89m	Y89(n,n')Y89m	15.6s	100.0	0.87	6%
Rb86m	Y89(n,α)Rb86m	1.0m	100.0	0.77	6%
Y88	Y89(n,2n)Y88	106.6d	100.0	0.96	20%

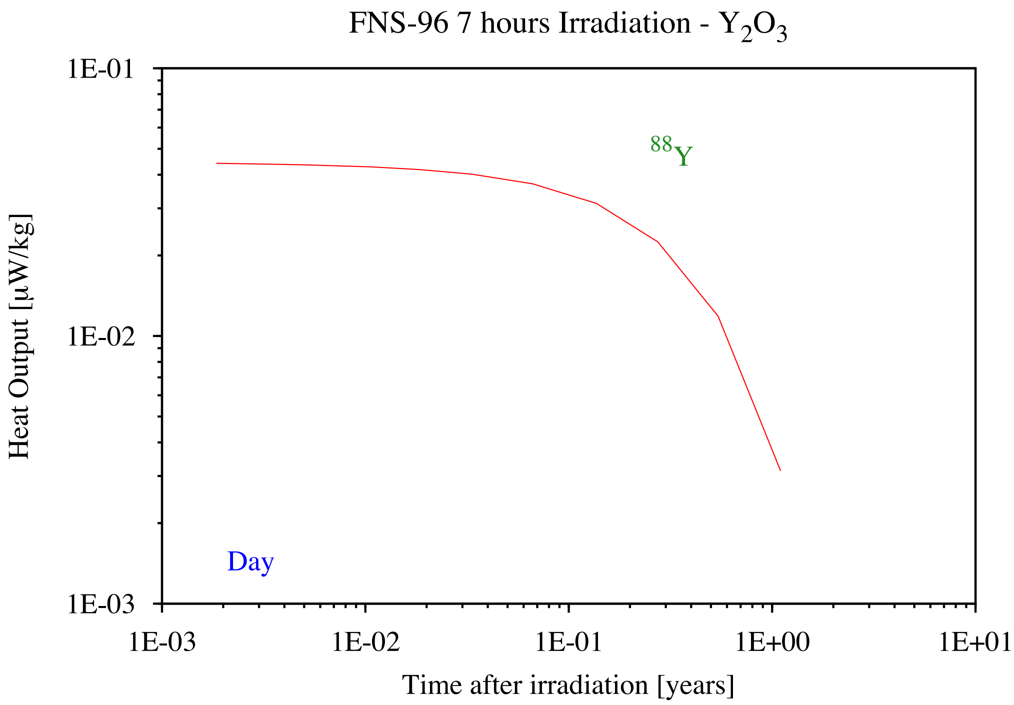




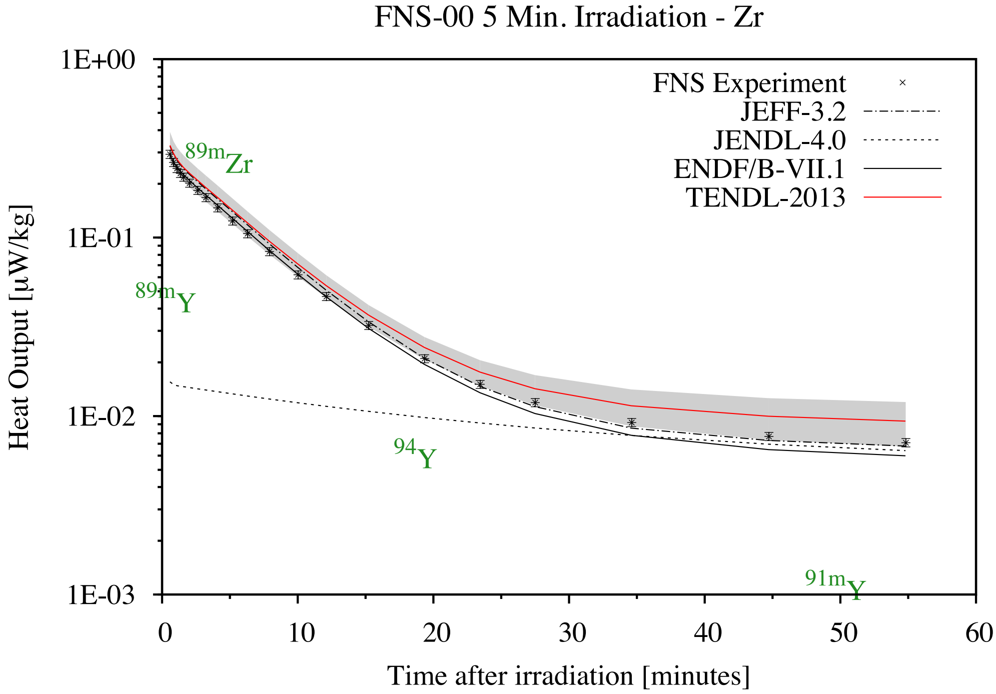
The code predictions underestimate the decay heat by around 20%, rather evenly and up to 400 days cooling for TENDL-2013 and JENDL-4.0. This unique (n,2n) pathway seems a perfect case to act on, although the question remains as to whether the change should be made to the cross section or decay file.

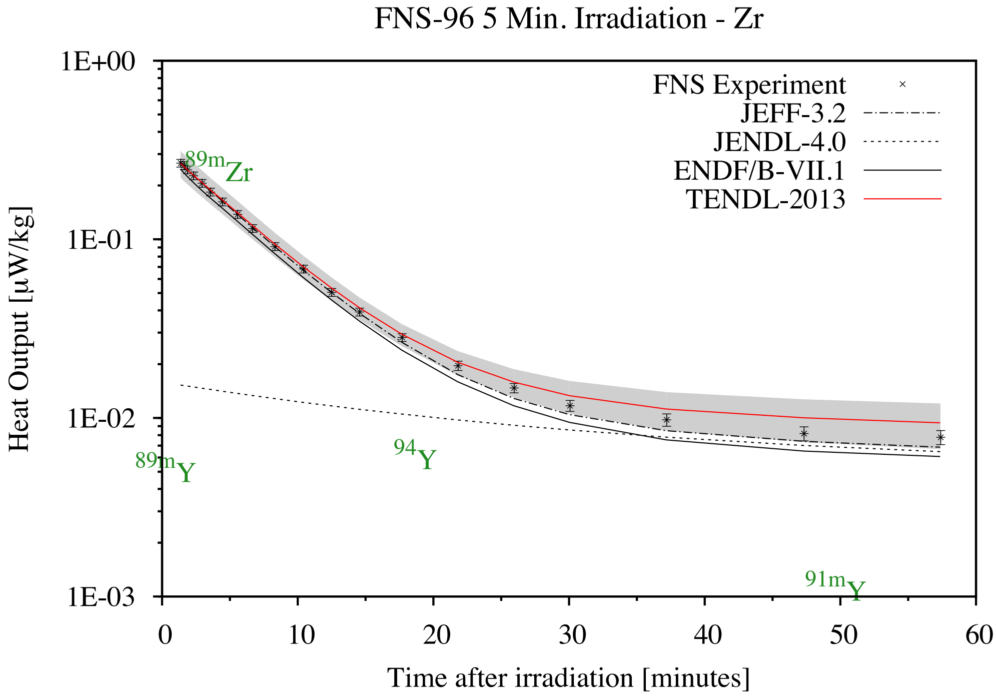
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.68	$5.35E{-}02$ +/-7%	$4.42E{-}02$ +/-5%	1.21	1.43	1.45	1.20
1.73	$5.27E{-}02$ +/-7%	$4.36E{-}02$ +/-5%	1.21	1.43	1.44	1.19
3.89	$5.14E{-}02$ +/-7%	$4.28E{-}02$ +/-6%	1.20	1.43	1.44	1.18
6.76	$5.00E{-}02$ +/-7%	$4.18E{-}02$ +/-6%	1.19	1.43	1.43	1.18
12.20	$4.76E{-}02$ +/-7%	$4.02E{-}02$ +/-6%	1.18	1.42	1.42	1.17
24.21	$4.45E{-}02$ +/-7%	$3.70E{-}02$ +/-6%	1.20	1.44	1.44	1.18
49.96	$3.81E{-}02$ +/-7%	$3.13E{-}02$ +/-6%	1.22	1.46	1.46	1.20
100.09	$2.68E{-}02$ +/-7%	$2.25E{-}02$ +/-6%	1.19	1.43	1.43	1.18
197.96	$1.42E{-}02$ +/-7%	$1.18E{-}02$ +/-6%	1.20	1.44	1.44	1.18
402.17	$3.67E{-}03$ +/-7%	$3.13E{-}03$ +/-6%	1.17	1.43	1.41	1.17

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Y88	Y89(n,2n)Y88	106d	100.0	1.19	7%


FNS-96 7 hours Irradiation - Y_2O_3
^{88}Y
Day
Heat Output [µW/kg]
1E-01
1E-02
1E-03
1E-03
1E-02
1E-01
1E+00
1E+01
Time after irradiation [years]

Zirconium

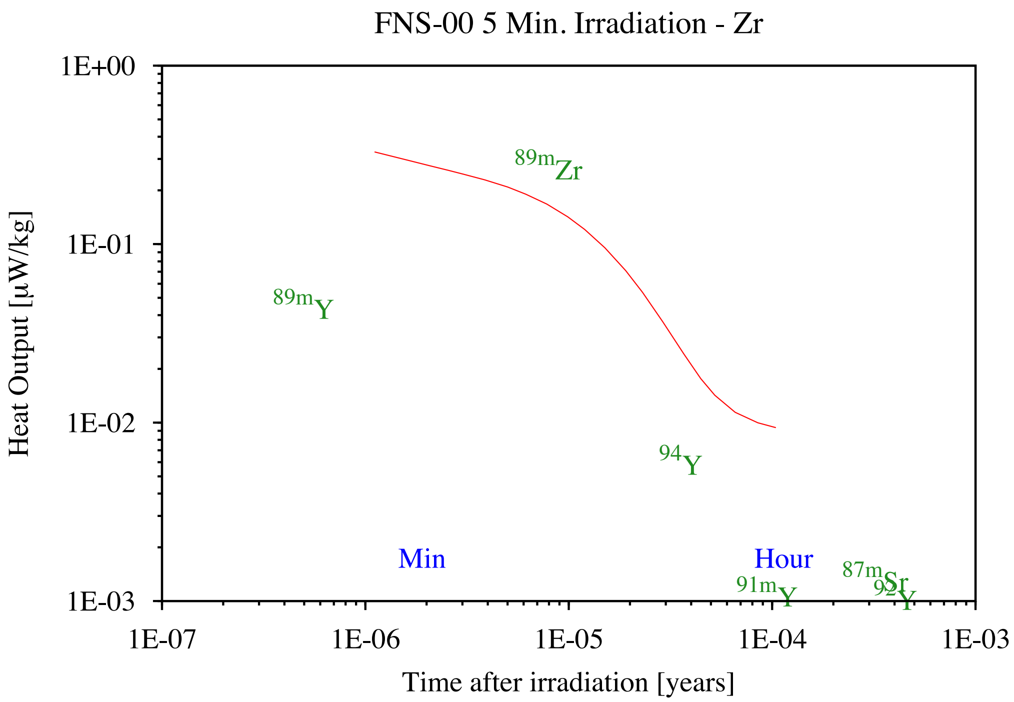


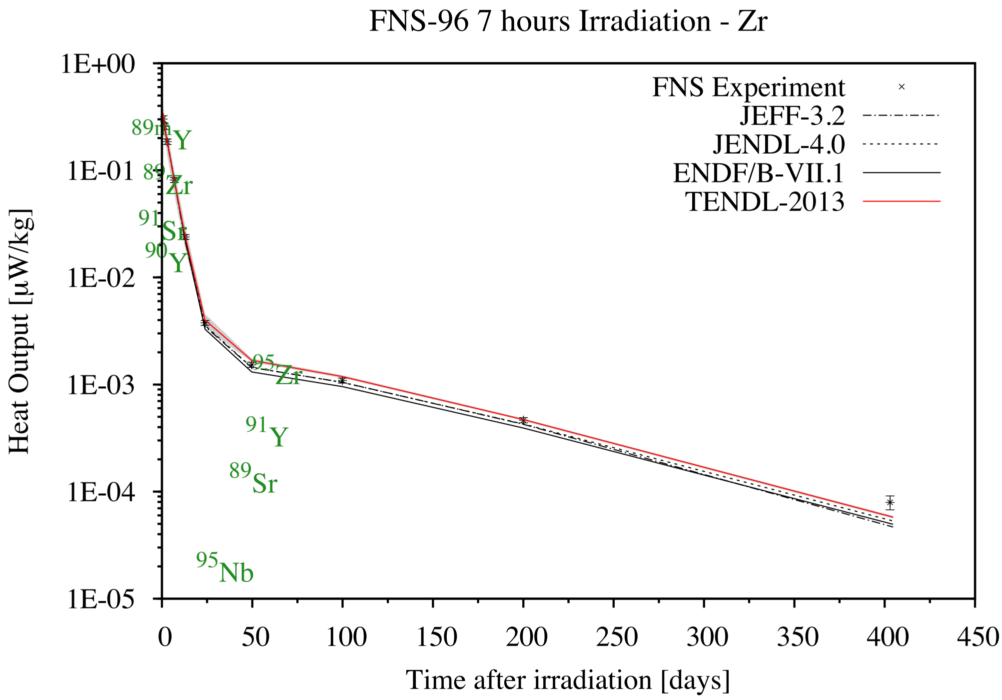


For Zirconium, a good agreement at all cooling times may be seen, when ENDF/B-VII.1 and JEFF-3.2 are used. TENDL-2013 seems to over-predict Y94 by circa 15%. JENDL-4.0 does not produce Zr89m.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	$2.93E{-}01$ +/-5%	$3.28E{-}01$ +/-19%	0.89	1.01	0.90	18.87
0.85	$2.64E{-}01$ +/-5%	$2.95E{-}01$ +/-17%	0.89	1.00	0.91	17.58
1.10	$2.44E{-}01$ +/-5%	$2.74E{-}01$ +/-17%	0.89	0.98	0.90	16.50
1.35	$2.29E{-}01$ +/-5%	$2.59E{-}01$ +/-17%	0.89	0.97	0.90	15.59
1.60	$2.18E{-}01$ +/-5%	$2.46E{-}01$ +/-17%	0.88	0.97	0.90	14.94
2.03	$2.02E{-}01$ +/-5%	$2.29E{-}01$ +/-17%	0.88	0.97	0.90	14.00
2.63	$1.84E{-}01$ +/-5%	$2.09E{-}01$ +/-17%	0.88	0.97	0.90	12.95
3.23	$1.68E{-}01$ +/-5%	$1.90E{-}01$ +/-17%	0.88	0.97	0.90	11.97
4.10	$1.47E{-}01$ +/-5%	$1.68E{-}01$ +/-17%	0.88	0.97	0.89	10.73
5.20	$1.24E{-}01$ +/-5%	$1.42E{-}01$ +/-16%	0.87	0.97	0.89	9.31
6.30	$1.05E{-}01$ +/-5%	$1.21E{-}01$ +/-16%	0.87	0.97	0.89	8.12
7.92	$8.35E{-}02$ +/-5%	$9.54E{-}02$ +/-16%	0.88	0.98	0.90	6.71
10.02	$6.19E{-}02$ +/-5%	$7.11E{-}02$ +/-15%	0.87	0.99	0.91	5.22
12.12	$4.67E{-}02$ +/-5%	$5.38E{-}02$ +/-15%	0.87	1.01	0.92	4.13
15.23	$3.22E{-}02$ +/-5%	$3.68E{-}02$ +/-14%	0.87	1.04	0.95	3.03
19.35	$2.10E{-}02$ +/-5%	$2.42E{-}02$ +/-14%	0.87	1.08	1.00	2.14
23.45	$1.51E{-}02$ +/-5%	$1.76E{-}02$ +/-17%	0.85	1.12	1.03	1.65
27.50	$1.19E{-}02$ +/-5%	$1.42E{-}02$ +/-19%	0.84	1.15	1.05	1.39
34.62	$9.20E{-}03$ +/-5%	$1.14E{-}02$ +/-23%	0.81	1.18	1.08	1.18
44.73	$7.69E{-}03$ +/-5%	$9.98E{-}03$ +/-26%	0.77	1.19	1.05	1.10
54.83	$7.09E{-}03$ +/-5%	$9.37E{-}03$ +/-28%	0.76	1.18	1.04	1.11

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Zr89m	Zr90(n,2n)Zr89m	4.1m	100.0	0.89	5%
Y94	Zr94(n,p)Y94	18.7m	100.0	0.87	5%

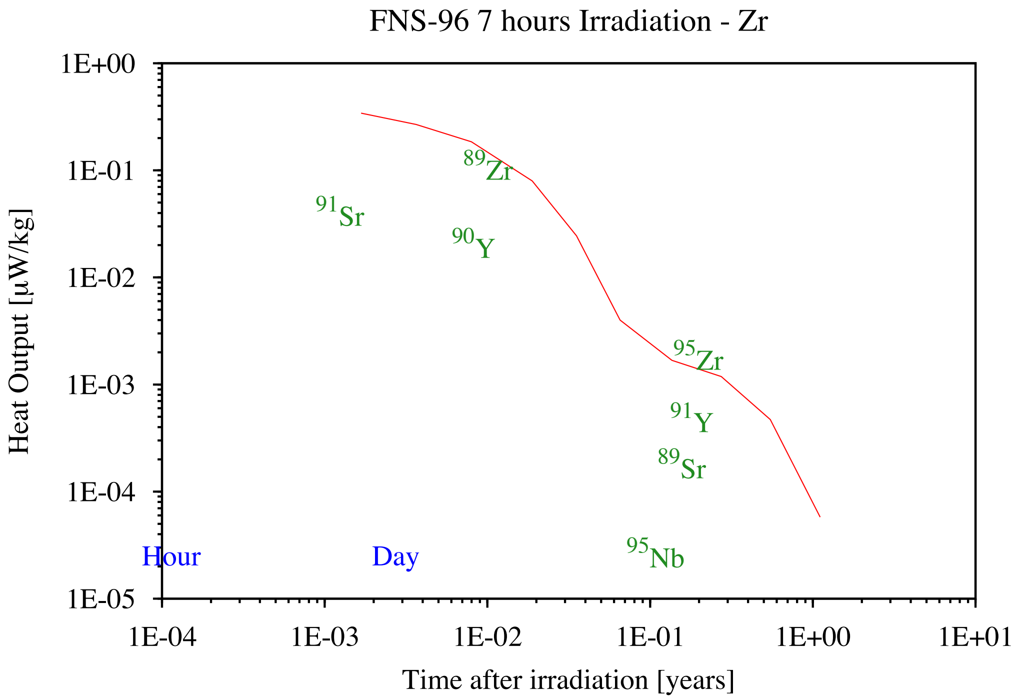




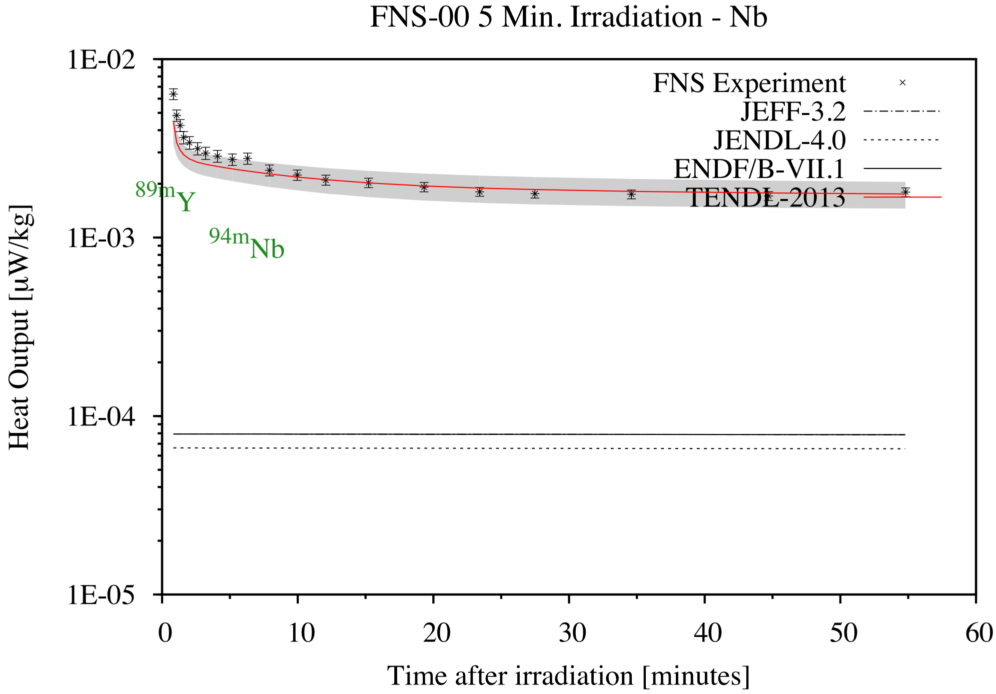
Although numerous radionuclides are present excellent agreements exist, within the experimental uncertainty, up to a year of cooling.

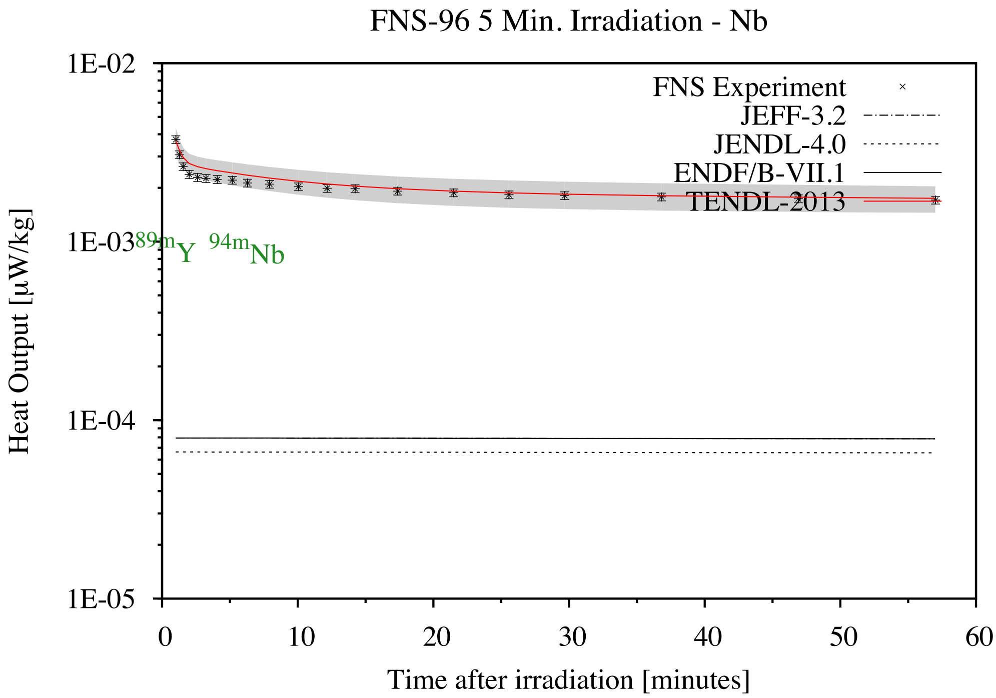
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.61	$3.02E{-}01$ +/-7%	$3.42E{-}01$ +/-23%	0.88	0.98	0.98	0.96
1.33	$2.57E{-}01$ +/-7%	$2.68E{-}01$ +/-25%	0.96	0.99	1.00	0.97
2.91	$1.85E{-}01$ +/-6%	$1.85E{-}01$ +/-26%	1.00	1.00	1.01	0.98
6.88	$8.12E{-}02$ +/-5%	$7.96E{-}02$ +/-25%	1.02	1.00	1.02	0.99
12.88	$2.39E{-}02$ +/-5%	$2.45E{-}02$ +/-24%	0.97	1.04	1.09	1.06
23.85	$3.77E{-}03$ +/-5%	$4.00E{-}03$ +/-14%	0.94	1.15	1.08	1.06
49.71	$1.53E{-}03$ +/-5%	$1.68E{-}03$ +/-4%	0.91	1.17	1.06	1.06
99.90	$1.09E{-}03$ +/-5%	$1.19E{-}03$ +/-3%	0.92	1.14	1.04	1.04
200.12	$4.64E{-}04$ +/-6%	$4.71E{-}04$ +/-2%	0.99	1.18	1.09	1.09
402.96	$7.94E{-}05$ +/-15%	$5.78E{-}05$ +/-3%	1.37	1.60	1.70	1.49

Product	Pathways	$T_{1/2}$	Path %	E/C	ΔE%
Zr89	Zr90(n,2n)Zr89	3.2d	83.4	1.00	6%
	Zr90(n,2n)Zr89m	4.18m	16.6	1.00	6%
Zr95	Zr96(n,2n)Zr95	64.0d	99.4	0.92	5%


FNS-96 7 hours Irradiation - Zr
Heat Output [µW/kg]
Time after irradiation [years]
1E+00
1E-01
1E-02
1E-03
1E-04
1E-05
1E-04
1E-03
1E-02
1E-01
1E+00
1E+01
89Zr
91Sr
90Y
95Zr
91Y
89Sr
95Nb
Hour
Day

Niobium

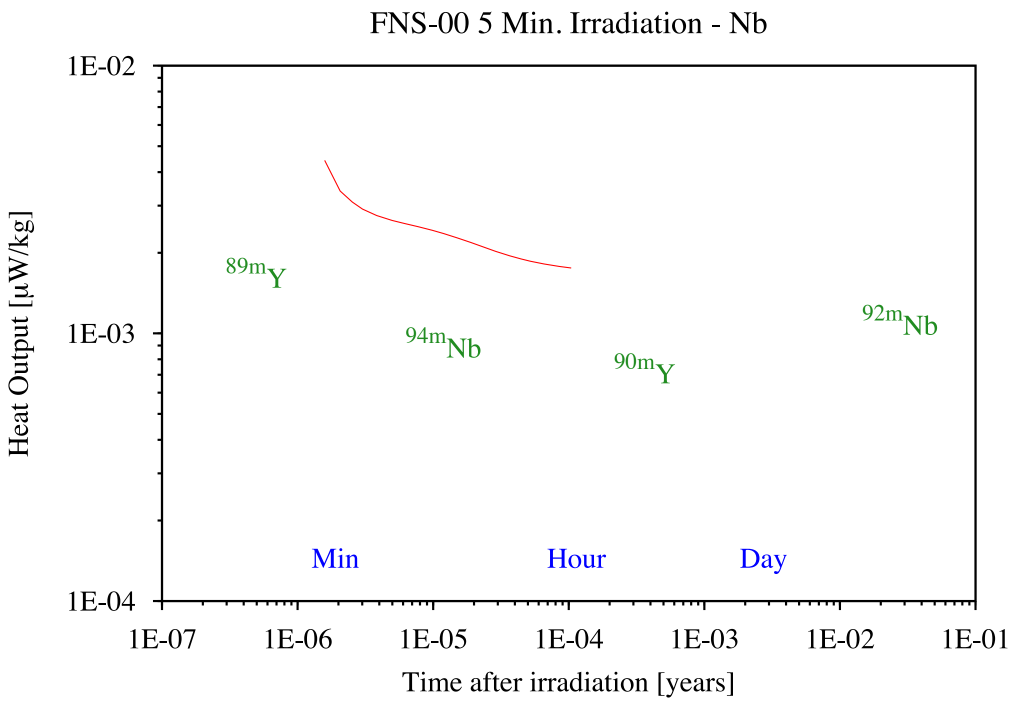


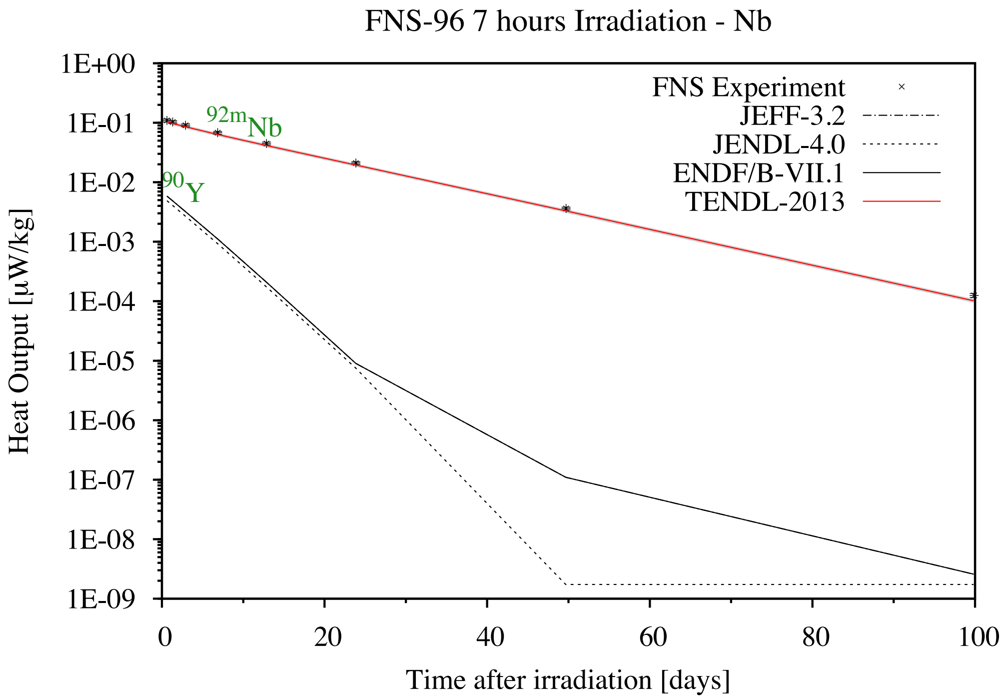


For Niobium, the difficulties in predicting its decay heat derive from the determination of the energy dependant isomeric branching ratios of the three isomers that dominate the response function. Obviously none of the major libraries, ENDF/B-VII.1, JEFF-3.2 or JENDL-4.0 contains such crucial branching informations.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.83	6.37E−03 +/-7%	4.43E−03 +/-25%	1.44	80.31	80.31	96.19
1.08	4.83E−03 +/-7%	3.40E−03 +/-16%	1.42	60.88	60.88	72.92
1.33	4.25E−03 +/-8%	3.09E−03 +/-14%	1.37	53.57	53.57	64.17
1.58	3.64E−03 +/-8%	2.91E−03 +/-13%	1.25	45.83	45.83	54.89
2.02	3.40E−03 +/-8%	2.75E−03 +/-13%	1.24	42.88	42.88	51.36
2.62	3.15E−03 +/-8%	2.64E−03 +/-14%	1.19	39.72	39.72	47.57
3.22	2.98E−03 +/-8%	2.57E−03 +/-14%	1.16	37.52	37.52	44.94
4.08	2.86E−03 +/-8%	2.50E−03 +/-14%	1.14	36.05	36.05	43.18
5.18	2.74E−03 +/-7%	2.43E−03 +/-15%	1.13	34.54	34.54	41.37
6.30	2.78E−03 +/-7%	2.36E−03 +/-15%	1.18	35.00	35.00	41.93
7.92	2.38E−03 +/-7%	2.27E−03 +/-15%	1.05	30.07	30.07	36.01
9.97	2.24E−03 +/-7%	2.18E−03 +/-16%	1.03	28.30	28.30	33.90
12.07	2.10E−03 +/-6%	2.11E−03 +/-16%	1.00	26.54	26.54	31.79
15.22	2.03E−03 +/-6%	2.03E−03 +/-17%	1.00	25.62	25.62	30.69
19.32	1.92E−03 +/-6%	1.95E−03 +/-17%	0.99	24.28	24.28	29.08
23.42	1.81E−03 +/-6%	1.89E−03 +/-17%	0.95	22.85	22.85	27.37
27.48	1.76E−03 +/-6%	1.86E−03 +/-17%	0.95	22.31	22.31	26.72
34.60	1.75E−03 +/-6%	1.82E−03 +/-17%	0.96	22.16	22.16	26.54
44.70	1.71E−03 +/-6%	1.78E−03 +/-17%	0.96	21.72	21.72	26.01
54.82	1.80E−03 +/-6%	1.75E−03 +/-17%	1.02	22.87	22.87	27.39

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Y89m	Nb93(n,nα)Y89m	15.6s	99.8	1.44	7%
Nb94m	Nb93(n,γ)Nb94m	6.2m	99.8	1.13	7%
Y90m	Nb93(n,α)Y90m	3.1h	100.0	1.02	6%

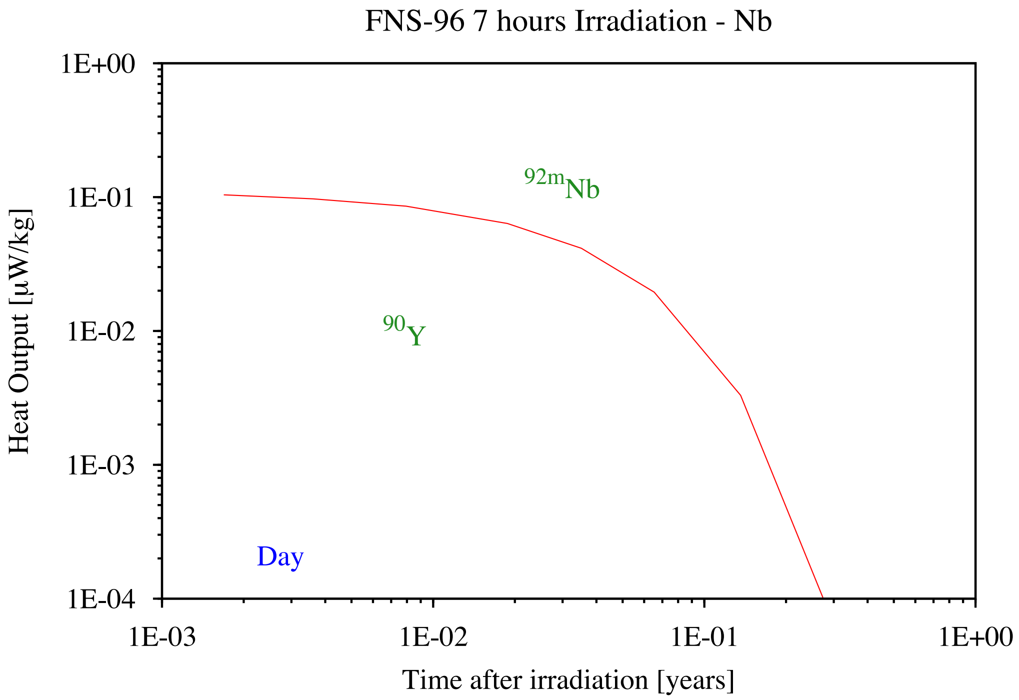




A superb agreement occurs on the route of production and decay data for the metastable isotope Nb92m, up to 100 days of cooling. However, no such production path exists in ENDF/B-VII.1, JEFF-3.2 or JENDL-4.0.

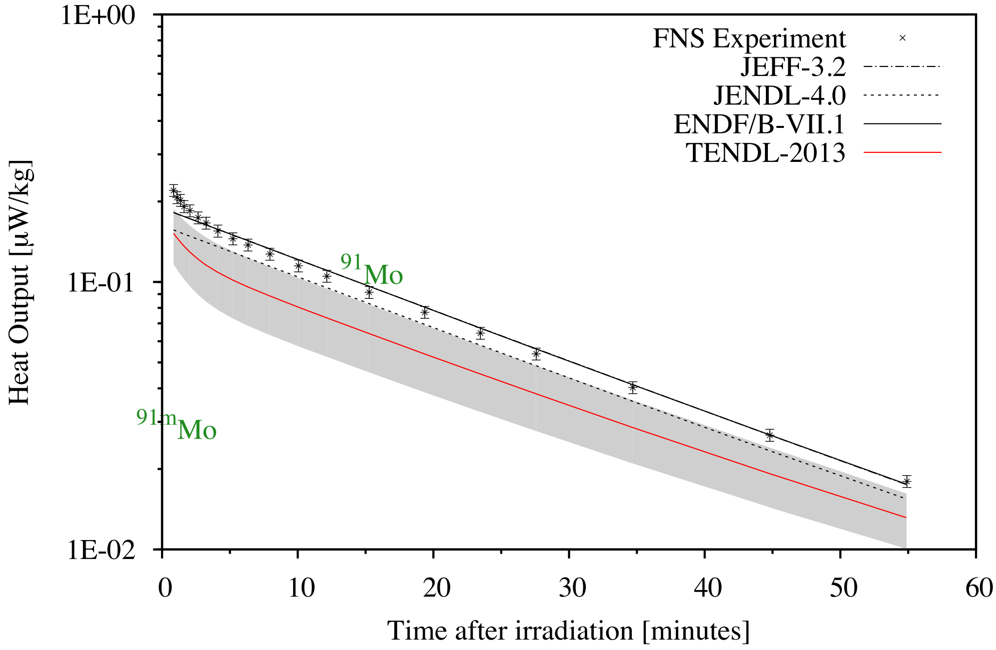
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.62	$1.09E{-}01$ +/-6%	$1.04E{-}01$ +/-7%	1.05	18.67	18.67	22.36
1.32	$1.03E{-}01$ +/-6%	$9.71E{-}02$ +/-7%	1.06	21.12	21.12	25.30
2.90	$9.08E{-}02$ +/-6%	$8.57E{-}02$ +/-6%	1.06	28.22	28.22	33.79
6.86	$6.81E{-}02$ +/-6%	$6.35E{-}02$ +/-6%	1.07	61.19	61.19	73.27
12.86	$4.48E{-}02$ +/-5%	$4.15E{-}02$ +/-6%	1.08	214.08	214.08	256.34
23.85	$2.10E{-}02$ +/-5%	$1.95E{-}02$ +/-7%	1.08	2330.21	2330.21	2794.93
49.70	$3.62E{-}03$ +/-5%	$3.30E{-}03$ +/-7%	1.10	32937.15	32937.15	2090523.96
99.89	$1.25E{-}04$ +/-8%	$1.02E{-}04$ +/-6%	1.23	48596.18	48596.18	72376.77

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Nb92m	Nb93(n,2n)Nb92m	10.1d	100.0	1.08	5%

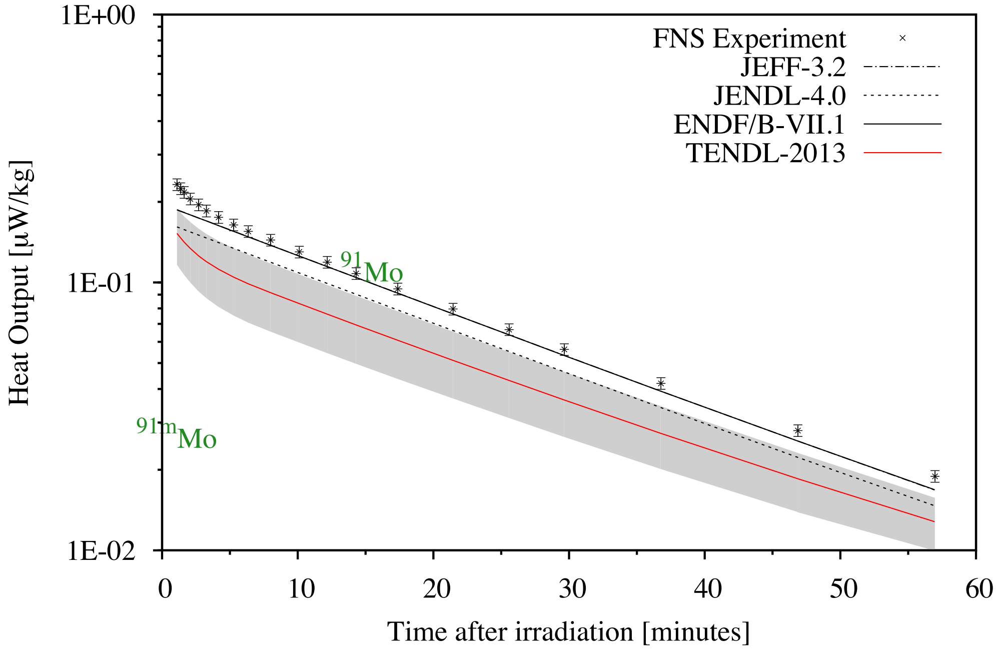

FNS-96 7 hours Irradiation - Nb
Heat Output [µW/kg]
1E+00
1E-01
1E-02
1E-03
1E-04
92mNb
90Y
Day
1E-03
1E-02
1E-01
1E+00
Time after irradiation [years]

Molybdenum

FNS-00 5 Min. Irradiation - Mo



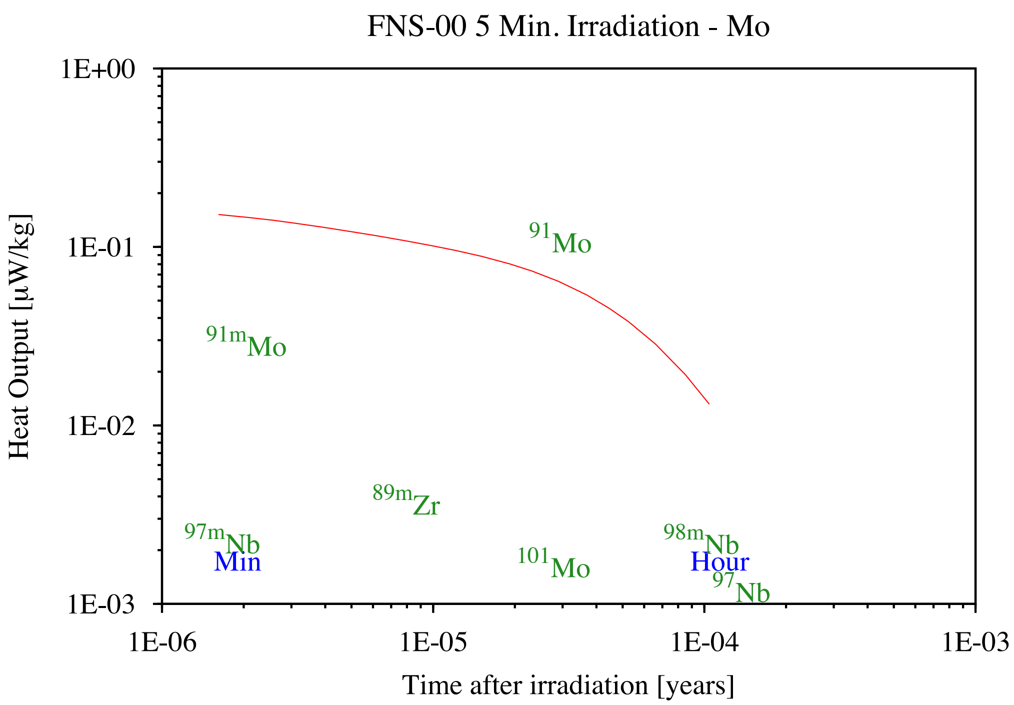
FNS-96 5 Min. Irradiation - Mo

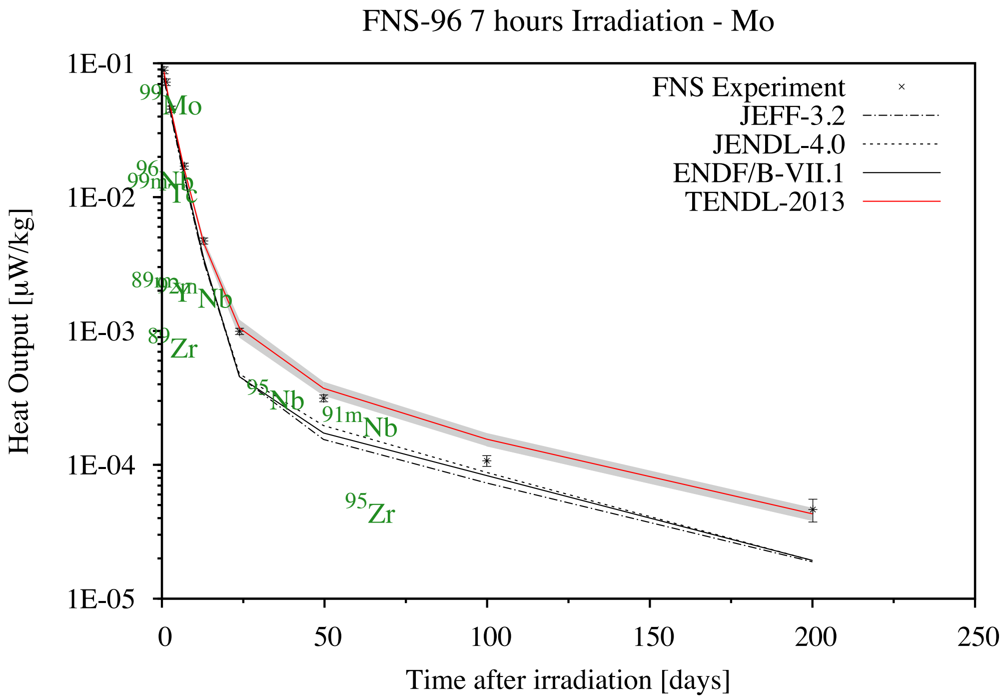


For Molybdenum, a better agreement with the experimental results was seen when the TENDL-2011 data library [13] was used to predict the experiment. However, the two experimental batches differ somewhat, well above the quoted experimental uncertainty. ENDF/B-VII.1 or JEFF-3.2 total (n,2n) lead to a better agreement.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.85	2.20E−01 +/-5%	1.52E−01 +/-23%	1.45	1.21	1.21	1.41
1.10	2.07E−01 +/-5%	1.46E−01 +/-24%	1.41	1.15	1.15	1.34
1.35	2.02E−01 +/-5%	1.41E−01 +/-24%	1.43	1.14	1.14	1.32
1.62	1.92E−01 +/-5%	1.36E−01 +/-25%	1.41	1.09	1.09	1.27
2.05	1.85E−01 +/-5%	1.29E−01 +/-26%	1.43	1.07	1.07	1.25
2.65	1.74E−01 +/-5%	1.22E−01 +/-26%	1.43	1.04	1.04	1.20
3.25	1.66E−01 +/-5%	1.16E−01 +/-27%	1.44	1.02	1.02	1.18
4.12	1.55E−01 +/-5%	1.09E−01 +/-28%	1.43	0.99	0.99	1.15
5.22	1.45E−01 +/-5%	1.02E−01 +/-28%	1.43	0.97	0.97	1.12
6.33	1.38E−01 +/-5%	9.58E−02 +/-28%	1.44	0.96	0.96	1.12
7.95	1.27E−01 +/-5%	8.86E−02 +/-29%	1.43	0.96	0.96	1.11
10.05	1.15E−01 +/-5%	8.05E−02 +/-29%	1.43	0.95	0.95	1.10
12.15	1.05E−01 +/-5%	7.34E−02 +/-29%	1.43	0.95	0.95	1.10
15.27	9.15E−02 +/-5%	6.41E−02 +/-28%	1.43	0.95	0.95	1.10
19.37	7.70E−02 +/-5%	5.38E−02 +/-28%	1.43	0.96	0.96	1.11
23.47	6.44E−02 +/-5%	4.53E−02 +/-28%	1.42	0.96	0.96	1.11
27.58	5.38E−02 +/-5%	3.82E−02 +/-27%	1.41	0.96	0.96	1.11
34.70	4.03E−02 +/-5%	2.86E−02 +/-27%	1.41	0.98	0.97	1.13
44.80	2.67E−02 +/-5%	1.92E−02 +/-25%	1.39	1.00	1.00	1.14
54.90	1.80E−02 +/-5%	1.31E−02 +/-23%	1.37	1.02	1.03	1.16

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Mo91	Mo92(n,2n)Mo91	15.49m	96.4	1.43	5%
	Mo92(n,2n)Mo91m	1.0m	3.9	1.43	5%

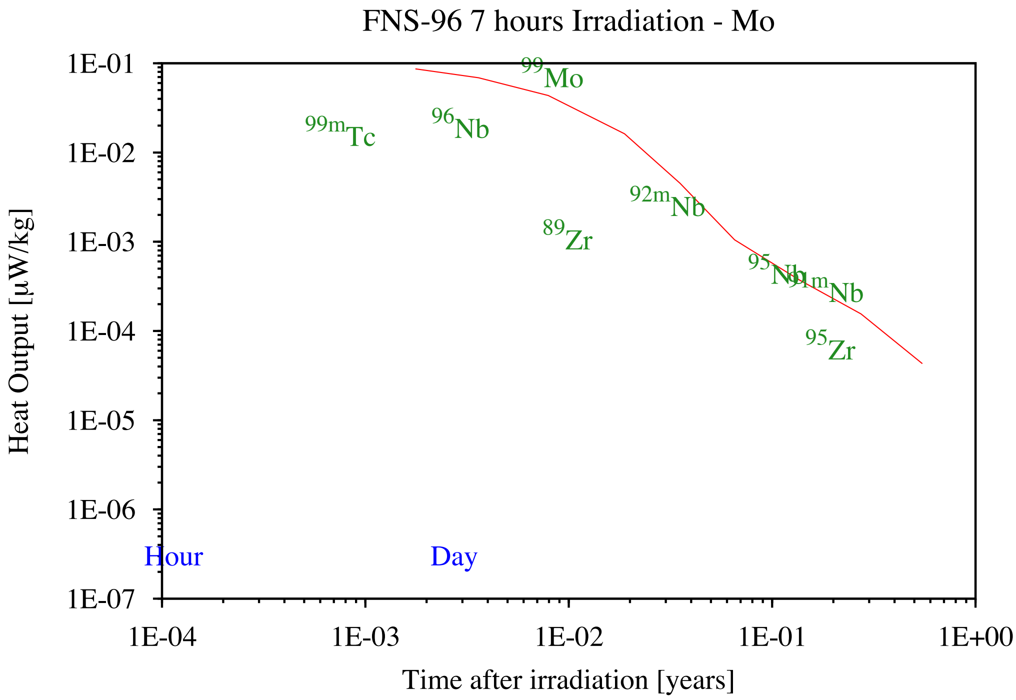




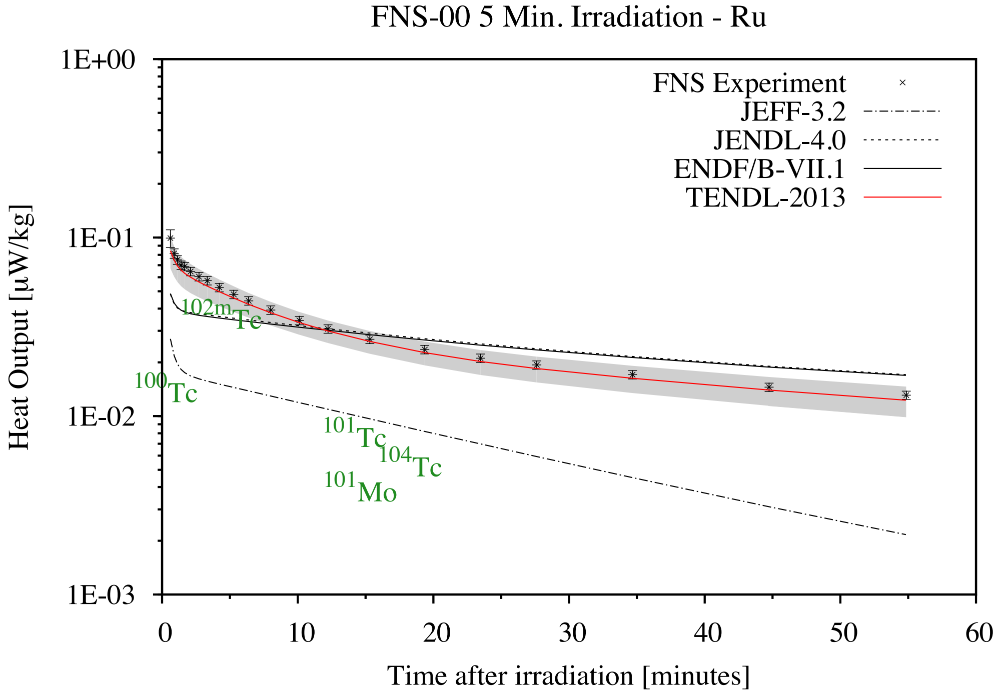
The complex time dependence of the decay heat arising from Mo is well shaped by the predicted results up to 200 days of cooling when the TENDL-2013 library is used.

Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.64	$8.87E-02$ +/-6%	$8.65E-02$ +/-4%	1.03	1.10	1.14	1.17
1.31	$7.23E-02$ +/-6%	$6.89E-02$ +/-4%	1.05	1.08	1.14	1.16
2.90	$4.54E-02$ +/-5%	$4.34E-02$ +/-3%	1.05	1.08	1.15	1.17
6.86	$1.70E-02$ +/-5%	$1.62E-02$ +/-4%	1.05	1.16	1.22	1.23
12.86	$4.71E-03$ +/-5%	$4.53E-03$ +/-8%	1.04	1.36	1.43	1.40
23.86	$9.95E-04$ +/-5%	$1.05E-03$ +/-15%	0.95	2.19	2.18	2.09
49.71	$3.14E-04$ +/-6%	$3.73E-04$ +/-12%	0.84	1.82	2.03	1.60
99.90	$1.07E-04$ +/-9%	$1.55E-04$ +/-11%	0.69	1.29	1.47	1.22
200.14	$4.64E-05$ +/-19%	$4.30E-05$ +/-11%	1.08	2.40	2.46	2.41

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Mo99	Mo100(n,2n)Mo99	2.7d	99.6	1.05	5%
Nb92m	Mo92(n,p)Nb92m	10.1d	99.9	1.04	5%
Nb95	Mo95(n,p)Nb95	34.9d	90.3	0.95	6%
	Mo96(n,d)Nb95		8.7	0.95	6%
Nb91m	Mo92(n,d+np)Nb91m	60.9d	97.8	0.84	9%
	Mo92(n,2n)Mo91m		2.2	0.84	9%
Zr95	Mo98(n,α)Zr95	64.0d	100.0	1.08	19%


FNS-96 7 hours Irradiation - Mo
Heat Output [µW/kg]
1E-01
1E-02
1E-03
1E-04
1E-05
1E-06
1E-07
1E-04
1E-03
1E-02
1E-01
1E+00
Time after irradiation [years]
99Mo
99mTc
96Nb
92mNb
89Zr
95Nb
91mNb
95Zr
Hour
Day

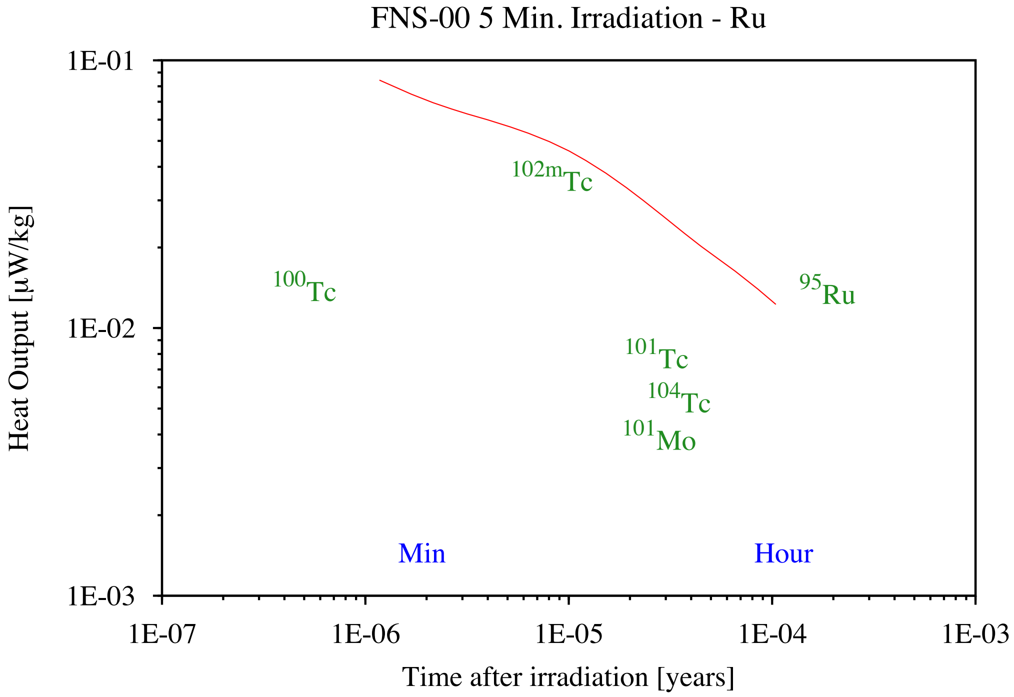
Ruthenium



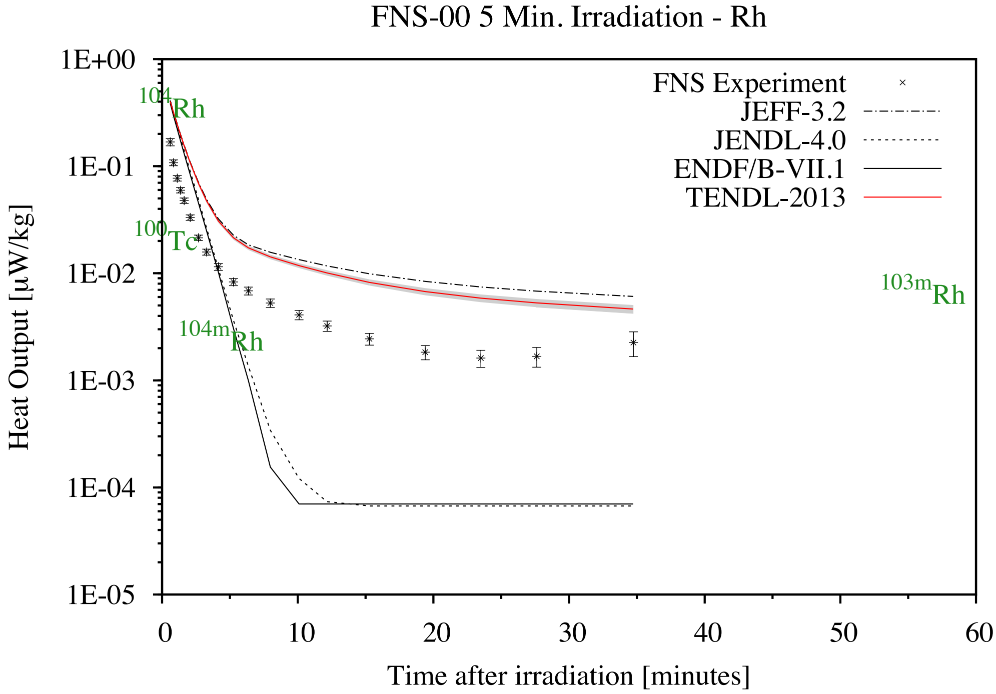
For Ruthenium, a superb fit can be seen in the short term prediction of the decay heat of this element when the TENDL-2013 databases is used. The short-lived Tc102m isomer was missing in TENDL-2012, causing the under prediction [13]. JEFF-3.2 predicts poorly.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.62	$9.93E{-}02$ +/-11%	$8.44E{-}02$ +/-20%	1.18	2.04	3.67	2.06
0.88	$8.15E{-}02$ +/-6%	$7.47E{-}02$ +/-19%	1.09	1.90	3.74	1.92
1.13	$7.50E{-}02$ +/-6%	$6.94E{-}02$ +/-19%	1.08	1.84	3.83	1.86
1.40	$7.00E{-}02$ +/-5%	$6.57E{-}02$ +/-19%	1.07	1.79	3.83	1.79
1.67	$6.89E{-}02$ +/-5%	$6.31E{-}02$ +/-19%	1.09	1.80	3.94	1.78
2.10	$6.46E{-}02$ +/-5%	$5.99E{-}02$ +/-18%	1.08	1.73	3.85	1.70
2.72	$6.04E{-}02$ +/-5%	$5.64E{-}02$ +/-18%	1.07	1.65	3.74	1.62
3.33	$5.74E{-}02$ +/-5%	$5.34E{-}02$ +/-18%	1.07	1.59	3.66	1.56
4.22	$5.25E{-}02$ +/-5%	$4.97E{-}02$ +/-17%	1.06	1.48	3.48	1.45
5.28	$4.81E{-}02$ +/-5%	$4.58E{-}02$ +/-16%	1.05	1.39	3.32	1.36
6.38	$4.42E{-}02$ +/-5%	$4.23E{-}02$ +/-16%	1.05	1.31	3.20	1.28
8.02	$3.93E{-}02$ +/-5%	$3.79E{-}02$ +/-15%	1.04	1.20	3.03	1.17
10.12	$3.43E{-}02$ +/-5%	$3.34E{-}02$ +/-15%	1.03	1.09	2.89	1.07
12.23	$3.08E{-}02$ +/-5%	$3.00E{-}02$ +/-14%	1.03	1.02	2.82	1.00
15.32	$2.69E{-}02$ +/-5%	$2.62E{-}02$ +/-15%	1.03	0.94	2.79	0.92
19.37	$2.36E{-}02$ +/-5%	$2.27E{-}02$ +/-15%	1.04	0.88	2.87	0.87
23.48	$2.11E{-}02$ +/-5%	$2.02E{-}02$ +/-16%	1.04	0.85	3.03	0.83
27.62	$1.93E{-}02$ +/-5%	$1.85E{-}02$ +/-17%	1.05	0.82	3.26	0.81
34.68	$1.70E{-}02$ +/-5%	$1.63E{-}02$ +/-17%	1.05	0.80	3.77	0.79
44.75	$1.45E{-}02$ +/-5%	$1.40E{-}02$ +/-18%	1.04	0.77	4.68	0.76
54.87	$1.31E{-}02$ +/-5%	$1.23E{-}02$ +/-19%	1.07	0.77	6.05	0.77

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Tc100	Ru100(n,p)Tc100	15.8s	84.6	1.18	11%
	Ru101(n,d+np)Tc100		15.4	1.18	11%
Tc102	Ru102(n,p)Tc102	5.3s	99.8	1.07	5%
Tc102m	Ru102(n,p)Tc102m	4.3m	0.0	1.07	5%
Ru95	Ru96(n,2n)Ru95	1.6h	100.0	1.07	5%



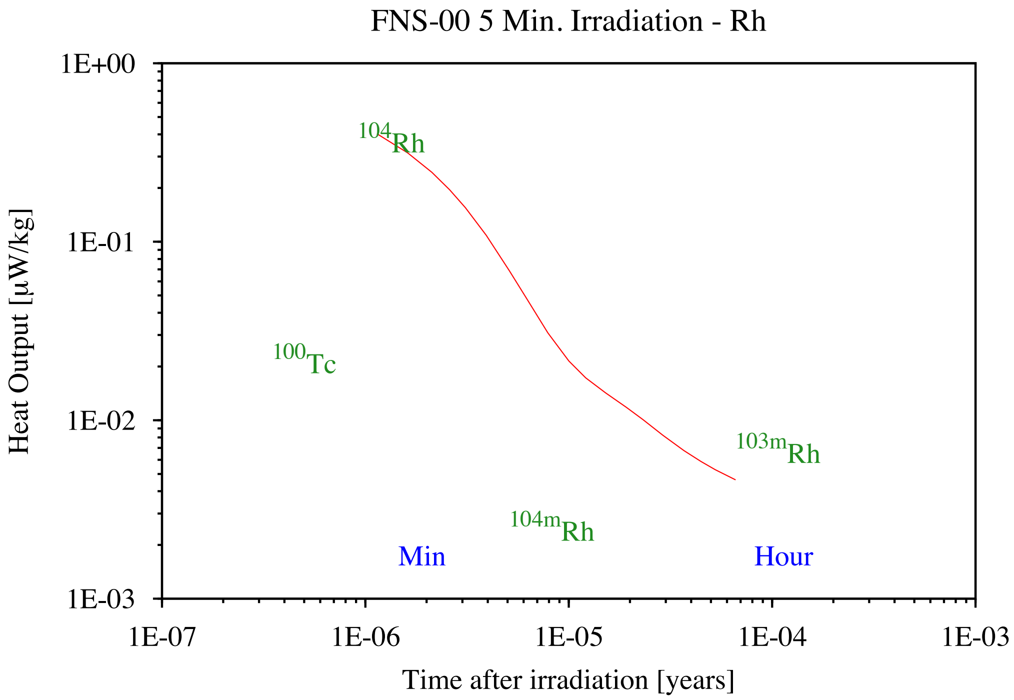
Rhodium



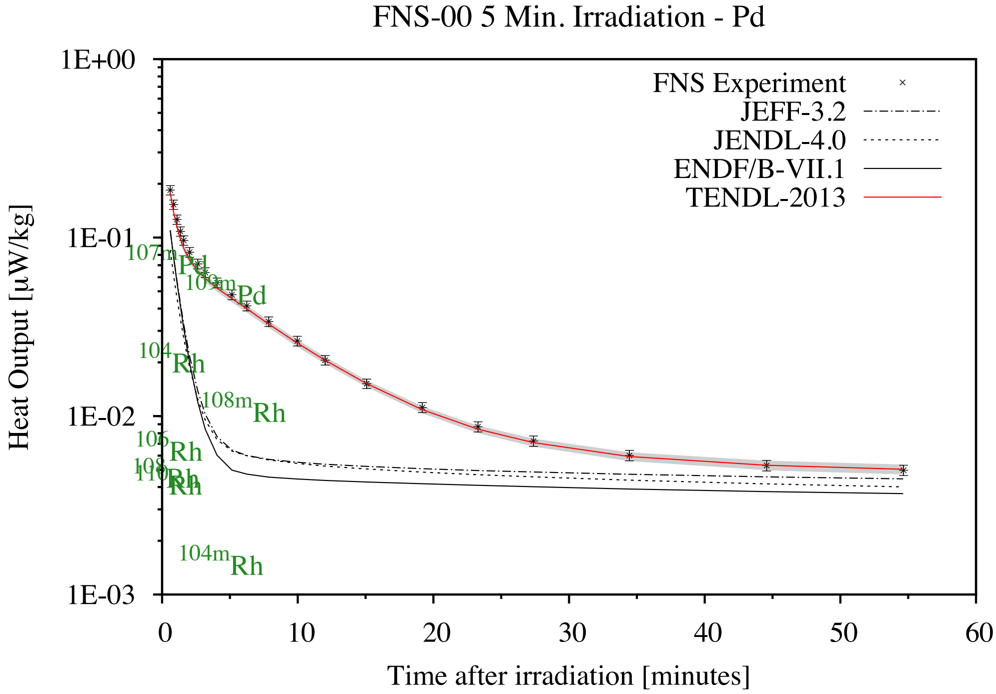
For Rhodium, the fit is poor with all libraries for this important element. The two predominant isotopes routes of production involve a branched capture channel, which cannot be well characterised in such neutron spectra, and a super-inelastic reaction that leads to the Rh103m isomer.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	1.69E−01 +/-8%	4.03E−01 +/-6%	0.42	0.44	0.41	0.41
0.85	1.08E−01 +/-6%	3.15E−01 +/-5%	0.34	0.37	0.34	0.35
1.12	7.72E−02 +/-6%	2.45E−01 +/-5%	0.32	0.35	0.31	0.33
1.37	5.97E−02 +/-6%	1.95E−01 +/-5%	0.31	0.35	0.30	0.33
1.63	4.78E−02 +/-6%	1.55E−01 +/-5%	0.31	0.37	0.30	0.34
2.07	3.32E−02 +/-6%	1.09E−01 +/-5%	0.31	0.39	0.30	0.37
2.68	2.15E−02 +/-6%	6.89E−02 +/-5%	0.31	0.47	0.30	0.44
3.28	1.58E−02 +/-6%	4.75E−02 +/-4%	0.33	0.63	0.32	0.59
4.15	1.15E−02 +/-7%	3.09E−02 +/-4%	0.37	1.12	0.36	1.04
5.27	8.31E−03 +/-8%	2.15E−02 +/-4%	0.39	2.72	0.37	2.30
6.37	6.85E−03 +/-8%	1.73E−02 +/-5%	0.40	6.90	0.37	5.07
7.98	5.27E−03 +/-9%	1.42E−02 +/-5%	0.37	34.03	0.34	15.39
10.10	4.08E−03 +/-10%	1.18E−02 +/-5%	0.35	58.27	0.30	33.63
12.17	3.22E−03 +/-11%	1.01E−02 +/-6%	0.32	45.96	0.27	43.69
15.28	2.44E−03 +/-13%	8.23E−03 +/-7%	0.30	34.81	0.25	36.31
19.40	1.83E−03 +/-15%	6.75E−03 +/-8%	0.27	26.15	0.22	27.28
23.50	1.61E−03 +/-18%	5.86E−03 +/-8%	0.28	23.03	0.22	24.03
27.62	1.68E−03 +/-21%	5.28E−03 +/-9%	0.32	23.90	0.25	24.93
34.75	2.25E−03 +/-26%	4.63E−03 +/-9%	0.49	32.10	0.37	33.49

Product	**Pathways**	**$T_{1/2}$**	**Path %**	**E/C**	**ΔE%**
Rh104	Rh103(n,γ)Rh104	42.3s	97.1	0.42	8%
	Rh103(n,γ)Rh104m	4.3m	2.1	0.42	7%
Rh103m	Rh103(n,n')Rh103m	56.1m	100.0	0.49	26%


FNS-00 5 Min. Irradiation - Rh
Heat Output [µW/kg]
1E+00
1E-01
1E-02
1E-03
104Rh
100Tc
103mRh
104mRh
Min
Hour
1E-07
1E-06
1E-05
1E-04
1E-03
Time after irradiation [years]

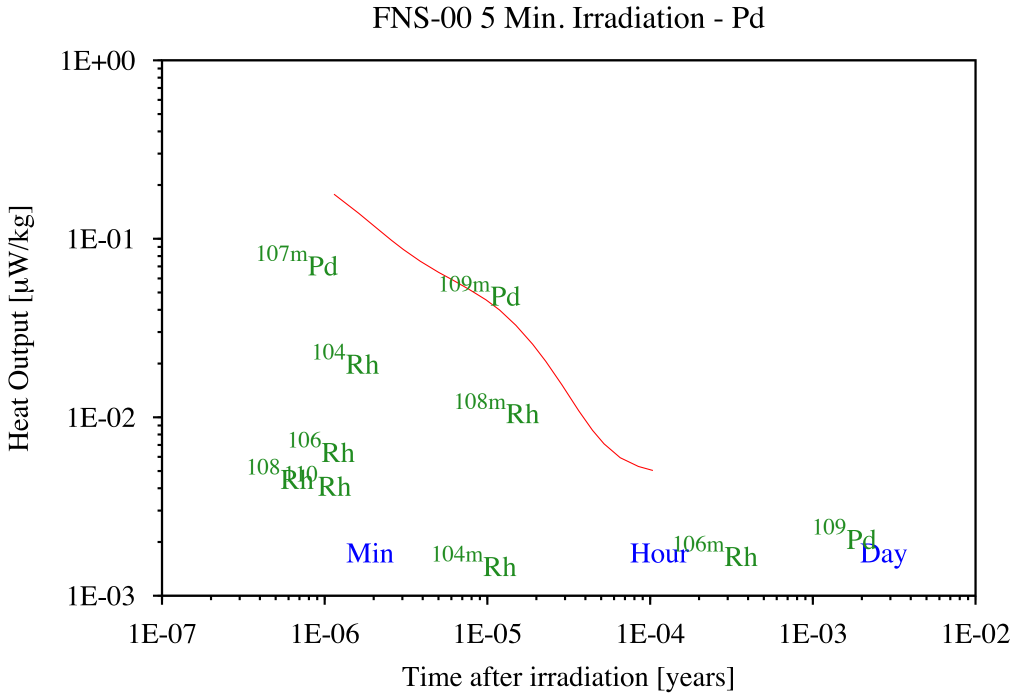
Palladium



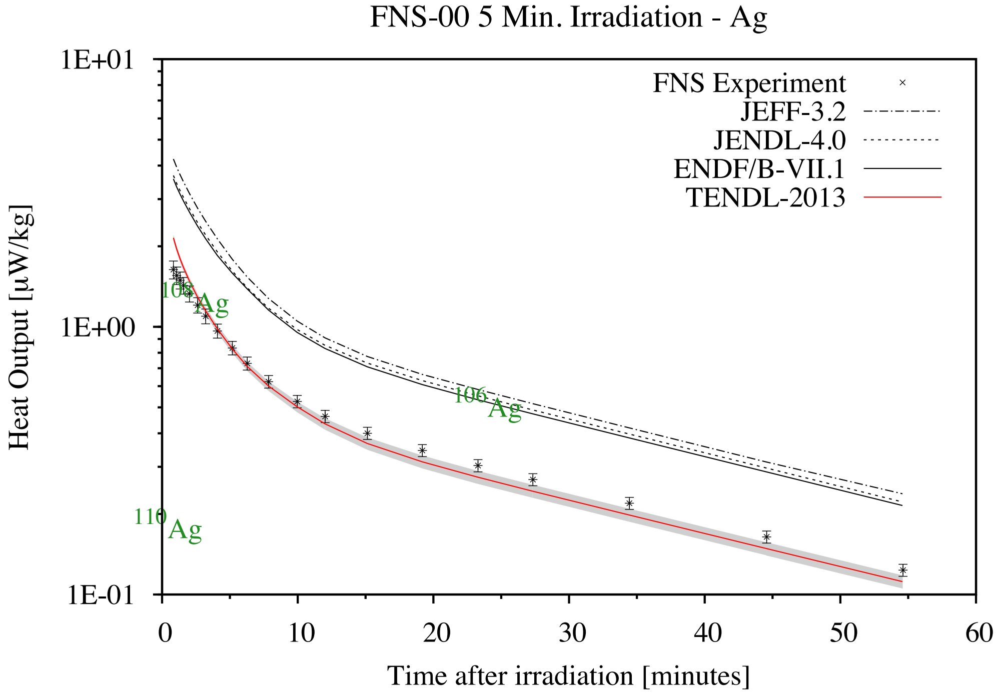
For Palladium, TENDL-2013 now perfectly fits the experimental data, particularly at cooling times of less than 30 minutes, where the decay heat is predominantly determined by the production of metastable isomers. This proves once again the strength of the TALYS modelling processes and a truly general purpose library.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	1.84$E-$01 +/-6%	1.78$E-$01 +/-3%	1.04	1.68	1.69	2.16
0.85	1.53$E-$01 +/-6%	1.39$E-$01 +/-3%	1.10	1.97	1.96	2.48
1.10	1.26$E-$01 +/-6%	1.15$E-$01 +/-4%	1.10	2.25	2.21	2.76
1.35	1.08$E-$01 +/-6%	9.82$E-$02 +/-4%	1.10	2.62	2.54	3.10
1.60	9.64$E-$02 +/-6%	8.71$E-$02 +/-4%	1.11	3.11	2.95	3.54
2.03	8.27$E-$02 +/-6%	7.48$E-$02 +/-5%	1.11	4.18	3.82	4.42
2.63	7.13$E-$02 +/-6%	6.49$E-$02 +/-5%	1.10	5.96	5.16	5.74
3.18	6.38$E-$02 +/-6%	5.91$E-$02 +/-5%	1.08	7.56	6.23	6.72
4.05	5.58$E-$02 +/-6%	5.21$E-$02 +/-5%	1.07	9.26	7.27	7.57
5.15	4.79$E-$02 +/-6%	4.55$E-$02 +/-5%	1.05	9.63	7.42	7.52
6.25	4.14$E-$02 +/-6%	3.99$E-$02 +/-5%	1.04	8.76	6.89	6.92
7.87	3.38$E-$02 +/-6%	3.27$E-$02 +/-5%	1.03	7.44	5.92	5.96
9.97	2.63$E-$02 +/-6%	2.56$E-$02 +/-5%	1.03	5.93	4.78	4.85
12.02	2.06$E-$02 +/-6%	2.05$E-$02 +/-4%	1.00	4.72	3.83	3.92
15.08	1.52$E-$02 +/-6%	1.52$E-$02 +/-4%	1.00	3.55	2.91	3.01
19.18	1.12$E-$02 +/-6%	1.09$E-$02 +/-5%	1.03	2.68	2.20	2.30
23.28	8.71$E-$03 +/-7%	8.45$E-$03 +/-5%	1.03	2.13	1.76	1.86
27.38	7.24$E-$03 +/-7%	7.10$E-$03 +/-5%	1.02	1.80	1.49	1.59
34.45	6.02$E-$03 +/-7%	5.93$E-$03 +/-6%	1.01	1.54	1.27	1.38
44.57	5.28$E-$03 +/-7%	5.30$E-$03 +/-6%	1.00	1.40	1.16	1.27
54.67	4.97$E-$03 +/-7%	5.04$E-$03 +/-6%	0.99	1.35	1.12	1.24

Product	Pathways	$T_{1/2}$	Path %	E/C	ΔE%
Pd107m	Pd108(n,2n)Pd107m	21.3s	99.5	1.04	5%
Pd109m	Pd110(n,2n)Pd109m	4.6m	99.2	1.07	6%
Pd109	Pd108(n,γ)Pd109	13.7h	6.9	0.99	6%
	Pd110(n,2n)Pd109		81.5	0.99	6%
	Pd110(n,2n)Pd109m	4.6m	11.6	0.99	6%



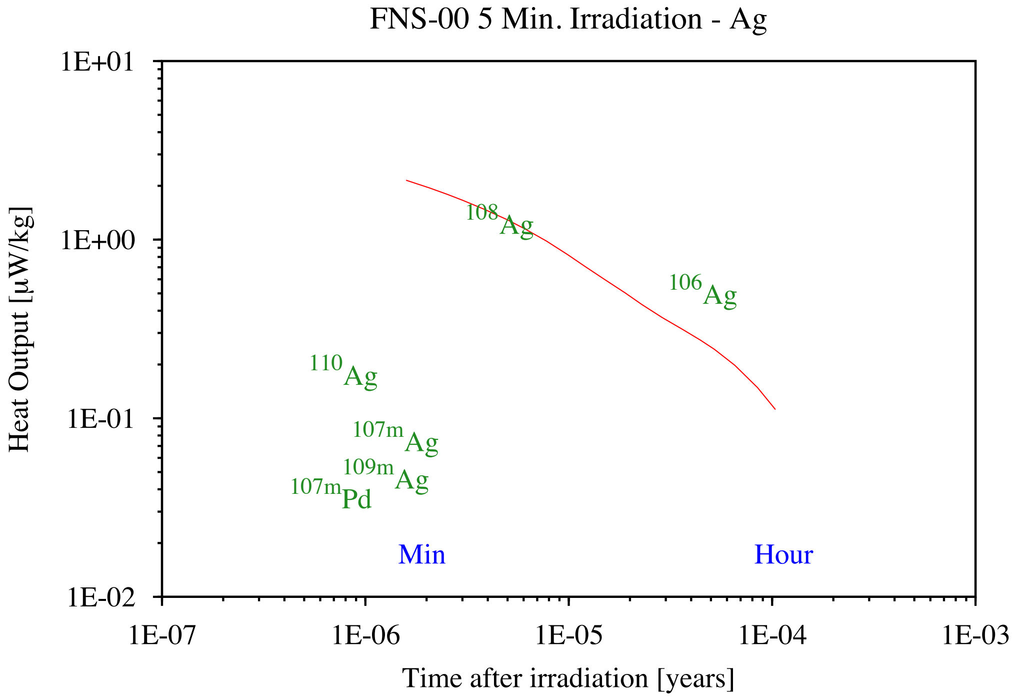
Silver



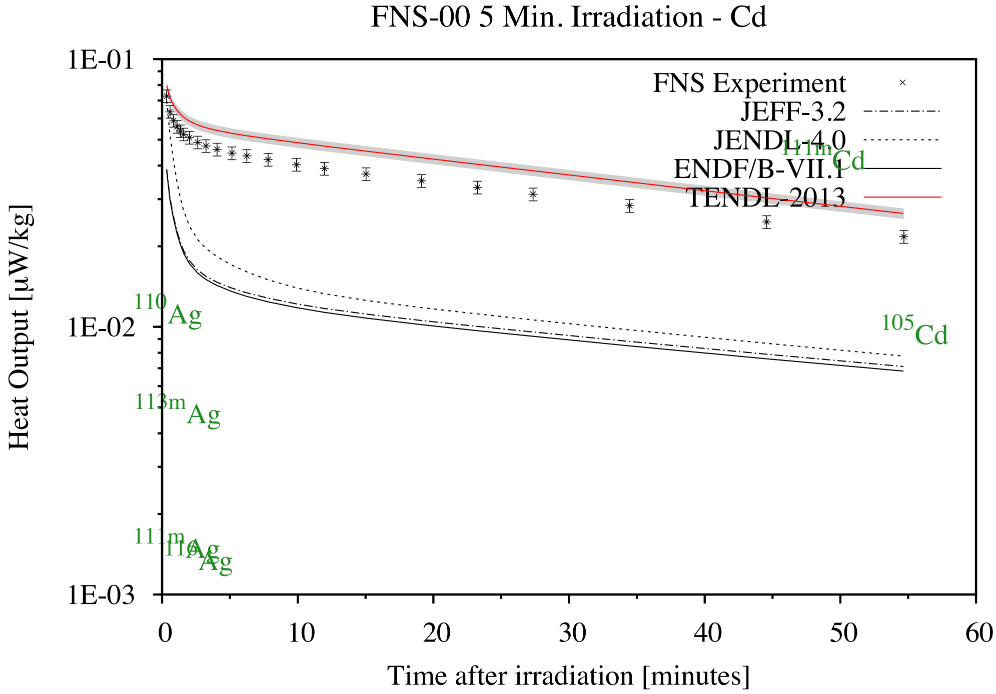
For Silver and TENDL-2013 there is a slight over-prediction up to 5 minutes cooling, followed by a marginal under prediction at longer cooling times – in both cases dominated by different (n,2n) channels. The short time decay heat arising from silver can be considered as rather well predicted. All the other simulations over-predict by a factor of 2.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.83	1.64E+00 +/-8%	2.15E+00 +/-3%	0.76	0.46	0.39	0.44
1.08	1.55E+00 +/-7%	1.95E+00 +/-3%	0.80	0.47	0.39	0.45
1.33	1.49E+00 +/-7%	1.79E+00 +/-3%	0.83	0.48	0.40	0.46
1.58	1.43E+00 +/-7%	1.66E+00 +/-3%	0.86	0.48	0.41	0.47
2.02	1.33E+00 +/-7%	1.48E+00 +/-3%	0.90	0.50	0.42	0.48
2.62	1.21E+00 +/-7%	1.29E+00 +/-3%	0.93	0.51	0.43	0.49
3.22	1.10E+00 +/-6%	1.15E+00 +/-3%	0.96	0.51	0.44	0.50
4.08	9.65E−01 +/-6%	9.82E−01 +/-3%	0.98	0.52	0.45	0.51
5.18	8.33E−01 +/-6%	8.26E−01 +/-4%	1.01	0.53	0.47	0.52
6.28	7.30E−01 +/-6%	7.11E−01 +/-4%	1.03	0.53	0.48	0.52
7.85	6.24E−01 +/-5%	6.01E−01 +/-4%	1.04	0.54	0.49	0.53
9.97	5.26E−01 +/-5%	5.03E−01 +/-5%	1.05	0.55	0.50	0.54
12.02	4.63E−01 +/-5%	4.34E−01 +/-5%	1.07	0.56	0.51	0.54
15.13	4.00E−01 +/-5%	3.67E−01 +/-5%	1.09	0.56	0.52	0.55
19.18	3.45E−01 +/-5%	3.13E−01 +/-6%	1.10	0.57	0.52	0.55
23.28	3.03E−01 +/-5%	2.74E−01 +/-6%	1.10	0.57	0.52	0.55
27.33	2.69E−01 +/-5%	2.43E−01 +/-6%	1.11	0.57	0.52	0.55
34.45	2.19E−01 +/-5%	1.98E−01 +/-6%	1.11	0.57	0.52	0.55
44.57	1.64E−01 +/-5%	1.49E−01 +/-6%	1.10	0.57	0.52	0.55
54.62	1.23E−01 +/-5%	1.12E−01 +/-6%	1.10	0.57	0.52	0.56

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ag108	Ag107(n,γ)Ag108	2.4m	7.2	0.93	7%
	Ag109(n,2n)Ag108		92.5	0.93	7%
Ag106	Ag107(n,2n)Ag106	24.0m	100.0	1.11	5%



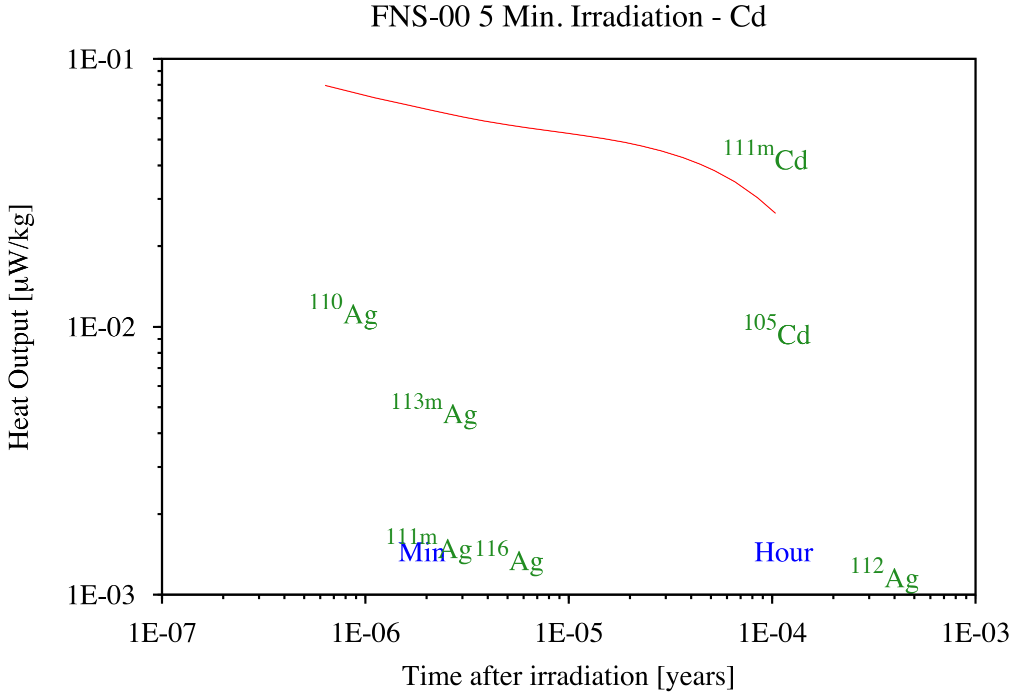
Cadmium



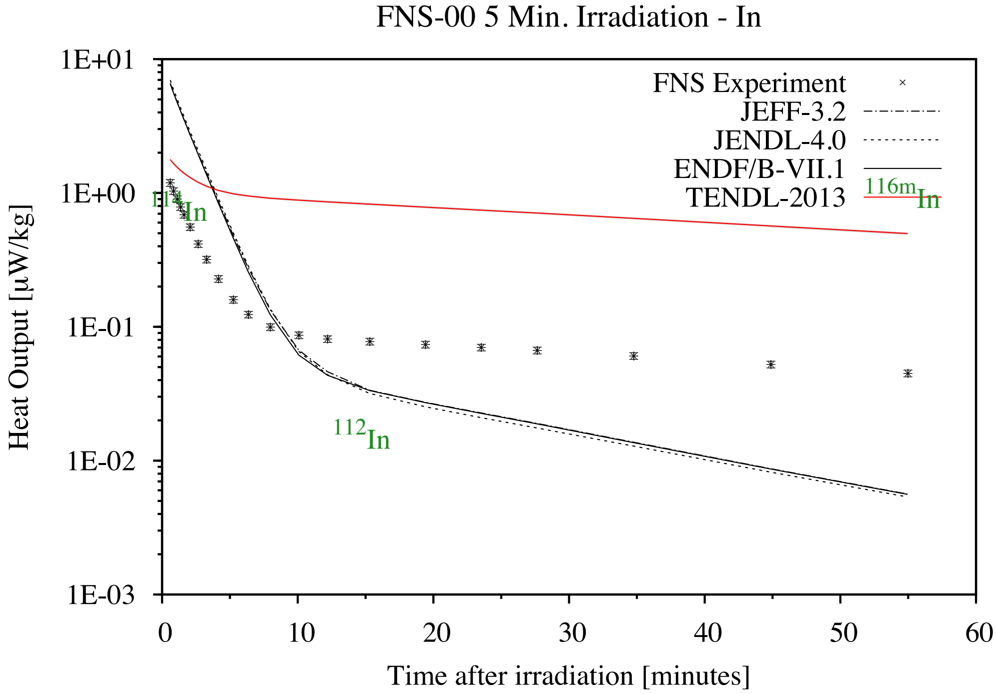
For Cadmium, there was a good time dependant agreement for EAF-2010 [13], within the quoted calculational uncertainty. TENDL-2013 libraries over-predict by 20%, but still out-perform the other libraries.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.33	7.28E−02 +/-5%	7.96E−02 +/-4%	0.91	1.90	1.88	1.04
0.58	6.36E−02 +/-5%	7.16E−02 +/-4%	0.89	2.13	2.10	1.22
0.83	5.88E−02 +/-5%	6.75E−02 +/-4%	0.87	2.31	2.27	1.40
1.10	5.59E−02 +/-5%	6.44E−02 +/-4%	0.87	2.51	2.46	1.61
1.35	5.38E−02 +/-5%	6.23E−02 +/-4%	0.86	2.66	2.60	1.79
1.60	5.24E−02 +/-5%	6.07E−02 +/-4%	0.86	2.78	2.72	1.93
2.02	5.09E−02 +/-5%	5.87E−02 +/-4%	0.87	2.95	2.88	2.14
2.63	4.89E−02 +/-5%	5.67E−02 +/-4%	0.86	3.08	3.00	2.31
3.23	4.74E−02 +/-5%	5.54E−02 +/-4%	0.85	3.16	3.07	2.41
4.05	4.60E−02 +/-5%	5.41E−02 +/-4%	0.85	3.23	3.14	2.52
5.15	4.45E−02 +/-5%	5.28E−02 +/-4%	0.84	3.29	3.19	2.62
6.25	4.35E−02 +/-5%	5.17E−02 +/-4%	0.84	3.35	3.25	2.71
7.82	4.21E−02 +/-5%	5.04E−02 +/-4%	0.84	3.40	3.29	2.81
9.92	4.03E−02 +/-5%	4.88E−02 +/-4%	0.83	3.42	3.31	2.88
11.97	3.90E−02 +/-5%	4.73E−02 +/-4%	0.82	3.44	3.33	2.93
15.03	3.72E−02 +/-5%	4.53E−02 +/-4%	0.82	3.45	3.33	2.97
19.13	3.51E−02 +/-5%	4.28E−02 +/-4%	0.82	3.45	3.32	2.98
23.25	3.32E−02 +/-5%	4.05E−02 +/-4%	0.82	3.43	3.30	2.97
27.35	3.13E−02 +/-5%	3.83E−02 +/-4%	0.82	3.40	3.27	2.95
34.47	2.83E−02 +/-5%	3.48E−02 +/-4%	0.82	3.34	3.21	2.91
44.57	2.46E−02 +/-5%	3.03E−02 +/-4%	0.81	3.24	3.12	2.84
54.68	2.17E−02 +/-5%	2.65E−02 +/-4%	0.82	3.18	3.05	2.79

Product	Pathways	$T_{1/2}$	Path %	E/C	ΔE%
Cd111m	Cd111(n,n')Cd111m	48.5m	19.7	0.81	5%
	Cd112(n,2n)Cd111m		80.2	0.81	5%



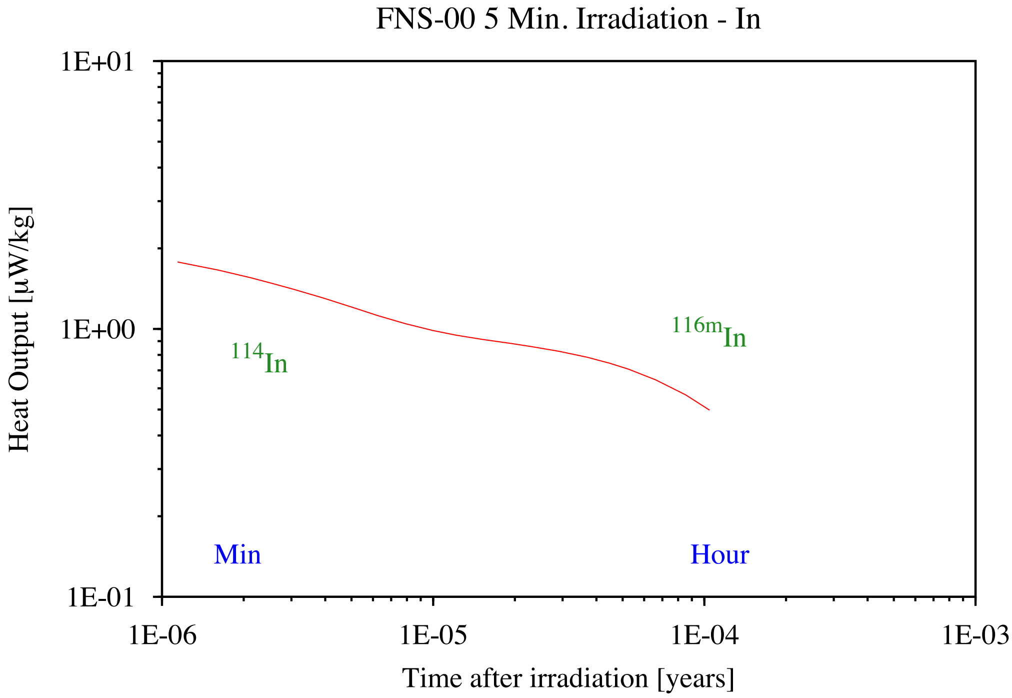
Indium



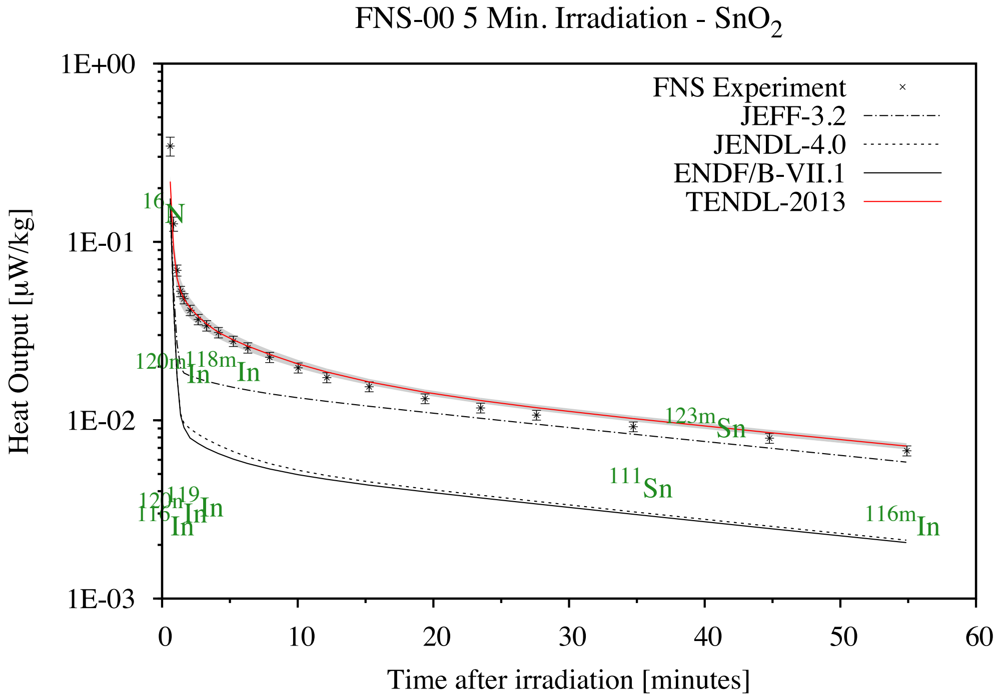
For Indium, a large over-prediction can be seen for this element at all cooling times when TENDL-2013 is used. The others libraries seem to better shape, if not follow, the decay heat profile. The poor characterisation of the thermal profile of the neutron spectrum may have an influence on the predicted results for this neutron absorber, although this tendency is not seen for all neutron absorbers.

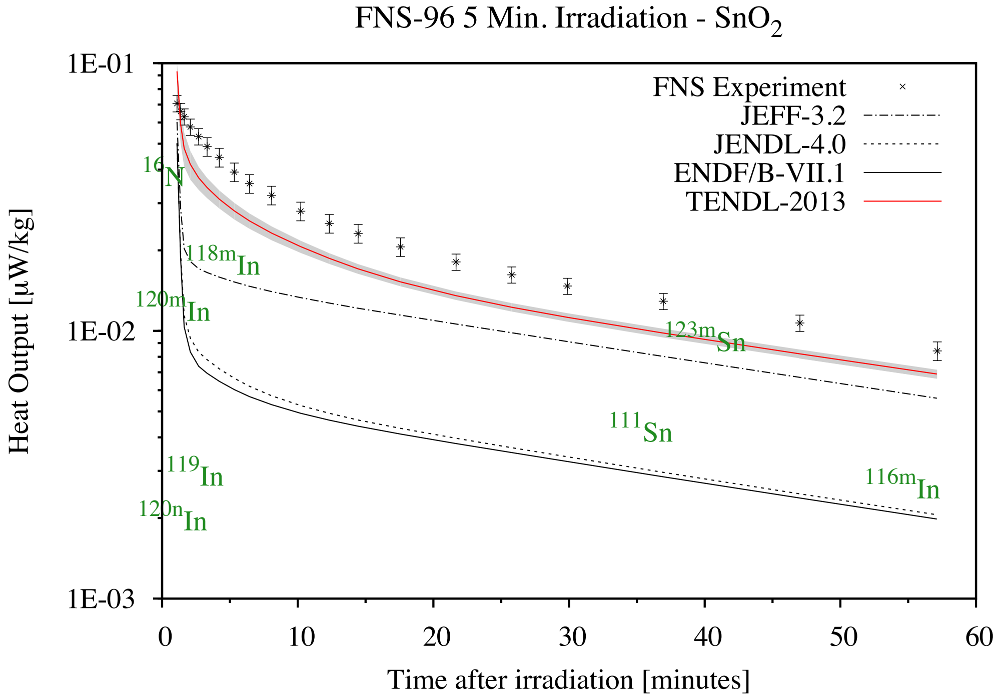
Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	1.19E+00 +/-6%	1.78E+00 +/-2%	0.67	0.18	0.18	0.17
0.85	1.03E+00 +/-6%	1.66E+00 +/-2%	0.62	0.19	0.18	0.17
1.12	9.00$E-$01 +/-6%	1.55E+00 +/-2%	0.58	0.19	0.19	0.18
1.37	7.85$E-$01 +/-6%	1.47E+00 +/-2%	0.53	0.19	0.19	0.18
1.62	6.87$E-$01 +/-6%	1.40E+00 +/-2%	0.49	0.19	0.19	0.18
2.07	5.56$E-$01 +/-6%	1.30E+00 +/-2%	0.43	0.20	0.20	0.19
2.67	4.15$E-$01 +/-6%	1.20E+00 +/-2%	0.35	0.21	0.21	0.20
3.28	3.19$E-$01 +/-6%	1.12E+00 +/-2%	0.28	0.23	0.23	0.21
4.15	2.28$E-$01 +/-6%	1.05E+00 +/-2%	0.22	0.27	0.26	0.25
5.25	1.59$E-$01 +/-6%	9.86$E-$01 +/-2%	0.16	0.35	0.33	0.32
6.37	1.24$E-$01 +/-6%	9.49$E-$01 +/-2%	0.13	0.48	0.45	0.44
7.98	9.95$E-$02 +/-6%	9.14$E-$01 +/-2%	0.11	0.81	0.75	0.73
10.08	8.65$E-$02 +/-6%	8.84$E-$01 +/-2%	0.10	1.41	1.29	1.32
12.20	8.10$E-$02 +/-6%	8.58$E-$01 +/-2%	0.09	1.86	1.75	1.84
15.32	7.76$E-$02 +/-6%	8.25$E-$01 +/-2%	0.09	2.32	2.31	2.44
19.42	7.37$E-$02 +/-6%	7.84$E-$01 +/-2%	0.09	2.72	2.70	2.92
23.53	7.01$E-$02 +/-6%	7.45$E-$01 +/-2%	0.09	3.11	3.09	3.35
27.65	6.66$E-$02 +/-6%	7.07$E-$01 +/-2%	0.09	3.53	3.51	3.79
34.77	6.05$E-$02 +/-6%	6.46$E-$01 +/-2%	0.09	4.43	4.40	4.71
44.88	5.23$E-$02 +/-6%	5.67$E-$01 +/-2%	0.09	6.04	6.00	6.37
54.98	4.49$E-$02 +/-6%	4.97$E-$01 +/-2%	0.09	8.01	7.96	8.37

Product	Pathways	$T_{1/2}$	Path %	E/C	ΔE%
In114	In115(n,2n)In114	1.1m	99.1	0.58	5%
In116m	In115(n,γ)In116m	54.6m	95.7	0.09	5%
	In115(n,γ)In116n	2.1s	4.3	0.09	5%



Tin

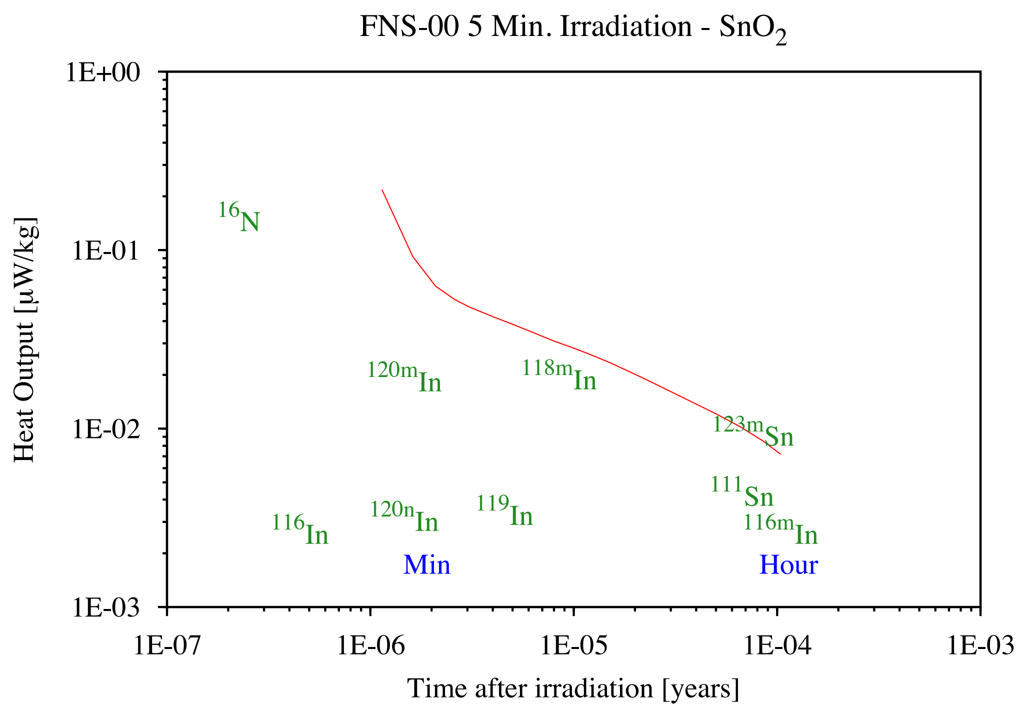


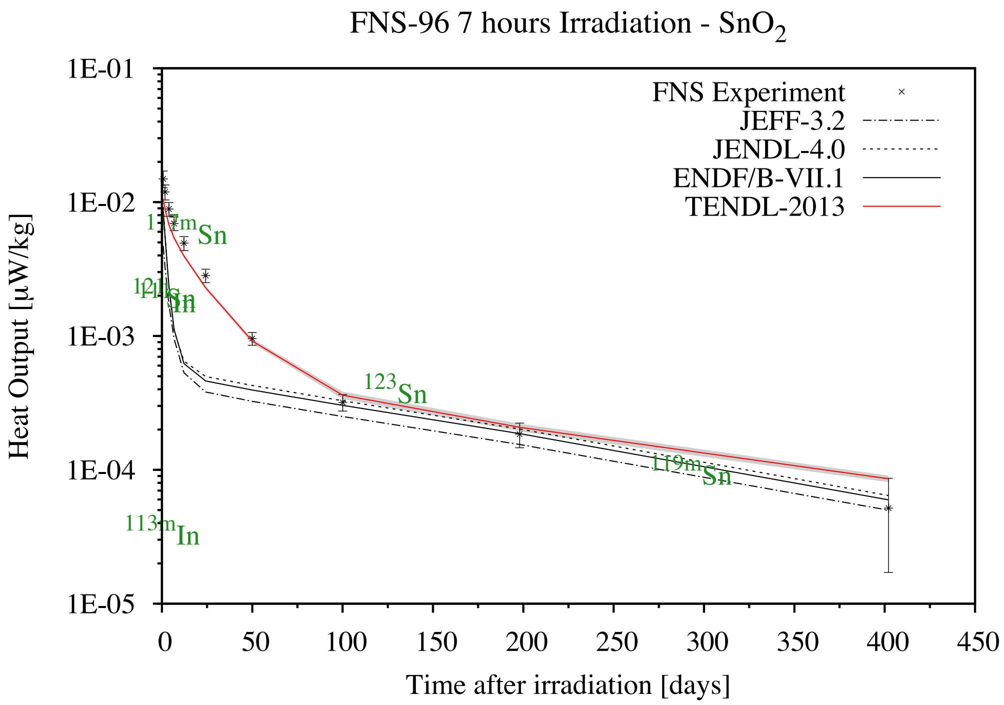


For Tin, the two experimental result sets differ, although the simulation produces much better agreement with the most recent one, particularly at very short cooling times, but only with TENDL-2013.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	$3.45E{-}01$ +/-12%	$2.18E{-}01$ +/-7%	1.58	2.09	1.97	2.19
0.85	$1.26E{-}01$ +/-9%	$9.19E{-}02$ +/-14%	1.37	2.82	2.32	2.90
1.10	$6.93E{-}02$ +/-7%	$6.28E{-}02$ +/-17%	1.10	3.91	2.56	3.89
1.37	$5.28E{-}02$ +/-7%	$5.29E{-}02$ +/-16%	1.00	4.95	2.67	4.85
1.62	$4.81E{-}02$ +/-7%	$4.79E{-}02$ +/-15%	1.00	5.29	2.61	5.00
2.07	$4.14E{-}02$ +/-7%	$4.28E{-}02$ +/-13%	0.97	5.21	2.33	4.61
2.67	$3.67E{-}02$ +/-7%	$3.82E{-}02$ +/-11%	0.96	4.96	2.15	4.40
3.28	$3.39E{-}02$ +/-7%	$3.47E{-}02$ +/-9%	0.98	4.87	2.05	4.33
4.15	$3.10E{-}02$ +/-7%	$3.11E{-}02$ +/-8%	1.00	4.77	1.95	4.28
5.25	$2.77E{-}02$ +/-7%	$2.82E{-}02$ +/-7%	0.98	4.58	1.81	4.15
6.32	$2.55E{-}02$ +/-7%	$2.60E{-}02$ +/-7%	0.98	4.46	1.73	4.09
7.93	$2.25E{-}02$ +/-7%	$2.34E{-}02$ +/-6%	0.96	4.23	1.60	3.94
10.03	$1.97E{-}02$ +/-6%	$2.07E{-}02$ +/-5%	0.95	3.97	1.47	3.75
12.15	$1.73E{-}02$ +/-6%	$1.86E{-}02$ +/-5%	0.93	3.72	1.36	3.54
15.27	$1.54E{-}02$ +/-6%	$1.64E{-}02$ +/-4%	0.94	3.56	1.29	3.41
19.38	$1.32E{-}02$ +/-6%	$1.43E{-}02$ +/-4%	0.92	3.33	1.19	3.20
23.48	$1.17E{-}02$ +/-6%	$1.29E{-}02$ +/-4%	0.91	3.19	1.14	3.09
27.60	$1.07E{-}02$ +/-6%	$1.18E{-}02$ +/-4%	0.91	3.15	1.12	3.04
34.73	$9.20E{-}03$ +/-6%	$1.02E{-}02$ +/-4%	0.90	3.10	1.10	3.00
44.78	$7.92E{-}03$ +/-6%	$8.52E{-}03$ +/-4%	0.93	3.21	1.14	3.11
54.90	$6.74E{-}03$ +/-6%	$7.16E{-}03$ +/-4%	0.94	3.27	1.16	3.17

Product	**Pathways**	**$T_{1/2}$**	**Path %**	**E/C**	**ΔE%**
In120m	Sn120(n,p)In120m	46.2s	99.9	1.58	12%
In118m	Sn118(n,p)In118m	4.4m	90.4	1.00	7%
	Sn118(n,p)In118n	8.5s	8.3	1.00	7%
	Sn119(n,d+np)In118m		0.8	1.00	7%
Sn123m	Sn124(n,2n)Sn123m	40.0m	99.8	0.93	6%

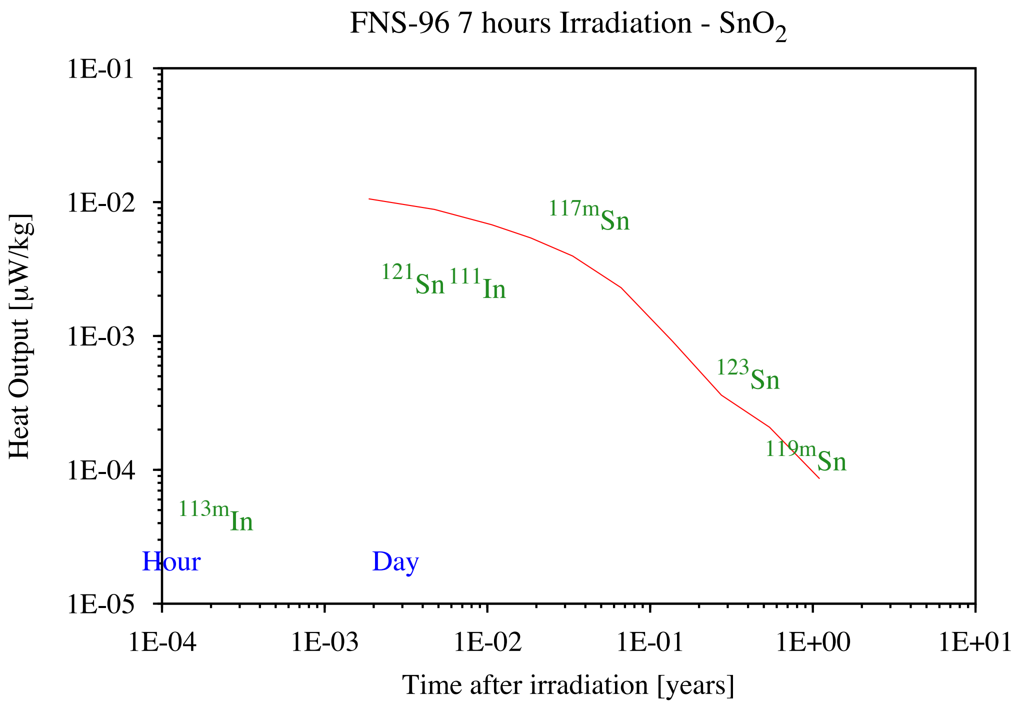




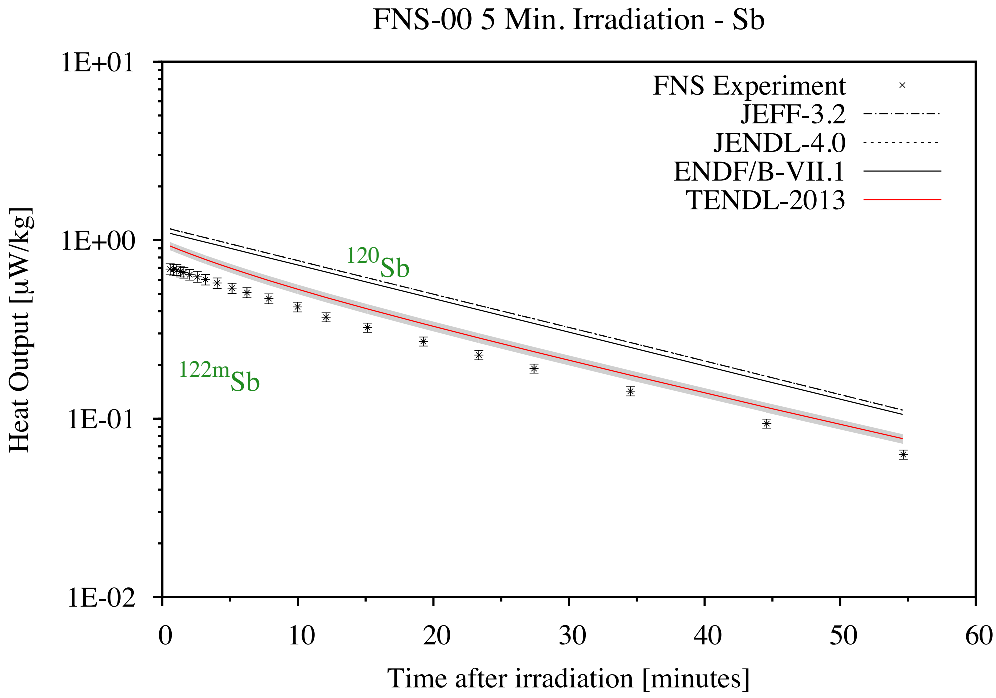
The above graph shows a relatively good agreement across all cooling times when TENDL-2013 is used. It also shows the limit of the experimental measurement technique, with the large uncertainty after 13 months of cooling reflecting the fact that the heat output is approaching the pico-watt limit of sensitivity.

Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.68	1.49E−02 +/-14%	1.06E−02 +/-4%	1.41	1.71	3.17	1.62
1.73	1.19E−02 +/-13%	8.82E−03 +/-4%	1.35	2.17	3.68	2.11
3.88	8.88E−03 +/-12%	6.78E−03 +/-4%	1.31	3.79	5.20	3.85
6.75	6.93E−03 +/-12%	5.40E−03 +/-3%	1.28	6.18	7.28	6.30
12.20	4.94E−03 +/-12%	3.96E−03 +/-3%	1.25	7.94	9.31	7.62
24.20	2.83E−03 +/-12%	2.29E−03 +/-3%	1.23	6.13	7.42	5.68
49.95	9.57E−04 +/-11%	9.18E−04 +/-4%	1.04	2.43	2.94	2.24
100.08	3.20E−04 +/-14%	3.61E−04 +/-6%	0.88	1.05	1.28	0.97
197.93	1.85E−04 +/-21%	2.08E−04 +/-6%	0.89	0.99	1.20	0.92
402.13	5.18E−05 +/-67%	8.59E−05 +/-5%	0.60	0.87	1.04	0.80

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Sn117m	Sn118(n,2n)Sn117m	13.6d	93.7	1.25	12%
	Sn117(n,n')Sn117m		6.2	1.25	12%
Sn123	Sn124(n,2n)Sn123	129d	99.9	0.89	14%
Sn119m	Sn120(n,2n)Sn119m	293d	94.0	0.60	67%
	Sn119(n,n')Sn119m		5.8	0.60	67%


FNS-96 7 hours Irradiation - SnO2
Heat Output [µW/kg]
1E-01
1E-02
1E-03
1E-04
1E-05
117mSn
121Sn
111In
123Sn
119mSn
113mIn
Hour
Day
1E-04
1E-03
1E-02
1E-01
1E+00
1E+01
Time after irradiation [years]

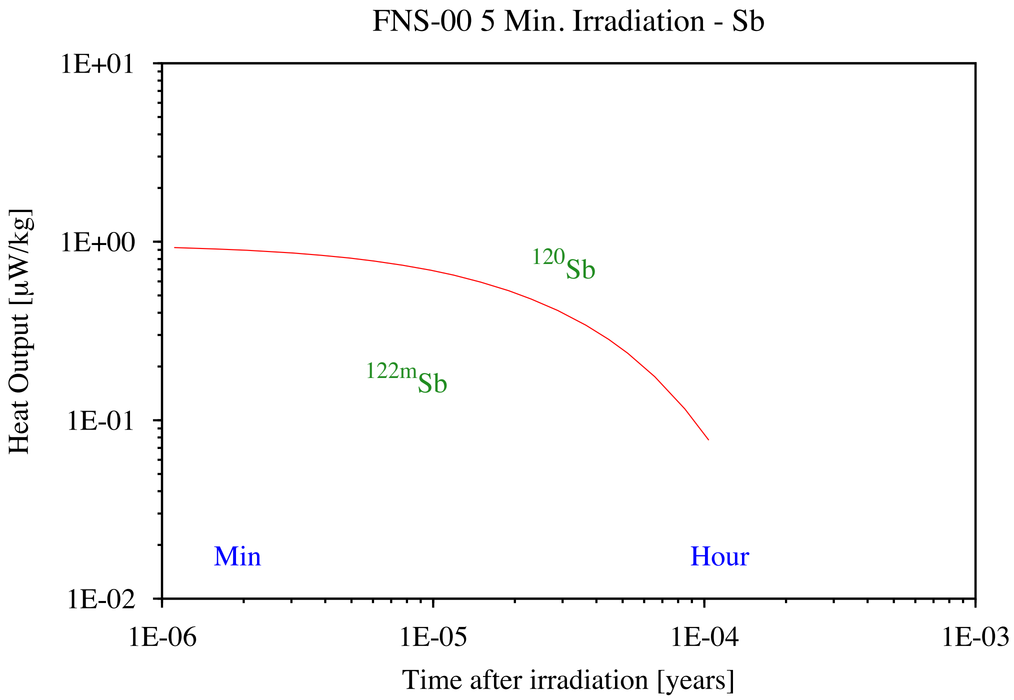
Antimony



For Antimony, TENDL-2013 results are very similar to EAF-2010 ones [13], but still over-predict by circa 20% at all cooling times.

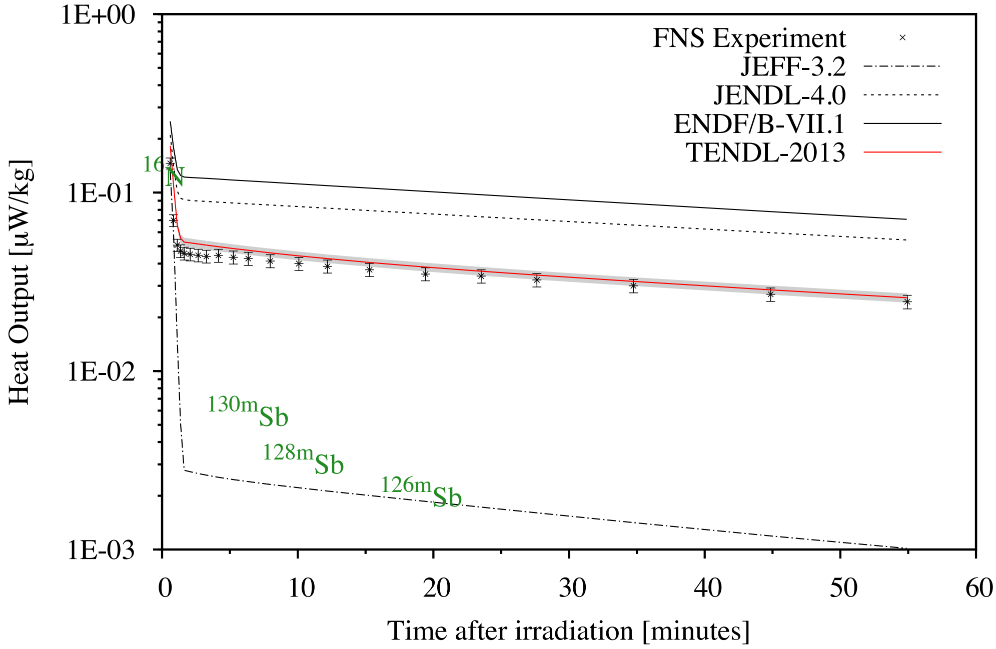
Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	$6.89E{-}01$ +/-7%	$9.27E{-}01$ +/-5%	0.74	0.63	0.60	0.60
0.83	$6.86E{-}01$ +/-7%	$9.11E{-}01$ +/-5%	0.75	0.63	0.60	0.60
1.08	$6.81E{-}01$ +/-7%	$8.95E{-}01$ +/-5%	0.76	0.64	0.60	0.60
1.33	$6.68E{-}01$ +/-7%	$8.80E{-}01$ +/-5%	0.76	0.63	0.60	0.60
1.60	$6.59E{-}01$ +/-7%	$8.64E{-}01$ +/-5%	0.76	0.63	0.60	0.60
2.03	$6.41E{-}01$ +/-7%	$8.39E{-}01$ +/-5%	0.76	0.63	0.59	0.59
2.58	$6.23E{-}01$ +/-7%	$8.10E{-}01$ +/-6%	0.77	0.62	0.59	0.59
3.18	$6.02E{-}01$ +/-7%	$7.80E{-}01$ +/-6%	0.77	0.62	0.58	0.58
4.05	$5.75E{-}01$ +/-7%	$7.39E{-}01$ +/-6%	0.78	0.61	0.58	0.58
5.15	$5.38E{-}01$ +/-7%	$6.92E{-}01$ +/-6%	0.78	0.60	0.57	0.57
6.25	$5.09E{-}01$ +/-6%	$6.50E{-}01$ +/-6%	0.78	0.60	0.56	0.56
7.87	$4.70E{-}01$ +/-6%	$5.94E{-}01$ +/-6%	0.79	0.59	0.56	0.56
9.98	$4.23E{-}01$ +/-6%	$5.32E{-}01$ +/-6%	0.80	0.58	0.55	0.55
12.08	$3.70E{-}01$ +/-6%	$4.78E{-}01$ +/-6%	0.77	0.56	0.53	0.53
15.15	$3.24E{-}01$ +/-6%	$4.12E{-}01$ +/-6%	0.79	0.56	0.53	0.53
19.25	$2.71E{-}01$ +/-6%	$3.41E{-}01$ +/-6%	0.80	0.56	0.53	0.53
23.35	$2.27E{-}01$ +/-6%	$2.83E{-}01$ +/-6%	0.80	0.56	0.53	0.53
27.42	$1.91E{-}01$ +/-6%	$2.37E{-}01$ +/-6%	0.81	0.56	0.53	0.53
34.53	$1.42E{-}01$ +/-6%	$1.75E{-}01$ +/-6%	0.81	0.57	0.53	0.53
44.58	$9.39E{-}02$ +/-6%	$1.16E{-}01$ +/-6%	0.81	0.58	0.54	0.54
54.65	$6.30E{-}02$ +/-6%	$7.72E{-}02$ +/-6%	0.82	0.60	0.56	0.56

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Sb120	Sb121(n,2n)Sb120	15.9m	100.0	0.79	6%


FNS-00 5 Min. Irradiation - Sb
Heat Output [µW/kg]
1E+01
1E+00
1E-01
1E-02
1E-06
1E-05
1E-04
1E-03
Time after irradiation [years]
120Sb
122mSb
Min
Hour

Tellurium

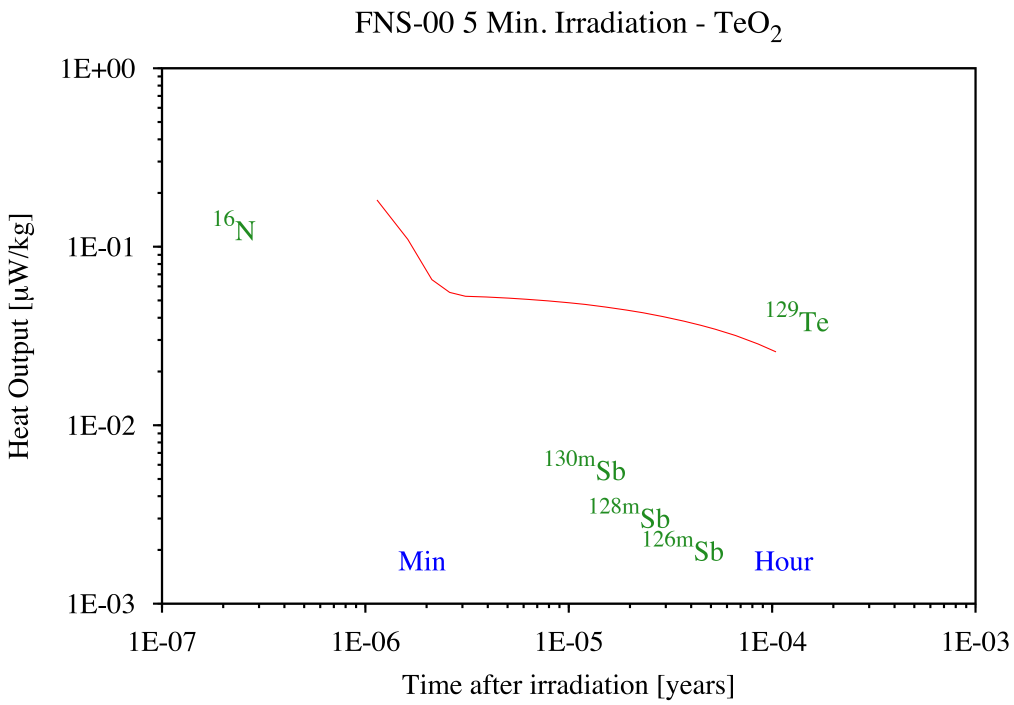
FNS-00 5 Min. Irradiation - TeO_2



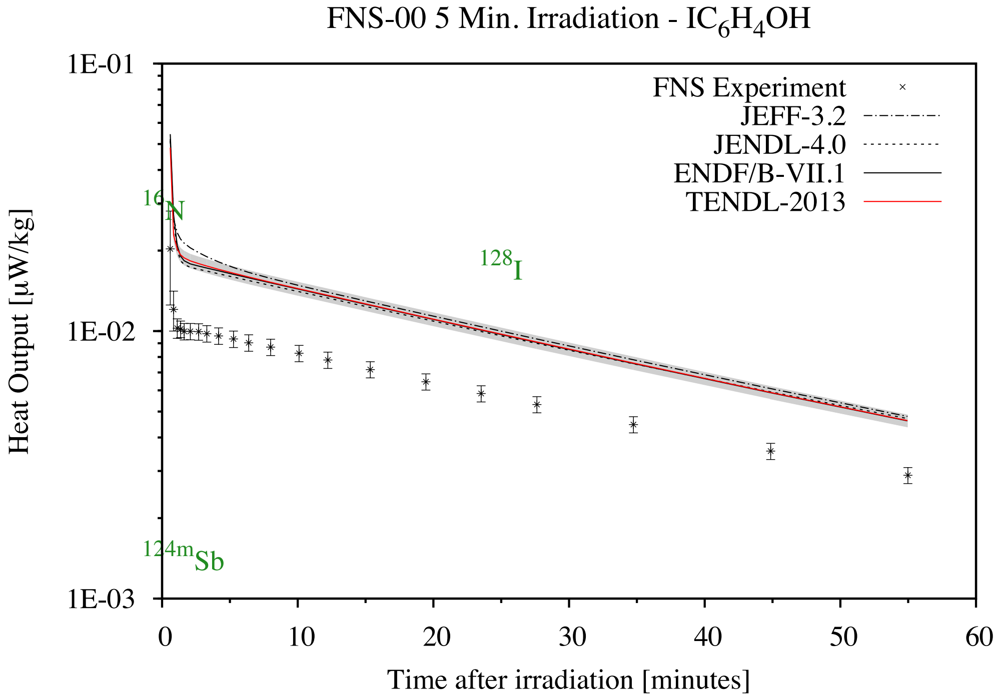
For Tellurium, and TENDL-2013, an excellent agreement can be seen, at all cooling times, within the uncertainty of the experiment, which even allows for the decay of the short-lived N16 to be observed. All the others libraries predict poorly.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	1.46E−01 +/-7%	1.83E−01 +/-2%	0.80	0.58	1.11	0.69
0.85	6.99E−02 +/-7%	1.10E−01 +/-3%	0.64	0.39	1.19	0.49
1.12	5.08E−02 +/-8%	6.54E−02 +/-5%	0.78	0.38	3.45	0.50
1.37	4.71E−02 +/-8%	5.54E−02 +/-6%	0.85	0.38	9.31	0.51
1.63	4.56E−02 +/-8%	5.28E−02 +/-6%	0.86	0.37	16.42	0.50
2.07	4.51E−02 +/-8%	5.22E−02 +/-6%	0.86	0.37	16.52	0.50
2.67	4.45E−02 +/-8%	5.15E−02 +/-6%	0.86	0.37	16.71	0.50
3.27	4.39E−02 +/-8%	5.08E−02 +/-6%	0.86	0.37	16.81	0.49
4.15	4.44E−02 +/-8%	4.97E−02 +/-6%	0.89	0.37	17.48	0.50
5.25	4.34E−02 +/-8%	4.86E−02 +/-6%	0.89	0.37	17.61	0.50
6.35	4.27E−02 +/-8%	4.75E−02 +/-6%	0.90	0.37	17.77	0.49
7.97	4.13E−02 +/-8%	4.60E−02 +/-6%	0.90	0.36	17.86	0.49
10.08	4.00E−02 +/-8%	4.42E−02 +/-6%	0.90	0.36	18.02	0.48
12.18	3.86E−02 +/-8%	4.27E−02 +/-6%	0.91	0.35	18.16	0.47
15.30	3.70E−02 +/-8%	4.06E−02 +/-6%	0.91	0.35	18.43	0.47
19.42	3.50E−02 +/-8%	3.83E−02 +/-6%	0.91	0.34	18.79	0.46
23.52	3.40E−02 +/-9%	3.63E−02 +/-6%	0.94	0.35	19.70	0.46
27.63	3.24E−02 +/-9%	3.45E−02 +/-6%	0.94	0.35	20.20	0.46
34.75	3.00E−02 +/-9%	3.18E−02 +/-6%	0.95	0.35	21.22	0.46
44.87	2.69E−02 +/-9%	2.85E−02 +/-6%	0.94	0.34	22.55	0.45
54.93	2.44E−02 +/-9%	2.57E−02 +/-6%	0.95	0.35	24.10	0.45

Product	**Pathways**	**$T_{1/2}$**	**Path %**	**E/C**	**ΔE%**
N16	O16(n,p)N16	7.1s	99.9	0.80	7%
Te129	Te130(n,2n)Te129	1.1h	99.7	0.95	8%


FNS-00 5 Min. Irradiation - TeO2
Heat Output [µW/kg]
1E+00
1E-01
1E-02
1E-03
16N
129Te
130mSb
128mSb
126mSb
Min
Hour
1E-07
1E-06
1E-05
1E-04
1E-03
Time after irradiation [years]

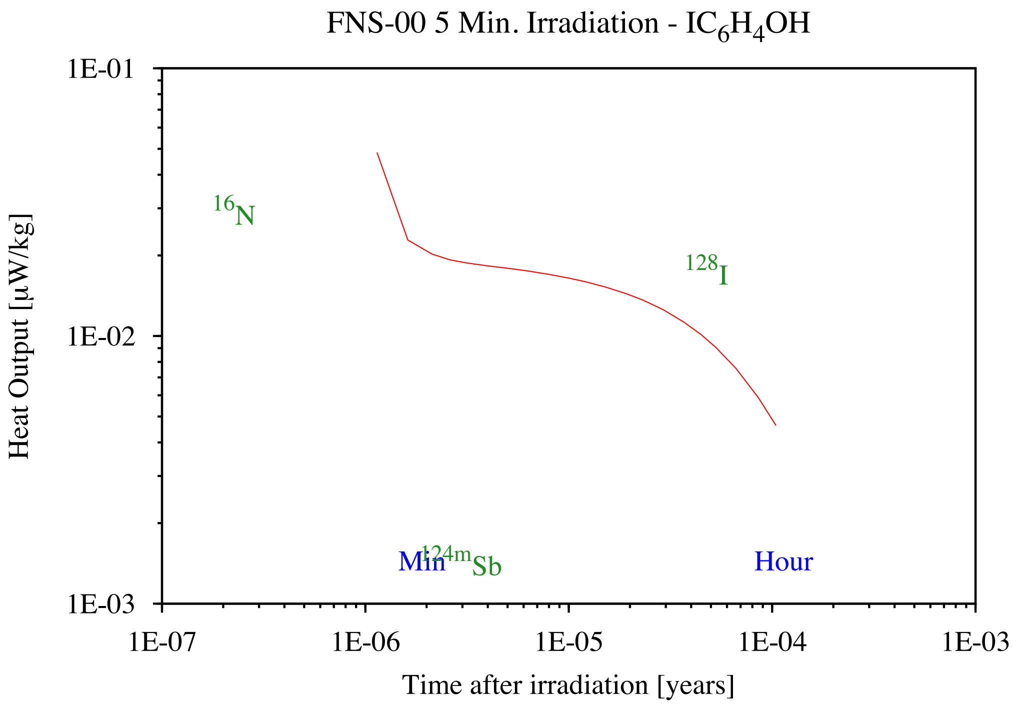
Iodine



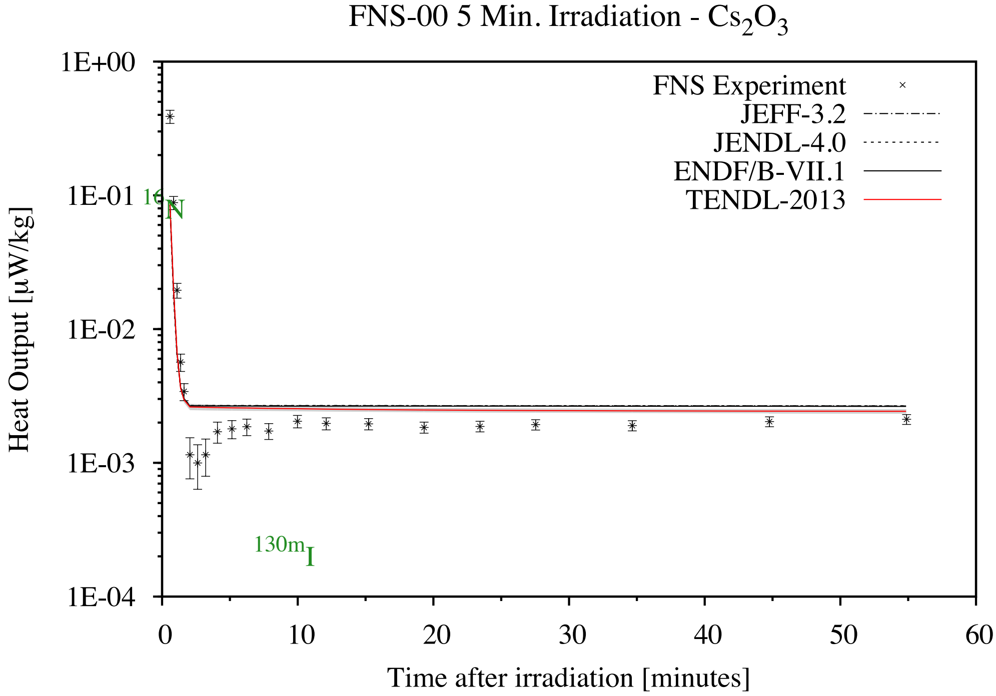
For Iodine, a rather systematic over-prediction is observed for the sample compound, however here again the major channel involved is a capture for which the thermal part has not been accurately predicted.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	2.03E−02 +/-38%	4.85E−02 +/-3%	0.42	0.37	0.39	0.39
0.85	1.20E−02 +/-17%	2.29E−02 +/-6%	0.53	0.44	0.46	0.47
1.12	1.03E−02 +/-8%	2.02E−02 +/-6%	0.51	0.49	0.44	0.51
1.37	1.02E−02 +/-7%	1.93E−02 +/-6%	0.53	0.53	0.46	0.56
1.63	9.97E−03 +/-7%	1.88E−02 +/-6%	0.53	0.54	0.47	0.56
2.08	9.98E−03 +/-7%	1.83E−02 +/-6%	0.55	0.56	0.49	0.58
2.70	9.95E−03 +/-7%	1.79E−02 +/-6%	0.56	0.57	0.51	0.58
3.30	9.78E−03 +/-7%	1.75E−02 +/-6%	0.56	0.57	0.52	0.58
4.17	9.59E−03 +/-7%	1.70E−02 +/-6%	0.56	0.57	0.53	0.59
5.27	9.34E−03 +/-7%	1.65E−02 +/-6%	0.57	0.57	0.54	0.59
6.38	9.04E−03 +/-7%	1.59E−02 +/-6%	0.57	0.57	0.55	0.58
8.00	8.71E−03 +/-7%	1.52E−02 +/-6%	0.57	0.58	0.55	0.59
10.10	8.26E−03 +/-7%	1.44E−02 +/-6%	0.57	0.58	0.56	0.59
12.22	7.80E−03 +/-7%	1.36E−02 +/-6%	0.57	0.58	0.56	0.59
15.35	7.18E−03 +/-7%	1.25E−02 +/-6%	0.57	0.58	0.56	0.59
19.45	6.47E−03 +/-7%	1.12E−02 +/-6%	0.58	0.58	0.56	0.59
23.52	5.84E−03 +/-7%	1.01E−02 +/-6%	0.58	0.58	0.56	0.59
27.63	5.31E−03 +/-7%	9.10E−03 +/-6%	0.58	0.59	0.57	0.59
34.75	4.47E−03 +/-7%	7.59E−03 +/-6%	0.59	0.59	0.57	0.59
44.87	3.56E−03 +/-7%	5.90E−03 +/-6%	0.60	0.60	0.58	0.60
54.98	2.89E−03 +/-7%	4.63E−03 +/-5%	0.62	0.63	0.60	0.61

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
I128	I127(n,γ)I128	24.9m	100.0	0.58	6%


FNS-00 5 Min. Irradiation - IC_6H_4OH
Heat Output [µW/kg]
1E-01
1E-02
1E-03
Time after irradiation [years]
1E-07
1E-06
1E-05
1E-04
1E-03
^{16}N
^{128}I
^{124m}Sb
Min
Hour

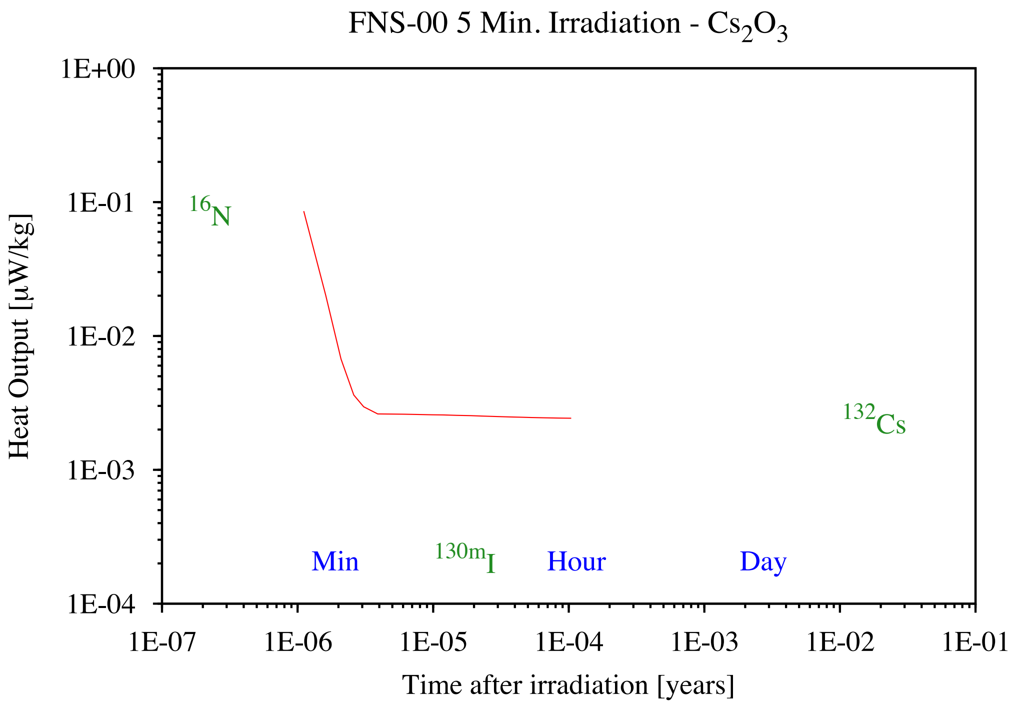
Caesium



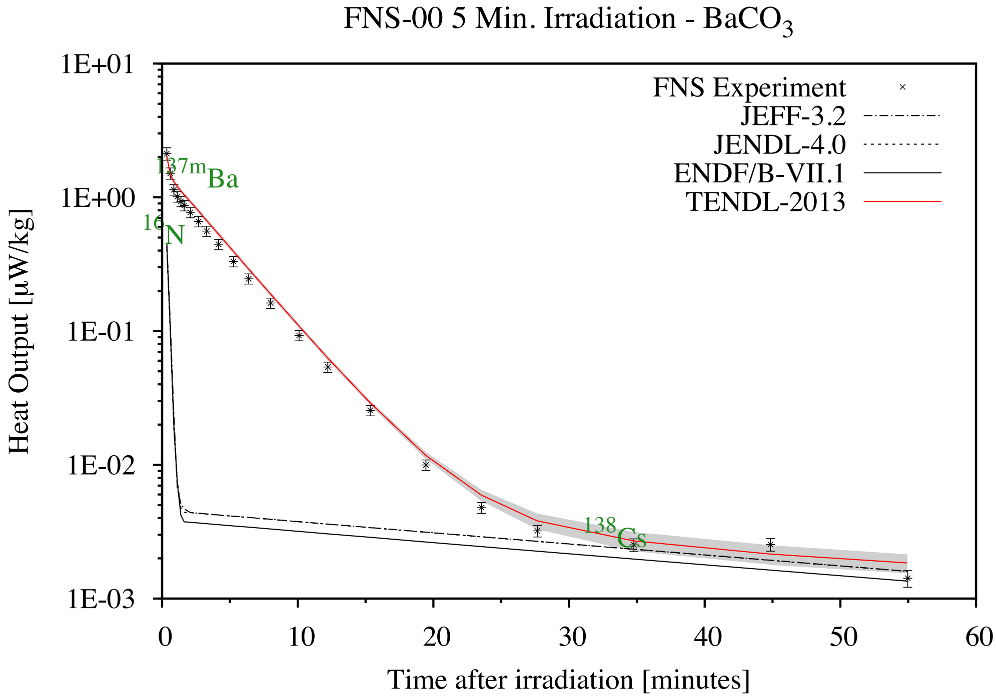
For Cesium, a surprising, but not un-physical upward short-term trend in the experimental heat measurements heat is observed, that may be caused by isomeric states that are unidentified in the calculational scheme, or by a larger than expected subtraction of the tape contribution.

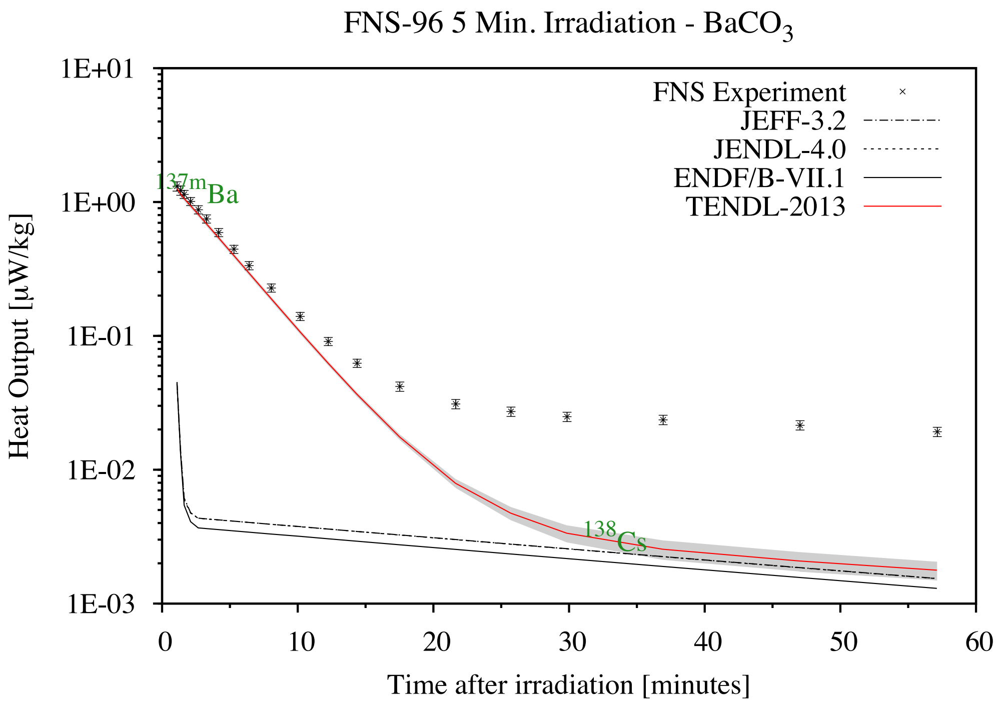
Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	3.89E−01 +/-11%	8.56E−02 +/-0%	4.54	4.60	4.54	4.92
0.85	8.81E−02 +/-11%	2.00E−02 +/-1%	4.40	4.62	4.39	5.15
1.10	1.95E−02 +/-13%	6.72E−03 +/-2%	2.90	2.97	2.88	3.16
1.37	5.66E−03 +/-15%	3.62E−03 +/-4%	1.56	1.54	1.54	1.55
1.62	3.42E−03 +/-15%	2.96E−03 +/-5%	1.16	1.14	1.13	1.13
2.05	1.15E−03 +/-34%	2.62E−03 +/-5%	0.44	0.43	0.43	0.43
2.62	9.98E−04 +/-37%	2.61E−03 +/-5%	0.38	0.38	0.37	0.37
3.22	1.15E−03 +/-31%	2.60E−03 +/-5%	0.44	0.43	0.43	0.43
4.08	1.71E−03 +/-18%	2.59E−03 +/-5%	0.66	0.64	0.64	0.64
5.15	1.79E−03 +/-16%	2.58E−03 +/-5%	0.69	0.67	0.67	0.67
6.25	1.86E−03 +/-14%	2.57E−03 +/-5%	0.72	0.70	0.69	0.69
7.87	1.73E−03 +/-14%	2.55E−03 +/-5%	0.68	0.65	0.65	0.65
9.98	2.04E−03 +/-11%	2.54E−03 +/-4%	0.81	0.77	0.76	0.76
12.10	1.97E−03 +/-10%	2.52E−03 +/-4%	0.78	0.74	0.74	0.73
15.22	1.95E−03 +/-10%	2.50E−03 +/-4%	0.78	0.74	0.73	0.73
19.32	1.84E−03 +/-9%	2.48E−03 +/-4%	0.74	0.69	0.69	0.69
23.43	1.87E−03 +/-9%	2.47E−03 +/-4%	0.76	0.71	0.70	0.70
27.53	1.93E−03 +/-9%	2.46E−03 +/-4%	0.78	0.73	0.72	0.72
34.67	1.90E−03 +/-9%	2.45E−03 +/-4%	0.78	0.72	0.71	0.71
44.78	2.03E−03 +/-9%	2.44E−03 +/-4%	0.83	0.77	0.76	0.76
54.88	2.12E−03 +/-8%	2.43E−03 +/-4%	0.87	0.80	0.79	0.79

Product	**Pathways**	**$T_{1/2}$**	**Path %**	**E/C**	**ΔE%**
Cs132	Cs133(n,2n)Cs132	6.5d	100.0	0.87	8%


FNS-00 5 Min. Irradiation - Cs2O3
1E+00
1E-01
1E-02
1E-03
1E-04
Heat Output [µW/kg]
16N
132Cs
Min
130mI
Hour
Day
1E-07
1E-06
1E-05
1E-04
1E-03
1E-02
1E-01
Time after irradiation [years]

Barium

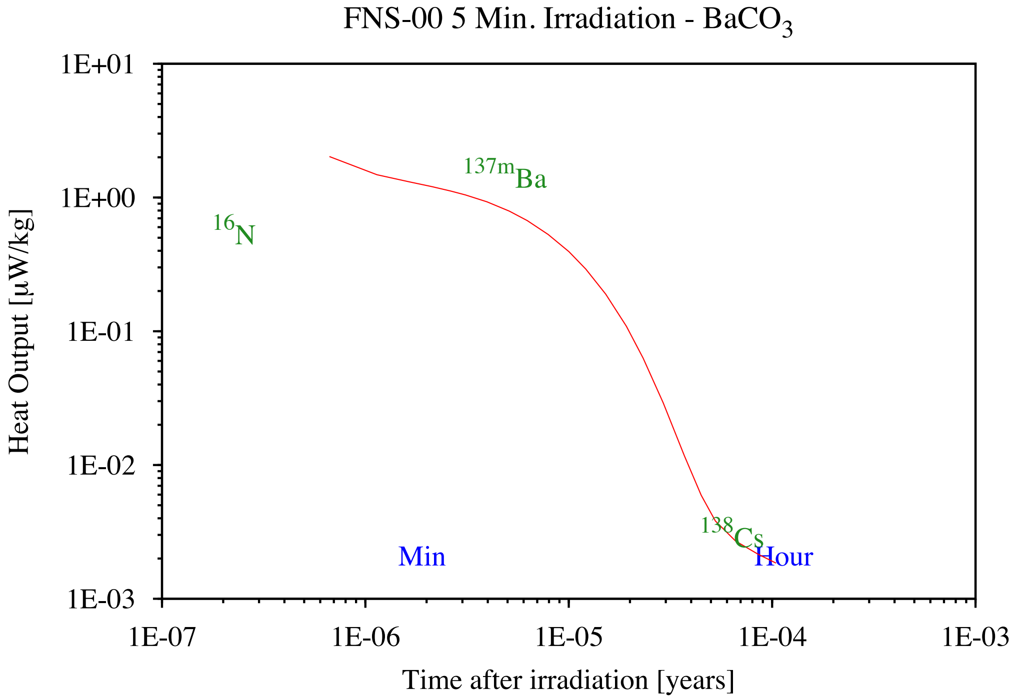


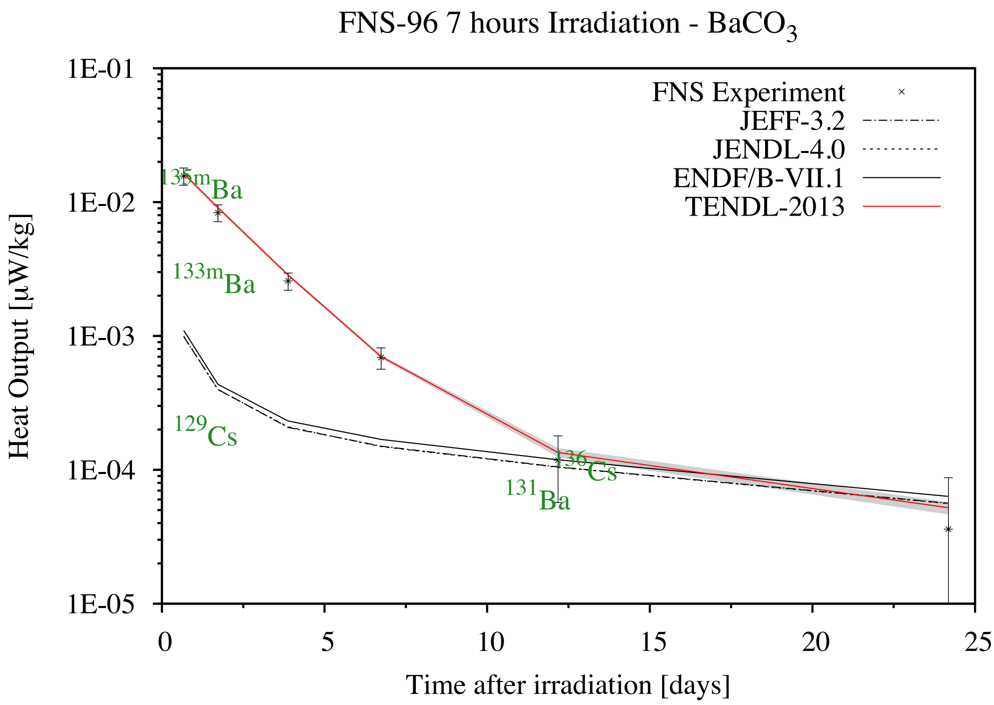


For Barium, once again the two sets of experimental measurements differ. The 1996 sample may have contained some unidentified impurities, possibly Fluorine. However, only TENDL-2013 E/C are reasonable below 30 min cooling.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.35	$2.12E{+}00$ +/-11%	$2.02E{+}00$ +/-3%	1.05	4.87	4.71	5.14
0.60	$1.51E{+}00$ +/-10%	$1.48E{+}00$ +/-4%	1.02	14.37	13.02	15.12
0.87	$1.14E{+}00$ +/-9%	$1.31E{+}00$ +/-4%	0.87	58.45	47.65	60.39
1.12	$1.01E{+}00$ +/-9%	$1.21E{+}00$ +/-4%	0.84	137.83	150.74	132.74
1.38	$9.32E{-}01$ +/-9%	$1.12E{+}00$ +/-4%	0.83	221.85	182.63	196.91
1.63	$8.69E{-}01$ +/-9%	$1.04E{+}00$ +/-4%	0.83	231.65	185.82	196.29
2.08	$7.72E{-}01$ +/-9%	$9.28E{-}01$ +/-4%	0.83	207.62	175.63	175.92
2.68	$6.58E{-}01$ +/-9%	$7.91E{-}01$ +/-4%	0.83	179.05	151.46	151.71
3.28	$5.59E{-}01$ +/-9%	$6.72E{-}01$ +/-4%	0.83	153.91	130.19	130.40
4.17	$4.45E{-}01$ +/-9%	$5.29E{-}01$ +/-4%	0.84	124.65	105.44	105.61
5.27	$3.31E{-}01$ +/-9%	$3.94E{-}01$ +/-4%	0.84	94.74	80.12	80.27
6.38	$2.46E{-}01$ +/-9%	$2.92E{-}01$ +/-4%	0.84	71.97	60.86	60.97
8.00	$1.62E{-}01$ +/-9%	$1.90E{-}01$ +/-4%	0.85	48.92	41.36	41.44
10.10	$9.27E{-}02$ +/-9%	$1.09E{-}01$ +/-4%	0.85	29.16	24.66	24.70
12.22	$5.38E{-}02$ +/-9%	$6.30E{-}02$ +/-4%	0.85	17.64	14.91	14.94
15.33	$2.55E{-}02$ +/-9%	$2.92E{-}02$ +/-4%	0.87	8.88	7.51	7.52
19.45	$9.97E{-}03$ +/-9%	$1.18E{-}02$ +/-6%	0.85	3.76	3.18	3.18
23.55	$4.78E{-}03$ +/-9%	$5.94E{-}03$ +/-10%	0.80	1.95	1.65	1.65
27.67	$3.21E{-}03$ +/-10%	$3.81E{-}03$ +/-13%	0.84	1.42	1.20	1.20
34.78	$2.52E{-}03$ +/-11%	$2.70E{-}03$ +/-16%	0.93	1.28	1.08	1.08
44.85	$2.54E{-}03$ +/-11%	$2.15E{-}03$ +/-17%	1.18	1.56	1.31	1.32
54.97	$1.42E{-}03$ +/-14%	$1.85E{-}03$ +/-16%	0.77	1.05	0.89	0.89

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
N16	O16(n,p)N16	7.1s	99.9	1.05	10%
Ba137m	Ba137(n,n')Ba137m	2.5m	3.6	0.83	8%
	Ba138(n,2n)Ba137m		95.3	0.83	8%
Cs138	Ba138(n,p)Cs138	33.4m	85.2	0.93	10%
	Ba138(n,p)Cs138m	2.9m	15.0	0.93	10%

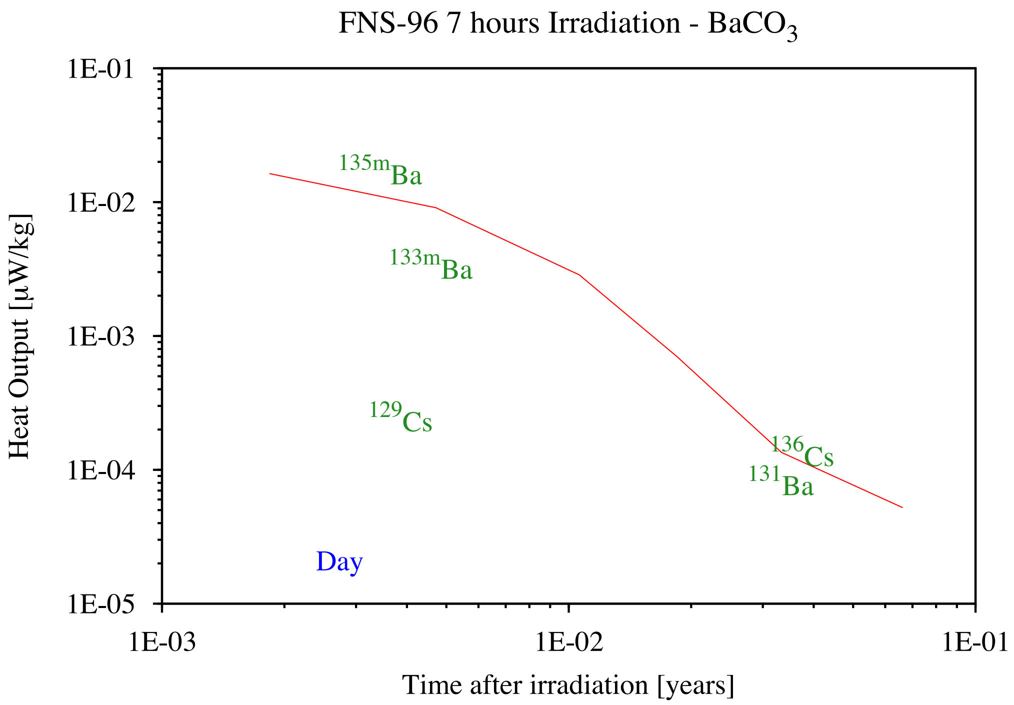




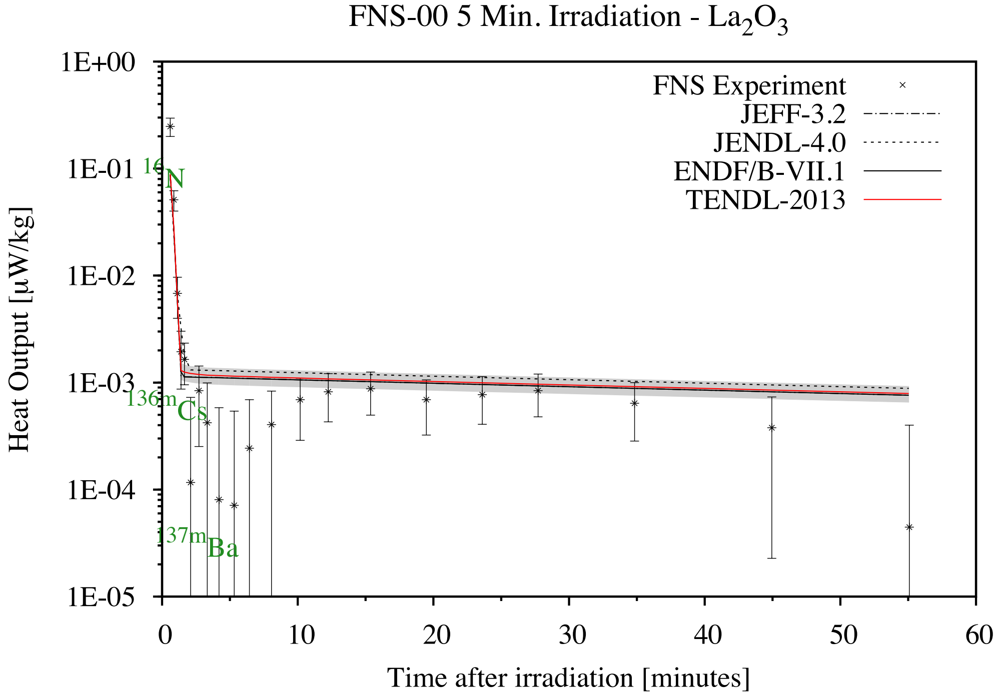
A relatively good agreement is seen between experiment and TENDL-2013 simulation for cooling times from one day up nearly a month.

Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.67	$1.57E{-}02$ +/-15%	$1.63E{-}02$ +/-3%	0.96	14.23	15.84	15.76
1.72	$8.33E{-}03$ +/-14%	$9.07E{-}03$ +/-3%	0.92	19.10	20.87	20.97
3.88	$2.58E{-}03$ +/-15%	$2.86E{-}03$ +/-3%	0.90	11.11	12.42	12.29
6.74	$6.90E{-}04$ +/-18%	$7.01E{-}04$ +/-3%	0.98	4.09	4.60	4.63
12.18	$1.18E{-}04$ +/-52%	$1.35E{-}04$ +/-8%	0.88	0.99	1.12	1.13
24.18	$3.60E{-}05$ +/-143%	$5.22E{-}05$ +/-10%	0.69	0.57	0.64	0.64

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ba135m	Ba136(n,2n)Ba135m	1.1d	88.2	0.96	15%
	Ba135(n,n')Ba135m		11.8	0.96	15%
Ba133m	Ba134(n,2n)Ba133m	1.5d	100.0	0.92	14%
Ba131	Ba132(n,2n)Ba131	11.5d	35.7	0.88	52%
	Ba132(n,2n)Ba131m		63.6	0.88	52%


FNS-96 7 hours Irradiation - BaCO3
Heat Output [µW/kg]
1E-01
1E-02
1E-03
1E-04
1E-05
1E-03
1E-02
1E-01
Time after irradiation [years]
135mBa
133mBa
129Cs
136Cs
131Ba
Day

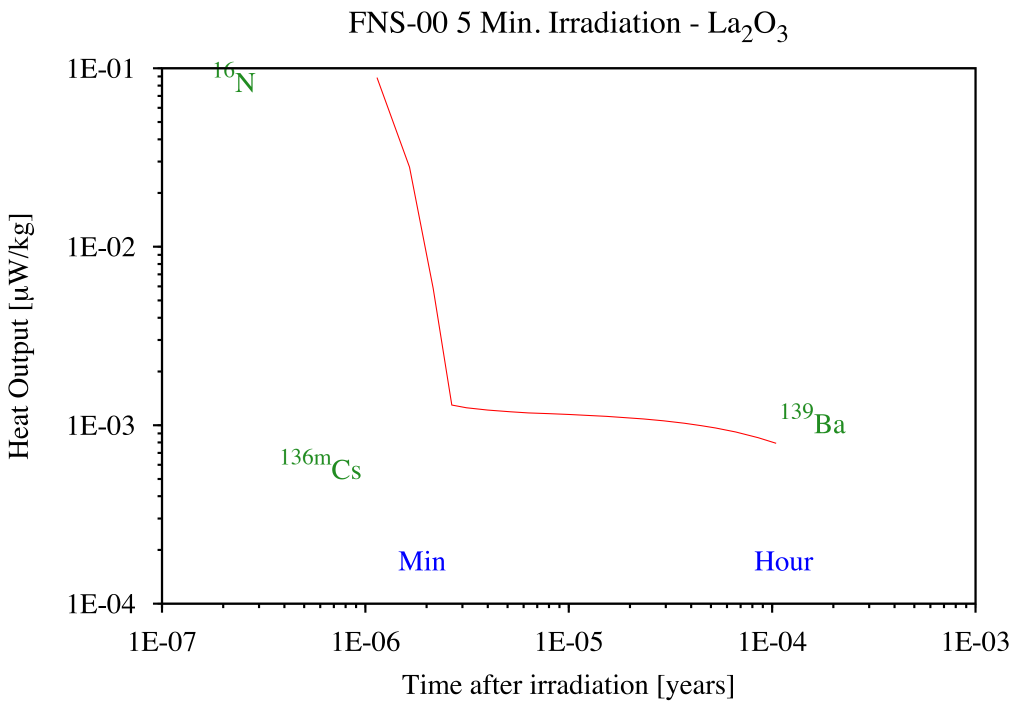
Lanthanum



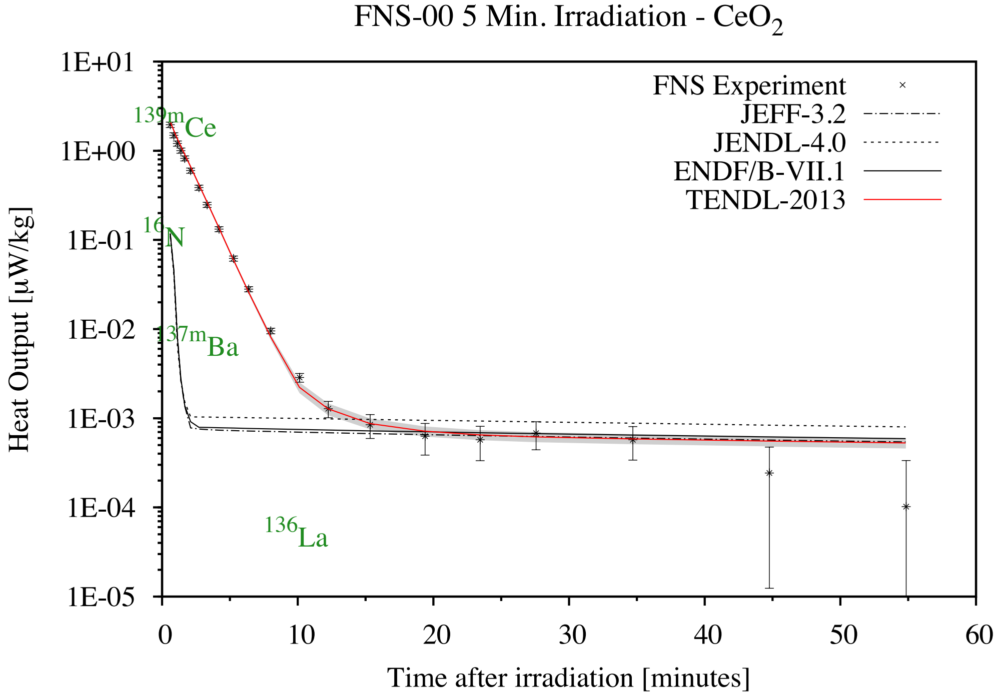
For Lanthanum, the rather large and honest experimental uncertainties do not permit an in-depth investigation, although the overall trend seems to be present in the simulations.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	µW/g	µW/g	E/C	E/C	E/C	E/C
0.60	2.48E−01 +/-19%	8.86E−02 +/-1%	2.80	2.85	2.82	3.07
0.87	5.11E−02 +/-22%	2.79E−02 +/-2%	1.83	1.90	1.86	2.17
1.13	6.81E−03 +/-41%	5.85E−03 +/-5%	1.17	1.22	1.22	1.02
1.40	1.94E−03 +/-55%	1.30E−03 +/-19%	1.50	1.55	1.71	0.60
1.65	1.65E−03 +/-42%	1.25E−03 +/-18%	1.32	1.46	1.45	0.93
2.10	1.17E−04 +/-524%	1.21E−03 +/-18%	0.10	0.10	0.10	0.09
2.72	8.40E−04 +/-70%	1.19E−03 +/-18%	0.71	0.75	0.75	0.64
3.33	4.22E−04 +/-135%	1.17E−03 +/-18%	0.36	0.38	0.38	0.32
4.20	8.05E−05 +/-623%	1.16E−03 +/-18%	0.07	0.07	0.07	0.06
5.32	7.13E−05 +/-659%	1.15E−03 +/-18%	0.06	0.06	0.06	0.06
6.43	2.43E−04 +/-184%	1.14E−03 +/-18%	0.21	0.22	0.22	0.19
8.07	4.05E−04 +/-106%	1.12E−03 +/-18%	0.36	0.38	0.38	0.32
10.18	6.91E−04 +/-58%	1.10E−03 +/-18%	0.63	0.65	0.65	0.56
12.25	8.20E−04 +/-48%	1.08E−03 +/-18%	0.76	0.79	0.79	0.67
15.37	8.76E−04 +/-43%	1.06E−03 +/-18%	0.83	0.86	0.86	0.74
19.48	6.92E−04 +/-53%	1.03E−03 +/-18%	0.67	0.70	0.70	0.60
23.60	7.72E−04 +/-47%	9.95E−04 +/-18%	0.78	0.80	0.80	0.69
27.72	8.40E−04 +/-43%	9.65E−04 +/-18%	0.87	0.90	0.90	0.78
34.83	6.42E−04 +/-56%	9.16E−04 +/-18%	0.70	0.73	0.73	0.63
44.95	3.78E−04 +/-94%	8.51E−04 +/-17%	0.44	0.46	0.46	0.40
55.08	4.45E−05 +/-799%	7.91E−04 +/-17%	0.06	0.06	0.06	0.05

Product	**Pathways**	**$T_{1/2}$**	**Path %**	**E/C**	**ΔE%**
Ba139	La139(n,p)Ba139	1.3h	100.0	0.87	43%


FNS-00 5 Min. Irradiation - La2O3
Heat Output [µW/kg]
Time after irradiation [years]
1E-01
1E-02
1E-03
1E-04
1E-07
1E-06
1E-05
1E-04
1E-03
16N
136mCs
139Ba
Min
Hour

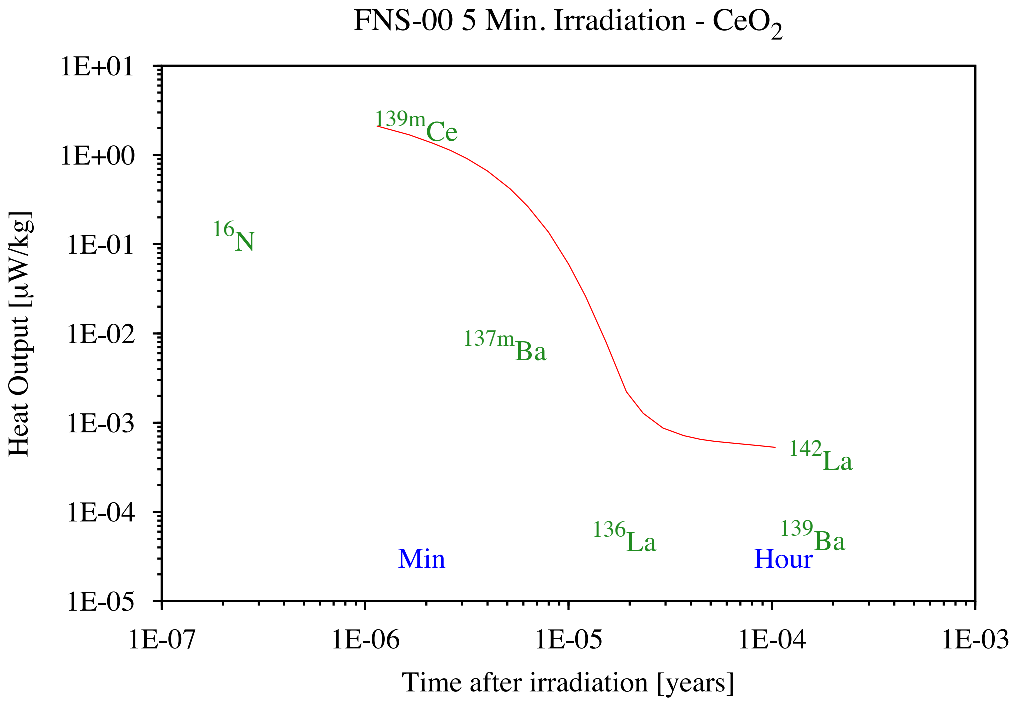
Cerium



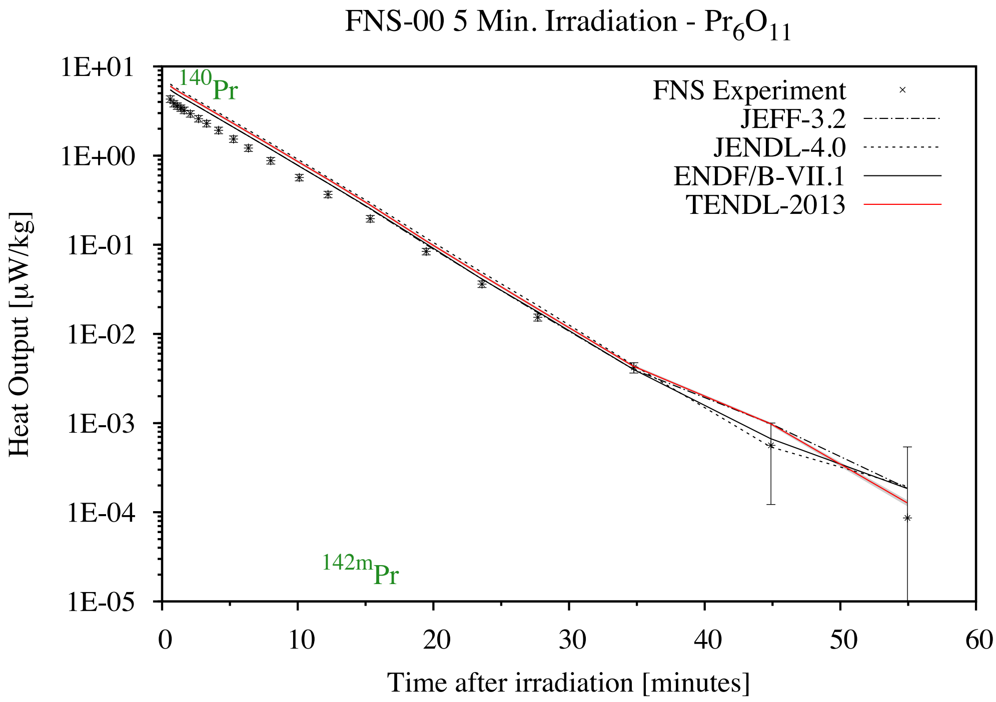
For Cerium and TENDL-2013, a good agreement exists up to 30 minutes cooling, and beyond this the large experimental uncertainties might explain the significant disagreement.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	1.96E+00 +/-7%	2.11E+00 +/-4%	0.93	16.73	16.52	17.83
0.87	1.49E+00 +/-7%	1.68E+00 +/-4%	0.89	33.09	32.11	36.88
1.13	1.21E+00 +/-7%	1.35E+00 +/-4%	0.89	152.14	142.94	189.28
1.38	1.00E+00 +/-7%	1.12E+00 +/-4%	0.89	359.04	377.15	384.15
1.67	8.21E−01 +/-7%	9.12E−01 +/-4%	0.90	591.34	602.66	536.24
2.10	5.99E−01 +/-7%	6.61E−01 +/-4%	0.91	654.89	767.25	577.46
2.72	3.86E−01 +/-7%	4.17E−01 +/-4%	0.93	486.78	509.72	373.14
3.32	2.47E−01 +/-7%	2.65E−01 +/-4%	0.93	313.62	331.93	239.94
4.20	1.32E−01 +/-7%	1.36E−01 +/-5%	0.97	168.89	180.08	128.86
5.27	6.19E−02 +/-7%	5.97E−02 +/-5%	1.04	79.76	85.30	60.67
6.38	2.80E−02 +/-7%	2.60E−02 +/-5%	1.08	36.46	39.01	27.65
8.02	9.53E−03 +/-7%	8.12E−03 +/-7%	1.17	12.54	13.42	9.47
10.13	2.86E−03 +/-11%	2.22E−03 +/-14%	1.29	3.82	4.10	2.88
12.25	1.28E−03 +/-21%	1.27E−03 +/-15%	1.00	1.74	1.86	1.30
15.33	8.47E−04 +/-30%	8.72E−04 +/-14%	0.97	1.17	1.26	0.87
19.38	6.29E−04 +/-39%	7.15E−04 +/-13%	0.88	0.89	0.96	0.66
23.45	5.73E−04 +/-42%	6.51E−04 +/-13%	0.88	0.83	0.90	0.62
27.57	6.79E−04 +/-35%	6.18E−04 +/-13%	1.10	1.01	1.09	0.75
34.70	5.73E−04 +/-41%	5.87E−04 +/-13%	0.98	0.88	0.96	0.65
44.77	2.43E−04 +/-95%	5.56E−04 +/-13%	0.44	0.39	0.43	0.29
54.85	1.02E−04 +/-229%	5.29E−04 +/-13%	0.19	0.17	0.19	0.13

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ce139m	Ce140(n,2n)Ce139m	56.1s	98.8	0.93	7%
Ba137m	Ce140(n,α)Ba137m	2.5m	99.3	0.93	7%
La142	Ce142(n,p)La142	1.5h	100.0	0.98	41%



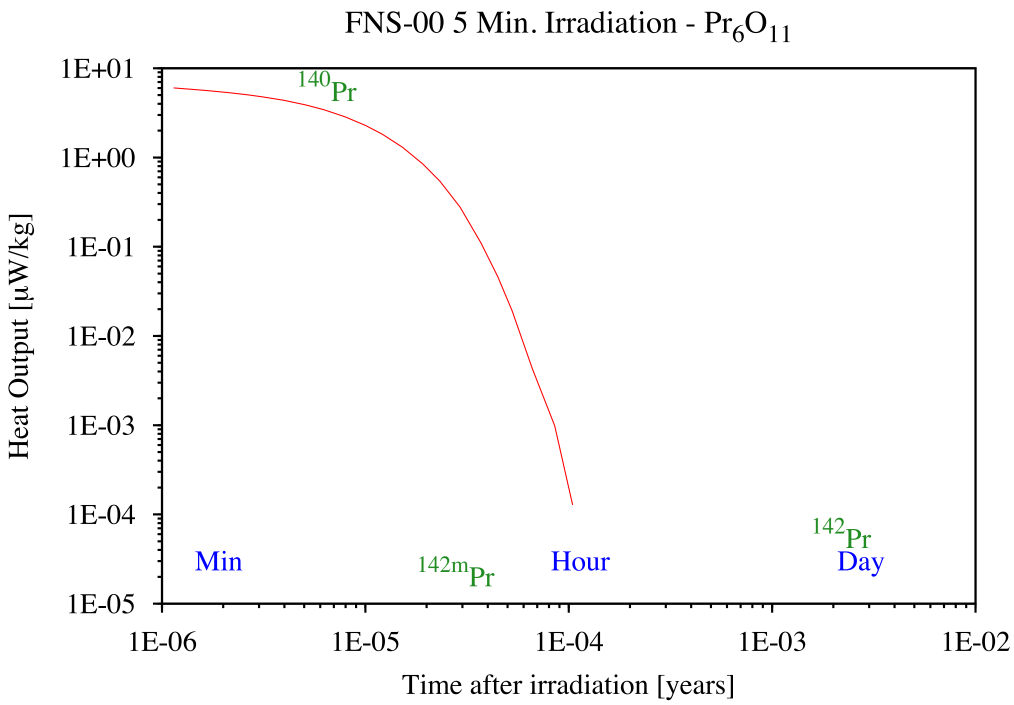
Praseodymium



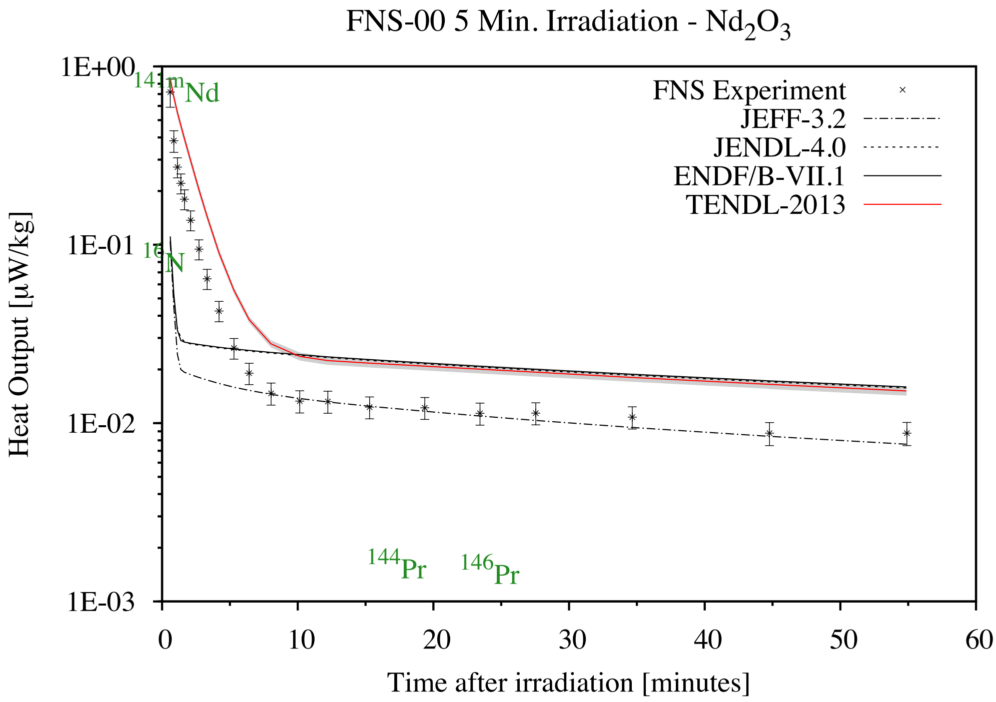
For Praseodymium, a systematic 30% over-prediction exists in the TENDL-2013 simulation, which may indicate that a cross section and/or decay data correction is foreseeable.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	µW/g	µW/g	E/C	E/C	E/C	E/C
0.60	4.31E+00 +/-9%	6.03E+00 +/-4%	0.72	0.79	0.79	0.68
0.87	3.83E+00 +/-8%	5.64E+00 +/-4%	0.68	0.75	0.75	0.64
1.12	3.60E+00 +/-8%	5.33E+00 +/-4%	0.68	0.74	0.74	0.64
1.38	3.42E+00 +/-8%	5.04E+00 +/-4%	0.68	0.75	0.75	0.64
1.63	3.22E+00 +/-8%	4.79E+00 +/-4%	0.67	0.74	0.74	0.64
2.08	2.95E+00 +/-8%	4.38E+00 +/-4%	0.67	0.74	0.74	0.64
2.68	2.60E+00 +/-8%	3.89E+00 +/-4%	0.67	0.74	0.74	0.63
3.28	2.29E+00 +/-8%	3.44E+00 +/-4%	0.67	0.73	0.73	0.63
4.17	1.92E+00 +/-8%	2.87E+00 +/-4%	0.67	0.74	0.74	0.63
5.27	1.53E+00 +/-8%	2.29E+00 +/-4%	0.67	0.74	0.74	0.63
6.37	1.22E+00 +/-8%	1.83E+00 +/-4%	0.67	0.73	0.73	0.63
8.02	8.77E−01 +/-8%	1.30E+00 +/-4%	0.68	0.74	0.74	0.64
10.12	5.68E−01 +/-8%	8.40E−01 +/-4%	0.68	0.75	0.75	0.64
12.23	3.67E−01 +/-8%	5.42E−01 +/-4%	0.68	0.75	0.75	0.64
15.35	1.96E−01 +/-8%	2.79E−01 +/-4%	0.71	0.77	0.78	0.66
19.47	8.40E−02 +/-8%	1.11E−01 +/-4%	0.76	0.81	0.84	0.70
23.58	3.62E−02 +/-8%	4.57E−02 +/-4%	0.79	0.87	0.87	0.74
27.70	1.53E−02 +/-9%	1.91E−02 +/-4%	0.80	0.86	0.88	0.74
34.78	4.20E−03 +/-13%	4.34E−03 +/-4%	0.97	1.05	1.05	0.94
44.88	5.63E−04 +/-78%	9.85E−04 +/-3%	0.57	0.84	0.57	1.04
54.95	8.63E−05 +/-526%	1.28E−04 +/-7%	0.68	0.47	0.46	0.44

Product	**Pathways**	**$T_{1/2}$**	**Path %**	**E/C**	**ΔE%**
Pr140	Pr141(n,2n)Pr140	3.3m	99.6	0.67	8%


FNS-00 5 Min. Irradiation - Pr_6O_{11}
Heat Output [µW/kg]
1E+01
1E+00
1E-01
1E-02
1E-03
1E-04
1E-05
1E-06
1E-05
1E-04
1E-03
1E-02
Time after irradiation [years]
^{140}Pr
^{142m}Pr
^{142}Pr
Min
Hour
Day

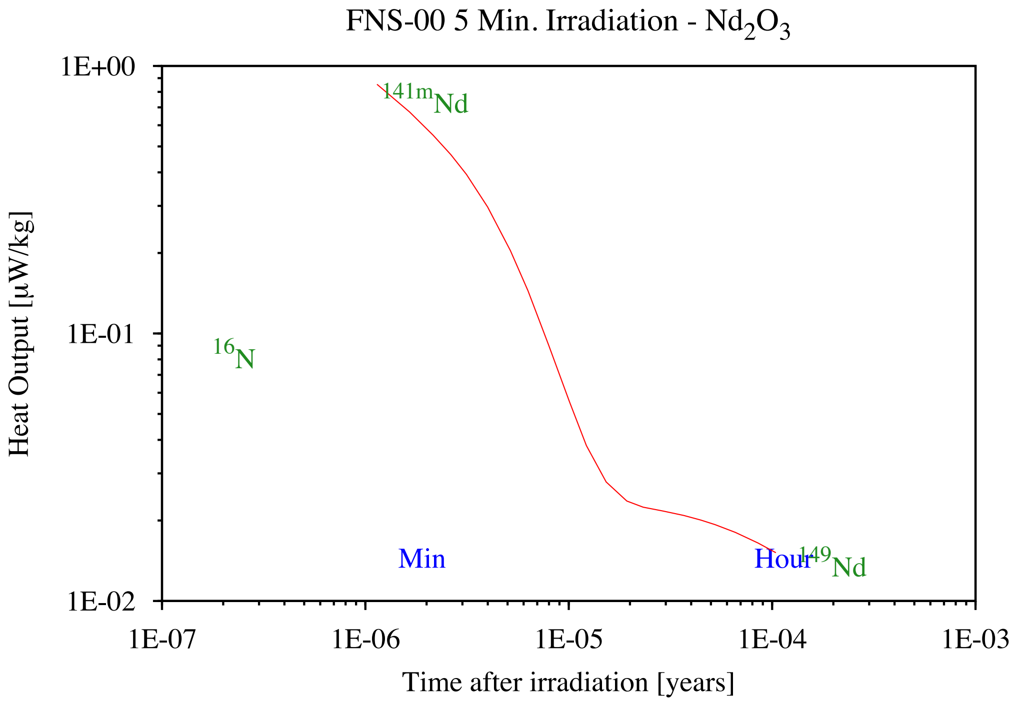
Neodymium

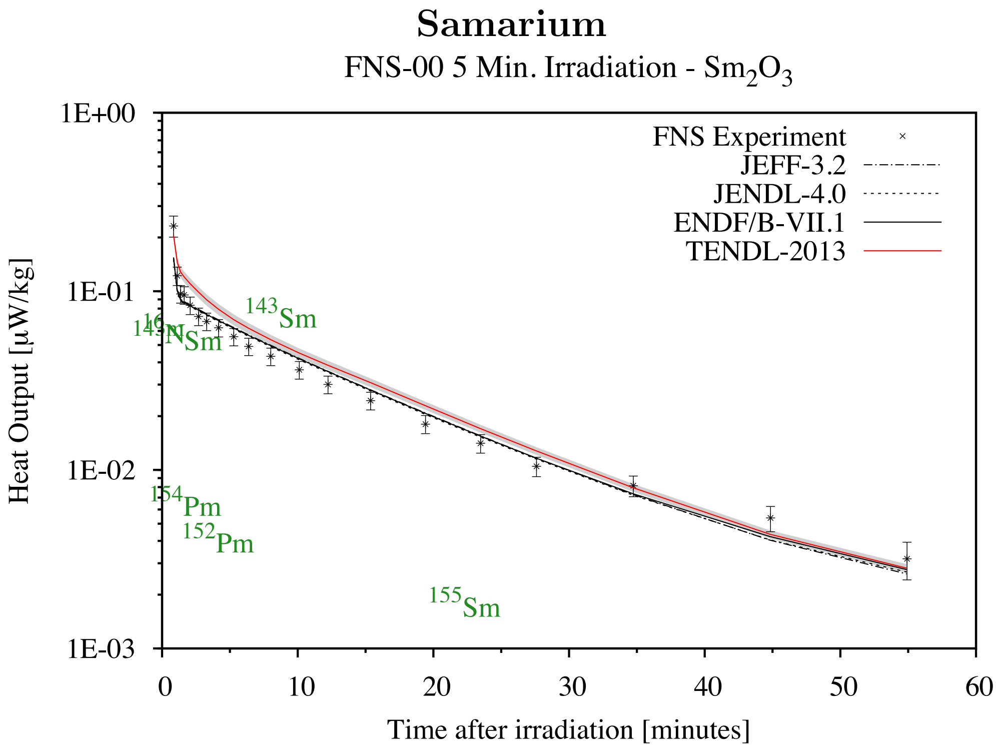


For Neodymium, the rather uniform and significant 50% over-prediction appearing after a few minutes of cooling for TENDL-2013 may need to be acted upon. The Nd141m isomer half life seems to be well predicted although its level may also be on the high side. JEFF-3.2 Nd149 production pathway better agree with the experiment after 8 min cooling.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	7.19E−01 +/-18%	8.54E−01 +/-5%	0.84	6.45	6.97	6.83
0.87	3.83E−01 +/-14%	6.73E−01 +/-6%	0.57	7.27	8.62	7.77
1.13	2.72E−01 +/-13%	5.51E−01 +/-6%	0.49	8.22	11.23	8.11
1.38	2.21E−01 +/-13%	4.66E−01 +/-6%	0.47	7.62	11.09	7.32
1.65	1.80E−01 +/-13%	3.93E−01 +/-6%	0.46	6.33	9.35	6.30
2.10	1.37E−01 +/-13%	2.97E−01 +/-6%	0.46	4.89	7.34	4.93
2.72	9.44E−02 +/-13%	2.04E−01 +/-6%	0.46	3.42	5.24	3.45
3.32	6.44E−02 +/-13%	1.44E−01 +/-5%	0.45	2.37	3.70	2.39
4.20	4.25E−02 +/-13%	9.01E−02 +/-5%	0.47	1.60	2.55	1.61
5.30	2.63E−02 +/-13%	5.55E−02 +/-4%	0.47	1.01	1.66	1.02
6.42	1.90E−02 +/-14%	3.81E−02 +/-4%	0.50	0.75	1.25	0.75
8.03	1.47E−02 +/-14%	2.79E−02 +/-5%	0.53	0.59	1.01	0.59
10.15	1.33E−02 +/-14%	2.37E−02 +/-5%	0.56	0.55	0.97	0.55
12.22	1.32E−02 +/-14%	2.24E−02 +/-5%	0.59	0.56	1.01	0.57
15.30	1.23E−02 +/-14%	2.17E−02 +/-5%	0.57	0.54	0.99	0.55
19.37	1.22E−02 +/-14%	2.09E−02 +/-5%	0.58	0.56	1.05	0.57
23.43	1.14E−02 +/-14%	2.01E−02 +/-5%	0.57	0.54	1.03	0.55
27.55	1.14E−02 +/-14%	1.93E−02 +/-5%	0.59	0.57	1.10	0.58
34.67	1.08E−02 +/-14%	1.80E−02 +/-6%	0.60	0.58	1.14	0.58
44.78	8.78E−03 +/-15%	1.65E−02 +/-6%	0.53	0.51	1.04	0.52
54.90	8.79E−03 +/-15%	1.52E−02 +/-6%	0.58	0.55	1.15	0.56

Product	Pathways	$T_{1/2}$	Path %	E/C	ΔE%
Nd141m	Nd142(n,2n)Nd141m	1.0m	98.6	0.49	13%
Nd149	Nd148(n,γ)Nd149	1.7h	0.7	0.58	15%
	Nd150(n,2n)Nd149		99.3	0.58	15%

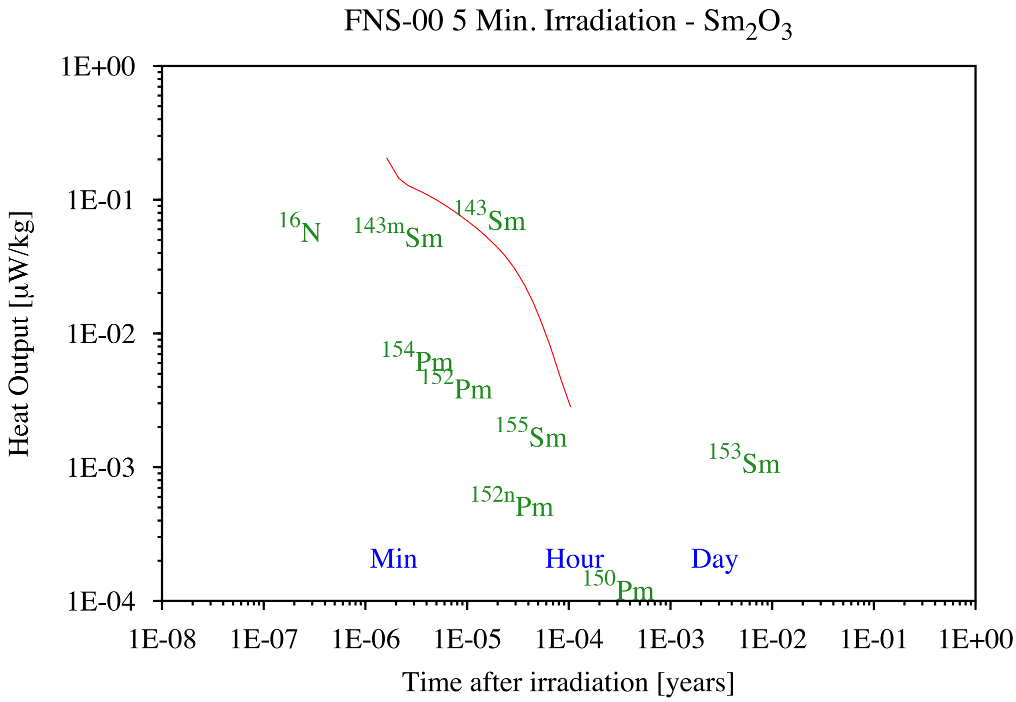




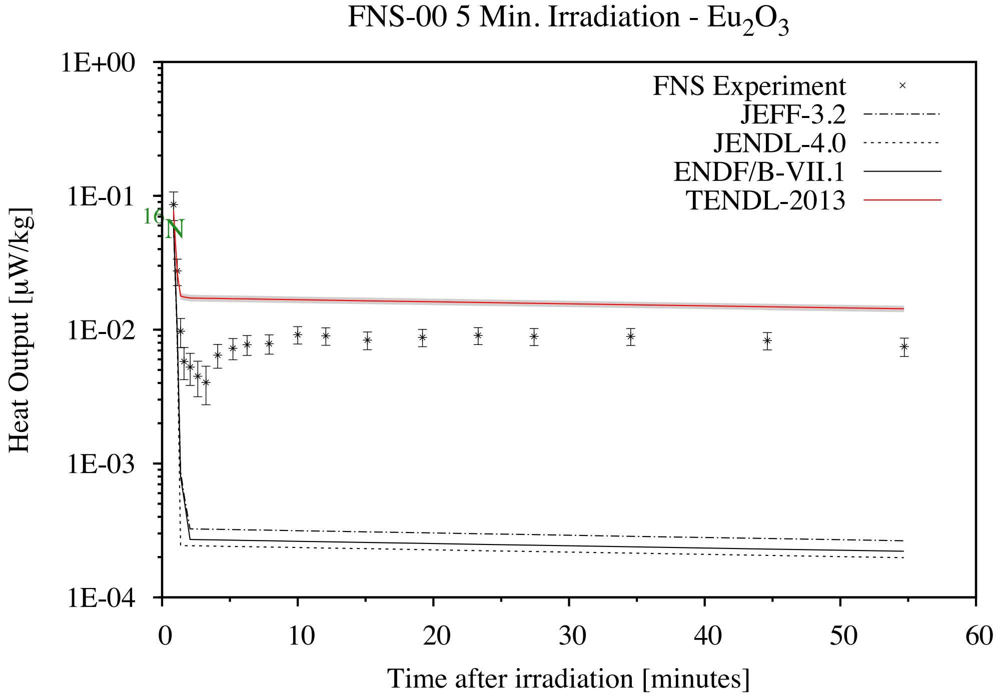
For Samarium, a good agreement exists, fully endorsed by both the quoted experimental and calculational uncertainties. This provides, once again, proof of the well founded processes that allow the build-up of the European Activation and TENDL covariance data files.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.85	$2.32E{-}01$ +/-14%	$2.06E{-}01$ +/-5%	1.13	1.51	1.50	1.54
1.12	$1.22E{-}01$ +/-12%	$1.45E{-}01$ +/-6%	0.84	1.22	1.21	1.24
1.37	$9.67E{-}02$ +/-11%	$1.28E{-}01$ +/-7%	0.75	1.08	1.07	1.10
1.63	$9.53E{-}02$ +/-11%	$1.20E{-}01$ +/-7%	0.79	1.10	1.09	1.11
2.07	$8.34E{-}02$ +/-11%	$1.10E{-}01$ +/-7%	0.76	1.01	1.00	1.01
2.68	$7.23E{-}02$ +/-11%	$9.89E{-}02$ +/-7%	0.73	0.92	0.91	0.93
3.28	$6.78E{-}02$ +/-11%	$8.96E{-}02$ +/-7%	0.76	0.91	0.91	0.92
4.17	$6.24E{-}02$ +/-11%	$7.92E{-}02$ +/-7%	0.79	0.91	0.90	0.92
5.28	$5.57E{-}02$ +/-11%	$6.94E{-}02$ +/-7%	0.80	0.90	0.89	0.91
6.38	$4.91E{-}02$ +/-11%	$6.21E{-}02$ +/-7%	0.79	0.87	0.86	0.88
8.02	$4.32E{-}02$ +/-11%	$5.36E{-}02$ +/-6%	0.81	0.87	0.87	0.88
10.12	$3.63E{-}02$ +/-11%	$4.51E{-}02$ +/-6%	0.81	0.87	0.86	0.88
12.23	$3.01E{-}02$ +/-11%	$3.86E{-}02$ +/-6%	0.78	0.85	0.84	0.86
15.37	$2.44E{-}02$ +/-11%	$3.08E{-}02$ +/-5%	0.79	0.87	0.87	0.88
19.42	$1.80E{-}02$ +/-12%	$2.29E{-}02$ +/-5%	0.79	0.87	0.87	0.88
23.48	$1.41E{-}02$ +/-12%	$1.70E{-}02$ +/-5%	0.83	0.91	0.91	0.92
27.60	$1.05E{-}02$ +/-12%	$1.28E{-}02$ +/-5%	0.82	0.90	0.90	0.91
34.73	$8.15E{-}03$ +/-13%	$7.94E{-}03$ +/-5%	1.03	1.11	1.12	1.13
44.85	$5.37E{-}03$ +/-16%	$4.35E{-}03$ +/-5%	1.23	1.27	1.33	1.33
54.92	$3.18E{-}03$ +/-24%	$2.81E{-}03$ +/-5%	1.13	1.15	1.22	1.19

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Sm143m	Sm144(n,2n)Sm143m	1.1m	98.5	0.84	12%
Sm143	Sm144(n,2n)Sm143	8.7m	58.7	0.81	11%
	Sm144(n,2n)Sm143m	1.1m	41.5	0.81	11%



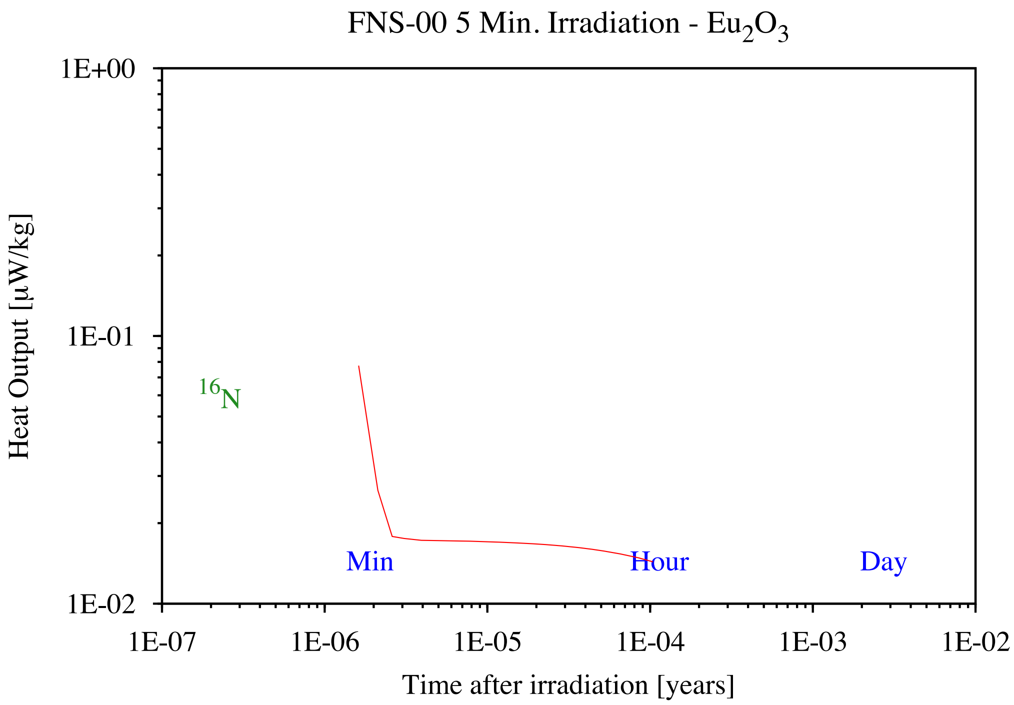
Europium



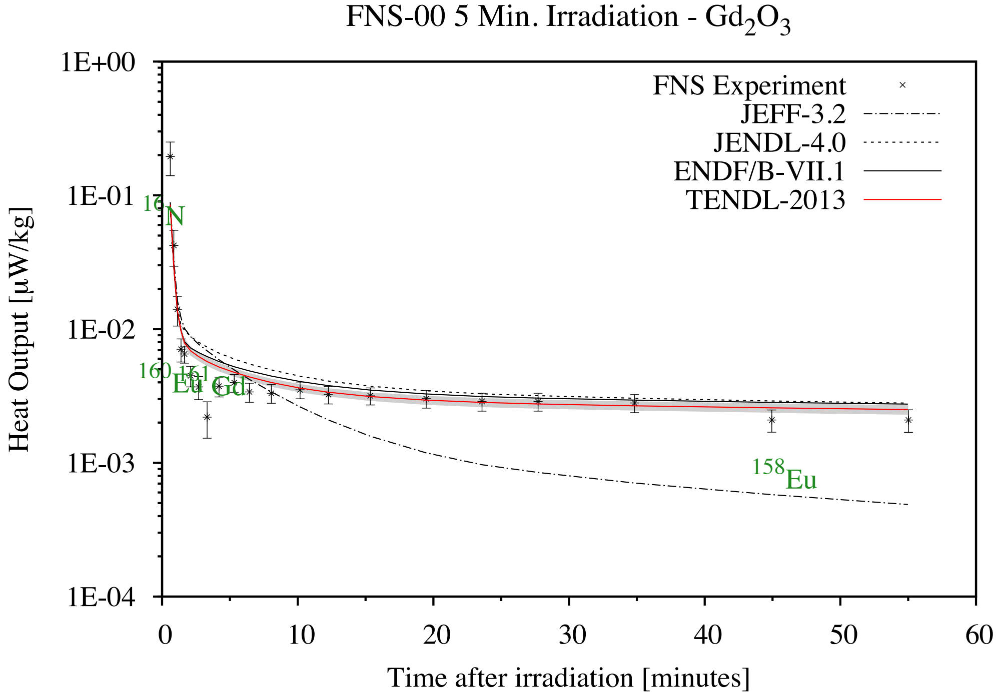
For Europium and TENDL-2013, as with Caesium, an upward trend can be seen at short cooling times, with the possibility of still missing isomeric states in the databases. It is clearly the reason behind the poor agreement seen in the other libraries

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.85	$8.60E{-}02$ +/-24%	$7.75E{-}02$ +/-1%	1.11	1.43	1.42	1.48
1.12	$2.75E{-}02$ +/-22%	$2.65E{-}02$ +/-4%	1.04	2.92	2.88	3.32
1.37	$9.72E{-}03$ +/-25%	$1.78E{-}02$ +/-6%	0.55	12.22	11.14	39.87
1.62	$5.79E{-}03$ +/-27%	$1.75E{-}02$ +/-6%	0.33	10.60	9.87	23.75
2.07	$5.25E{-}03$ +/-27%	$1.72E{-}02$ +/-6%	0.30	19.41	16.17	21.59
2.63	$4.49E{-}03$ +/-30%	$1.72E{-}02$ +/-6%	0.26	16.62	13.84	18.49
3.23	$4.04E{-}03$ +/-32%	$1.72E{-}02$ +/-6%	0.24	14.99	12.49	16.68
4.10	$6.45E{-}03$ +/-20%	$1.71E{-}02$ +/-6%	0.38	24.02	20.01	26.73
5.22	$7.27E{-}03$ +/-18%	$1.70E{-}02$ +/-6%	0.43	27.18	22.65	30.25
6.27	$7.72E{-}03$ +/-17%	$1.70E{-}02$ +/-6%	0.46	29.02	24.17	32.29
7.90	$7.85E{-}03$ +/-16%	$1.69E{-}02$ +/-6%	0.47	29.69	24.74	33.05
10.00	$9.18E{-}03$ +/-15%	$1.67E{-}02$ +/-6%	0.55	34.97	29.14	38.93
12.07	$8.99E{-}03$ +/-15%	$1.66E{-}02$ +/-6%	0.54	34.53	28.77	38.44
15.13	$8.34E{-}03$ +/-15%	$1.64E{-}02$ +/-6%	0.51	32.44	27.03	36.12
19.20	$8.76E{-}03$ +/-15%	$1.62E{-}02$ +/-6%	0.54	34.58	28.82	38.52
23.30	$9.05E{-}03$ +/-14%	$1.60E{-}02$ +/-6%	0.57	36.32	30.27	40.47
27.42	$8.90E{-}03$ +/-15%	$1.57E{-}02$ +/-6%	0.57	36.29	30.25	40.45
34.55	$8.91E{-}03$ +/-14%	$1.53E{-}02$ +/-5%	0.58	37.35	31.15	41.66
44.62	$8.29E{-}03$ +/-15%	$1.48E{-}02$ +/-5%	0.56	36.10	30.12	40.29
54.72	$7.47E{-}03$ +/-16%	$1.43E{-}02$ +/-5%	0.52	33.83	28.23	37.79

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Eu152m	Eu151(n,γ)Eu152m	9.2h	93.2	0.56	15%
	Eu153(n,2n)Eu152m		6.8	0.56	15%


FNS-00 5 Min. Irradiation - Eu2O3
Heat Output [µW/kg]
1E+00
1E-01
1E-02
16N
Min
Hour
Day
1E-07
1E-06
1E-05
1E-04
1E-03
1E-02
Time after irradiation [years]

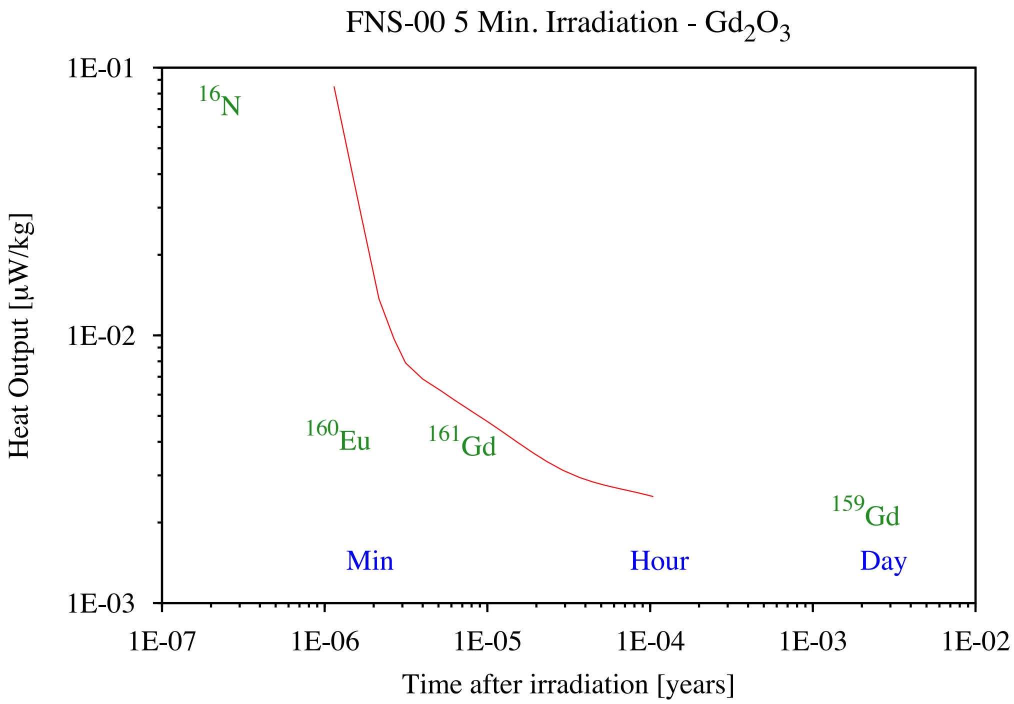
Gadolinium



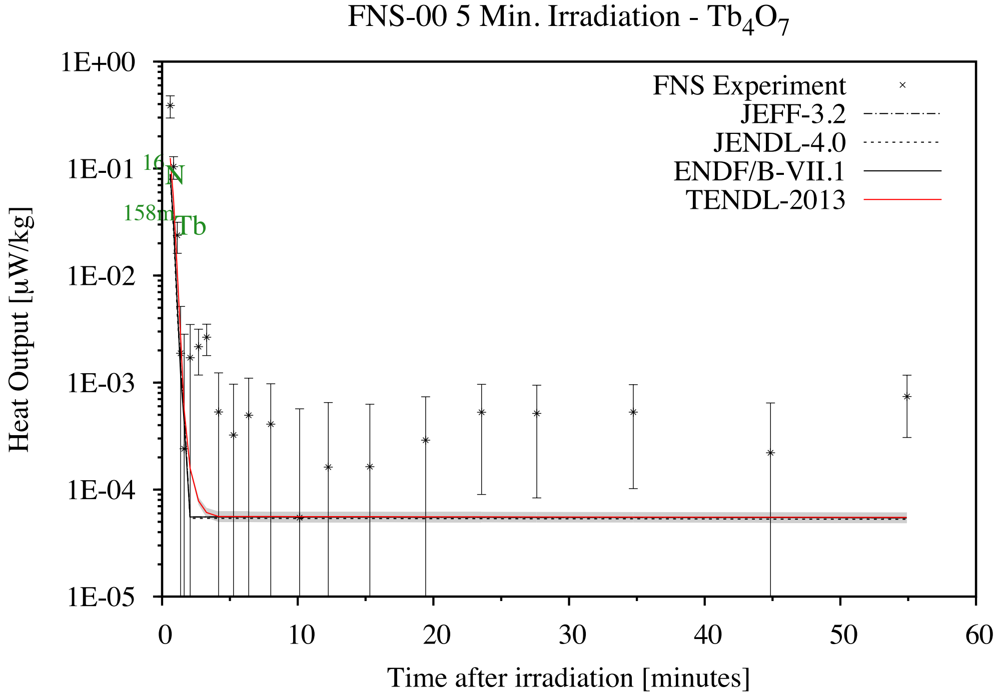
For Gadolinium, the fluctuation with time of the measured decay heat, as well as the large number of contributing isotopes and their complex production routes, leads to difficulties in the interpretation, although the TENDL-2013 E/C are fairly consistent.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	1.95$E-$01 +/-28%	8.52$E-$02 +/-1%	2.29	2.32	2.20	2.38
0.87	4.22$E-$02 +/-30%	2.95$E-$02 +/-3%	1.43	1.47	1.30	1.47
1.13	1.41$E-$02 +/-25%	1.37$E-$02 +/-6%	1.03	1.05	0.86	0.97
1.40	7.06$E-$03 +/-20%	9.71$E-$03 +/-7%	0.73	0.73	0.58	0.66
1.65	6.51$E-$03 +/-15%	7.90$E-$03 +/-8%	0.82	0.81	0.64	0.66
2.10	4.48$E-$03 +/-17%	6.88$E-$03 +/-8%	0.65	0.62	0.51	0.51
2.70	3.69$E-$03 +/-20%	6.23$E-$03 +/-8%	0.59	0.55	0.48	0.46
3.32	2.19$E-$03 +/-30%	5.72$E-$03 +/-7%	0.38	0.35	0.32	0.30
4.20	3.74$E-$03 +/-17%	5.21$E-$03 +/-7%	0.72	0.65	0.63	0.56
5.32	3.97$E-$03 +/-15%	4.74$E-$03 +/-7%	0.84	0.76	0.80	0.67
6.43	3.39$E-$03 +/-16%	4.39$E-$03 +/-7%	0.77	0.70	0.81	0.62
8.05	3.32$E-$03 +/-16%	3.98$E-$03 +/-7%	0.83	0.74	0.98	0.67
10.17	3.51$E-$03 +/-14%	3.62$E-$03 +/-7%	0.97	0.87	1.34	0.79
12.27	3.23$E-$03 +/-15%	3.37$E-$03 +/-7%	0.96	0.86	1.54	0.79
15.35	3.17$E-$03 +/-15%	3.13$E-$03 +/-7%	1.01	0.90	2.00	0.85
19.47	3.01$E-$03 +/-15%	2.94$E-$03 +/-8%	1.02	0.92	2.54	0.87
23.58	2.88$E-$03 +/-15%	2.83$E-$03 +/-8%	1.02	0.92	2.97	0.88
27.72	2.87$E-$03 +/-15%	2.75$E-$03 +/-8%	1.04	0.94	3.39	0.91
34.83	2.80$E-$03 +/-15%	2.67$E-$03 +/-8%	1.05	0.95	3.96	0.92
44.95	2.09$E-$03 +/-19%	2.58$E-$03 +/-8%	0.81	0.74	3.61	0.72
55.02	2.09$E-$03 +/-19%	2.50$E-$03 +/-8%	0.84	0.76	4.29	0.75

Product	Pathways	$T_{1/2}$	Path %	E/C	ΔE%
Eu160	Gd160(n,p)Eu160	38.0s	98.9	1.03	25%
Gd161	Gd160(n,γ)Gd161	3.6m	99.4	0.72	17%
Gd159	Gd158(n,γ)Gd159	18.4h	1.5	0.84	19%
	Gd160(n,2n)Gd159		98.5	0.84	19%



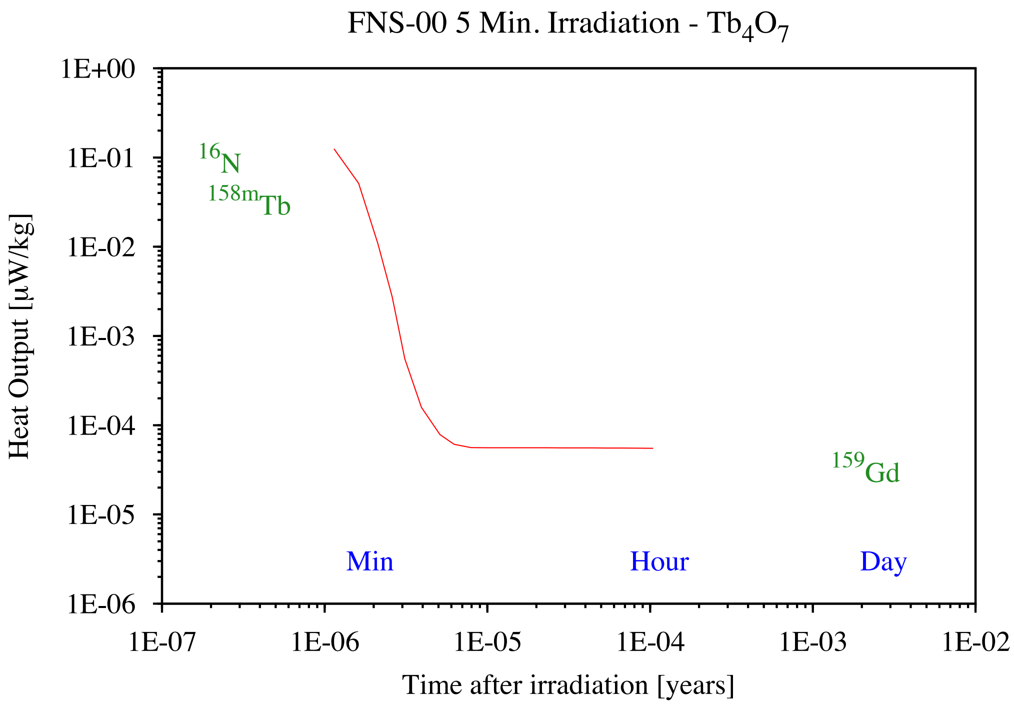
Terbium



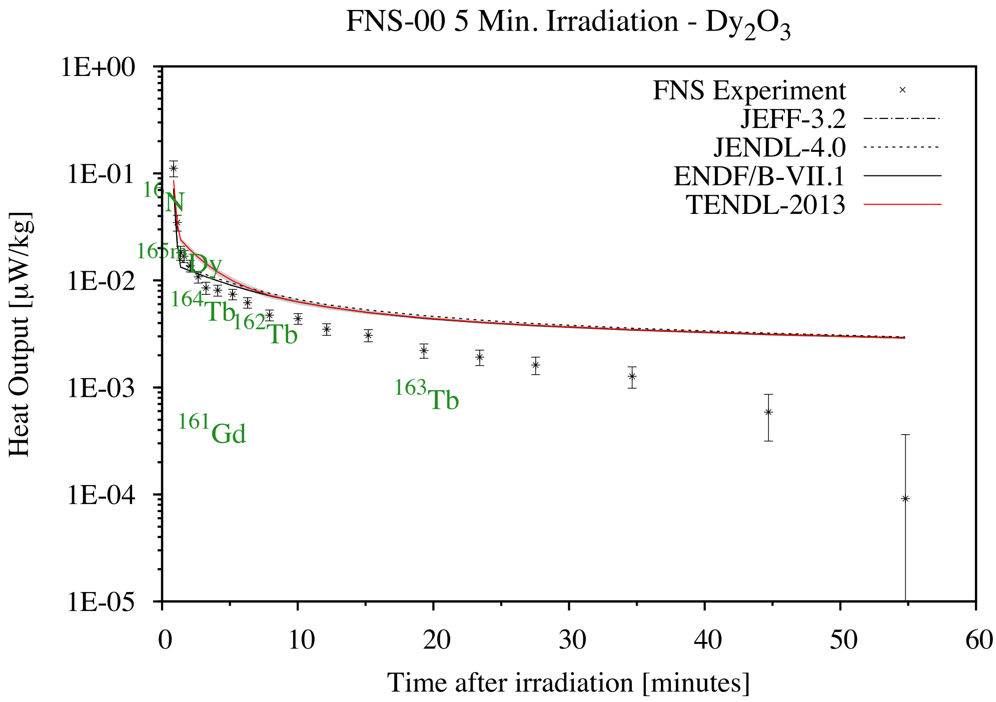
For Terbium, the short lived Tb158m isomer seems to be predicted with some accuracy. At longer cooling times the measurements need to be viewed with caution due to the large, uneven uncertainties.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	$3.88E-01$ +/-23%	$1.25E-01$ +/-1%	3.10	4.40	4.36	4.76
0.85	$1.04E-01$ +/-24%	$5.14E-02$ +/-1%	2.03	3.50	3.42	4.05
1.12	$2.38E-02$ +/-32%	$1.09E-02$ +/-1%	2.19	4.50	4.23	5.60
1.37	$1.88E-03$ +/-174%	$2.75E-03$ +/-2%	0.68	1.57	1.34	1.29
1.63	$2.41E-04$ +/-1077%	$5.55E-04$ +/-3%	0.43	0.56	0.47	0.47
2.07	$1.70E-03$ +/-105%	$1.59E-04$ +/-5%	10.74	30.71	30.71	31.67
2.68	$2.16E-03$ +/-46%	$7.85E-05$ +/-8%	27.58	38.99	38.99	40.21
3.28	$2.65E-03$ +/-32%	$6.11E-05$ +/-10%	43.35	47.74	47.74	49.23
4.17	$5.31E-04$ +/-132%	$5.60E-05$ +/-11%	9.47	9.56	9.56	9.86
5.27	$3.23E-04$ +/-199%	$5.60E-05$ +/-11%	5.77	5.82	5.82	6.01
6.38	$4.94E-04$ +/-122%	$5.60E-05$ +/-11%	8.83	8.92	8.92	9.20
8.02	$4.08E-04$ +/-139%	$5.59E-05$ +/-11%	7.30	7.37	7.37	7.60
10.13	$5.46E-05$ +/-942%	$5.59E-05$ +/-11%	0.98	0.99	0.99	1.02
12.25	$1.62E-04$ +/-302%	$5.58E-05$ +/-11%	2.90	2.93	2.93	3.02
15.32	$1.64E-04$ +/-283%	$5.58E-05$ +/-11%	2.94	2.96	2.96	3.06
19.43	$2.90E-04$ +/-154%	$5.57E-05$ +/-11%	5.20	5.25	5.25	5.42
23.55	$5.27E-04$ +/-83%	$5.56E-05$ +/-11%	9.48	9.56	9.56	9.86
27.62	$5.14E-04$ +/-84%	$5.55E-05$ +/-11%	9.26	9.35	9.35	9.64
34.73	$5.29E-04$ +/-81%	$5.54E-05$ +/-11%	9.56	9.64	9.64	9.95
44.85	$2.20E-04$ +/-193%	$5.52E-05$ +/-11%	3.99	4.03	4.03	4.15
54.92	$7.40E-04$ +/-59%	$5.50E-05$ +/-11%	13.45	13.56	13.56	13.99

Product	**Pathways**	$T_{1/2}$	**Path %**	**E/C**	Δ**E%**
Tb158m	Tb159(n,2n)Tb158m	10.8s	100.0	0.68	174%
Gd159	Tb159(n,p)Gd159	18.4h	100.0	3.99	193%


FNS-00 5 Min. Irradiation - Tb4O7
1E+00
1E-01
1E-02
1E-03
1E-04
1E-05
1E-06
Heat Output [µW/kg]
16N
158mTb
159Gd
Min
Hour
Day
1E-07
1E-06
1E-05
1E-04
1E-03
1E-02
Time after irradiation [years]

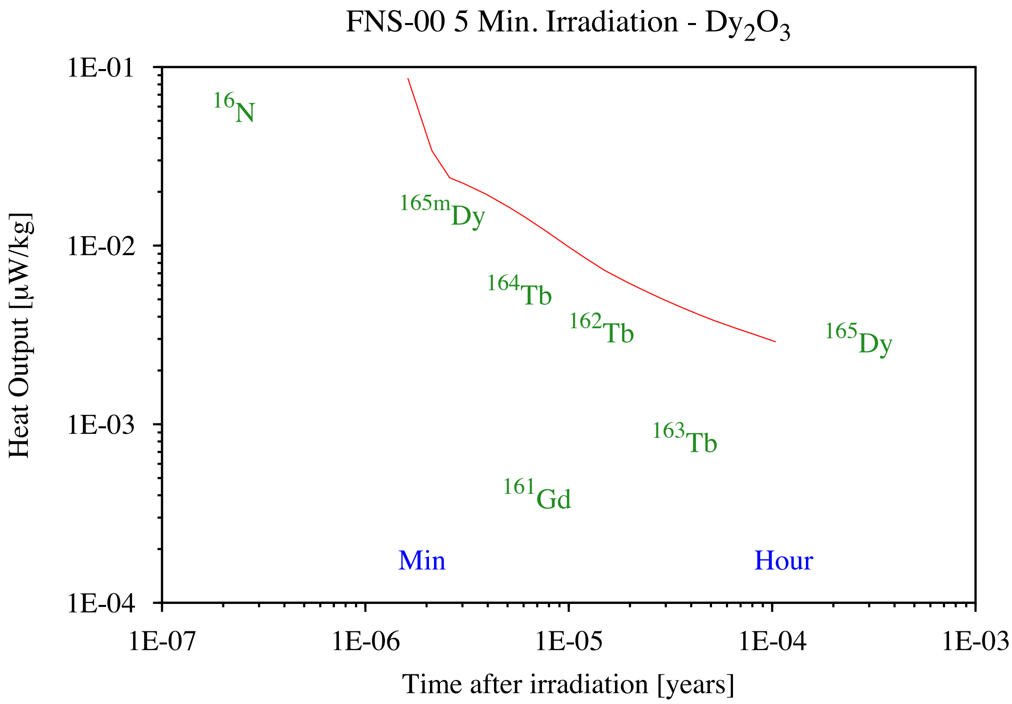
Dysprosium



For Dysprosium, the complex routes of production and the presence of many contributing isotopes, make interpretation of the results extremely difficult. However, the production pathways from all libraries need to be carefully examined.

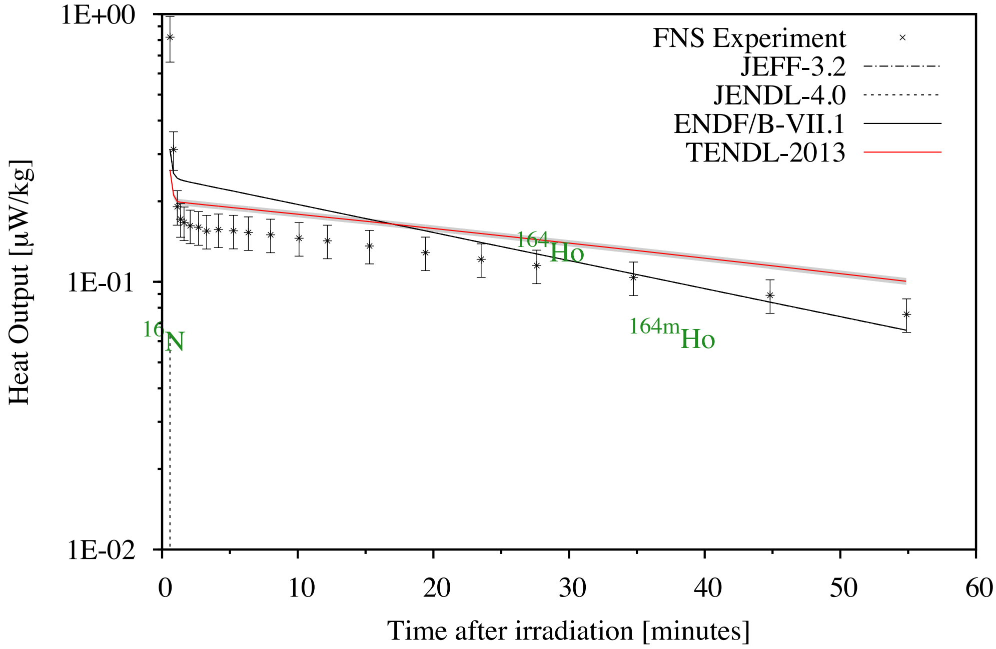
Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.85	$1.12E{-}01$ +/-17%	$8.67E{-}02$ +/-2%	1.29	1.55	1.54	1.58
1.12	$3.48E{-}02$ +/-17%	$3.40E{-}02$ +/-4%	1.02	1.60	1.60	1.62
1.37	$1.81E{-}02$ +/-15%	$2.40E{-}02$ +/-6%	0.76	1.36	1.36	1.13
1.62	$1.69E{-}02$ +/-13%	$2.22E{-}02$ +/-6%	0.76	1.30	1.30	1.18
2.07	$1.37E{-}02$ +/-13%	$1.94E{-}02$ +/-6%	0.71	1.12	1.12	1.06
2.67	$1.08E{-}02$ +/-13%	$1.65E{-}02$ +/-7%	0.66	0.94	0.94	0.90
3.23	$8.50E{-}03$ +/-13%	$1.44E{-}02$ +/-7%	0.59	0.79	0.79	0.75
4.10	$8.08E{-}03$ +/-12%	$1.20E{-}02$ +/-7%	0.68	0.82	0.82	0.78
5.20	$7.42E{-}03$ +/-11%	$9.92E{-}03$ +/-7%	0.75	0.83	0.83	0.79
6.30	$6.20E{-}03$ +/-11%	$8.57E{-}03$ +/-7%	0.72	0.76	0.76	0.72
7.92	$4.74E{-}03$ +/-12%	$7.26E{-}03$ +/-6%	0.65	0.66	0.66	0.62
10.02	$4.39E{-}03$ +/-11%	$6.31E{-}03$ +/-6%	0.70	0.70	0.70	0.66
12.13	$3.50E{-}03$ +/-12%	$5.66E{-}03$ +/-5%	0.62	0.62	0.62	0.59
15.20	$3.07E{-}03$ +/-13%	$5.02E{-}03$ +/-4%	0.61	0.61	0.61	0.58
19.30	$2.21E{-}03$ +/-15%	$4.46E{-}03$ +/-4%	0.50	0.50	0.50	0.47
23.42	$1.92E{-}03$ +/-17%	$4.08E{-}03$ +/-3%	0.47	0.47	0.47	0.45
27.53	$1.62E{-}03$ +/-19%	$3.79E{-}03$ +/-3%	0.43	0.43	0.43	0.41
34.65	$1.27E{-}03$ +/-23%	$3.46E{-}03$ +/-2%	0.37	0.37	0.37	0.35
44.70	$5.88E{-}04$ +/-46%	$3.13E{-}03$ +/-2%	0.19	0.19	0.19	0.18
54.80	$9.15E{-}05$ +/-296%	$2.90E{-}03$ +/-2%	0.03	0.03	0.03	0.03

Product	Pathways	$T_{1/2}$	Path %	E/C	ΔE%
Dy165m	Dy164(n,γ)Dy165m	1.2m	98.5	0.76	15%
Tb164	Dy164(n,p)Tb164	3.0m	99.2	0.59	13%
Tb162	Dy162(n,p)Tb162	7.6m	95.4	0.65	12%
	Dy163(n,d+np)Tb162		4.4	0.65	12%
Dy165	Dy164(n,γ)Dy165	2.3h	41.5	0.19	23%
	Dy164(n,γ)Dy165m	1.2m	58.9	0.19	23%



Holmium

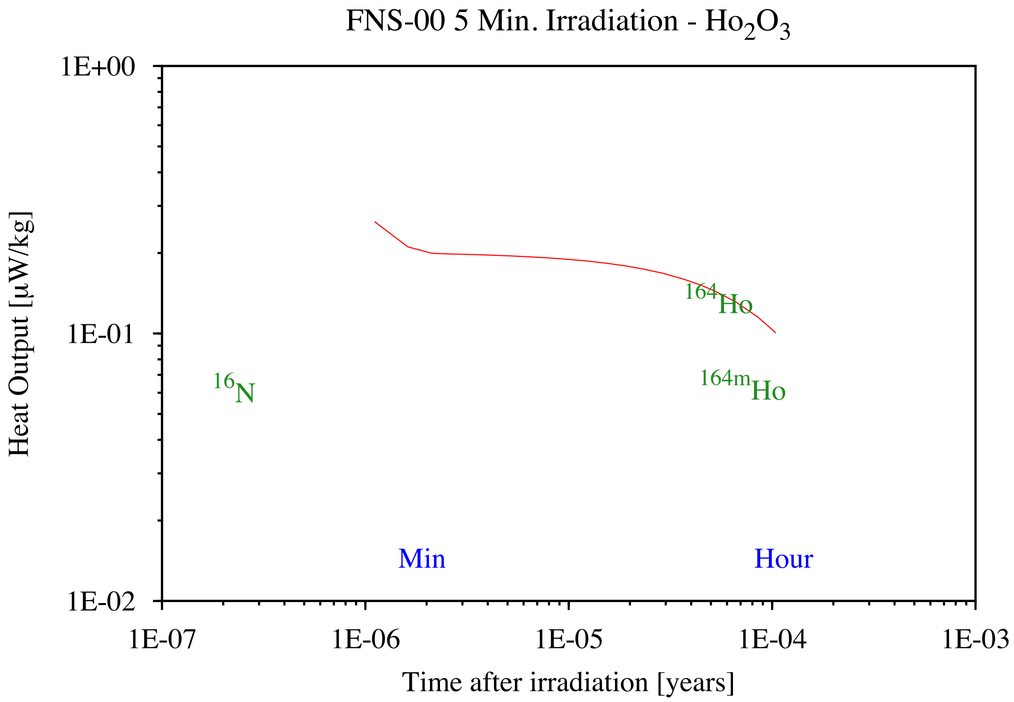
FNS-00 5 Min. Irradiation - Ho_2O_3



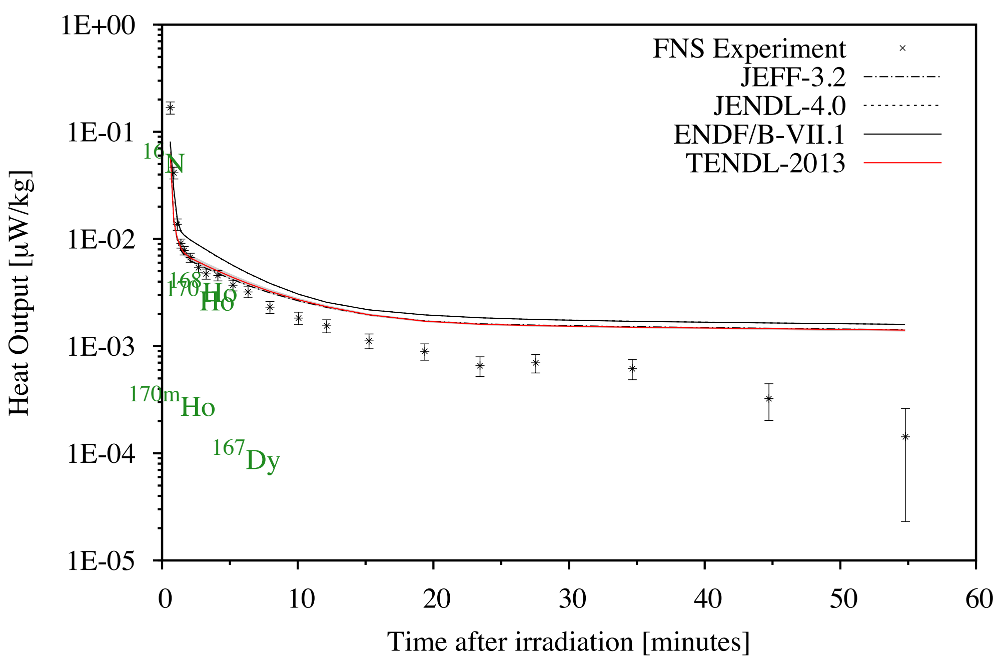
For the lanthanide Holmium, the interpretation is not too bad (except with JENDL-4.0), and the experiment gives a rare insight into possible half life and/or branching ratio corrections. As a reminder, the decay data was the only reason behind the factor two over-prediction in the previous generation of libraries.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	8.20$E-$01 +/-19%	2.62$E-$01 +/-2%	3.13	2.63	2.63	13.07
0.85	3.12$E-$01 +/-16%	2.11$E-$01 +/-3%	1.48	1.23	1.23	0.00
1.12	1.91$E-$01 +/-15%	1.99$E-$01 +/-3%	0.96	0.78	0.78	0.00
1.37	1.71$E-$01 +/-14%	1.98$E-$01 +/-3%	0.86	0.71	0.71	0.00
1.62	1.67$E-$01 +/-14%	1.98$E-$01 +/-3%	0.84	0.70	0.70	0.00
2.07	1.62$E-$01 +/-14%	1.97$E-$01 +/-3%	0.82	0.69	0.69	0.00
2.68	1.60$E-$01 +/-14%	1.95$E-$01 +/-3%	0.82	0.69	0.69	0.00
3.28	1.55$E-$01 +/-14%	1.94$E-$01 +/-3%	0.80	0.68	0.68	0.00
4.15	1.57$E-$01 +/-14%	1.92$E-$01 +/-3%	0.82	0.70	0.70	0.00
5.27	1.55$E-$01 +/-14%	1.89$E-$01 +/-3%	0.82	0.71	0.71	0.00
6.37	1.53$E-$01 +/-14%	1.87$E-$01 +/-3%	0.82	0.72	0.72	0.00
8.00	1.50$E-$01 +/-14%	1.83$E-$01 +/-3%	0.82	0.73	0.73	0.00
10.10	1.45$E-$01 +/-14%	1.79$E-$01 +/-3%	0.81	0.75	0.75	0.00
12.18	1.42$E-$01 +/-14%	1.74$E-$01 +/-3%	0.82	0.77	0.77	0.00
15.30	1.36$E-$01 +/-14%	1.68$E-$01 +/-3%	0.81	0.80	0.80	0.00
19.42	1.29$E-$01 +/-14%	1.59$E-$01 +/-3%	0.81	0.83	0.83	0.00
23.52	1.21$E-$01 +/-14%	1.51$E-$01 +/-3%	0.80	0.86	0.86	0.00
27.62	1.15$E-$01 +/-14%	1.44$E-$01 +/-3%	0.80	0.90	0.90	0.00
34.75	1.04$E-$01 +/-14%	1.31$E-$01 +/-3%	0.79	0.97	0.97	0.00
44.82	8.90$E-$02 +/-14%	1.15$E-$01 +/-3%	0.77	1.06	1.06	0.00
54.88	7.56$E-$02 +/-14%	1.01$E-$01 +/-3%	0.75	1.14	1.15	0.00

Product	Pathways	$T_{1/2}$	Path %	E/C	ΔE%
Ho164	Ho165(n,2n)Ho164	28.6m	95.7	0.80	14%
	Ho165(n,2n)Ho164m	37.6m	4.3	0.80	14%
Ho164m	Ho165(n,2n)Ho164m	37.6m	100.0	0.79	14%



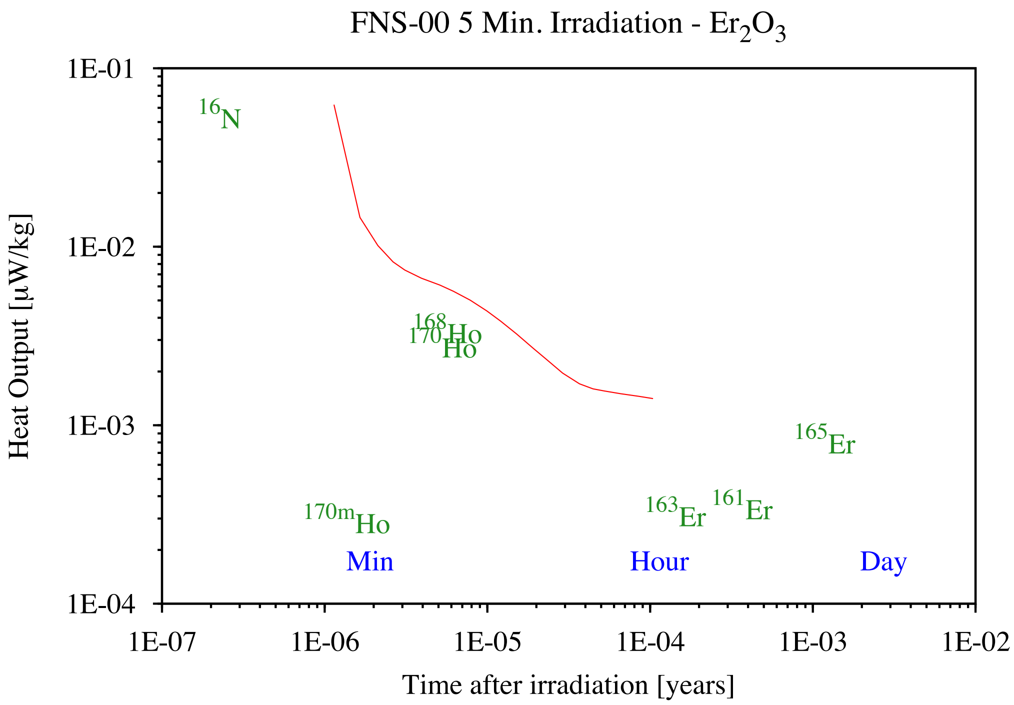
Erbium



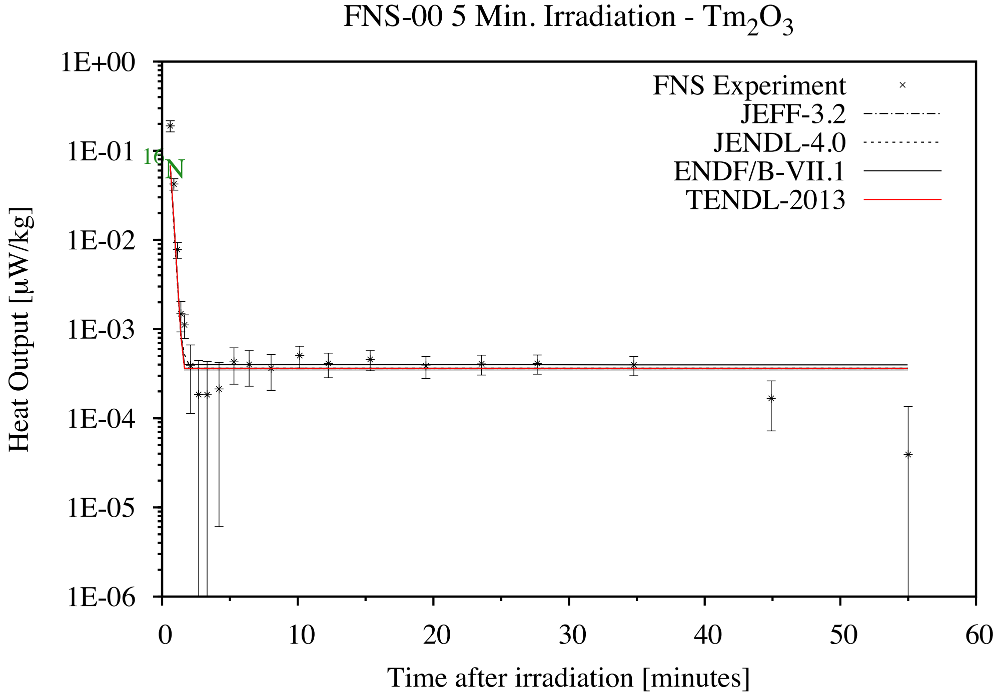
For Erbium, here again a rare insight of what may be a half life problem, shadowing the response of the isotopes that shape the decay heat underneath.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	1.68E−01 +/-13%	6.25E−02 +/-1%	2.69	2.07	2.69	2.20
0.87	4.15E−02 +/-12%	1.46E−02 +/-4%	2.85	1.44	2.89	1.57
1.12	1.37E−02 +/-12%	1.01E−02 +/-6%	1.35	0.89	1.39	0.91
1.38	9.10E−03 +/-10%	8.23E−03 +/-7%	1.11	0.77	1.16	0.77
1.63	7.79E−03 +/-9%	7.41E−03 +/-7%	1.05	0.72	1.11	0.72
2.07	6.71E−03 +/-10%	6.66E−03 +/-7%	1.01	0.68	1.07	0.68
2.68	5.39E−03 +/-10%	6.09E−03 +/-7%	0.89	0.61	0.94	0.62
3.25	4.73E−03 +/-11%	5.63E−03 +/-7%	0.84	0.60	0.89	0.60
4.12	4.57E−03 +/-11%	5.02E−03 +/-6%	0.91	0.67	0.96	0.67
5.22	3.70E−03 +/-11%	4.37E−03 +/-6%	0.85	0.65	0.89	0.65
6.33	3.20E−03 +/-12%	3.84E−03 +/-6%	0.83	0.67	0.87	0.67
7.95	2.31E−03 +/-13%	3.24E−03 +/-5%	0.71	0.60	0.74	0.60
10.07	1.83E−03 +/-13%	2.70E−03 +/-4%	0.68	0.60	0.69	0.60
12.13	1.54E−03 +/-14%	2.33E−03 +/-3%	0.66	0.60	0.67	0.60
15.25	1.12E−03 +/-16%	1.96E−03 +/-3%	0.57	0.51	0.57	0.51
19.37	8.93E−04 +/-17%	1.71E−03 +/-2%	0.52	0.46	0.52	0.46
23.43	6.57E−04 +/-21%	1.60E−03 +/-2%	0.41	0.36	0.41	0.36
27.55	6.98E−04 +/-20%	1.55E−03 +/-2%	0.45	0.39	0.44	0.39
34.67	6.16E−04 +/-21%	1.50E−03 +/-2%	0.41	0.36	0.41	0.36
44.73	3.24E−04 +/-37%	1.45E−03 +/-2%	0.22	0.20	0.22	0.20
54.80	1.42E−04 +/-84%	1.41E−03 +/-2%	0.10	0.09	0.10	0.09

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ho168	Er168(n,p)Ho168	2.9m	74.2	0.89	10%
	Er168(n,p)Ho168m	2.2m	25.9	0.89	10%
Er165	Er166(n,2n)Er165	10.3h	99.6	0.22	37%


FNS-00 5 Min. Irradiation - Er_2O_3
Heat Output [µW/kg]
1E-01
1E-02
1E-03
1E-04
Time after irradiation [years]
1E-07
1E-06
1E-05
1E-04
1E-03
1E-02
^{16}N
^{168}Ho
^{170}Ho
^{165}Er
^{170m}Ho
^{163}Er
^{161}Er
Min
Hour
Day

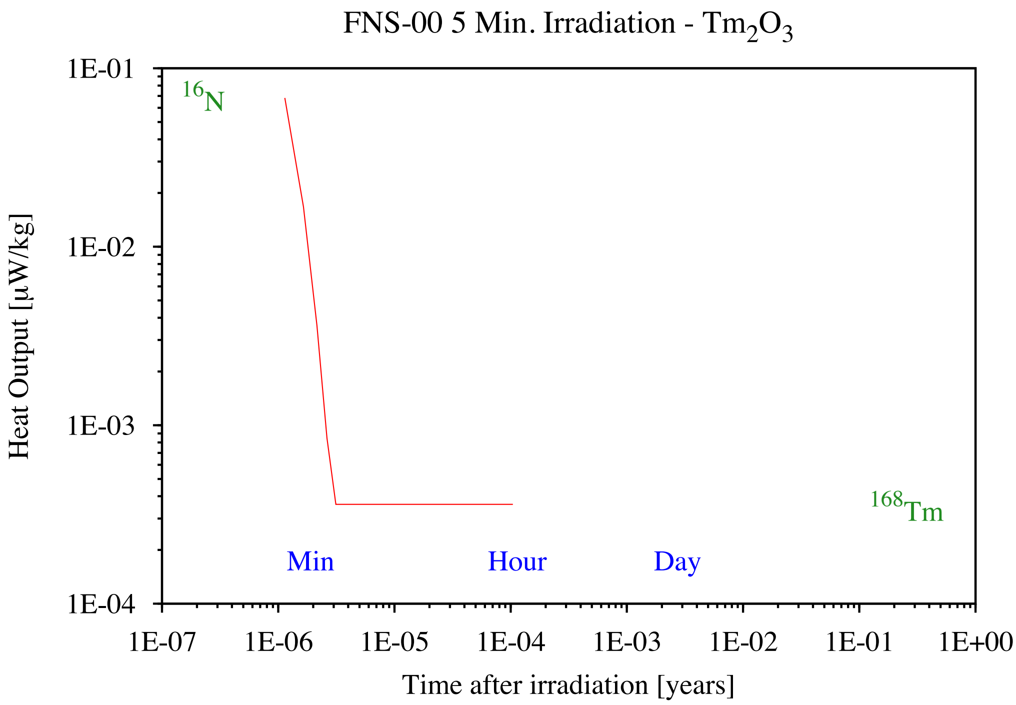
Thulium

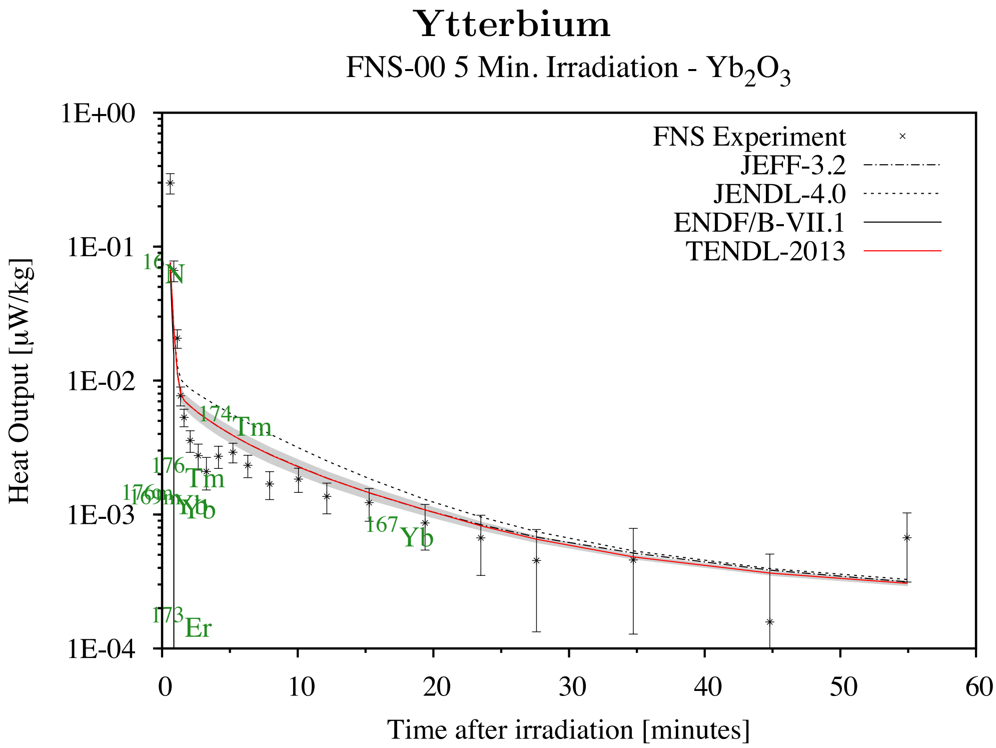


For the lanthanide Thulium, the representation of the experimental data is not too bad, allowing for the large experimental uncertainties at short and long cooling times, and the possibility of some missing isomers in the calculational paths.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	1.90E−01 +/-14%	6.81E−02 +/-0%	2.79	2.79	2.79	3.02
0.87	4.24E−02 +/-15%	1.67E−02 +/-0%	2.53	2.57	2.53	3.01
1.13	7.78E−03 +/-20%	3.62E−03 +/-0%	2.15	2.15	2.15	2.43
1.38	1.49E−03 +/-38%	8.47E−04 +/-2%	1.76	1.69	1.76	1.74
1.65	1.12E−03 +/-30%	3.60E−04 +/-5%	3.09	2.80	3.11	2.15
2.10	3.88E−04 +/-71%	3.60E−04 +/-5%	1.08	0.97	1.08	1.07
2.70	1.85E−04 +/-140%	3.60E−04 +/-5%	0.51	0.46	0.51	0.51
3.32	1.84E−04 +/-136%	3.60E−04 +/-5%	0.51	0.46	0.51	0.50
4.20	2.14E−04 +/-97%	3.60E−04 +/-5%	0.59	0.54	0.59	0.59
5.30	4.29E−04 +/-44%	3.60E−04 +/-5%	1.19	1.08	1.19	1.18
6.42	4.01E−04 +/-43%	3.60E−04 +/-5%	1.11	1.01	1.12	1.10
8.03	3.62E−04 +/-43%	3.60E−04 +/-5%	1.01	0.91	1.01	1.00
10.15	5.04E−04 +/-27%	3.60E−04 +/-5%	1.40	1.27	1.40	1.38
12.25	4.11E−04 +/-31%	3.60E−04 +/-5%	1.14	1.03	1.15	1.13
15.33	4.57E−04 +/-25%	3.60E−04 +/-5%	1.27	1.15	1.27	1.25
19.45	3.87E−04 +/-28%	3.60E−04 +/-5%	1.07	0.97	1.08	1.06
23.55	4.07E−04 +/-25%	3.60E−04 +/-5%	1.13	1.02	1.14	1.12
27.65	4.12E−04 +/-24%	3.60E−04 +/-5%	1.14	1.04	1.15	1.13
34.78	3.97E−04 +/-25%	3.60E−04 +/-5%	1.10	1.00	1.11	1.09
44.90	1.67E−04 +/-57%	3.60E−04 +/-5%	0.46	0.42	0.47	0.46
55.00	3.92E−05 +/-245%	3.60E−04 +/-5%	0.11	0.10	0.11	0.11

Product	Pathways	$T_{1/2}$	Path %	E/C	ΔE%
Tm168	Tm169(n,2n)Tm168	93.1d	100.0	1.10	25%

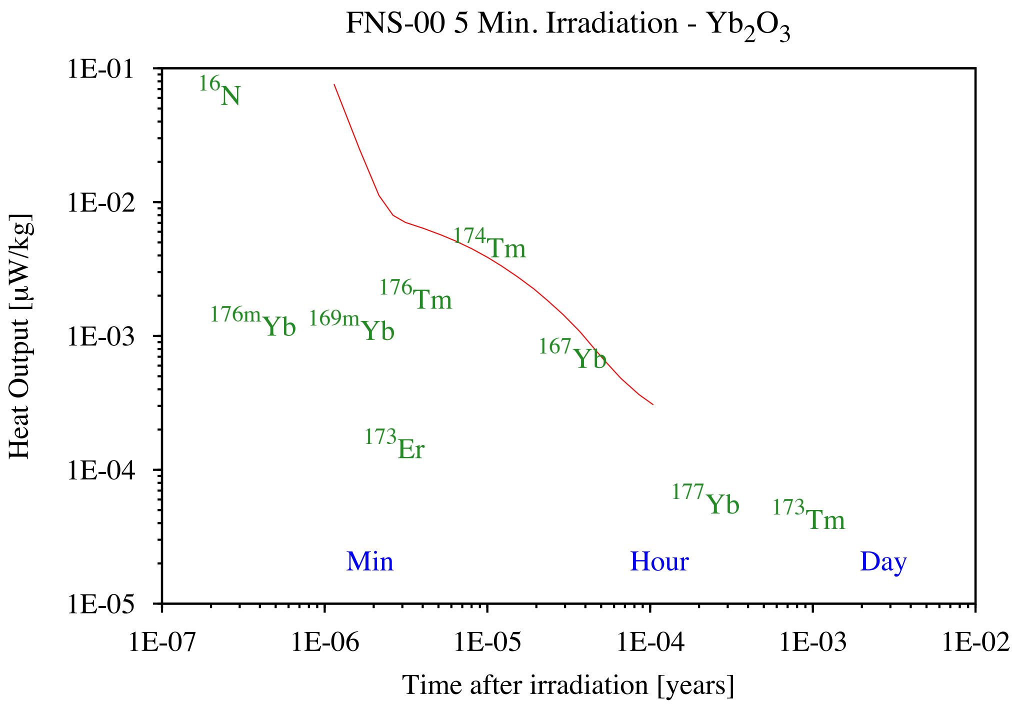

FNS-00 5 Min. Irradiation - Tm2O3
Heat Output [µW/kg]
1E-01
1E-02
1E-03
1E-04
16N
168Tm
Min
Hour
Day
1E-07
1E-06
1E-05
1E-04
1E-03
1E-02
1E-01
1E+00
Time after irradiation [years]

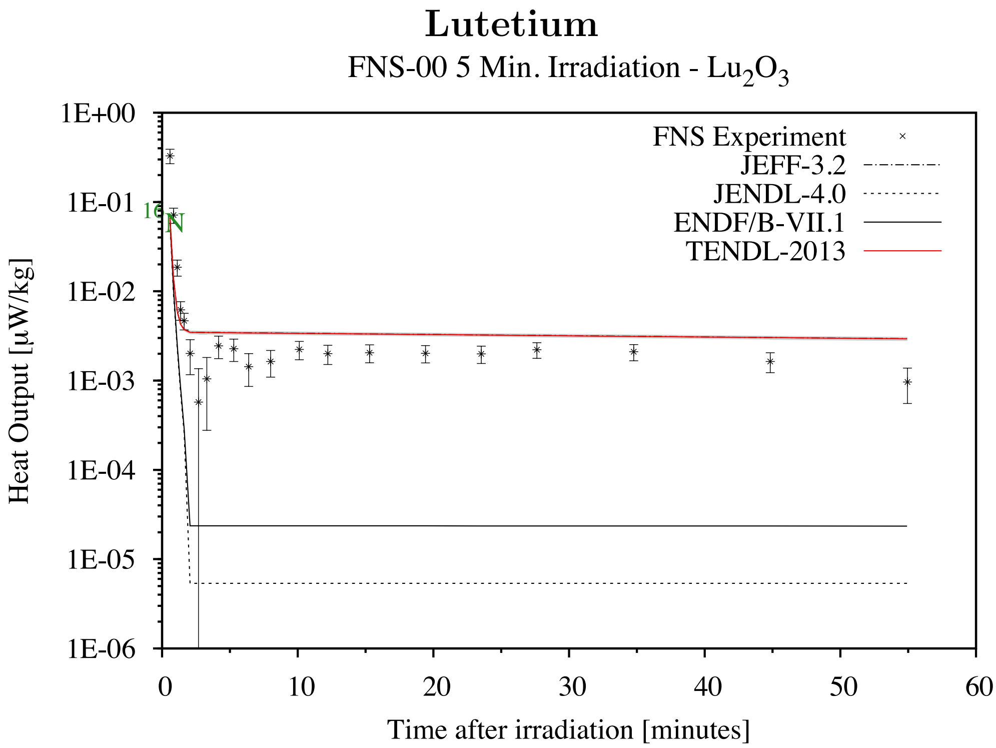


For Ytterbium, one can see a reasonable agreement for this element except with ENDF/B-VII.1, even allowing for the high experimental uncertainties and the many isotopes underlying the response function.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	$2.99E{-}01$ +/-17%	$7.62E{-}02$ +/-1%	3.92	4.56	3.92	4.17
0.87	$6.64E{-}02$ +/-18%	$2.44E{-}02$ +/-4%	2.72	4.39	2.72	2.83
1.12	$2.07E{-}02$ +/-16%	$1.12E{-}02$ +/-9%	1.85	0.00	1.85	1.61
1.37	$7.71E{-}03$ +/-16%	$7.98E{-}03$ +/-12%	0.97	0.00	0.97	0.76
1.62	$5.31E{-}03$ +/-15%	$7.04E{-}03$ +/-13%	0.75	0.00	0.75	0.56
2.07	$3.57E{-}03$ +/-18%	$6.40E{-}03$ +/-14%	0.56	0.00	0.56	0.41
2.67	$2.75E{-}03$ +/-22%	$5.72E{-}03$ +/-14%	0.48	0.00	0.48	0.35
3.27	$2.10E{-}03$ +/-27%	$5.15E{-}03$ +/-14%	0.41	0.00	0.41	0.29
4.15	$2.72E{-}03$ +/-19%	$4.49E{-}03$ +/-15%	0.61	0.00	0.61	0.43
5.22	$2.92E{-}03$ +/-17%	$3.85E{-}03$ +/-15%	0.76	0.00	0.76	0.53
6.32	$2.33E{-}03$ +/-19%	$3.34E{-}03$ +/-15%	0.70	0.00	0.70	0.49
7.93	$1.69E{-}03$ +/-24%	$2.77E{-}03$ +/-14%	0.61	0.00	0.61	0.43
10.05	$1.84E{-}03$ +/-21%	$2.25E{-}03$ +/-14%	0.82	0.00	0.82	0.59
12.15	$1.36E{-}03$ +/-26%	$1.85E{-}03$ +/-13%	0.74	0.00	0.74	0.55
15.27	$1.23E{-}03$ +/-27%	$1.45E{-}03$ +/-12%	0.85	0.00	0.85	0.67
19.38	$8.66E{-}04$ +/-37%	$1.08E{-}03$ +/-10%	0.80	0.00	0.80	0.67
23.50	$6.69E{-}04$ +/-48%	$8.22E{-}04$ +/-8%	0.81	0.00	0.80	0.70
27.60	$4.53E{-}04$ +/-71%	$6.52E{-}04$ +/-6%	0.69	0.00	0.67	0.61
34.73	$4.57E{-}04$ +/-72%	$4.82E{-}04$ +/-4%	0.95	0.00	0.89	0.86
44.80	$1.58E{-}04$ +/-221%	$3.64E{-}04$ +/-4%	0.43	0.00	0.41	0.40
54.92	$6.70E{-}04$ +/-53%	$3.07E{-}04$ +/-4%	2.19	0.00	2.14	2.05

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Tm174	Yb174(n,p)Tm174	5.4m	99.6	0.76	17%
Yb167	Yb168(n,2n)Yb167	17.5m	100.0	0.80	37%

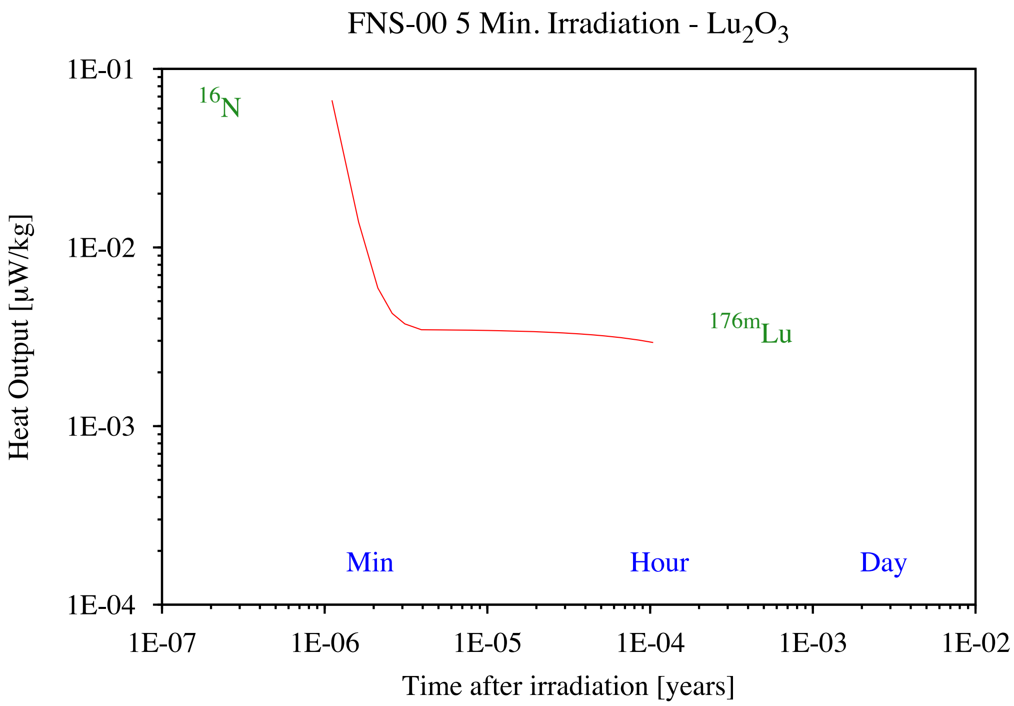

FNS-00 5 Min. Irradiation - Yb2O3
Heat Output [µW/kg]
Time after irradiation [years]
1E-01
1E-02
1E-03
1E-04
1E-05
1E-07
1E-06
1E-05
1E-04
1E-03
1E-02
16N
174Tm
176Tm
176mYb
169mYb
167Yb
173Er
177Yb
173Tm
Min
Hour
Day



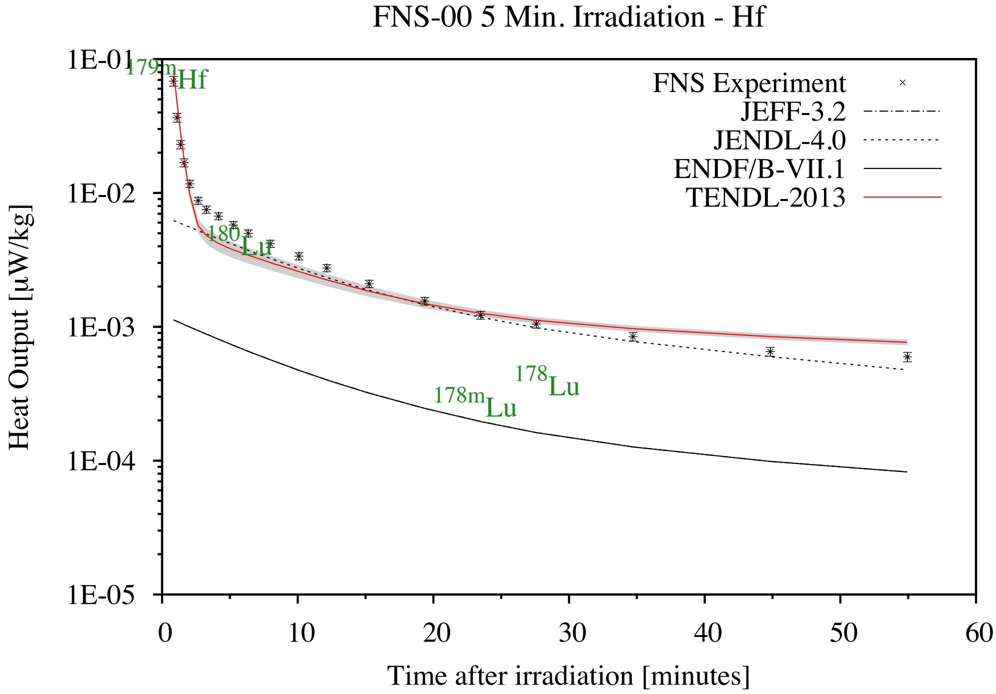
For Lutetium, once again the experimental results in the minute ranges show some structures missing in the simulations, possibly underlying a lack of isomeric state and associated decay data, or an incorrect level of the subtracted tape contribution in the experiment. ENDF/B.VII.1, JEFF-3.2 and JEND-4.0 lack the Lu176m isomeric production pathways.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	3.29$E-$01 +/-18%	6.67$E-$02 +/-0%	4.93	5.20	4.93	5.58
0.85	7.14$E-$02 +/-19%	1.39$E-$02 +/-1%	5.15	6.93	5.15	7.86
1.12	1.86$E-$02 +/-20%	5.93$E-$03 +/-3%	3.13	7.52	3.12	8.19
1.37	6.19$E-$03 +/-24%	4.28$E-$03 +/-4%	1.45	7.42	1.44	8.37
1.63	4.67$E-$03 +/-21%	3.73$E-$03 +/-4%	1.25	16.20	1.25	18.11
2.07	2.01$E-$03 +/-42%	3.47$E-$03 +/-5%	0.58	85.18	0.58	375.06
2.68	5.73$E-$04 +/-137%	3.46$E-$03 +/-5%	0.17	24.26	0.17	106.84
3.30	1.05$E-$03 +/-74%	3.45$E-$03 +/-5%	0.30	44.27	0.30	194.89
4.17	2.45$E-$03 +/-28%	3.44$E-$03 +/-5%	0.71	103.74	0.71	456.67
5.28	2.27$E-$03 +/-28%	3.43$E-$03 +/-5%	0.66	96.18	0.66	423.32
6.38	1.43$E-$03 +/-40%	3.42$E-$03 +/-5%	0.42	60.63	0.42	266.81
8.00	1.63$E-$03 +/-33%	3.40$E-$03 +/-5%	0.48	69.20	0.48	304.45
10.12	2.23$E-$03 +/-23%	3.38$E-$03 +/-5%	0.66	94.39	0.66	415.12
12.22	2.00$E-$03 +/-24%	3.36$E-$03 +/-5%	0.60	84.79	0.60	372.83
15.30	2.05$E-$03 +/-23%	3.32$E-$03 +/-5%	0.62	86.83	0.62	381.59
19.42	2.02$E-$03 +/-22%	3.28$E-$03 +/-5%	0.62	85.77	0.62	376.74
23.53	1.99$E-$03 +/-22%	3.24$E-$03 +/-5%	0.61	84.43	0.61	370.59
27.63	2.21$E-$03 +/-20%	3.20$E-$03 +/-5%	0.69	94.07	0.69	412.70
34.77	2.10$E-$03 +/-21%	3.13$E-$03 +/-5%	0.67	89.28	0.67	391.27
44.83	1.64$E-$03 +/-25%	3.03$E-$03 +/-5%	0.54	69.74	0.54	305.19
54.95	9.65$E-$04 +/-43%	2.93$E-$03 +/-5%	0.33	41.15	0.33	179.82

Product	Pathways	$T_{1/2}$	Path %	E/C	ΔE%
Lu176m	Lu175(n,γ)Lu176m	3.6h	91.6	0.67	21%
	Lu176(n,n')Lu176m		8.4	0.67	21%



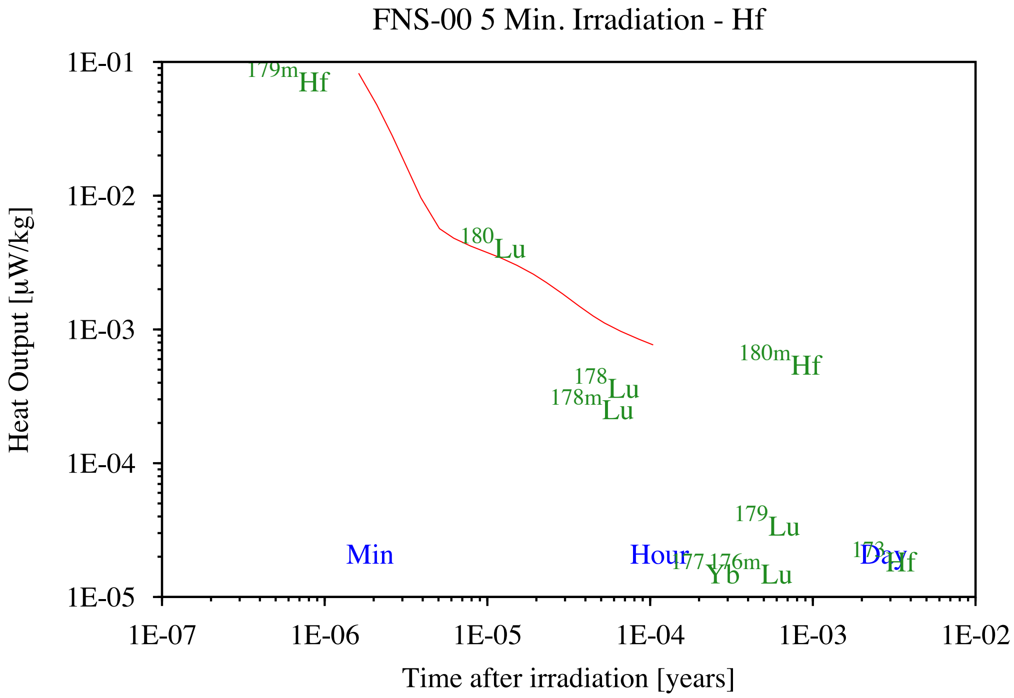
Hafnium



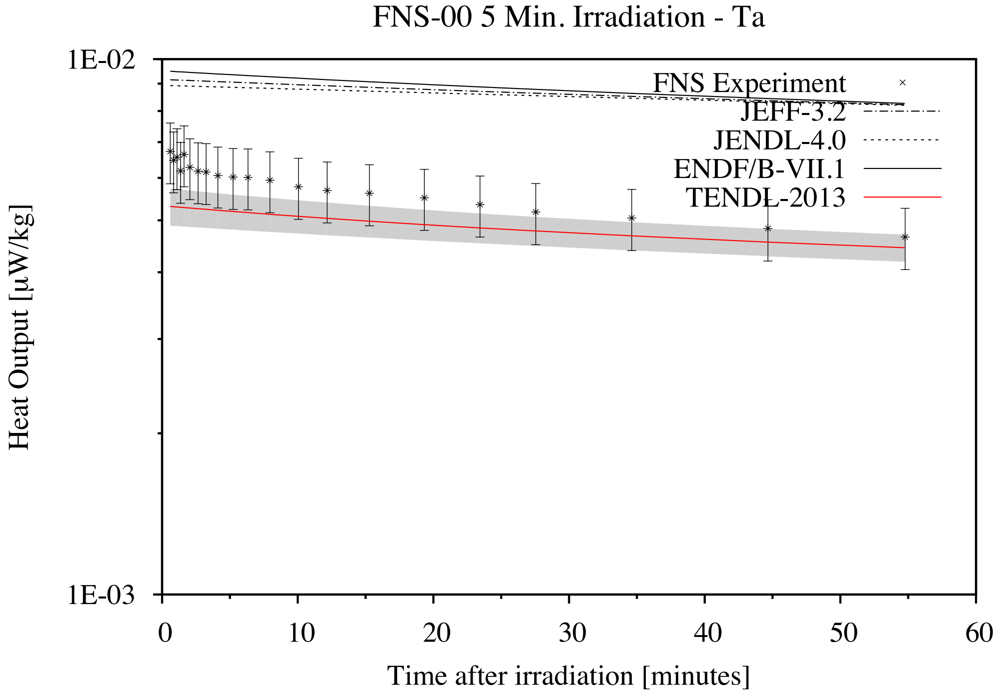
For Hafnium, the analysis of this element with anterior databases was extremely poorly interpreted because of a gross overestimation of the Hf177(n,n') channel. With this overshadowing effect now taken out one can still observe half life and/or branching ratio inconsistencies, but TENDL's libraries shows a significant improvement over the earlier databases, with only JENDL-4.0 following closely.

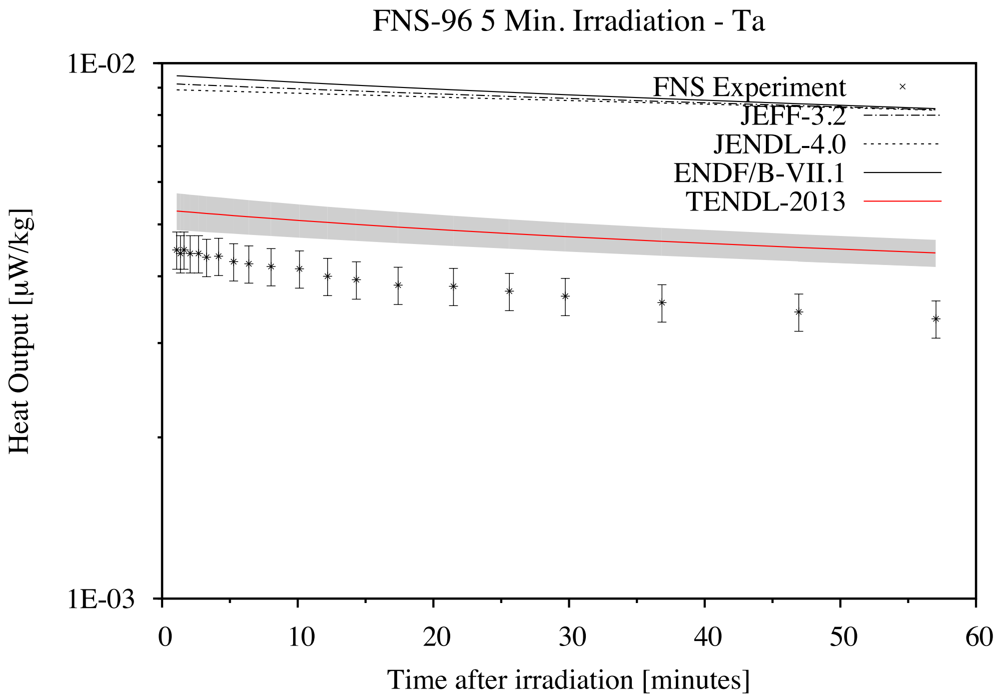
Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.85	6.84E−02 +/-8%	8.22E−02 +/-5%	0.83	60.71	60.70	10.97
1.10	3.65E−02 +/-8%	4.77E−02 +/-5%	0.77	33.30	33.30	6.01
1.37	2.30E−02 +/-7%	2.82E−02 +/-5%	0.82	21.54	21.53	3.88
1.62	1.68E−02 +/-7%	1.81E−02 +/-6%	0.93	16.17	16.16	2.91
2.05	1.17E−02 +/-6%	9.66E−03 +/-8%	1.21	11.76	11.76	2.11
2.67	8.75E−03 +/-6%	5.67E−03 +/-12%	1.54	9.36	9.36	1.68
3.27	7.51E−03 +/-6%	4.81E−03 +/-13%	1.56	8.52	8.52	1.52
4.15	6.71E−03 +/-6%	4.20E−03 +/-14%	1.60	8.31	8.30	1.48
5.25	5.76E−03 +/-6%	3.76E−03 +/-14%	1.53	7.92	7.91	1.40
6.35	4.99E−03 +/-6%	3.43E−03 +/-13%	1.46	7.61	7.60	1.34
7.98	4.18E−03 +/-6%	3.02E−03 +/-12%	1.38	7.36	7.36	1.29
10.08	3.37E−03 +/-6%	2.59E−03 +/-11%	1.30	7.10	7.10	1.23
12.15	2.75E−03 +/-6%	2.24E−03 +/-10%	1.22	6.84	6.84	1.18
15.27	2.10E−03 +/-6%	1.84E−03 +/-9%	1.14	6.56	6.56	1.12
19.37	1.55E−03 +/-6%	1.49E−03 +/-7%	1.04	6.32	6.32	1.06
23.48	1.22E−03 +/-7%	1.26E−03 +/-6%	0.97	6.22	6.22	1.04
27.58	1.05E−03 +/-7%	1.12E−03 +/-6%	0.94	6.47	6.47	1.07
34.72	8.44E−04 +/-7%	9.69E−04 +/-5%	0.87	6.66	6.65	1.08
44.83	6.53E−04 +/-8%	8.45E−04 +/-5%	0.77	6.62	6.61	1.09
54.95	5.96E−04 +/-8%	7.67E−04 +/-5%	0.78	7.24	7.23	1.25

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Hf179m	Hf178(n,γ)Hf179m	18.6s	15.4	0.83	8%
	Hf179(n,n')Hf179m		2.6	0.83	8%
	Hf180(n,2n)Hf179m		81.9	0.83	8%
Lu180	Hf180(n,p)Lu180	5.7m	100.0	1.53	6%
Lu178	Hf178(n,p)Lu178	28.4m	96.3	0.94	7%
	Hf179(n,d)Lu178		3.5	0.94	7%



Tantalum

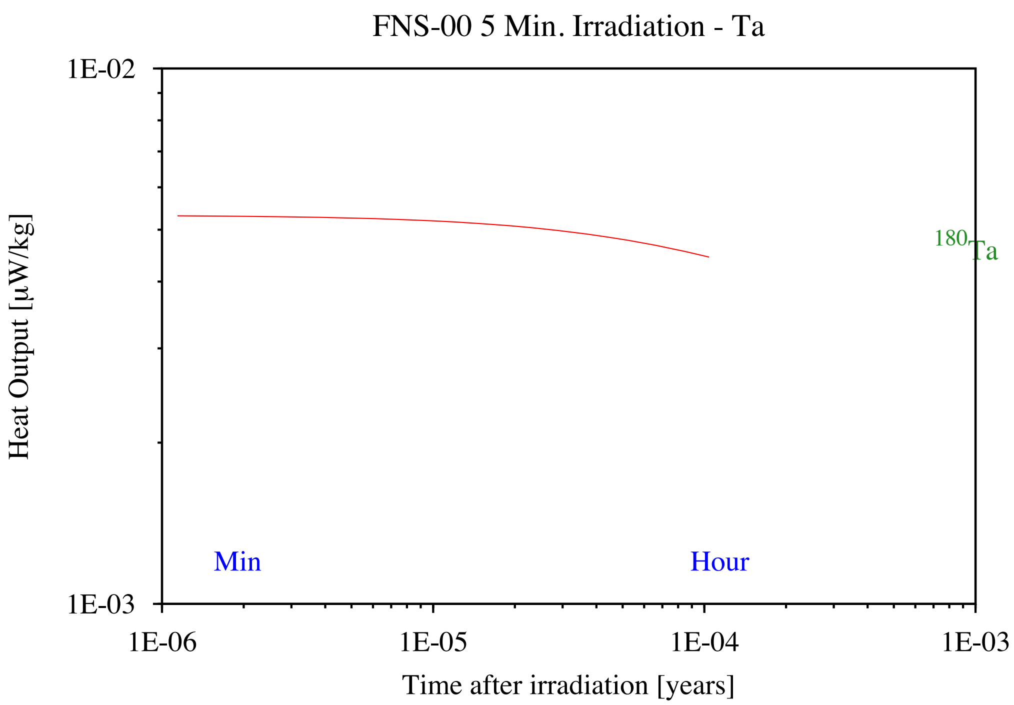


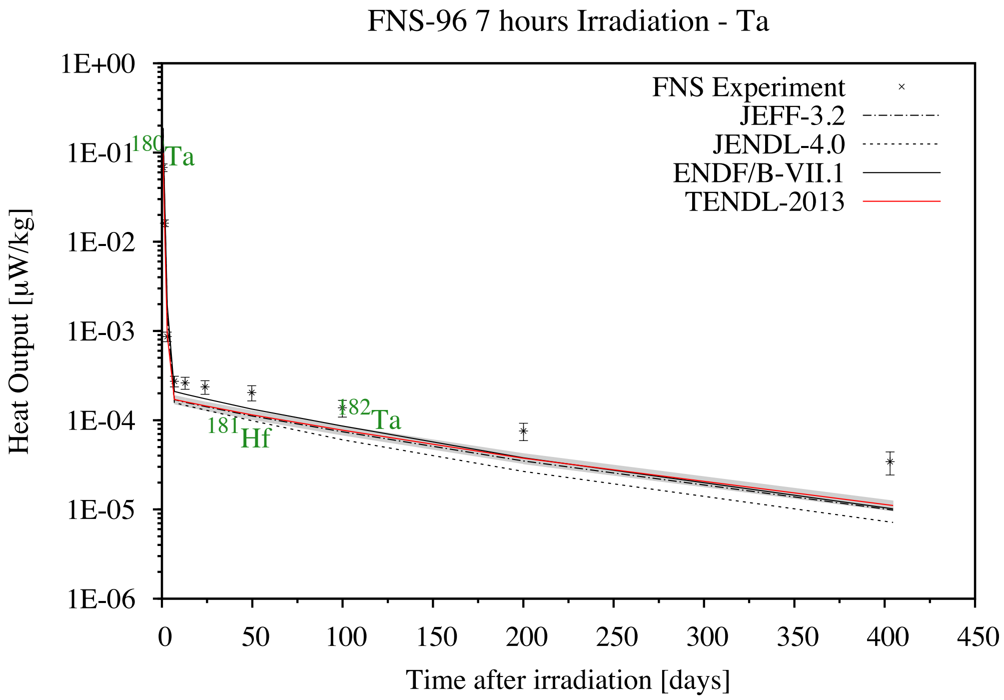


For Tantalum, once again there are some noticeable differences between the two experiments, but a within the experimental uncertainty band agreement exists for the latest, 2000, experiment when TENDL-2013 is used.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	$6.72E{-}03$ +/-13%	$5.31E{-}03$ +/-8%	1.27	0.71	0.73	0.75
0.85	$6.47E{-}03$ +/-13%	$5.30E{-}03$ +/-8%	1.22	0.68	0.71	0.73
1.10	$6.56E{-}03$ +/-13%	$5.29E{-}03$ +/-8%	1.24	0.69	0.72	0.74
1.37	$6.18E{-}03$ +/-13%	$5.29E{-}03$ +/-8%	1.17	0.65	0.68	0.69
1.62	$6.64E{-}03$ +/-13%	$5.28E{-}03$ +/-8%	1.26	0.70	0.73	0.75
2.05	$6.28E{-}03$ +/-13%	$5.27E{-}03$ +/-8%	1.19	0.67	0.69	0.71
2.65	$6.17E{-}03$ +/-13%	$5.26E{-}03$ +/-8%	1.17	0.65	0.68	0.69
3.25	$6.15E{-}03$ +/-13%	$5.24E{-}03$ +/-8%	1.17	0.65	0.68	0.69
4.12	$6.06E{-}03$ +/-13%	$5.22E{-}03$ +/-8%	1.16	0.65	0.67	0.68
5.23	$6.02E{-}03$ +/-13%	$5.19E{-}03$ +/-8%	1.16	0.64	0.67	0.68
6.33	$6.01E{-}03$ +/-13%	$5.17E{-}03$ +/-7%	1.16	0.65	0.67	0.68
7.95	$5.94E{-}03$ +/-13%	$5.13E{-}03$ +/-7%	1.16	0.64	0.66	0.67
10.05	$5.77E{-}03$ +/-13%	$5.09E{-}03$ +/-7%	1.14	0.63	0.64	0.66
12.17	$5.68E{-}03$ +/-13%	$5.04E{-}03$ +/-7%	1.13	0.62	0.64	0.65
15.28	$5.62E{-}03$ +/-13%	$4.98E{-}03$ +/-7%	1.13	0.62	0.63	0.64
19.33	$5.51E{-}03$ +/-13%	$4.91E{-}03$ +/-7%	1.12	0.61	0.63	0.64
23.43	$5.35E{-}03$ +/-13%	$4.84E{-}03$ +/-6%	1.11	0.60	0.61	0.62
27.55	$5.18E{-}03$ +/-13%	$4.78E{-}03$ +/-6%	1.08	0.59	0.60	0.61
34.62	$5.05E{-}03$ +/-13%	$4.68E{-}03$ +/-6%	1.08	0.58	0.59	0.60
44.67	$4.83E{-}03$ +/-13%	$4.55E{-}03$ +/-6%	1.06	0.57	0.58	0.58
54.78	$4.66E{-}03$ +/-13%	$4.44E{-}03$ +/-6%	1.05	0.56	0.57	0.57

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ta180	Ta181(n,2n)Ta180	8.0h	99.9	1.05	13%

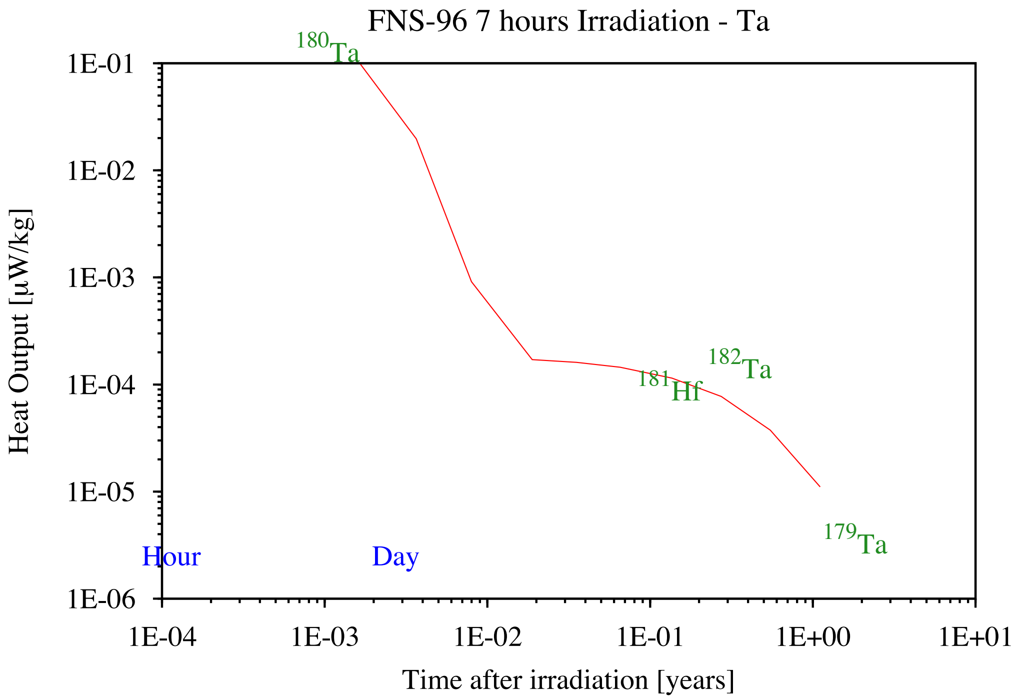




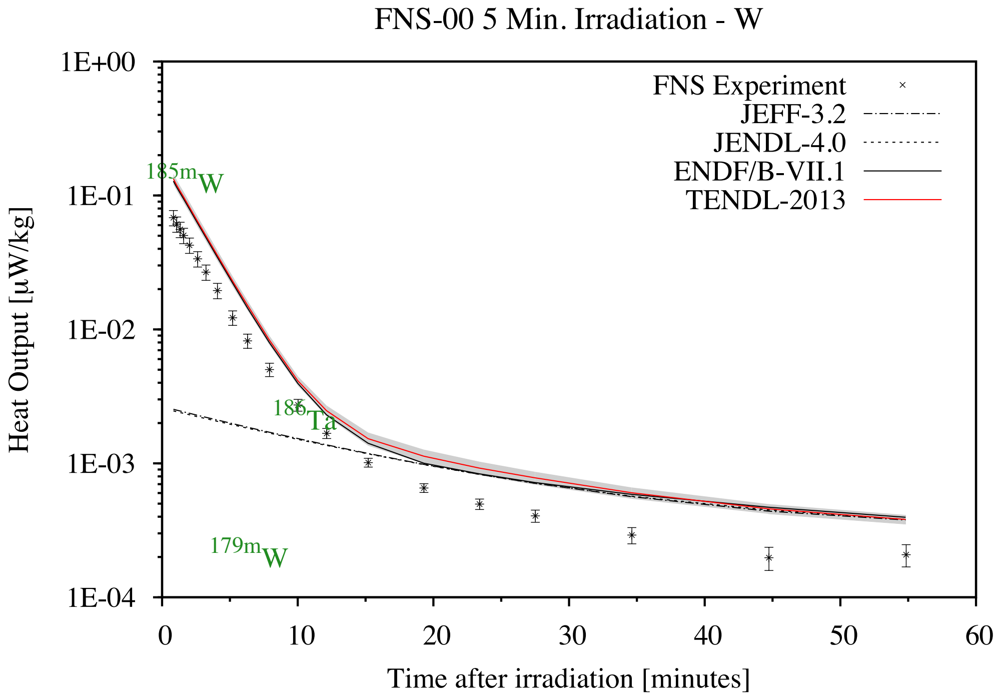
The presence of capture pathways and multiple isomeric states, do not allow for a definite interpretation to be made in this case.

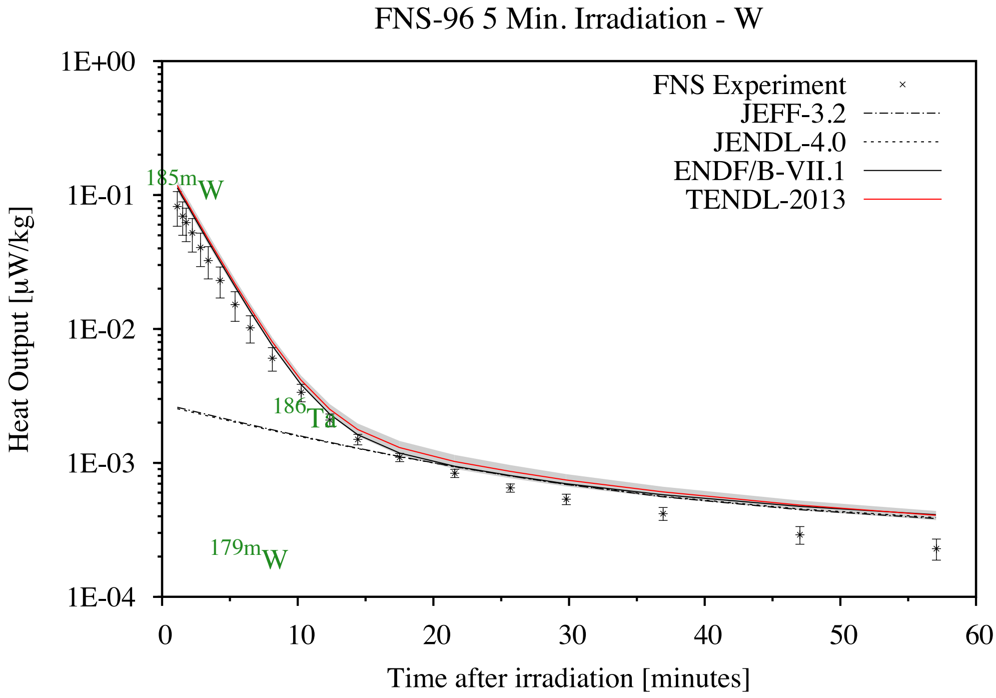
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	6.79E−02 +/-10%	9.89E−02 +/-6%	0.69	0.37	0.36	0.36
1.33	1.62E−02 +/-9%	1.97E−02 +/-6%	0.82	0.38	0.45	0.45
2.91	8.64E−04 +/-12%	9.13E−04 +/-5%	0.95	0.44	0.60	0.51
6.88	2.73E−04 +/-14%	1.71E−04 +/-12%	1.60	1.30	1.61	1.74
12.88	2.63E−04 +/-15%	1.61E−04 +/-12%	1.63	1.34	1.65	1.79
23.88	2.36E−04 +/-17%	1.45E−04 +/-12%	1.63	1.36	1.66	1.81
49.72	2.04E−04 +/-19%	1.15E−04 +/-12%	1.78	1.53	1.82	2.07
99.91	1.38E−04 +/-21%	7.73E−05 +/-13%	1.78	1.60	1.86	2.28
200.13	7.57E−05 +/-22%	3.75E−05 +/-14%	2.02	2.00	2.17	2.84
402.97	3.42E−05 +/-29%	1.11E−05 +/-13%	3.09	3.37	3.48	4.78

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ta180	Ta181(n,2n)Ta180	8.0h	99.7	0.69	10%
Hf181	Ta181(n,p)Hf181	42.3d	100.0	1.78	19%
Ta182	Ta181(n,γ)Ta182	114d	59.6	2.02	22%
	Ta181(n,γ)Ta182m	0.3s	38.2	2.02	22%
	Ta181(n,γ)Ta182n	15.8m	2.2	2.02	22%


FNS-96 7 hours Irradiation - Ta
Heat Output [µW/kg]
Time after irradiation [years]
1E-01
1E-02
1E-03
1E-04
1E-05
1E-06
1E-04
1E-03
1E-02
1E-01
1E+00
1E+01
180Ta
182Ta
181Hf
179Ta
Hour
Day

Tungsten

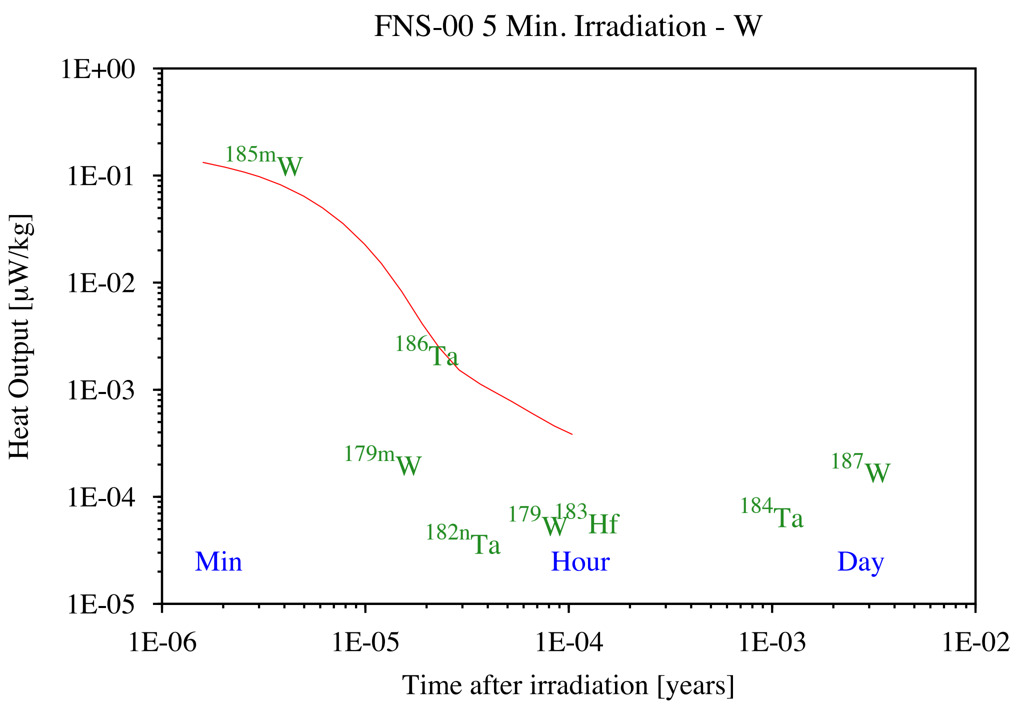


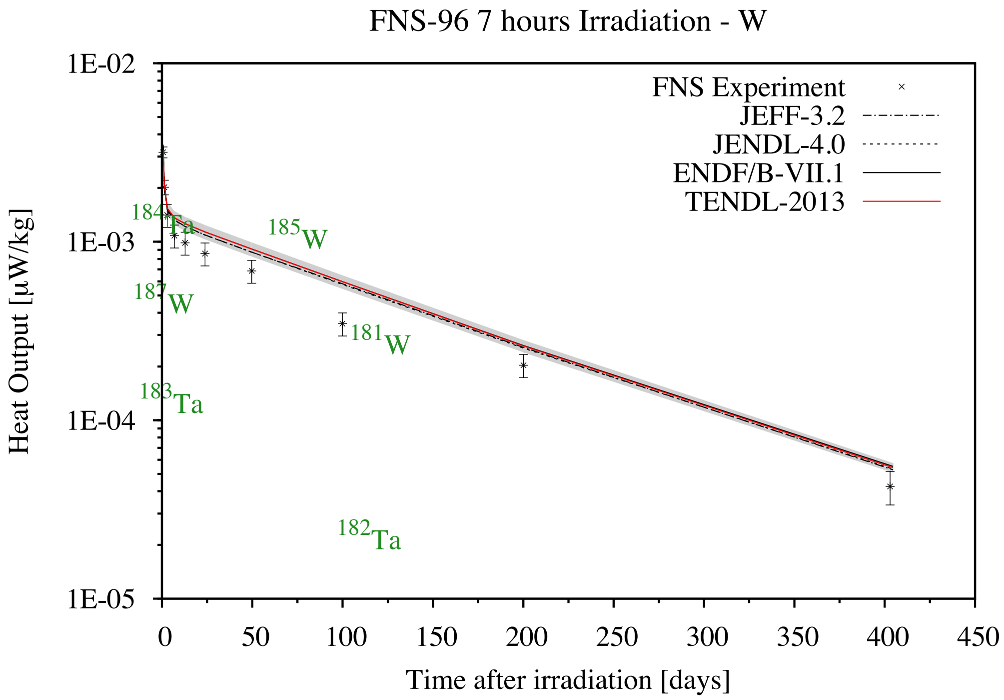


For Tungsten, a better than expected level of agreement is observed for this particularly troublesome, in nuclear data terms, element even at short cooling time for ENDF/B-VII.1 and TENDL-2013. The systematic code over-prediction on both batches (although by more in the 2000 case) may need to be addressed via an in-depth analysis of the two production routes involved.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.83	$6.83E{-}02$ +/-13%	$1.33E{-}01$ +/-9%	0.51	0.53	26.98	27.72
1.08	$6.11E{-}02$ +/-13%	$1.19E{-}01$ +/-9%	0.51	0.53	24.51	25.17
1.33	$5.57E{-}02$ +/-13%	$1.08E{-}01$ +/-9%	0.52	0.54	22.67	23.28
1.58	$5.03E{-}02$ +/-13%	$9.75E{-}02$ +/-9%	0.52	0.53	20.75	21.29
2.02	$4.25E{-}02$ +/-13%	$8.18E{-}02$ +/-9%	0.52	0.54	17.98	18.43
2.62	$3.36E{-}02$ +/-13%	$6.41E{-}02$ +/-9%	0.52	0.54	14.72	15.08
3.23	$2.67E{-}02$ +/-13%	$5.01E{-}02$ +/-9%	0.53	0.55	12.12	12.40
4.08	$1.95E{-}02$ +/-13%	$3.57E{-}02$ +/-9%	0.55	0.57	9.26	9.46
5.20	$1.22E{-}02$ +/-12%	$2.29E{-}02$ +/-9%	0.53	0.55	6.18	6.30
6.30	$8.22E{-}03$ +/-12%	$1.51E{-}02$ +/-8%	0.54	0.57	4.41	4.49
7.92	$5.02E{-}03$ +/-11%	$8.33E{-}03$ +/-8%	0.60	0.63	2.94	2.98
10.02	$2.73E{-}03$ +/-10%	$4.13E{-}03$ +/-8%	0.66	0.69	1.78	1.81
12.13	$1.68E{-}03$ +/-9%	$2.47E{-}03$ +/-9%	0.68	0.73	1.22	1.23
15.20	$1.01E{-}03$ +/-8%	$1.53E{-}03$ +/-11%	0.66	0.72	0.85	0.86
19.30	$6.55E{-}04$ +/-8%	$1.13E{-}03$ +/-12%	0.58	0.65	0.67	0.67
23.40	$4.96E{-}04$ +/-9%	$9.22E{-}04$ +/-12%	0.54	0.59	0.60	0.60
27.52	$4.05E{-}04$ +/-11%	$7.79E{-}04$ +/-11%	0.52	0.56	0.57	0.57
34.63	$2.91E{-}04$ +/-14%	$6.03E{-}04$ +/-10%	0.48	0.50	0.52	0.51
44.73	$1.97E{-}04$ +/-20%	$4.58E{-}04$ +/-8%	0.43	0.42	0.45	0.44
54.85	$2.08E{-}04$ +/-19%	$3.82E{-}04$ +/-8%	0.54	0.53	0.55	0.55

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
W185m	W186(n,2n)W185m	1.6m	98.1	0.52	13%
Ta186	W186(n,p)Ta186	10.5m	100.0	0.66	13%

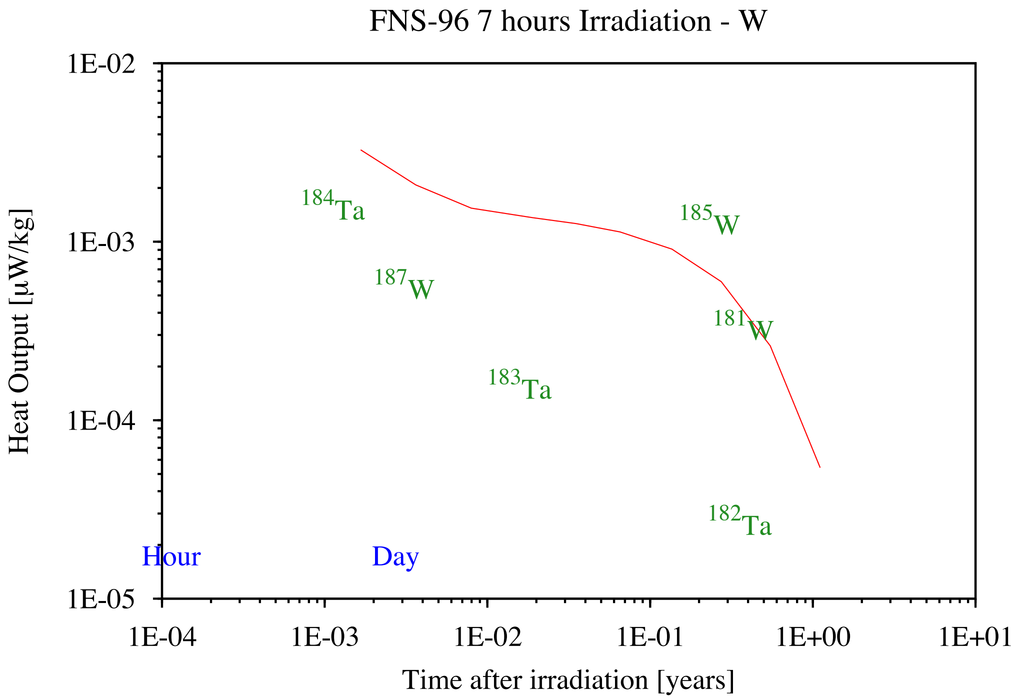




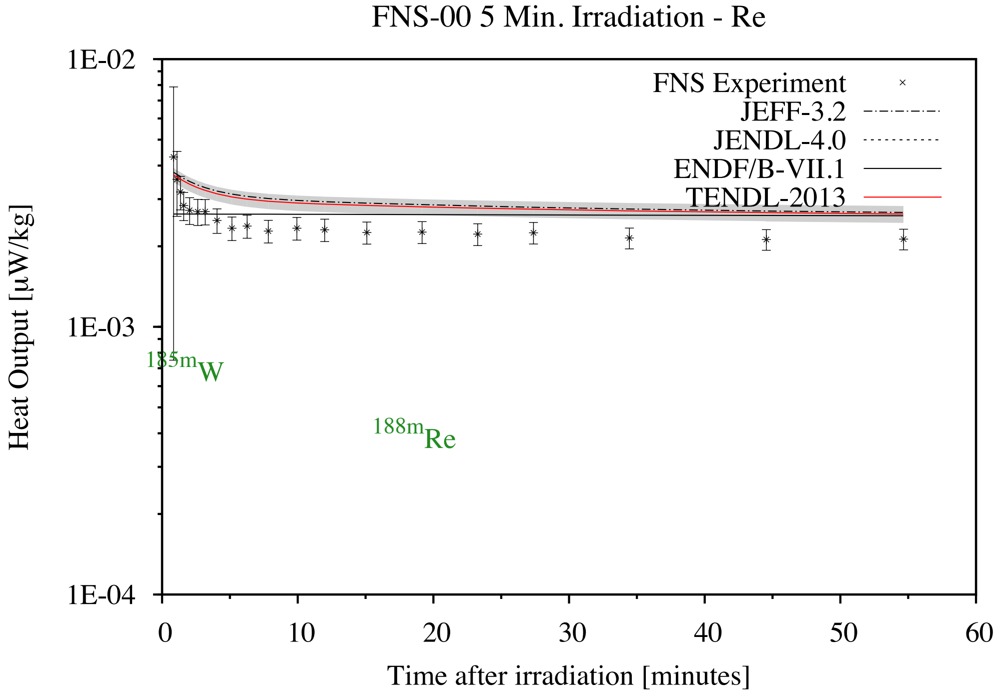
There seems to be a systematic 20-30% overestimation for some of the predominant isotopes, most notably W181 and W185.

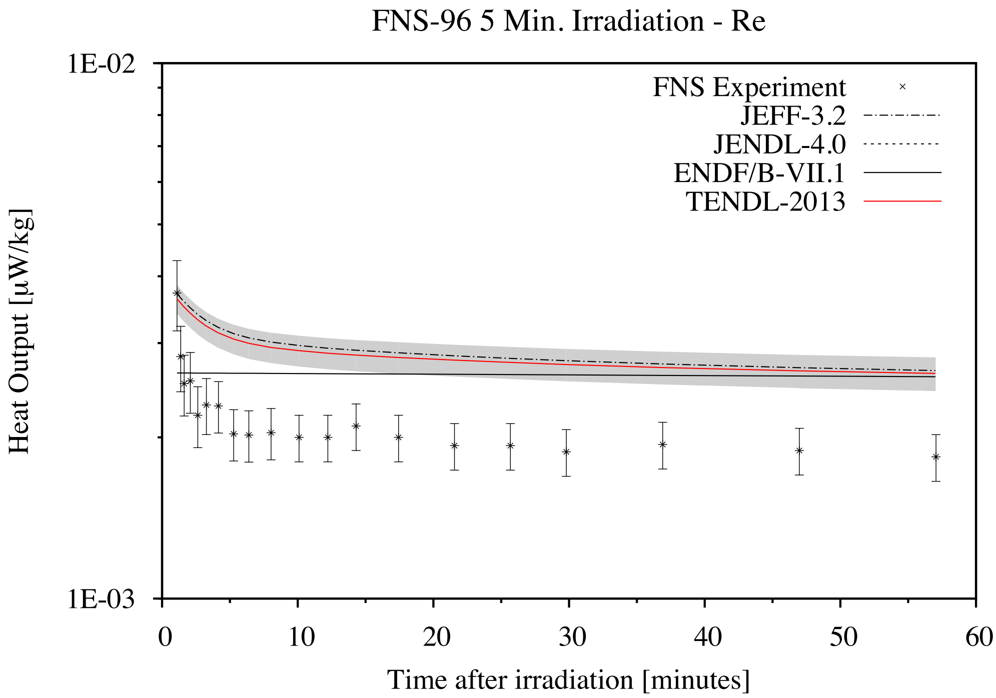
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.61	3.17E−03 +/-7%	3.28E−03 +/-9%	0.97	0.91	0.92	0.94
1.33	2.02E−03 +/-9%	2.08E−03 +/-8%	0.97	0.96	0.96	1.00
2.91	1.41E−03 +/-15%	1.54E−03 +/-9%	0.91	0.92	0.93	0.95
6.88	1.08E−03 +/-15%	1.36E−03 +/-9%	0.79	0.80	0.82	0.82
12.87	9.86E−04 +/-15%	1.26E−03 +/-9%	0.78	0.78	0.81	0.81
23.87	8.58E−04 +/-15%	1.13E−03 +/-9%	0.76	0.76	0.79	0.79
49.71	6.87E−04 +/-15%	9.08E−04 +/-9%	0.76	0.75	0.79	0.79
99.90	3.48E−04 +/-15%	5.97E−04 +/-9%	0.58	0.58	0.60	0.60
200.12	2.03E−04 +/-15%	2.61E−04 +/-8%	0.78	0.77	0.79	0.80
402.95	4.26E−05 +/-21%	5.42E−05 +/-6%	0.79	0.77	0.81	0.80

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ta184	W184(n,p)Ta184	8.7h	99.7	0.97	7%
W185	W186(n,2n)W185	75.1d	63.9	0.76	15%
	W186(n,2n)W185m	1.6m	35.8	0.76	15%
W181	W182(n,2n)W181	120d	99.3	0.78	15%
	W183(n,3n)W181	120d	0.7	0.78	15%


FNS-96 7 hours Irradiation - W
Heat Output [µW/kg]
1E-02
1E-03
1E-04
1E-05
Time after irradiation [years]
1E-04
1E-03
1E-02
1E-01
1E+00
1E+01
184Ta
187W
183Ta
185W
181W
182Ta
Hour
Day

Rhenium

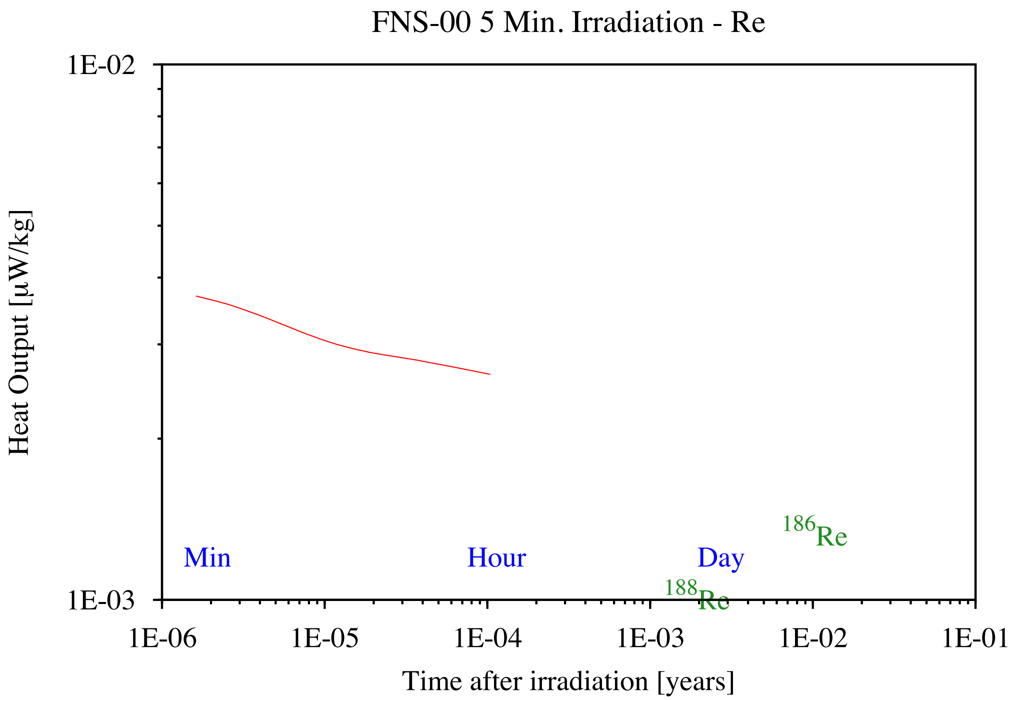


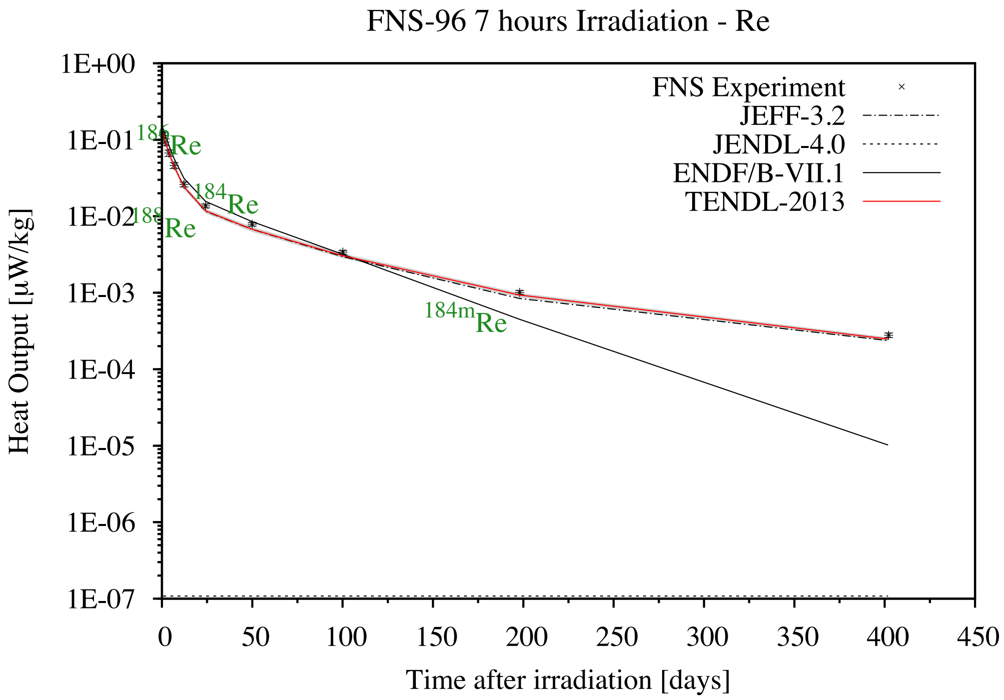


Rhenium: there was quite good agreement to the newer experimental results for this element with EAF-2010 [13], nearly within the experimental uncertainties. However, the experimental result from the 1996 batch is significantly different. This could be due to the rarely observed shadow or iceberg effect. Furthermore, Re188 response is over-predicted by all libraries, shadowing the Re186 one. Effect seen in the Log-Log graph on the next page. JENDL-4.0 library predicts poorly.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.85	4.31E−03 +/-83%	3.69E−03 +/-6%	1.17	1.63	1.14	0.00
1.10	3.55E−03 +/-27%	3.62E−03 +/-6%	0.98	1.35	0.96	0.00
1.35	3.19E−03 +/-14%	3.56E−03 +/-6%	0.90	1.21	0.88	0.00
1.60	2.84E−03 +/-12%	3.50E−03 +/-6%	0.81	1.07	0.79	0.00
2.03	2.72E−03 +/-12%	3.41E−03 +/-6%	0.80	1.03	0.78	0.00
2.63	2.69E−03 +/-11%	3.31E−03 +/-6%	0.81	1.02	0.79	0.00
3.18	2.69E−03 +/-11%	3.23E−03 +/-6%	0.83	1.02	0.81	0.00
4.05	2.50E−03 +/-11%	3.14E−03 +/-6%	0.80	0.95	0.78	0.00
5.15	2.33E−03 +/-10%	3.06E−03 +/-6%	0.76	0.89	0.75	0.00
6.27	2.38E−03 +/-10%	3.00E−03 +/-6%	0.79	0.90	0.77	0.00
7.83	2.28E−03 +/-10%	2.95E−03 +/-7%	0.77	0.87	0.76	0.00
9.93	2.33E−03 +/-10%	2.90E−03 +/-7%	0.81	0.89	0.79	0.00
11.98	2.30E−03 +/-10%	2.87E−03 +/-7%	0.80	0.88	0.79	0.00
15.10	2.25E−03 +/-9%	2.84E−03 +/-7%	0.79	0.86	0.78	0.00
19.17	2.26E−03 +/-9%	2.81E−03 +/-7%	0.80	0.86	0.79	0.00
23.27	2.22E−03 +/-9%	2.78E−03 +/-7%	0.80	0.85	0.79	0.00
27.38	2.25E−03 +/-9%	2.75E−03 +/-7%	0.82	0.86	0.80	0.00
34.45	2.15E−03 +/-9%	2.71E−03 +/-7%	0.79	0.82	0.78	0.00
44.55	2.12E−03 +/-9%	2.67E−03 +/-7%	0.79	0.81	0.78	0.00
54.67	2.13E−03 +/-9%	2.64E−03 +/-7%	0.81	0.82	0.80	0.00

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
W185m	Re185(n,p)W185m	1.6m	96.7	0.81	12%
	Re187(n,t+nd)W185m		3.1	0.81	12%
Re188	Re187(n,γ)Re188	16.9h	100.0	0.81	9%
Re186	Re185(n,γ)Re186	3.7d	9.2	0.81	9%
	Re187(n,2n)Re186		90.8	0.81	9%

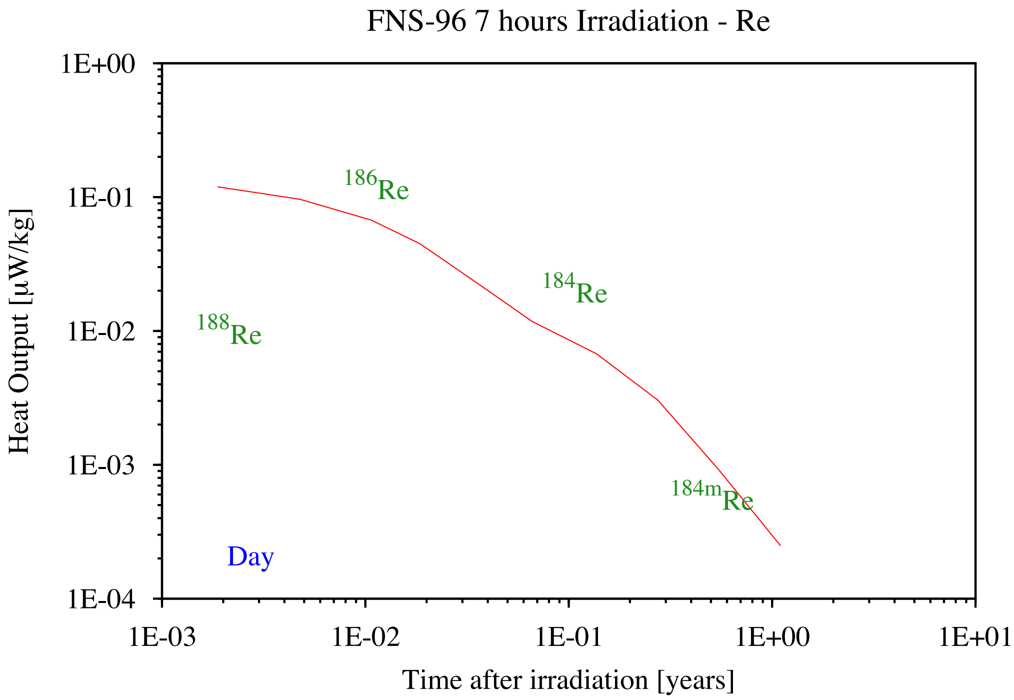




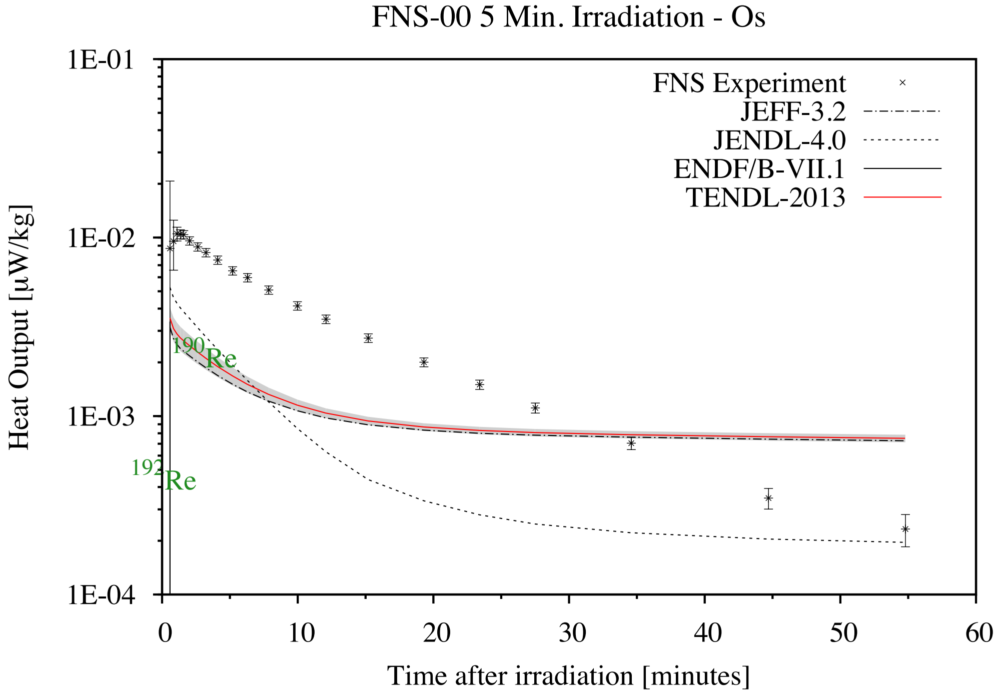
A much better agreement, compared to the 5-minutes analysis, is seen from half a day up to more than a year of cooling. Note in this case the unusual occurrence of metastable isomer having a half-life greater than the ground (Re184m vs. Re184). JENDL-4.0 predicts poorly.

Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.69	1.14E−01 +/-11%	1.19E−01 +/-10%	0.96	0.81	0.95	1055504.16
1.74	9.32E−02 +/-10%	9.63E−02 +/-10%	0.97	0.80	0.97	861887.14
3.90	6.71E−02 +/-10%	6.74E−02 +/-10%	0.99	0.80	0.99	620444.03
6.76	4.61E−02 +/-9%	4.50E−02 +/-9%	1.02	0.81	1.02	425994.45
12.21	2.61E−02 +/-8%	2.42E−02 +/-7%	1.08	0.83	1.07	241350.60
24.22	1.37E−02 +/-6%	1.17E−02 +/-7%	1.16	0.88	1.18	126364.48
49.97	7.88E−03 +/-6%	6.76E−03 +/-7%	1.17	0.93	1.17	72904.72
100.10	3.39E−03 +/-6%	3.04E−03 +/-7%	1.11	1.06	1.14	31332.10
197.96	1.01E−03 +/-6%	9.32E−04 +/-6%	1.08	2.24	1.20	9352.45
402.17	2.78E−04 +/-7%	2.48E−04 +/-6%	1.12	27.28	1.18	2574.47

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Re186	Re187(n,2n)Re186	3.7d	98.6	0.99	10%
	Re185(n,γ)Re186	3.7d	1.3	0.99	10%
Re184	Re185(n,2n)Re184	37.9d	99.9	1.17	5%
Re184m	Re185(n,2n)Re184m	168d	100.0	1.08	6%


FNS-96 7 hours Irradiation - Re
Heat Output [µW/kg]
1E+00
1E-01
1E-02
1E-03
1E-04
1E-03
1E-02
1E-01
1E+00
1E+01
Time after irradiation [years]
186Re
184Re
188Re
184mRe
Day

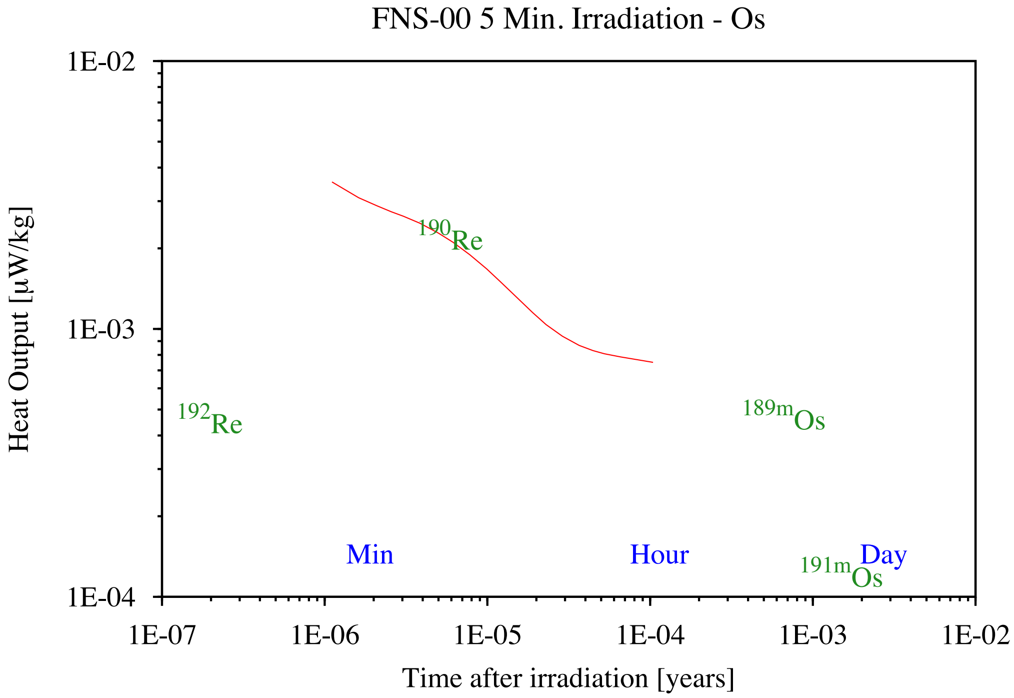
Osmium



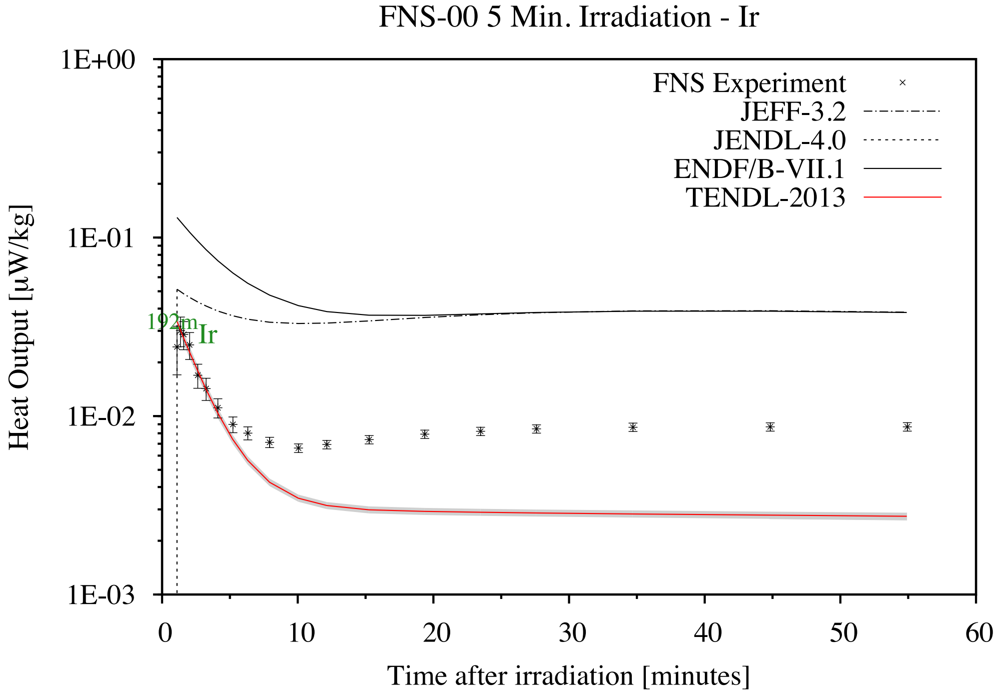
For Osmium, here again the correction made on a grossly overestimated (n,n') channel provide a better estimate of the heat output levels (compared with EAF-2010), although major disagreement still exists between databases for both the isotopic contributions and their heat-output levels. All libraries are lacking production pathways for Os190m.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	8.70E−03 +/-138%	3.54E−03 +/-15%	2.46	2.57	2.76	1.66
0.85	9.54E−03 +/-31%	3.09E−03 +/-15%	3.09	0.00	3.52	2.07
1.10	1.05E−02 +/-9%	2.88E−03 +/-16%	3.64	0.00	4.17	2.45
1.35	1.04E−02 +/-6%	2.74E−03 +/-16%	3.82	0.00	4.37	2.59
1.60	1.04E−02 +/-5%	2.64E−03 +/-15%	3.94	0.00	4.50	2.71
2.03	9.59E−03 +/-5%	2.48E−03 +/-15%	3.87	0.00	4.41	2.73
2.63	8.88E−03 +/-5%	2.28E−03 +/-14%	3.90	0.00	4.42	2.84
3.23	8.24E−03 +/-5%	2.10E−03 +/-14%	3.92	0.00	4.42	2.97
4.10	7.48E−03 +/-5%	1.89E−03 +/-13%	3.95	0.00	4.44	3.18
5.20	6.51E−03 +/-5%	1.68E−03 +/-12%	3.89	0.00	4.32	3.37
6.30	5.96E−03 +/-5%	1.50E−03 +/-11%	3.96	0.00	4.37	3.77
7.87	5.08E−03 +/-5%	1.32E−03 +/-9%	3.85	0.00	4.20	4.24
9.98	4.15E−03 +/-5%	1.15E−03 +/-7%	3.60	0.00	3.87	4.87
12.08	3.49E−03 +/-5%	1.04E−03 +/-6%	3.36	0.00	3.57	5.53
15.20	2.74E−03 +/-6%	9.39E−04 +/-5%	2.91	0.00	3.06	6.21
19.30	2.00E−03 +/-6%	8.68E−04 +/-5%	2.31	0.00	2.40	5.97
23.42	1.50E−03 +/-6%	8.30E−04 +/-5%	1.81	0.00	1.87	5.36
27.52	1.11E−03 +/-7%	8.08E−04 +/-5%	1.38	0.00	1.42	4.47
34.58	7.04E−04 +/-8%	7.86E−04 +/-5%	0.90	0.00	0.93	3.18
44.70	3.47E−04 +/-13%	7.66E−04 +/-5%	0.45	0.00	0.47	1.69
54.80	2.33E−04 +/-21%	7.51E−04 +/-5%	0.31	0.00	0.32	1.19

Product	Pathways	$T_{1/2}$	Path %	E/C	ΔE%
Re190	Os190(n,p)Re190	3.1m	100.0	3.90	5%
Os190m	Os190(n,n')Os190m	9.9m	0.0	0.00	5%
	Os192(n,3n)Os190m		0.0	0.00	5%



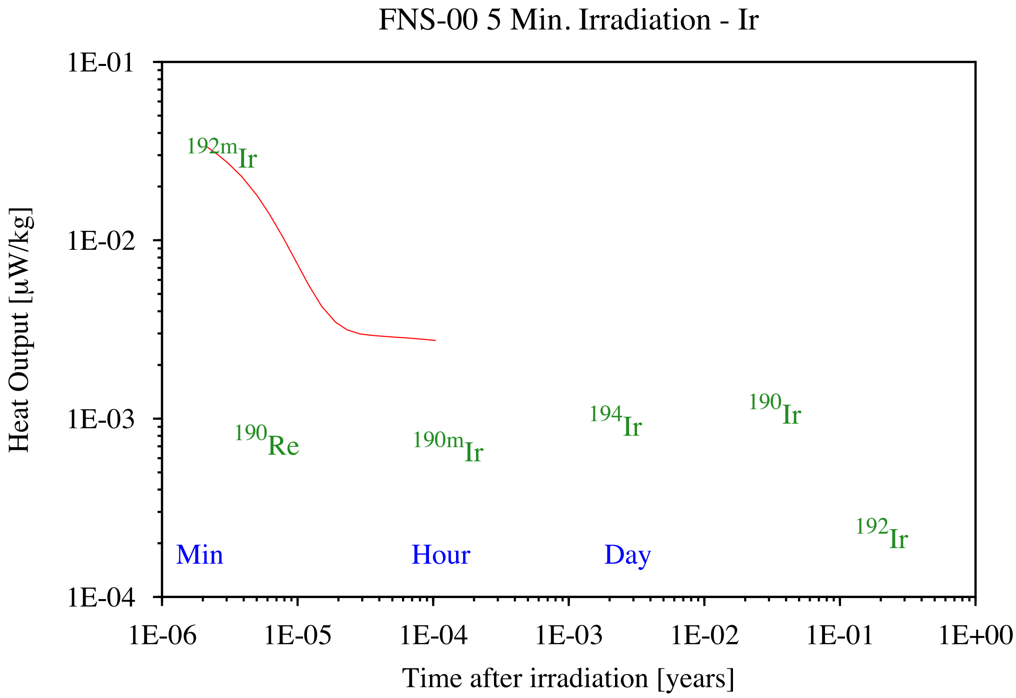
Iridium



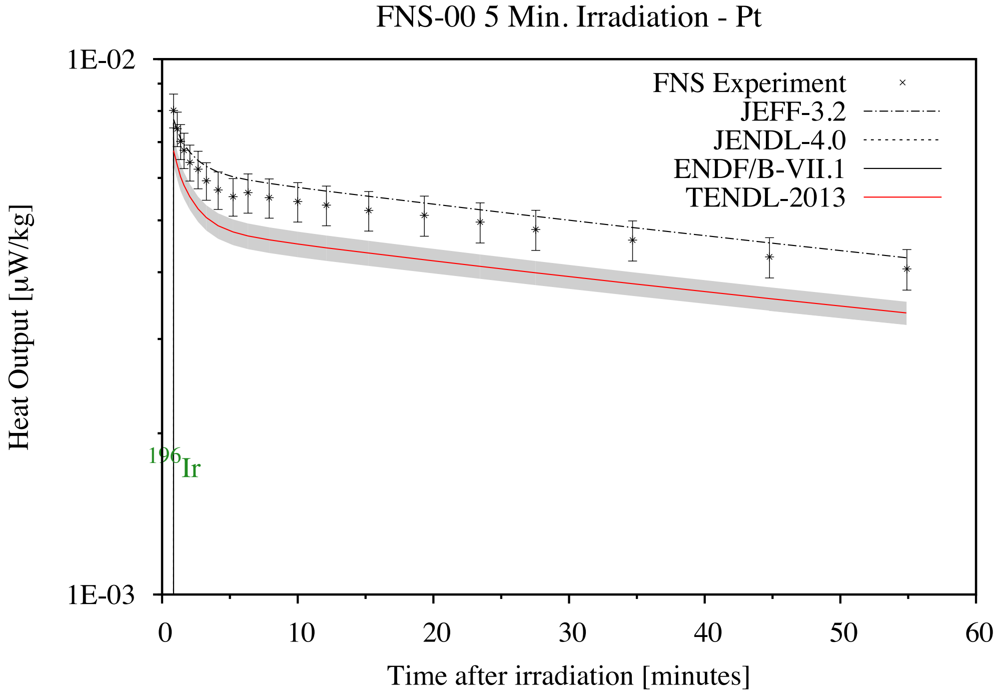
For Iridium, a most interesting experimental decay heat shape can be seen, underpinning an increase in heat due to the presence of an isomeric daughter with a half-life shorter that the parent, coupled with a potent decay heat. TENDL's libraries are lacking the Os190m and Ir192n production pathways that are present in EAF-2010 [13]. Note that along the direct (n,d) production route for Os190m there is also a decay path from the long-lived Ir192n.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
1.10	2.44$E-$02 +/-30%	3.39$E-$02 +/-7%	0.72	0.19	0.48	0.48
1.35	3.01$E-$02 +/-19%	3.03$E-$02 +/-7%	0.99	0.24	0.60	0.00
1.60	2.87$E-$02 +/-18%	2.73$E-$02 +/-7%	1.05	0.24	0.59	0.00
2.03	2.50$E-$02 +/-17%	2.28$E-$02 +/-7%	1.10	0.23	0.54	0.00
2.63	1.69$E-$02 +/-15%	1.79$E-$02 +/-7%	0.95	0.18	0.39	0.00
3.25	1.43$E-$02 +/-14%	1.41$E-$02 +/-7%	1.01	0.17	0.35	0.00
4.12	1.11$E-$02 +/-12%	1.04$E-$02 +/-6%	1.07	0.15	0.29	0.00
5.22	8.98$E-$03 +/-10%	7.40$E-$03 +/-6%	1.21	0.14	0.25	0.00
6.32	8.02$E-$03 +/-8%	5.65$E-$03 +/-5%	1.42	0.14	0.23	0.00
7.93	7.13$E-$03 +/-7%	4.25$E-$03 +/-5%	1.68	0.15	0.21	0.00
10.05	6.61$E-$03 +/-5%	3.47$E-$03 +/-5%	1.91	0.16	0.20	0.00
12.15	6.92$E-$03 +/-5%	3.15$E-$03 +/-5%	2.20	0.18	0.21	0.00
15.27	7.38$E-$03 +/-5%	2.98$E-$03 +/-5%	2.47	0.20	0.22	0.00
19.37	7.91$E-$03 +/-5%	2.92$E-$03 +/-5%	2.71	0.22	0.22	0.00
23.48	8.22$E-$03 +/-5%	2.89$E-$03 +/-5%	2.84	0.22	0.22	0.00
27.60	8.48$E-$03 +/-5%	2.86$E-$03 +/-5%	2.96	0.22	0.22	0.00
34.72	8.66$E-$03 +/-5%	2.83$E-$03 +/-5%	3.06	0.22	0.22	0.00
44.83	8.70$E-$03 +/-5%	2.78$E-$03 +/-5%	3.13	0.23	0.22	0.00
54.93	8.70$E-$03 +/-5%	2.74$E-$03 +/-5%	3.17	0.23	0.23	0.00

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Ir192m	Ir191(n,γ)Ir192m	1.4m	51.1	0.99	19%
	Ir193(n,2n)Ir192m		47.8	0.99	19%
Os190m	Ir191(n,d)Os190m	9.9m	0.0	3.17	5%
Ir192n	Ir191(n,2n)Ir192n(β^+)	241y	0.0	3.17	5%
Ir194	Ir193(n,γ)Ir194	19.3h	100.0	3.17	5%
Ir190	Ir191(n,2n)Ir190	12d	100.0	3.17	5%



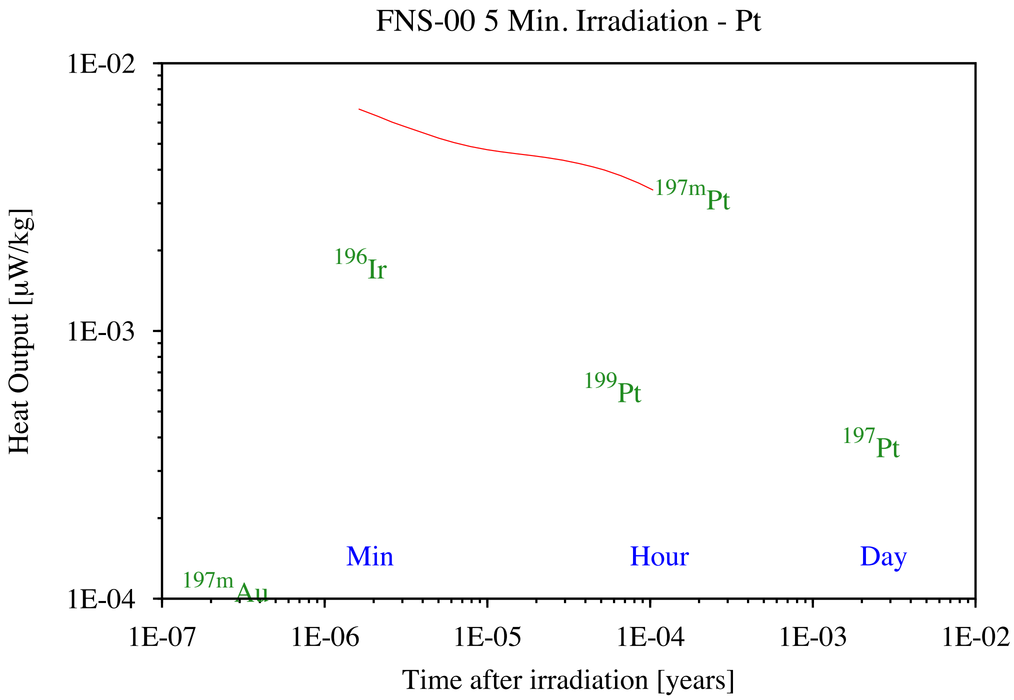
Platinum



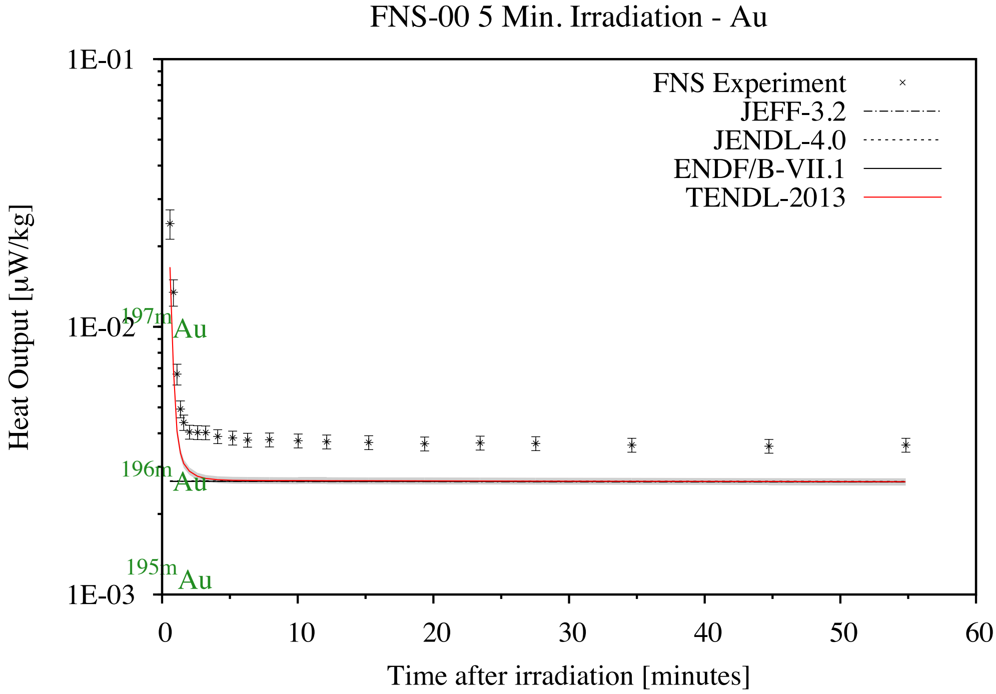
For Platinum, the above graph may indicate an under-prediction, of 20%, in the production of Pt197m when TENDL-2013 is used, while it is within the experimental uncertainty if it is JEFF-3.2. However, TENDL-2012 [13] gives better results.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.85	8.02E−03 +/-7%	6.75E−03 +/-6%	1.19	1.05	1.04	1.05
1.12	7.41E−03 +/-7%	6.34E−03 +/-6%	1.17	0.00	1.01	0.00
1.37	7.02E−03 +/-8%	6.03E−03 +/-6%	1.16	0.00	0.99	0.00
1.62	6.76E−03 +/-8%	5.81E−03 +/-6%	1.16	0.00	0.98	0.00
2.05	6.41E−03 +/-8%	5.53E−03 +/-6%	1.16	0.00	0.96	0.00
2.65	6.23E−03 +/-8%	5.25E−03 +/-5%	1.19	0.00	0.96	0.00
3.27	5.93E−03 +/-8%	5.06E−03 +/-5%	1.17	0.00	0.94	0.00
4.13	5.70E−03 +/-8%	4.88E−03 +/-5%	1.17	0.00	0.93	0.00
5.23	5.53E−03 +/-8%	4.76E−03 +/-6%	1.16	0.00	0.92	0.00
6.33	5.63E−03 +/-8%	4.67E−03 +/-6%	1.20	0.00	0.95	0.00
7.90	5.51E−03 +/-8%	4.60E−03 +/-6%	1.20	0.00	0.94	0.00
10.00	5.42E−03 +/-8%	4.51E−03 +/-5%	1.20	0.00	0.94	0.00
12.12	5.34E−03 +/-9%	4.44E−03 +/-5%	1.20	0.00	0.94	0.00
15.23	5.22E−03 +/-9%	4.34E−03 +/-5%	1.20	0.00	0.94	0.00
19.33	5.11E−03 +/-9%	4.22E−03 +/-5%	1.21	0.00	0.95	0.00
23.45	4.96E−03 +/-9%	4.10E−03 +/-5%	1.21	0.00	0.95	0.00
27.55	4.81E−03 +/-9%	3.99E−03 +/-5%	1.20	0.00	0.94	0.00
34.68	4.59E−03 +/-9%	3.81E−03 +/-5%	1.21	0.00	0.95	0.00
44.78	4.27E−03 +/-9%	3.57E−03 +/-5%	1.20	0.00	0.94	0.00
54.90	4.06E−03 +/-9%	3.36E−03 +/-5%	1.21	0.00	0.95	0.00

Product	**Pathways**	$T_{1/2}$	**Path %**	**E/C**	**ΔE%**
Pt197m	Pt198(n,2n)Pt197m	1.5m	100.0	1.16	8%


FNS-00 5 Min. Irradiation - Pt
1E-02
1E-03
1E-04
Heat Output [µW/kg]
197mPt
196Ir
199Pt
197Pt
197mAu
Min
Hour
Day
1E-07
1E-06
1E-05
1E-04
1E-03
1E-02
Time after irradiation [years]

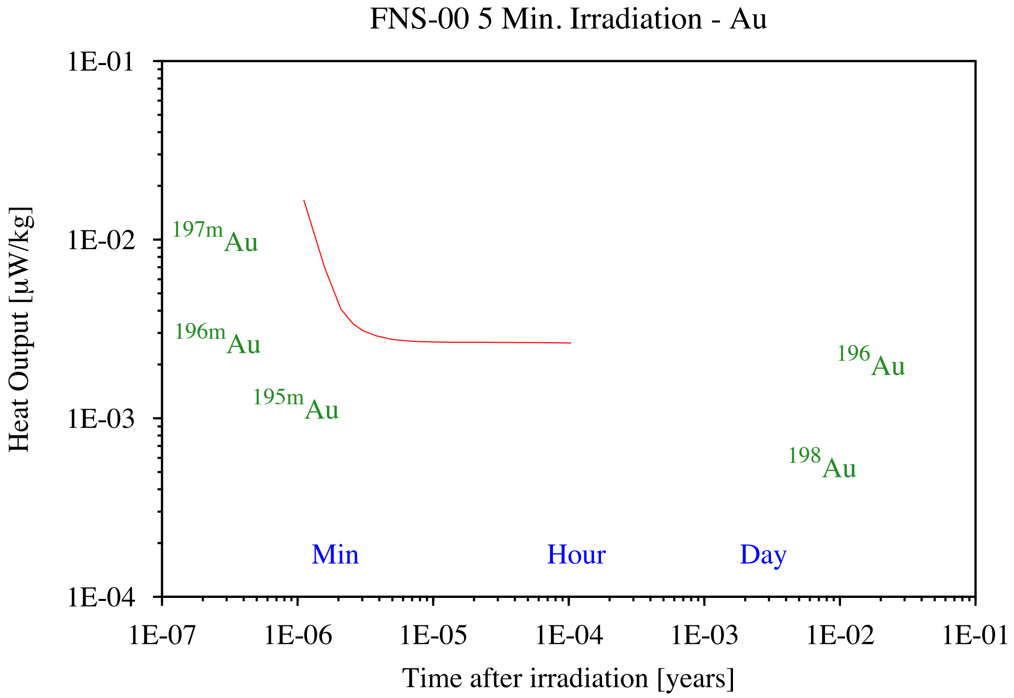
Gold



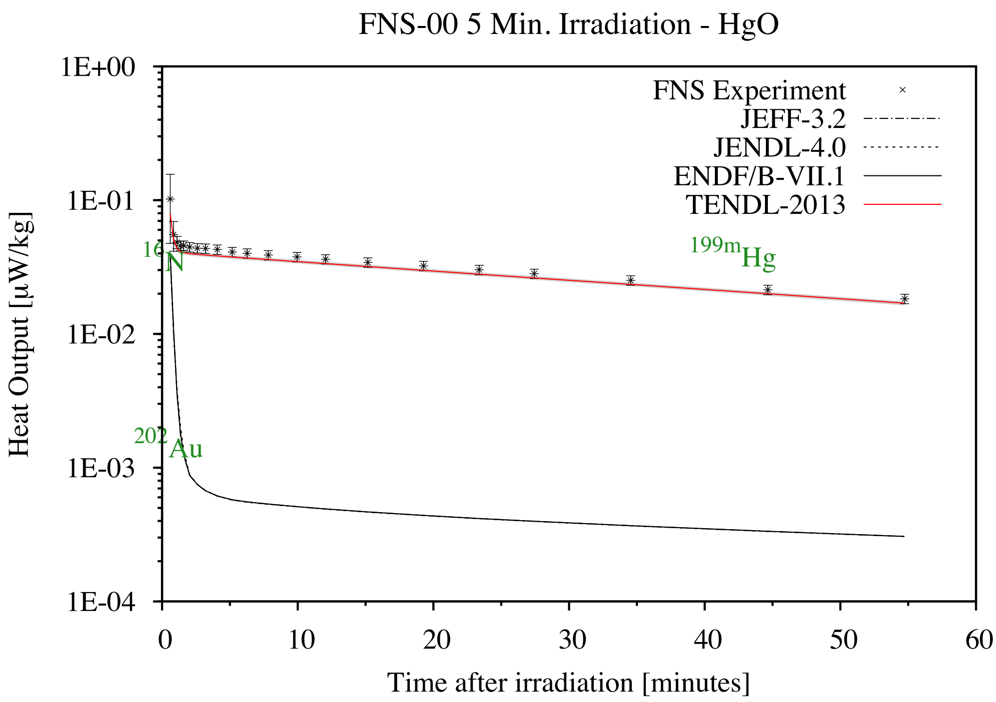
Gold: from such a picture above one may deduce that there could be an under-prediction with all libraries of the heat generated by the Au196 at a level of about 30%. However, some Au196n and Au196m production paths are lacking in the different libraries.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.58	$2.43E{-}02$ +/-13%	$1.67E{-}02$ +/-4%	1.45	9.16	9.18	9.13
0.83	$1.35E{-}02$ +/-11%	$6.97E{-}03$ +/-4%	1.93	5.08	5.09	5.06
1.10	$6.66E{-}03$ +/-9%	$4.07E{-}03$ +/-4%	1.63	2.51	2.52	2.50
1.35	$4.93E{-}03$ +/-7%	$3.38E{-}03$ +/-4%	1.46	1.86	1.86	1.85
1.60	$4.39E{-}03$ +/-7%	$3.08E{-}03$ +/-4%	1.42	1.66	1.66	1.65
2.02	$4.05E{-}03$ +/-6%	$2.89E{-}03$ +/-3%	1.40	1.53	1.53	1.52
2.62	$4.03E{-}03$ +/-6%	$2.76E{-}03$ +/-3%	1.46	1.52	1.52	1.52
3.22	$4.02E{-}03$ +/-6%	$2.71E{-}03$ +/-3%	1.48	1.52	1.52	1.51
4.10	$3.89E{-}03$ +/-6%	$2.69E{-}03$ +/-3%	1.45	1.47	1.47	1.46
5.20	$3.85E{-}03$ +/-6%	$2.67E{-}03$ +/-3%	1.44	1.45	1.45	1.45
6.30	$3.78E{-}03$ +/-6%	$2.67E{-}03$ +/-3%	1.42	1.43	1.43	1.42
7.92	$3.79E{-}03$ +/-6%	$2.66E{-}03$ +/-3%	1.42	1.43	1.43	1.43
10.03	$3.75E{-}03$ +/-6%	$2.66E{-}03$ +/-3%	1.41	1.42	1.42	1.41
12.13	$3.72E{-}03$ +/-6%	$2.66E{-}03$ +/-3%	1.40	1.41	1.41	1.40
15.23	$3.70E{-}03$ +/-6%	$2.66E{-}03$ +/-3%	1.39	1.40	1.40	1.39
19.35	$3.66E{-}03$ +/-6%	$2.66E{-}03$ +/-3%	1.38	1.38	1.38	1.38
23.45	$3.68E{-}03$ +/-6%	$2.66E{-}03$ +/-3%	1.39	1.39	1.40	1.39
27.55	$3.67E{-}03$ +/-6%	$2.65E{-}03$ +/-3%	1.38	1.39	1.39	1.38
34.63	$3.62E{-}03$ +/-6%	$2.65E{-}03$ +/-3%	1.37	1.37	1.37	1.37
44.73	$3.58E{-}03$ +/-6%	$2.64E{-}03$ +/-3%	1.36	1.36	1.36	1.35
54.83	$3.62E{-}03$ +/-6%	$2.64E{-}03$ +/-3%	1.37	1.37	1.37	1.37

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Au197m	Au197(n,n')Au197m	7.7s	100.0	1.45	13%
Au196	Au197(n,2n)Au196m	8.1s	5.6	1.37	6%
	Au197(n,2n)Au196	6.1d	94.4	1.37	6%



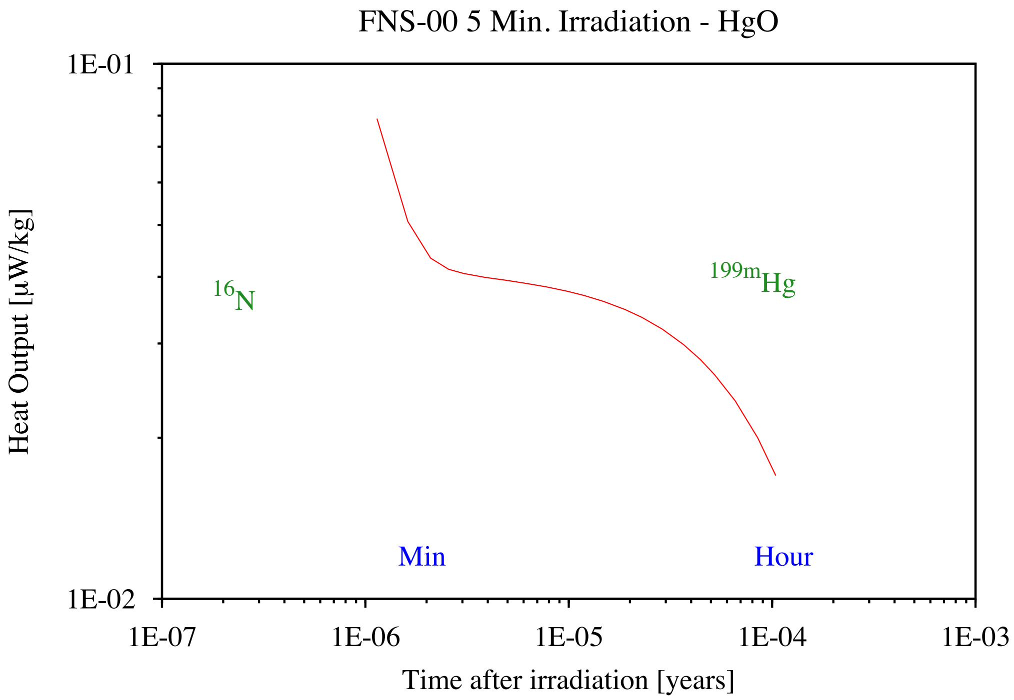
Mercury

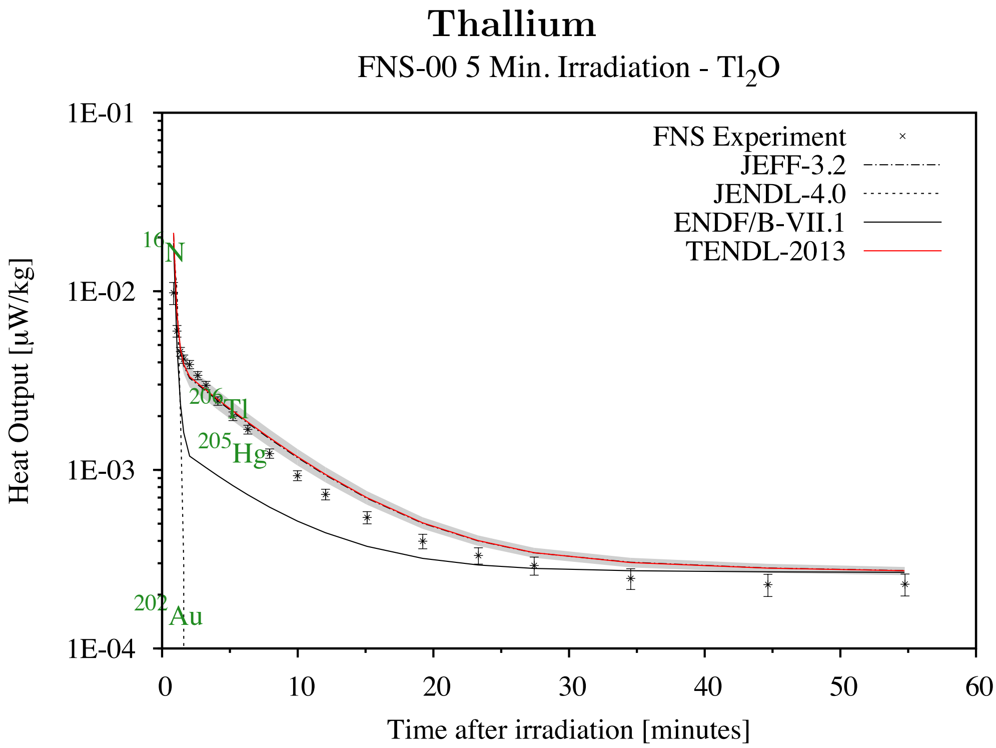


For Mercury, with both (n,2n) and (n,n') routes of production for the unique predominant Hg199m isotope, the choices for small modification to TENDL-2013 are both manyfold and also subtle in their requirements. However, the TENDL-2013 C/E agreement is excellent. Experimental and calculational uncertainties are also fairly similar. A text book case to exemplify the impact of missing isomer production in ENDF/B-VII.1, JEFF-3,2 and JENDL-4.0.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.60	1.02E−01 +/-53%	7.90E−02 +/-2%	1.29	2.63	2.63	2.80
0.85	5.54E−02 +/-25%	5.07E−02 +/-3%	1.09	5.15	5.14	5.56
1.10	4.85E−02 +/-11%	4.33E−02 +/-3%	1.12	13.53	13.52	12.64
1.35	4.56E−02 +/-8%	4.13E−02 +/-3%	1.10	24.88	25.78	22.27
1.60	4.58E−02 +/-8%	4.06E−02 +/-3%	1.13	36.62	37.01	33.95
2.03	4.46E−02 +/-8%	3.99E−02 +/-3%	1.12	50.74	50.93	50.36
2.60	4.38E−02 +/-8%	3.94E−02 +/-3%	1.11	58.55	58.64	58.26
3.20	4.35E−02 +/-8%	3.89E−02 +/-3%	1.12	64.73	64.76	64.63
4.07	4.28E−02 +/-8%	3.83E−02 +/-3%	1.12	69.53	69.54	69.65
5.17	4.10E−02 +/-8%	3.76E−02 +/-3%	1.09	71.14	71.18	71.43
6.27	4.00E−02 +/-8%	3.69E−02 +/-3%	1.09	72.17	72.18	72.50
7.83	3.89E−02 +/-8%	3.60E−02 +/-3%	1.08	72.76	72.77	73.06
9.95	3.76E−02 +/-8%	3.47E−02 +/-3%	1.08	73.55	73.56	73.83
12.05	3.62E−02 +/-8%	3.36E−02 +/-3%	1.08	73.57	73.58	73.84
15.17	3.43E−02 +/-8%	3.19E−02 +/-3%	1.07	73.31	73.31	73.55
19.27	3.23E−02 +/-8%	2.99E−02 +/-3%	1.08	73.28	73.28	73.49
23.37	3.01E−02 +/-8%	2.80E−02 +/-3%	1.08	72.26	72.27	72.46
27.43	2.82E−02 +/-8%	2.62E−02 +/-3%	1.08	71.02	71.02	71.20
34.55	2.51E−02 +/-8%	2.35E−02 +/-3%	1.07	68.26	68.27	68.42
44.65	2.14E−02 +/-8%	2.00E−02 +/-3%	1.07	63.91	63.91	64.04
54.75	1.83E−02 +/-8%	1.70E−02 +/-3%	1.08	59.67	59.68	59.79

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Hg199m	Hg199(n,n')Hg199m	42.1m	12.1	1.08	8%
	Hg200(n,2n)Hg199m		87.6	1.08	8%

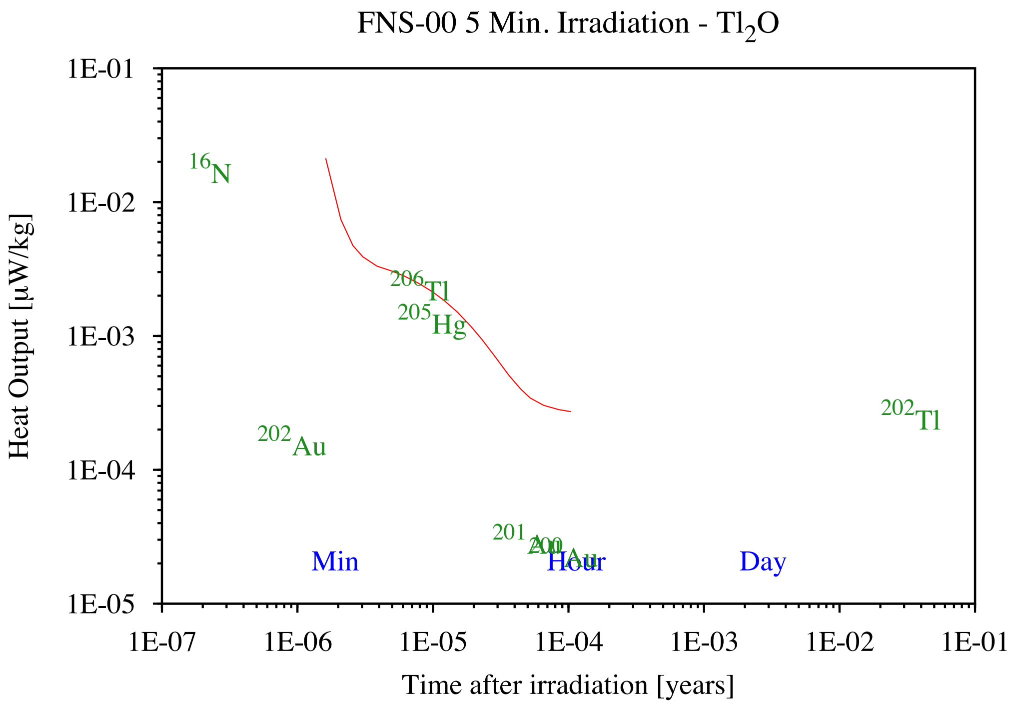




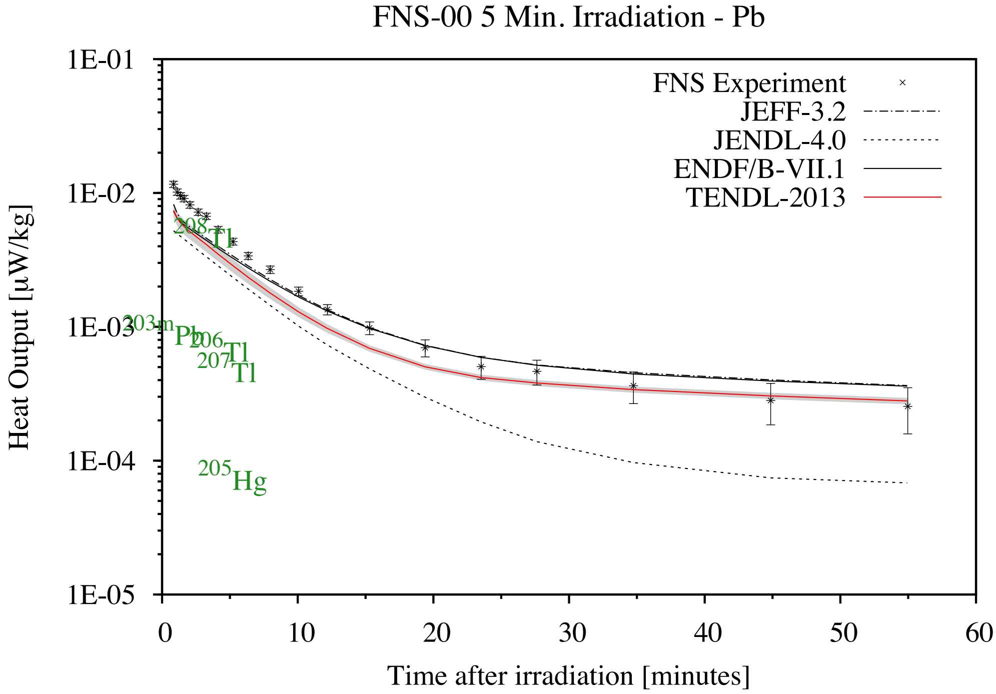
For Thallium, an excellent agreement can be seen when the TENDL-2013 and to a certain extend ENDF/B-VII.1 databases are used. TENDL-2011 [13] performed poorly.

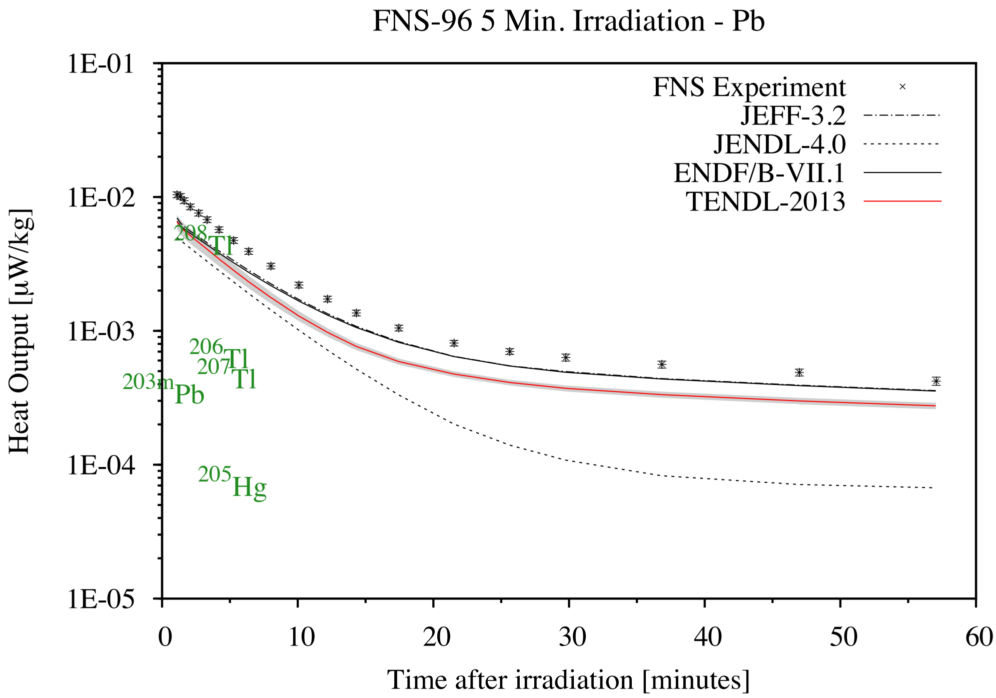
Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.85	9.81E−03 +/-14%	2.12E−02 +/-2%	0.46	0.53	0.46	0.57
1.10	5.99E−03 +/-7%	7.42E−03 +/-7%	0.81	1.22	0.82	0.60
1.35	4.59E−03 +/-6%	4.74E−03 +/-10%	0.97	1.96	0.98	2.23
1.60	4.17E−03 +/-5%	3.90E−03 +/-12%	1.07	2.59	1.09	13.87
2.03	3.89E−03 +/-5%	3.32E−03 +/-13%	1.17	3.26	1.19	0.00
2.63	3.38E−03 +/-5%	3.05E−03 +/-13%	1.11	3.05	1.13	0.00
3.23	2.97E−03 +/-5%	2.80E−03 +/-13%	1.06	2.88	1.08	0.00
4.12	2.43E−03 +/-5%	2.48E−03 +/-12%	0.98	2.62	1.00	0.00
5.22	2.00E−03 +/-6%	2.14E−03 +/-12%	0.93	2.45	0.95	0.00
6.32	1.68E−03 +/-6%	1.85E−03 +/-12%	0.91	2.32	0.92	0.00
7.93	1.23E−03 +/-6%	1.51E−03 +/-11%	0.82	2.00	0.83	0.00
9.98	9.29E−04 +/-6%	1.18E−03 +/-11%	0.78	1.80	0.79	0.00
12.05	7.29E−04 +/-7%	9.44E−04 +/-10%	0.77	1.64	0.78	0.00
15.12	5.41E−04 +/-8%	6.99E−04 +/-9%	0.77	1.45	0.78	0.00
19.22	3.99E−04 +/-9%	5.05E−04 +/-7%	0.79	1.25	0.79	0.00
23.32	3.31E−04 +/-11%	4.02E−04 +/-7%	0.82	1.13	0.83	0.00
27.43	2.91E−04 +/-12%	3.44E−04 +/-6%	0.85	1.04	0.85	0.00
34.55	2.47E−04 +/-13%	3.03E−04 +/-6%	0.81	0.91	0.81	0.00
44.67	2.28E−04 +/-14%	2.82E−04 +/-6%	0.81	0.85	0.81	0.00
54.77	2.29E−04 +/-14%	2.72E−04 +/-5%	0.84	0.86	0.84	0.00

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Tl206	Tl205(n,γ)Tl206	4.2m	99.5	0.98	5%
Hg205	Tl205(n,p)Hg205	5.2m	99.7	0.94	6%
Tl202	Tl203(n,2n)Tl202	12.2d	100.0	0.84	14%


FNS-00 5 Min. Irradiation - Tl2O
Heat Output [µW/kg]
Time after irradiation [years]
1E-01
1E-02
1E-03
1E-04
1E-05
1E-07
1E-06
1E-05
1E-04
1E-03
1E-02
1E-01
16N
206Tl
205Hg
202Au
202Tl
201Au
200Au
Min
Hour
Day

Lead

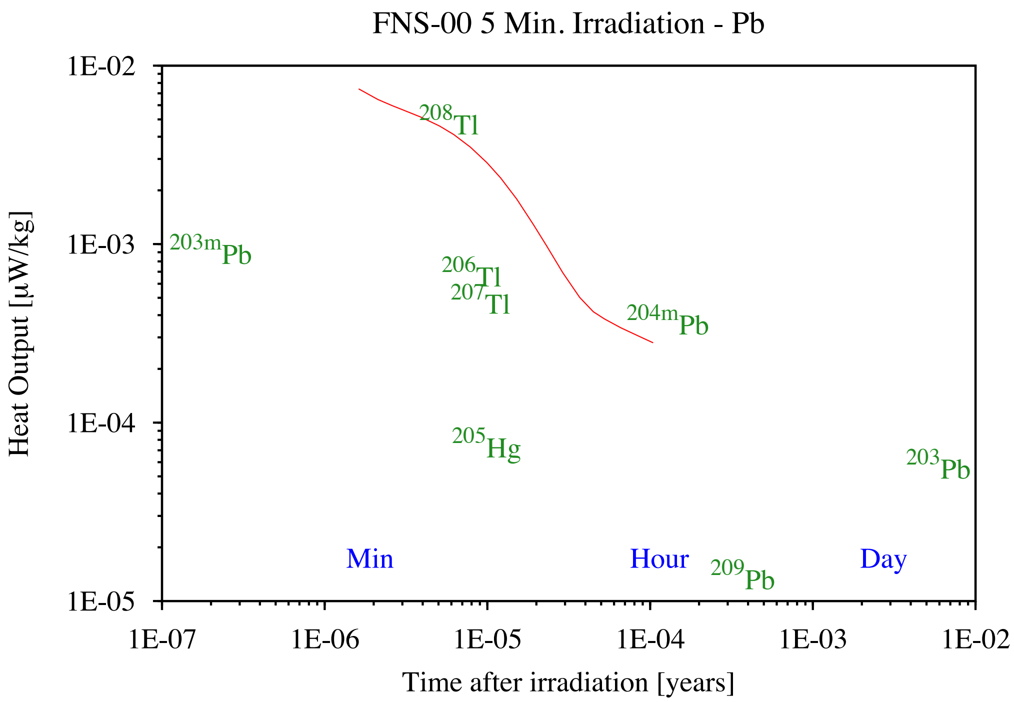


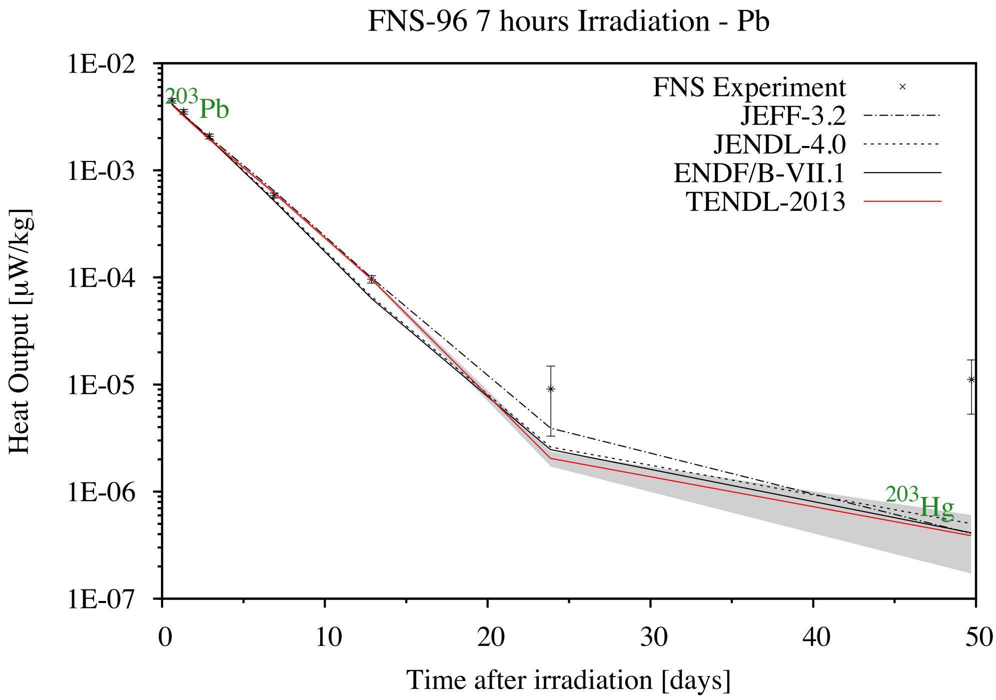


For Lead, the experimental data sets are somewhat different, although the more recent one seems better predicted by the calculations, particularly at longer cooling times. However, in both batches the short term heat predictions seem to be low compared with the measured ones.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.85	1.16$E-$02 +/-6%	7.41$E-$03 +/-12%	1.57	1.59	1.41	2.22
1.12	1.01$E-$02 +/-6%	6.46$E-$03 +/-12%	1.57	1.57	1.45	2.04
1.37	9.53$E-$03 +/-6%	5.97$E-$03 +/-13%	1.60	1.57	1.49	2.01
1.62	9.09$E-$03 +/-6%	5.61$E-$03 +/-13%	1.62	1.57	1.51	2.01
2.05	8.14$E-$03 +/-6%	5.15$E-$03 +/-13%	1.58	1.52	1.46	1.95
2.67	7.19$E-$03 +/-6%	4.59$E-$03 +/-12%	1.57	1.48	1.42	1.93
3.27	6.69$E-$03 +/-6%	4.11$E-$03 +/-12%	1.63	1.51	1.46	2.01
4.13	5.32$E-$03 +/-6%	3.49$E-$03 +/-12%	1.52	1.38	1.33	1.87
5.23	4.33$E-$03 +/-6%	2.86$E-$03 +/-11%	1.52	1.33	1.29	1.85
6.35	3.39$E-$03 +/-6%	2.35$E-$03 +/-11%	1.44	1.23	1.19	1.77
7.97	2.67$E-$03 +/-6%	1.79$E-$03 +/-10%	1.50	1.22	1.18	1.85
10.07	1.84$E-$03 +/-7%	1.29$E-$03 +/-9%	1.43	1.10	1.07	1.82
12.18	1.35$E-$03 +/-9%	9.73$E-$04 +/-7%	1.38	1.03	1.01	1.84
15.30	9.80$E-$04 +/-11%	6.90$E-$04 +/-6%	1.42	1.01	1.00	2.02
19.40	6.98$E-$04 +/-15%	5.03$E-$04 +/-5%	1.39	0.96	0.96	2.34
23.52	5.04$E-$04 +/-19%	4.18$E-$04 +/-5%	1.21	0.85	0.85	2.58
27.63	4.65$E-$04 +/-21%	3.80$E-$04 +/-5%	1.22	0.90	0.89	3.35
34.75	3.63$E-$04 +/-27%	3.40$E-$04 +/-5%	1.07	0.82	0.80	3.75
44.87	2.82$E-$04 +/-34%	3.05$E-$04 +/-5%	0.92	0.71	0.70	3.78
54.97	2.55$E-$04 +/-38%	2.80$E-$04 +/-5%	0.91	0.71	0.70	3.73

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Pb203m	Pb204(n,2n)Pb203m	6.2s	100.0	1.57	6%
Tl208	Pb208(n,p)Tl208	3.0m	100.0	1.63	6%
Pb204m	Pb204(n,n')Pb204m	1.1h	100.0	0.91	38%

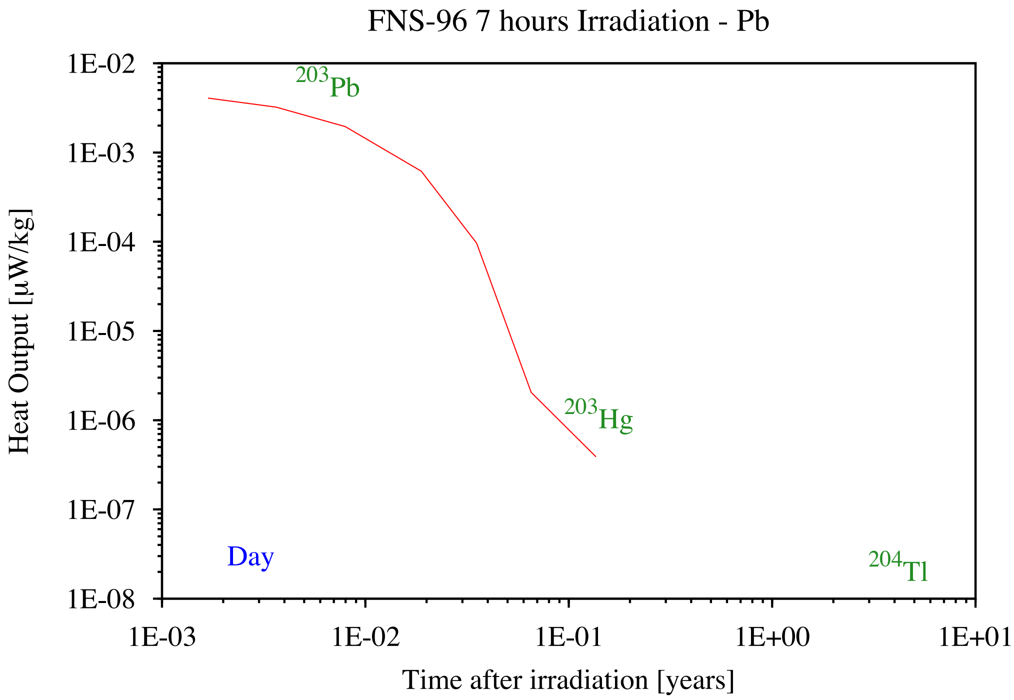




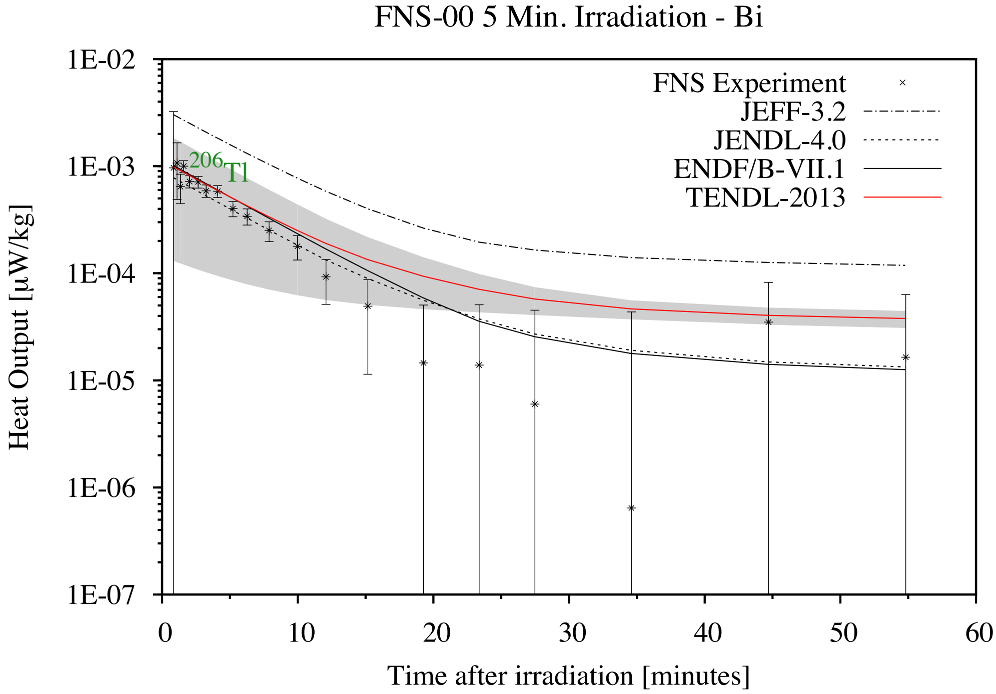
A good agreement is seen in the above graph, although large discrepancies and uncertainties occur in both the measurements and TENDL's results beyond 20 days of cooling.

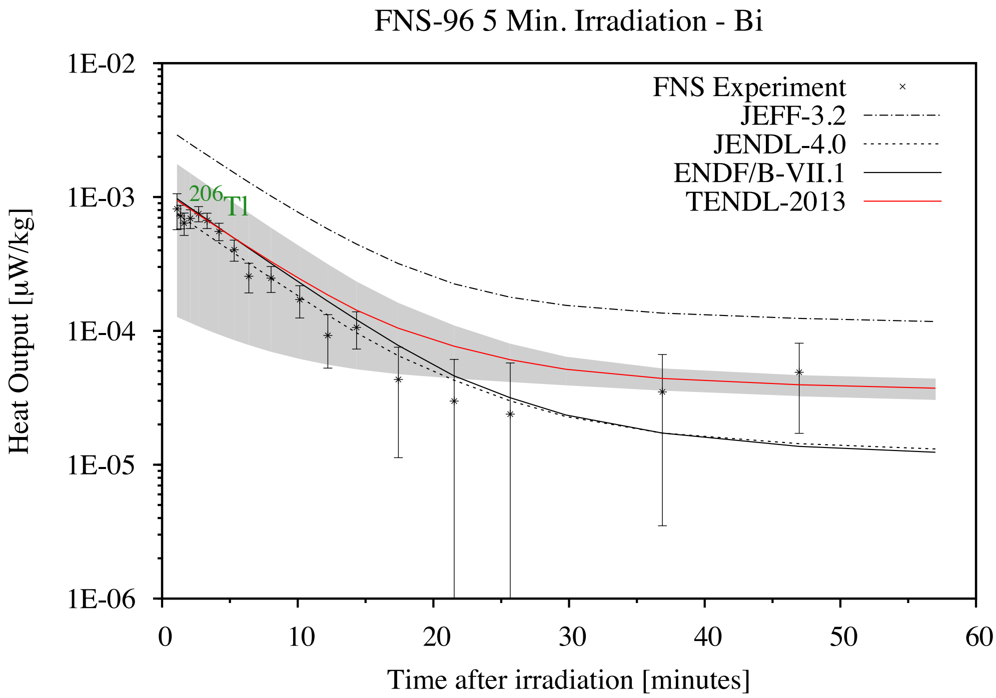
Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.61	4.46$E-$03 +/-5%	4.07$E-$03 +/-4%	1.09	1.07	1.07	1.07
1.33	3.52$E-$03 +/-5%	3.22$E-$03 +/-4%	1.09	1.07	1.07	1.07
2.91	2.08$E-$03 +/-5%	1.95$E-$03 +/-4%	1.07	1.05	1.01	1.04
6.88	5.83$E-$04 +/-5%	6.17$E-$04 +/-4%	0.95	1.12	0.90	1.08
12.87	9.62$E-$05 +/-8%	9.64$E-$05 +/-4%	1.00	1.51	0.97	1.45
23.88	9.09$E-$06 +/-64%	2.04$E-$06 +/-16%	4.45	3.69	2.32	3.48
49.73	1.11$E-$05 +/-53%	3.89$E-$07 +/-56%	28.64	26.96	27.41	22.14

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Pb203	Pb204(n,2n)Pb203	2.1d	49.4	1.07	5%
	Pb204(n,2n)Pb203m		50.6	1.07	5%
Hg203	Pb206(n,α)Hg203	46.6d	97.3	4.45	64%
Hg203	Pb207(n,nα)Hg203	46.6d	2.7	4.45	64%


FNS-96 7 hours Irradiation - Pb
Heat Output [µW/kg]
1E-02
1E-03
1E-04
1E-05
1E-06
1E-07
1E-08
203Pb
203Hg
204Tl
Day
1E-03
1E-02
1E-01
1E+00
1E+01
Time after irradiation [years]

Bismuth

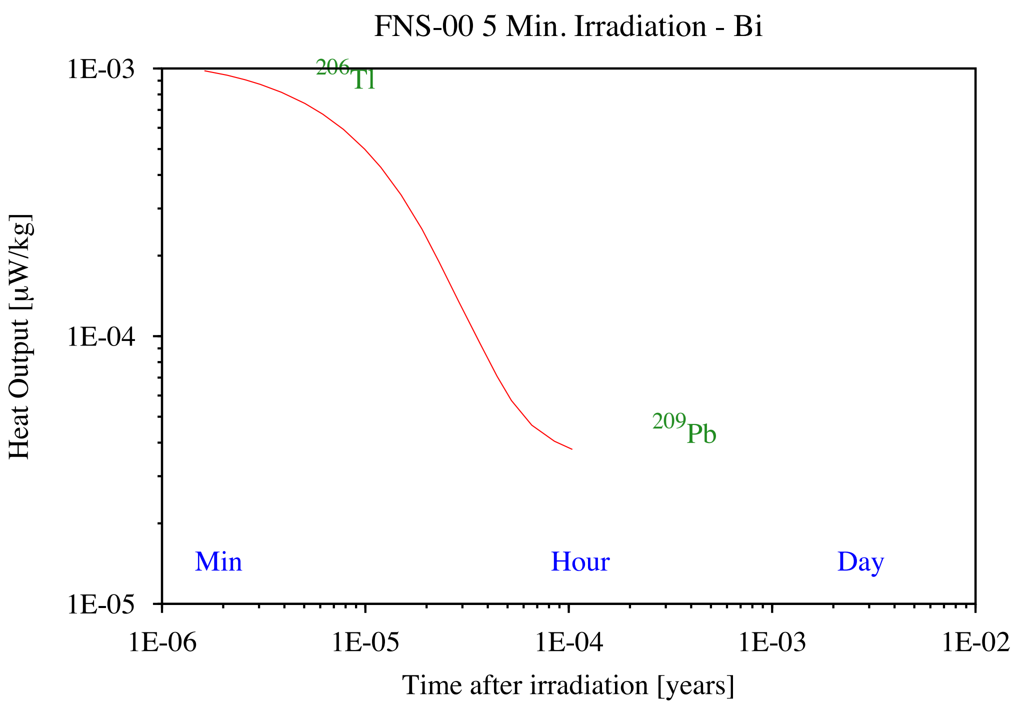


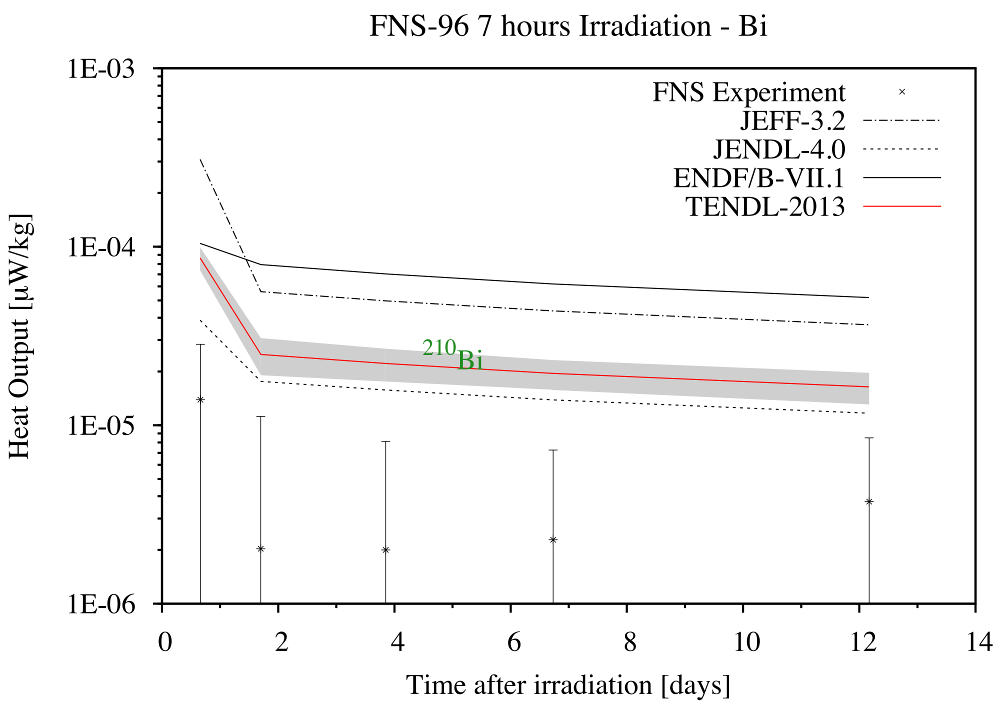


For Bismuth, some large differences and uncertainties can be seen between the two experimental data-sets. This is also the case in the predictions derived from the different databases.

Times	FNS EXP. 5 mins	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Min.	μW/g	μW/g	E/C	E/C	E/C	E/C
0.85	$9.65E{-}04$ +/-235%	$9.81E{-}04$ +/-87%	0.98	0.95	0.32	1.24
1.10	$1.07E{-}03$ +/-54%	$9.43E{-}04$ +/-87%	1.14	1.10	0.37	1.43
1.35	$6.44E{-}04$ +/-31%	$9.07E{-}04$ +/-86%	0.71	0.69	0.23	0.90
1.60	$1.00E{-}03$ +/-12%	$8.72E{-}04$ +/-86%	1.15	1.12	0.37	1.45
2.03	$7.20E{-}04$ +/-13%	$8.15E{-}04$ +/-86%	0.88	0.86	0.29	1.12
2.65	$7.12E{-}04$ +/-12%	$7.41E{-}04$ +/-85%	0.96	0.94	0.31	1.22
3.25	$5.89E{-}04$ +/-13%	$6.75E{-}04$ +/-85%	0.87	0.86	0.28	1.11
4.10	$5.83E{-}04$ +/-13%	$5.92E{-}04$ +/-84%	0.99	0.97	0.32	1.26
5.22	$4.02E{-}04$ +/-16%	$5.00E{-}04$ +/-83%	0.81	0.80	0.26	1.04
6.27	$3.41E{-}04$ +/-17%	$4.27E{-}04$ +/-82%	0.80	0.81	0.26	1.04
7.88	$2.51E{-}04$ +/-21%	$3.37E{-}04$ +/-79%	0.74	0.77	0.24	0.99
9.98	$1.79E{-}04$ +/-26%	$2.51E{-}04$ +/-75%	0.71	0.76	0.23	0.98
12.08	$9.27E{-}05$ +/-45%	$1.90E{-}04$ +/-70%	0.49	0.55	0.16	0.70
15.17	$4.92E{-}05$ +/-77%	$1.34E{-}04$ +/-62%	0.37	0.46	0.12	0.55
19.27	$1.46E{-}05$ +/-247%	$9.39E{-}05$ +/-51%	0.16	0.25	0.06	0.26
23.37	$1.39E{-}05$ +/-266%	$7.08E{-}05$ +/-39%	0.20	0.39	0.07	0.37
27.48	$6.00E{-}06$ +/-653%	$5.75E{-}05$ +/-29%	0.10	0.23	0.04	0.22
34.60	$6.43E{-}07$ +/-6683%	$4.65E{-}05$ +/-20%	0.01	0.04	0.00	0.03
44.70	$3.50E{-}05$ +/-134%	$4.05E{-}05$ +/-18%	0.87	2.48	0.28	2.36
54.82	$1.64E{-}05$ +/-285%	$3.78E{-}05$ +/-18%	0.44	1.30	0.14	1.23

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Tl206	Bi209(n,α)Tl206	4.2m	100.0	0.81	16%
Pb209	Bi209(n,p)Pb209	3.2h	100.0	0.44	285%

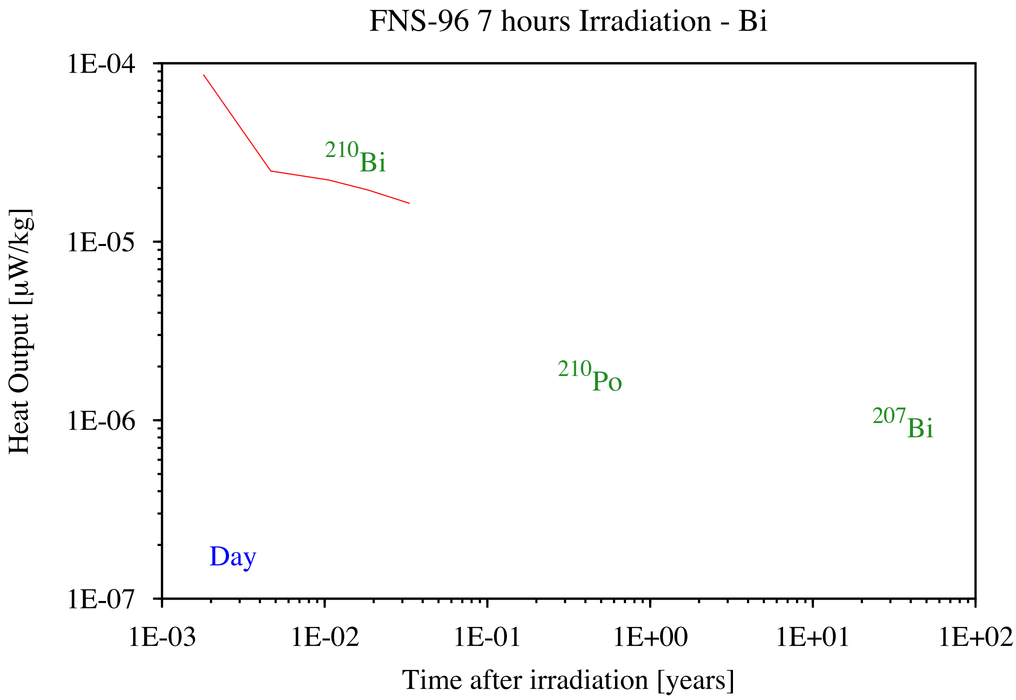




A poor C/E agreement on this important element, but the response profile seems to be reasonably shaped.

Times	FNS EXP. 7 hrs	TENDL-2013		ENDF/B-VII.1	JEFF-3.2	JENDL-4.0
Days	μW/g	μW/g	E/C	E/C	E/C	E/C
0.66	$1.39E{-}05$ +/-105%	$8.65E{-}05$ +/-15%	0.16	0.13	0.04	0.36
1.70	$2.03E{-}06$ +/-451%	$2.49E{-}05$ +/-23%	0.08	0.03	0.04	0.12
3.85	$2.00E{-}06$ +/-307%	$2.22E{-}05$ +/-21%	0.09	0.03	0.04	0.13
6.73	$2.28E{-}06$ +/-218%	$1.95E{-}05$ +/-19%	0.12	0.04	0.05	0.16
12.17	$3.73E{-}06$ +/-128%	$1.64E{-}05$ +/-20%	0.23	0.07	0.10	0.32

Product	**Pathways**	$\mathbf{T_{1/2}}$	**Path %**	**E/C**	**ΔE%**
Tl206	Bi209(n,α)Tl206	4.2m	100.0	0.16	105%
Pb209	Bi209(n,p)Pb209	3.2h	100.0	0.08	105%
Bi210	Bi209(n,γ)Bi210	5.0d	100.0	0.12	218%


FNS-96 7 hours Irradiation - Bi
1E-04
1E-05
1E-06
1E-07
Heat Output [µW/kg]
210Bi
210Po
207Bi
Day
1E-03
1E-02
1E-01
1E+00
1E+01
1E+02
Time after irradiation [years]

5 Analysis of the results

From such a validation exercise a lot of information can be extracted from the results. However, its uniqueness and specificities require caution to be applied when drawing or projecting conclusions from the results.

5.1 General comments

The time dependence of the comparison has been clearly established and it was not surprising to see some fluctuations in the degree of agreement with cooling time. This is due to the fact that the set of predominant radionuclides evolves with time in direct relation with their appropriate half-lives. A clear picture emerges in that the comparative results for short cooling times, less than one hour, tend to be worse than the results for cooling times greater than a day but shorter than a year. This was expected, since the nuclear database (production cross sections and decay data) tends to be less qualified for these short-lived nuclides. This is due to difficulties encountered when assessing short half-life isotopes and isomers. Having said that, the agreement reached on the prediction of some short lived isomers when the TENDL library is used is rather good – a specificity that is unique to properly assembled nuclear data file that contains all necessary branching rations. All the other major transport libraries are missing details of such information. The overall results are surprisingly good on exotic material samples, even more so when allowing for certain experimental difficulties.

What has been clearly demonstrated by this validation exercise is that the calculational method used by the FISPACT-II to predict the decay power and associated uncertainty of structural materials under a hard fusion neutron field is adequate. When the nuclear data are known with sufficient accuracy the code predictions are within the boundaries defined by the experimental uncertainty. However, the nuclear databases, TENDL-2013, ENDF/B-VII.1, JEFF-3.2 and FENDL-4.0 tend to give different results because of variation in the data they contain for the cross sections and decay of the radionuclides involved. The majority of the results are satisfactory and give credit to the work performed in assembling such large libraries. However, the level of accuracy of the cross sections and decay data tested by this validation exercise span from a few percent, which is acceptable, to orders of magnitude, which is not. When the latter case occurs then very specific and time consuming studies need to be performed before any action is taken to correct the nuclear databases. Such remarks are in line with the results of earlier international code comparisons on decay heat, including [4, 5] and some performed on fission fuel materials [15].

All the cross section paths linked with an E/C values greater than 10% have been analysed in line with other validation studies, (FNG Frascati, SNEG-13 Sergiev Posad, D-Be Cyclotron Karlsruhe, etc.) and compared with the experimental database EXFOR [16]. The decay data of the radionuclides produced still needs to be checked in more detail. If the results corroborate one another there will be more incentive and firm grounds to apply an appropriate correction in the next generation of truly general-purpose nuclear data-files.

5.2 Experimental, calculational uncertainty and E/C

When concerned with uncertainties related to the activation calculations themselves, one has to acknowledge the complexity and magnitude of the nuclear data libraries. The TENDL-2013 general-purpose file [8] contains the neutron-induced reactions on stable and unstable targets including actinides. If a reaction can produce one, two or more isomers, the cross sections for producing the ground and the different isomeric states are all given separately.

In contrast the other libraries, ENDF/B-VII.1, JEFF-3.2 or JENDL-4.0, only contain a handful of isomeric states, which seriously impairs their ability to properly simulate any responses when these are predominant. This is particularly obvious at short cooling times. Furthermore, these three libraries are often identical to each other, containing the same data for legacy reasons, and thus have the same failures and deficeincies.

The TENDL-2013 library contains 2630 target nuclides ranging from ^{1}H to ^{281}Ds with all reactions kinematically allowed up to 200 MeV. Quite importantly covariance-variances information (mf31-35, 40) are uniquely stored for incident particles with energies from 10^{-5}eV up to 200 MeV. Above the upper energy of the resolved resonance range, for each of the 2630 isotopes, a Monte Carlo method, in which the covariance data come from uncertainties of the nuclear model calculations, is used. Short-range, self-scaling variance components are also specified for each (mt) reaction type. The data format used to store the variance-covariance information has been made fully compliant with the ENDF-6 format [17] description and the files are read directly by FISPACT-II without any further intermediate processing. Variance and covariance data are re-used by FISPACT-II to create uncertainty predictions and sensitivity analyses.

Systematic experimental uncertainty, calculational uncertainty and E over C values have been quoted and calculated in a way that allows a direct comparison to be made. The Total Monte Carlo (TMC) method method used for the generation of qualitative variance information in TENDL-2013, compared to what was done in EAF_2010 uncertainty file is a significant achievement, when the calculational uncertainties quoted in the tables are of the same order of the E/C values. This demonstrates that the method chosen to calculate these uncertainties in the TALYS code system is not only valid but adequate. Of course, the same remarks as for the cross section and decay data file apply: even if the bulk of the data seems to be satisfactory, certain specific data entries need to be revisited in line with the findings of this validation exercise and other studies.

6 Conclusions

The experimental time-dependent decay-power measurement program at JAEA FNS combined with the code simulations performed in this study provide a unique check of the calculational method and nuclear databases associated with the prediction of decay power for the set of material samples analysed. The results of the comparison give confidence in most of the decay heat values calculated, although the predominantly 14 MeV neutron spectrum in FNS means that the low neutron energy reactions of importance in other devices have not yet been fully considered [18]. This statement limits the scope of validation and possible conclusions reached in this study to the decay power predicted through the identified pathways. However, it covers the decay data of all the isotopes involved irrespective of their production routes.

For the third time, experimental uncertainty, calculational uncertainty and E/C values have been systematically produced. Their direct comparison demonstrates that the method chosen to calculate and propagate these uncertainties in the EASY-II code system is verified and validated (V&V), and that the uncertainties file should be further improved along the same lines.

From the results, a set of inadequacies, not only in the cross sections but also in the decay libraries, have been identified that will require some corrective actions to be taken. These corrections and/or amendments will benefit the next generation of the TENDL library cross sections, associated variance and covariances, and decays data files. As expected, they impact both the production paths and/or decay data of some specific radionuclides without impairing the overall picture. A large proportion of the decay powers calculated in this validation exercise are in good agreement (within a few %) with the experimental values for cooling times spanning from tens of seconds, and this is a unique insight, up to more than a year.

Maintenance and testing of activation inventory code systems and libraries is essential for many projects in order to present a sound and well validated safety assessment. Licensing authorities will require evidence of experimental validation. However, the relevance of the experimental irradiation conditions and set-up to those that are likely to exist in a device needs to be carefully considered in order for such an assessment and validation to be applicable to the data predicted for the next generation of plants.

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