Results of CIEMAT simulations of SAD target decay heat

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Targets simulations

- The decay heating and radioactivity in two different targets (Pb and W) have been calculated. For every target, three high energy models have been used: INCL4/ABLA, Bertini/Dresner and CEM2k.
- Codes MCNPX, EVOLCODE and ORIGEN were used in order to make the proper calculations, using the ENDF-VI library.

Target geometry and input data

- Protons energy of 660 MeV and beam power of 1 kW.
- Irradiation time of 1000 hours.
- Diameter of beam cross section of 22 mm.
- Proton guide channel depth of 10 cm and diameter of 5 cm.
- Target length of 60 cm and diameter of 16.5 cm (Pb) and 10 cm (W).

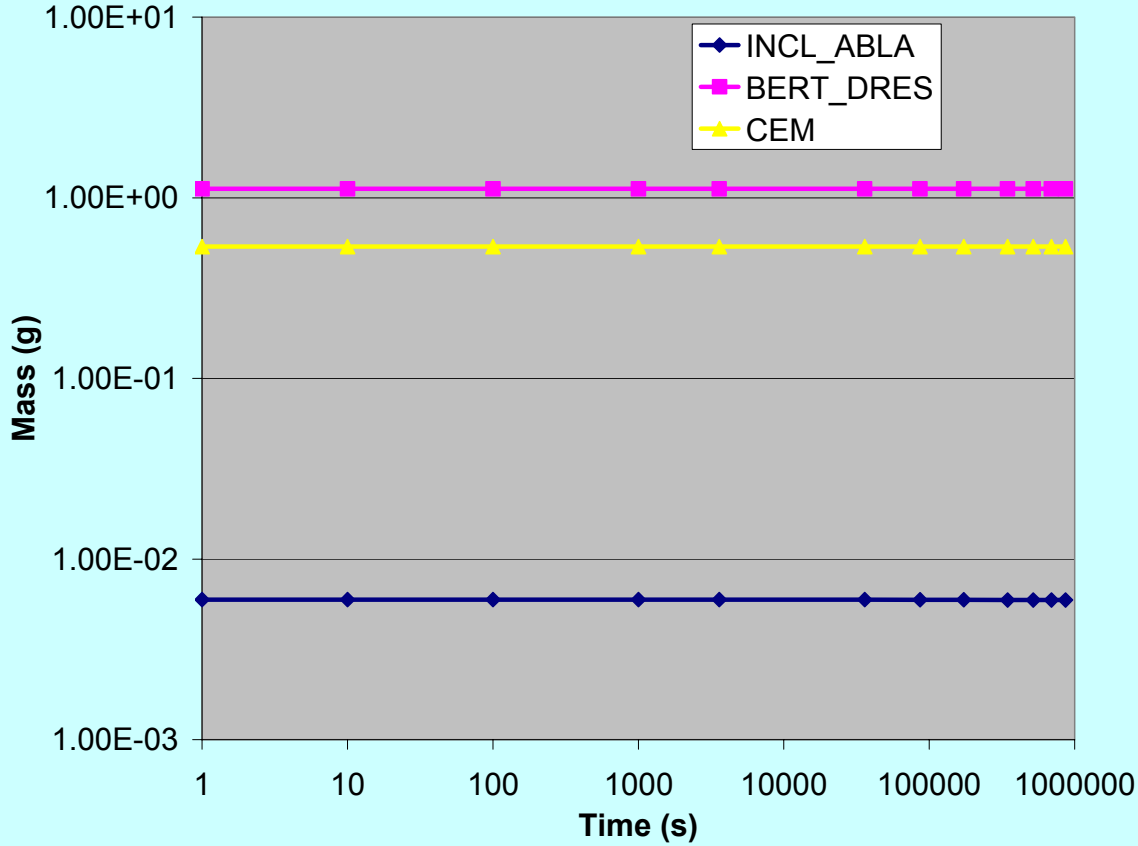
Solving the problem (1/2)

- The spallation process produces spallation products and also a neutron flux in the target. These quantities have been obtained using MCNPX version 2.5e.
- During the irradiation, the neutron flux can activate the target by itself. This activation and the spallation products continual production induced activation were obtained separately.
- In order to calculate the required cross sections library for ORIGEN, the code EVOLCODE has been utilized.
- After the irradiation, the decay heat and the radioactivity have been also obtained using ORIGEN2.2 for fast reactors.

Solving the problem (2/2)

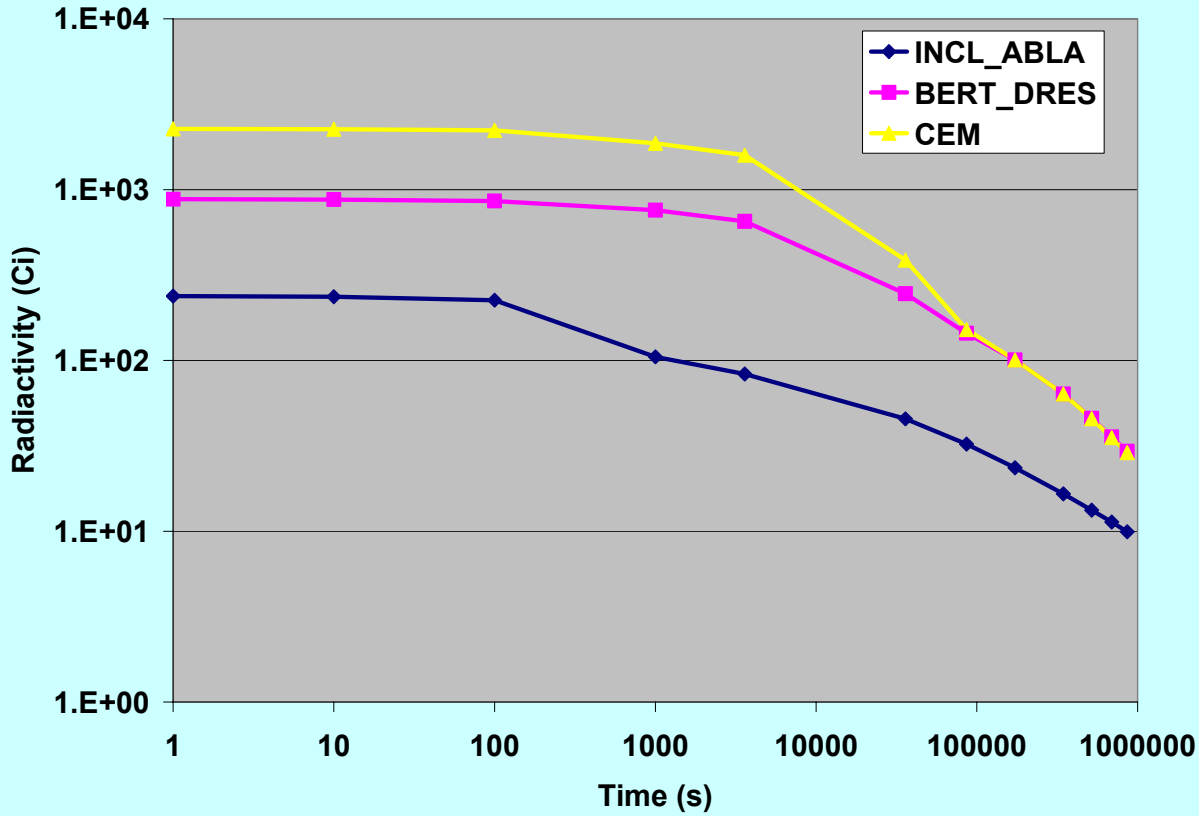
- As many of the spallation products created according to the models are not included in the ORIGEN DECAY library, it has been necessary to extend largely this database. The information of more than 1900 isotopes have been added from the NuDat2.1 database of the National Nuclear Data Center (Brookhaven, USA).
- Nevertheless, the information of the average energy per decay has only been added for the 90 isotopes with higher contribution to the radioactivity after irradiation. This should provide a precision better than 3%.
- In addition, some of the non-usual spallation products do not have complete nuclear databases so the nuclear reactions are not considered for them, only radioactive decay.

Results – Pb – Mass (spallation products)



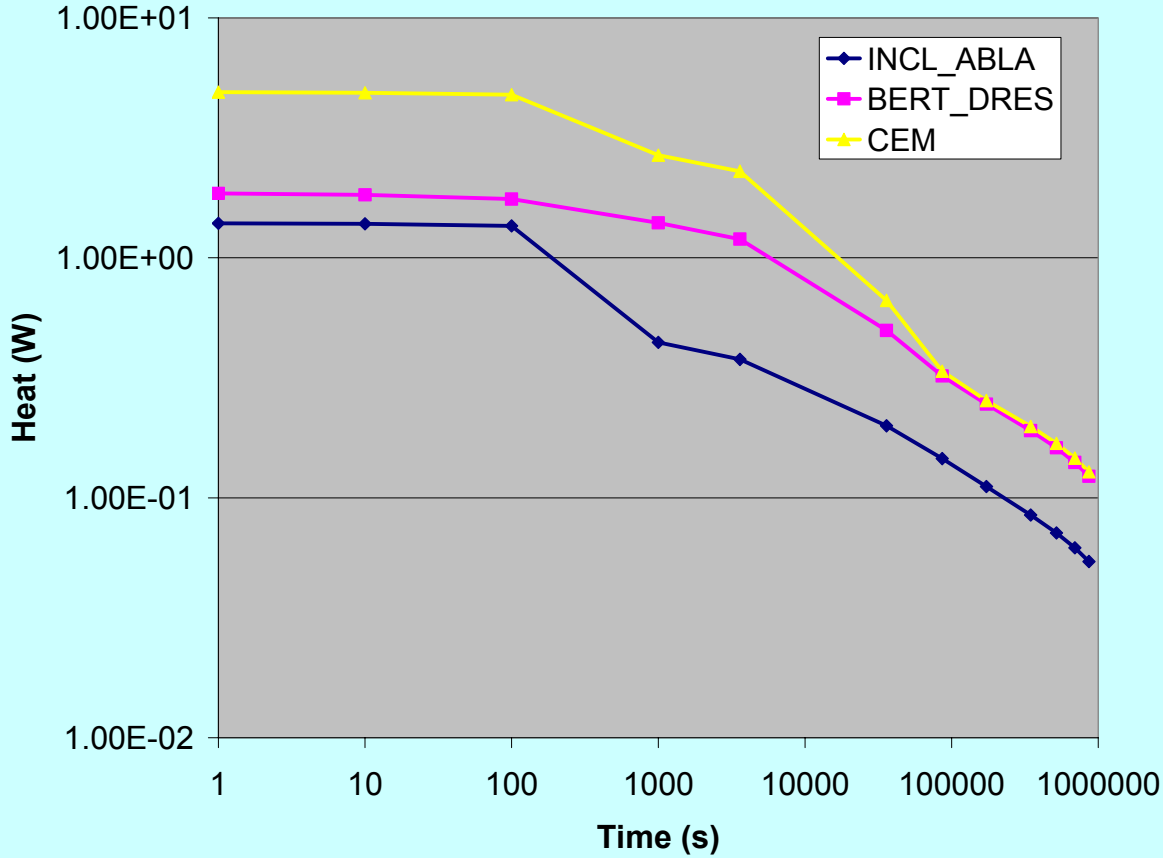
MASS (Grams)	1.0S	10.0S	1000.0S	1.0H	10.0H	1.0D	2.0D	6.0D	10.0D
INCL_ABLA	5.96E-03	5.96E-03	5.96E-03	5.96E-03	5.96E-03	5.95E-03	5.95E-03	5.93E-03	5.93E-03
BERT_DRES	1.12E+00	1.12E+00	1.12E+00	1.12E+00	1.12E+00	1.12E+00	1.12E+00	1.12E+00	1.12E+00
CEM	5.37E-01	5.37E-01	5.37E-01	5.37E-01	5.37E-01	5.36E-01	5.36E-01	5.36E-01	5.36E-01
ratio cem/incl	89.96	89.96	89.96	89.97	90.05	90.11	90.18	90.38	90.45

Results – Pb – Radioactivity



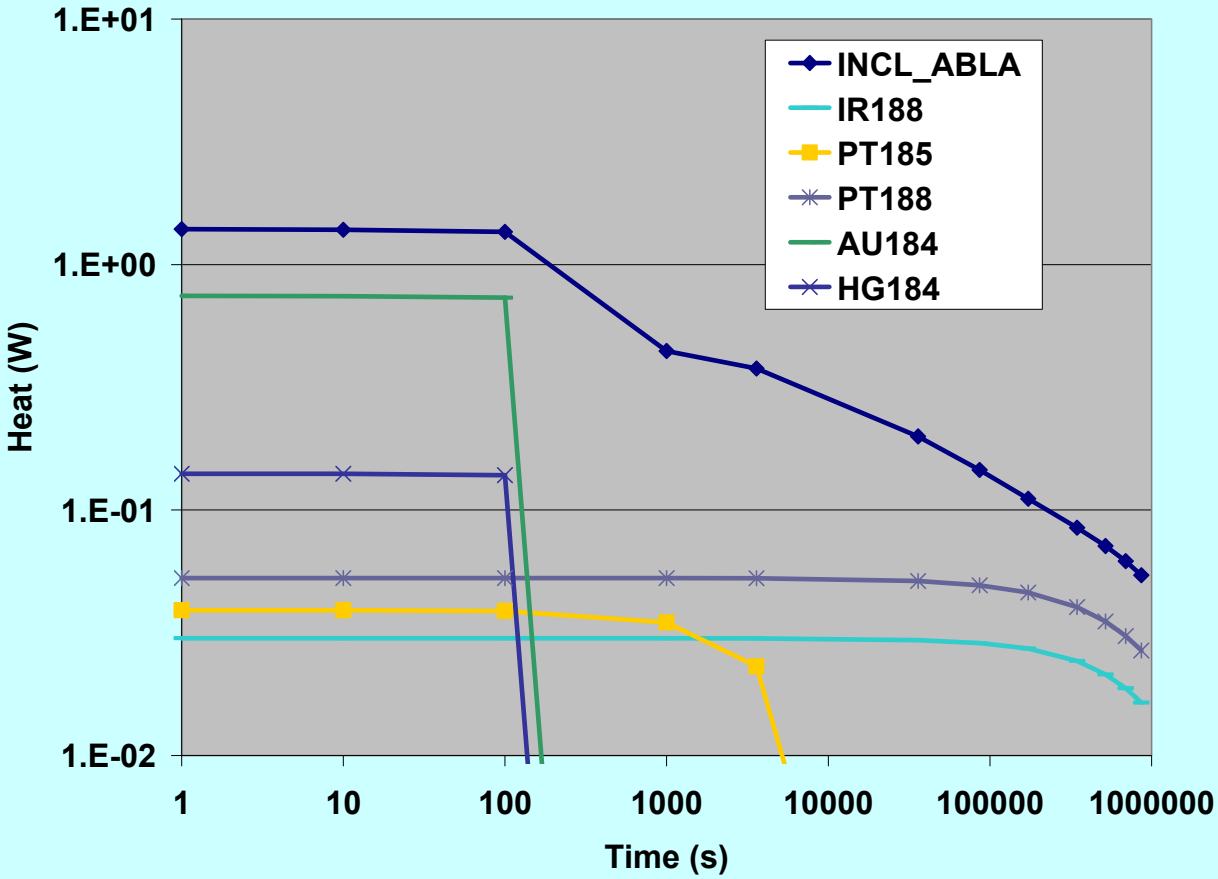
RADIACT (Ci)	1.0S	10.0S	1000.0S	1.0H	10.0H	1.0D	2.0D	6.0D	10.0D
INCL_ABLA	2.38E+02	2.36E+02	1.05E+02	8.33E+01	4.55E+01	3.24E+01	2.35E+01	1.33E+01	9.93E+00
BERT_DRES	8.79E+02	8.76E+02	7.57E+02	6.51E+02	2.46E+02	1.44E+02	1.01E+02	4.58E+01	2.94E+01
CEM	2.27E+03	2.26E+03	1.87E+03	1.59E+03	3.87E+02	1.52E+02	1.01E+02	4.56E+01	2.89E+01
ratio cem/incl	9.51	9.57	17.76	19.13	8.49	4.68	4.28	3.43	2.91

Results – Pb – Decay heat

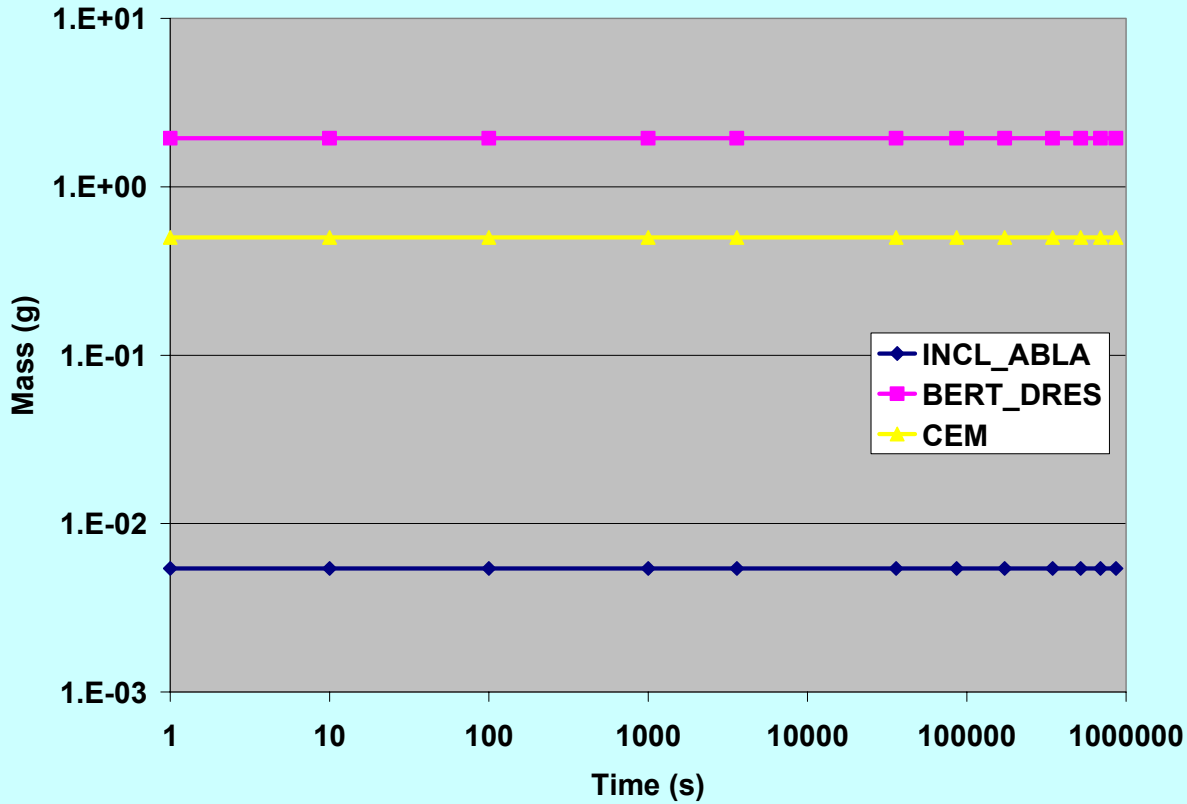


TH_POWER (W)	1.0S	10.0S	1000.0S	1.0H	10.0H	1.0D	2.0D	6.0D	10.0D
INCL_ABLA	1.39E+00	1.39E+00	4.44E-01	3.77E-01	2.00E-01	1.46E-01	1.11E-01	7.14E-02	5.43E-02
BERT_DRES	1.86E+00	1.83E+00	1.40E+00	1.20E+00	4.99E-01	3.22E-01	2.46E-01	1.62E-01	1.23E-01
CEM	4.90E+00	4.87E+00	2.68E+00	2.29E+00	6.65E-01	3.37E-01	2.54E-01	1.69E-01	1.28E-01
ratio cem/incl	3.52	3.52	6.03	6.08	3.33	2.32	2.28	2.36	2.36

Results – Pb
Isotopes with higher contribution – INCL4/ABLA

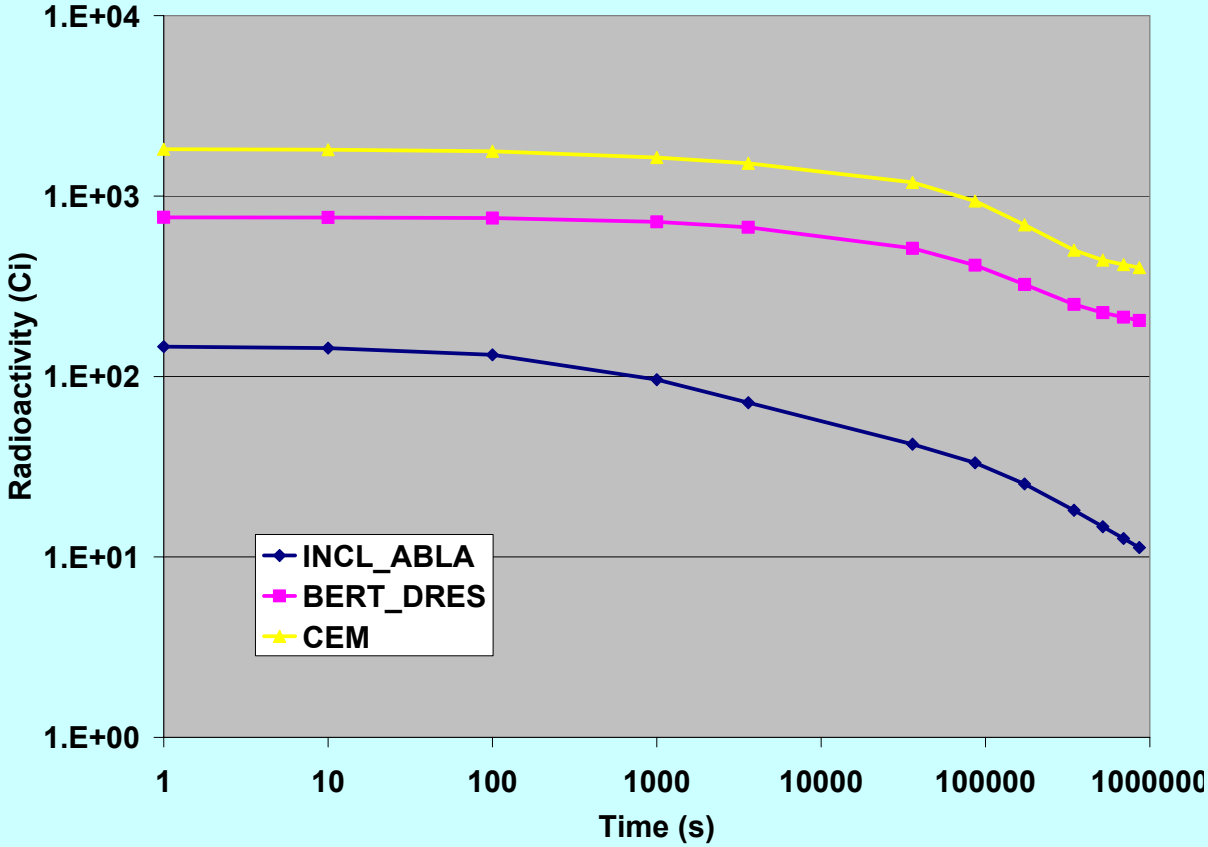


Results – W – Mass (spallation products)



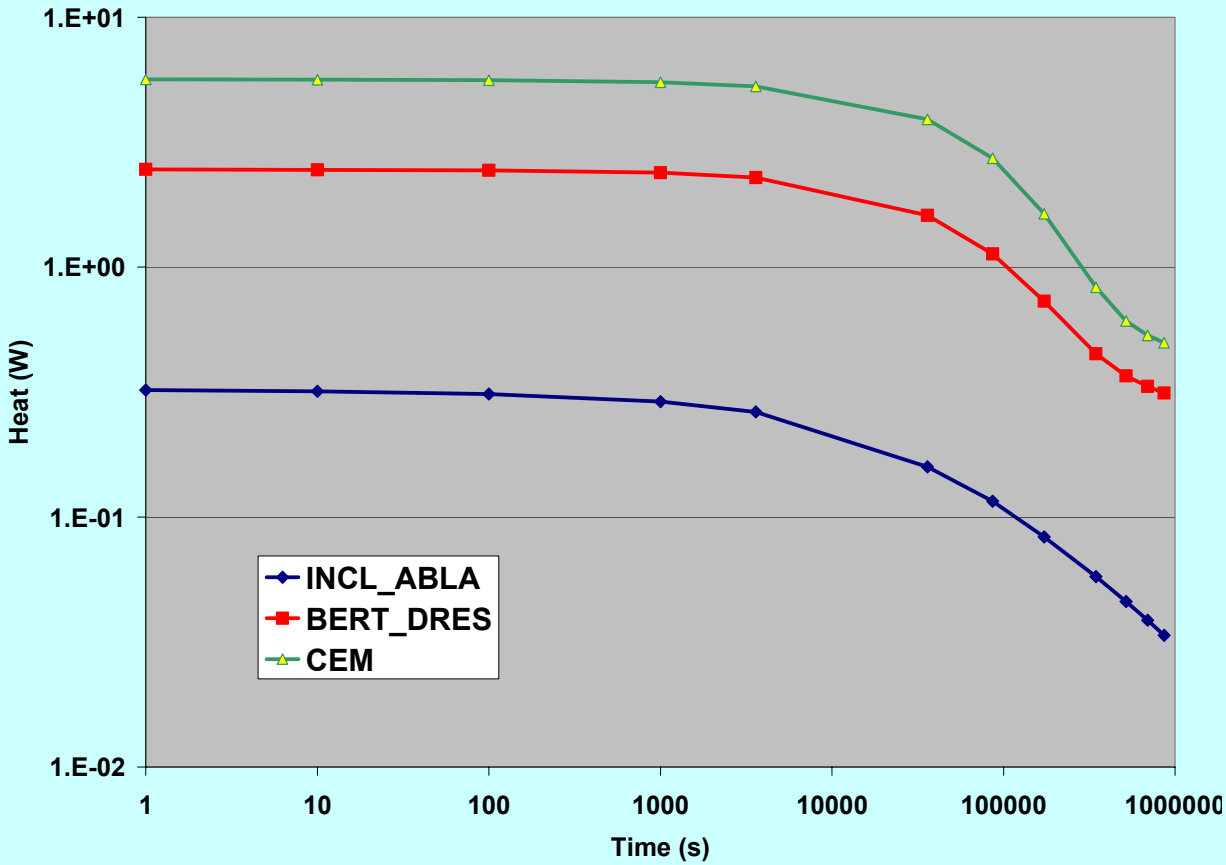
MASS (Grams)	1.0S	10.0S	1000.0S	1.0H	10.0H	1.0D	2.0D	6.0D	10.0D
INCL_ABLA	5.42E-03	5.42E-03	5.42E-03	5.42E-03	5.42E-03	5.42E-03	5.42E-03	5.42E-03	5.42E-03
BERT_DRES	1.94E+00	1.94E+00	1.94E+00	1.94E+00	1.94E+00	1.94E+00	1.94E+00	1.94E+00	1.94E+00
CEM	5.00E-01	5.00E-01	5.00E-01	5.00E-01	5.00E-01	5.00E-01	5.00E-01	5.00E-01	5.00E-01
ratio cem/incl	92.39	92.39	92.39	92.39	92.39	92.39	92.39	92.39	92.39

Results – W – Radioactivity



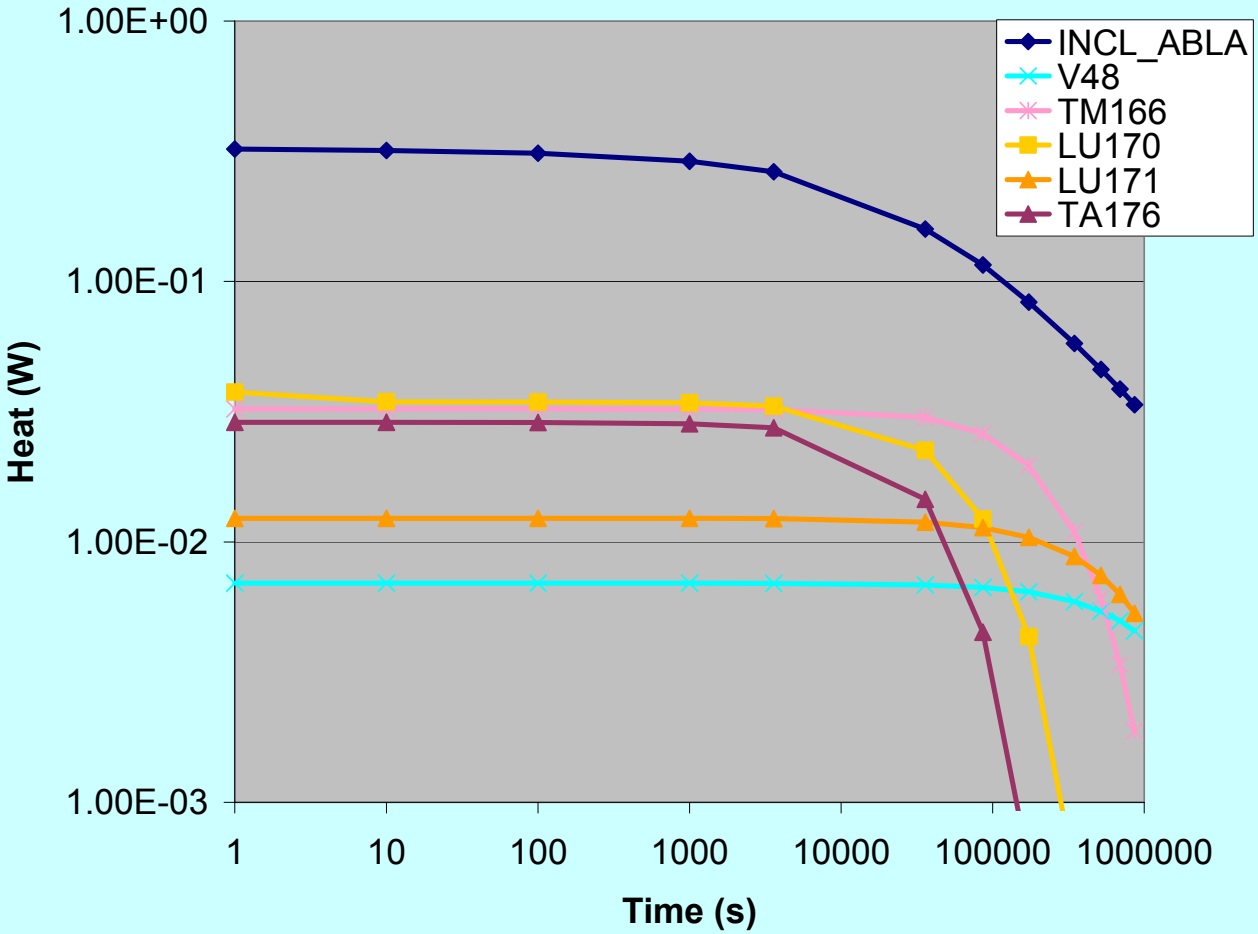
RADIACT (Ci)	1.0S	10.0S	1000.0S	1.0H	10.0H	1.0D	2.0D	6.0D	10.0D
INCL_ABLA	1.46E+02	1.44E+02	9.61E+01	7.16E+01	4.22E+01	3.32E+01	2.54E+01	1.47E+01	1.13E+01
BERT_DRES	7.63E+02	7.61E+02	7.20E+02	6.71E+02	5.13E+02	4.14E+02	3.23E+02	2.26E+02	2.05E+02
CEM	1.82E+03	1.81E+03	1.64E+03	1.52E+03	1.19E+03	9.38E+02	6.93E+02	4.42E+02	4.02E+02
ratio cem/incl	12.42	12.58	17.04	21.21	28.23	28.26	27.31	30.05	35.66

Results – W – Decay heat

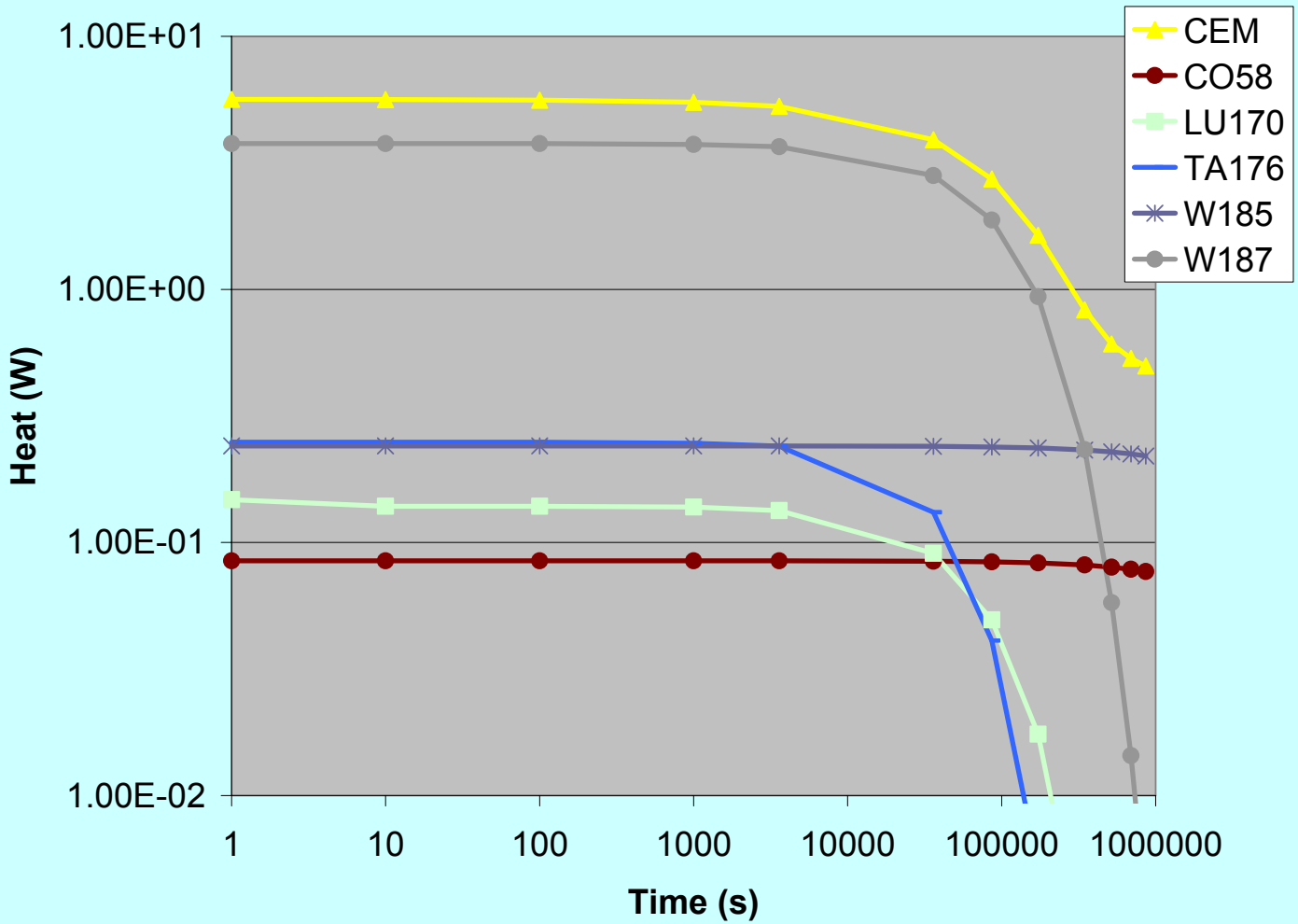


TH_POWER (W)	1.0S	10.0S	1000.0S	1.0H	10.0H	1.0D	2.0D	6.0D	10.0D
INCL_ABLA	3.23E-01	3.18E-01	2.90E-01	2.64E-01	1.59E-01	1.16E-01	8.33E-02	4.59E-02	3.36E-02
BERT_DRES	2.46E+00	2.45E+00	2.39E+00	2.28E+00	1.61E+00	1.13E+00	7.31E-01	3.67E-01	3.14E-01
CEM	5.64E+00	5.63E+00	5.49E+00	5.29E+00	3.90E+00	2.73E+00	1.64E+00	6.09E-01	4.99E-01
ratio cem/incl	17.48	17.67	18.95	20.06	24.56	23.58	19.64	13.25	14.83

Results – W
Isotopes with higher contribution – INCL4/ABLA



Results – W
Isotopes with higher contribution - CEM



Conclusions

- For Pb: The contribution to the decay heat and radioactivity of the neutron flux activation of the target looks to be negligible in comparison with the spallation products.
- For W: The contribution to the decay heat is small (factor 1/10 to 1/3) in comparison with the spallation products, but the radioactivity is comparable and even larger in the INC model (lower by factor 100 in the CEM model). Production of W185 (75d) and W187(24h).
- The decay heat and the radioactivity from spallation products vary considerably with the model used in MCNP.
- Results presented by CIEMAT are not very reliable, shortly after the irradiation, because the average energy per decay data is not complete for all the "*non-usual*" spallation products.
- Even the list of isotopes with higher contribution depend on the model, at least in the W target case.
- In all models and both for the Pb or the W targets the decay heat is lower than 10W, few minutes after beam shut down.