Fission induced by high energy particles and energy release in massive fissionable targets applied for ADS

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Motivation

The last two decades many experiments and theoretical studies have been conducted concerning transmutation and energy production by ADS.

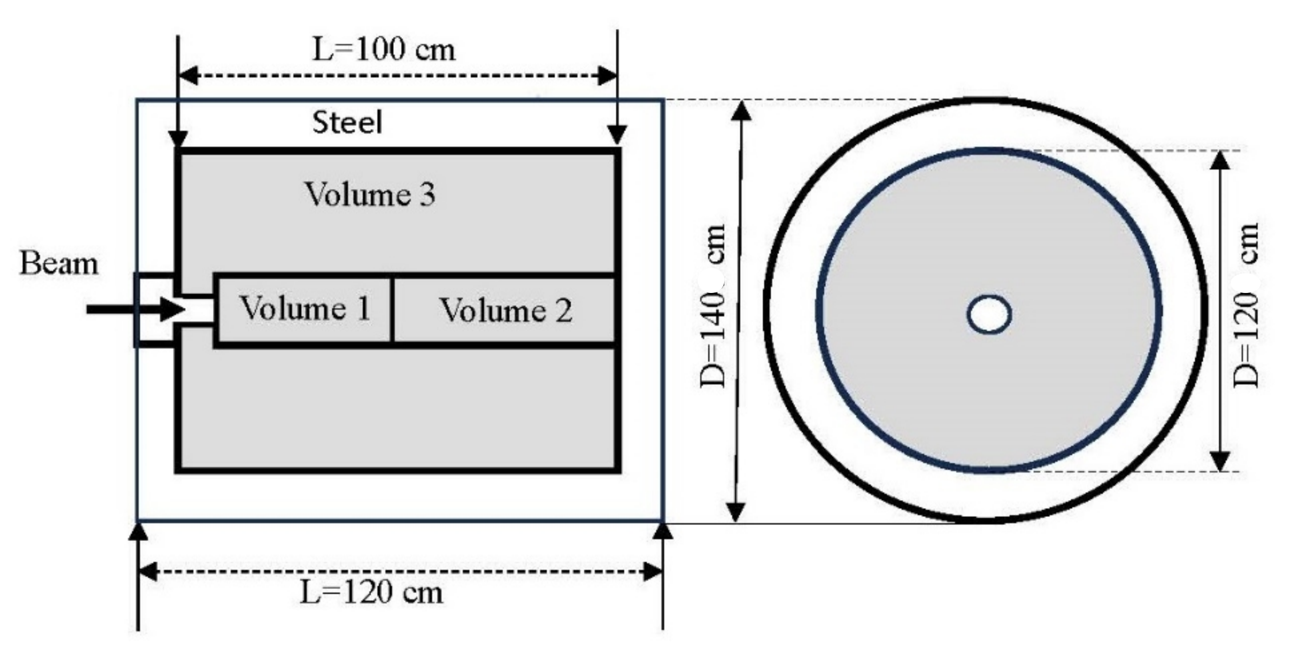
- **The aims are:**

    1) calculation (estimation) of the nigh energy fission release in the central part of Buran set up with U target irradiated by high energy proton beam.

    2) Investigation of the fission release in massive uranium target in case of different neutron libraries.

    - **Calculation of (n,f)U, (En<20 MeV) reactions**
    - **Calculation of (n,f)U, (En>20 MeV) reactions**

Cross section of BURAN set up



It is made of depleted uranium 0.3% packed in steel cage with thickness of the walls 10cm. The proton beam enters by beam window in the steel cage. The volume 1, is cylinder with diameter 18cm and length 35, volume 2, is cylinder with diameter 18 and length 45 cm and volume 3, is the rest of the uranium target

MCNP6 transport code

- **Cross sections libraries used for the calculations, defined for incident neutron energy from 20 to 1000 MeV**

ENDF-vi.2	(20 MeV),	USA
endf/b-vii.0	(30 MeV),	USA
Endf71x	(30 MeV),	USA
TENDL 2017	(30 MeV),	PSI
TENDL2015	(200 MeV),	PSI
JENDL-40/he	(200 MeV),	Japan
JENDL-5	(200 MeV),	Japan
ADS-II	(1000 MeV),	for ADS simulation by IAEA

- **High energy nuclear models INCL4, Bertini, LAQGSM, CEM and evaporation models**
- **Proton beam energy Ep= 1GeV**

Nuclear data for MCNP6

- **MCNP6 uses ACE files.**

  ACE stands for A Compact ENDF

- **ACE files are created by processing of the Evaluated Nuclear Data Files (ENDF).**

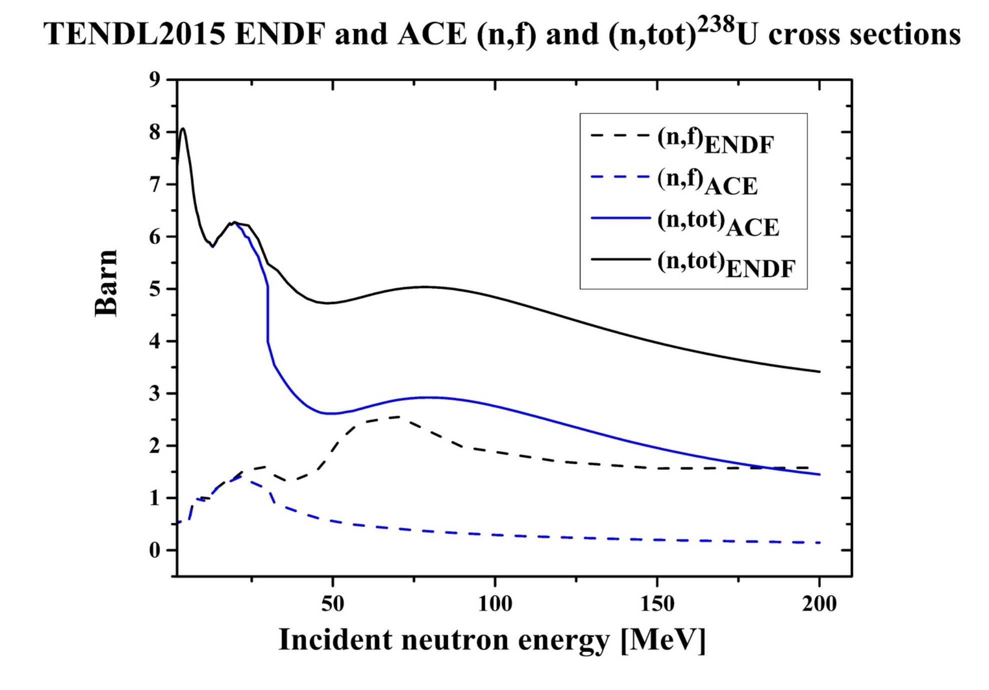
Software used for processing :

A) NJOY 77, 99, 16 or 21 versions or other modifications in LANL

B) FRENDY in Japan Atomic Energy Agency (JAEA)

C) PrePro

Errors in extended TENDL2015 ACE files processing by NJOY

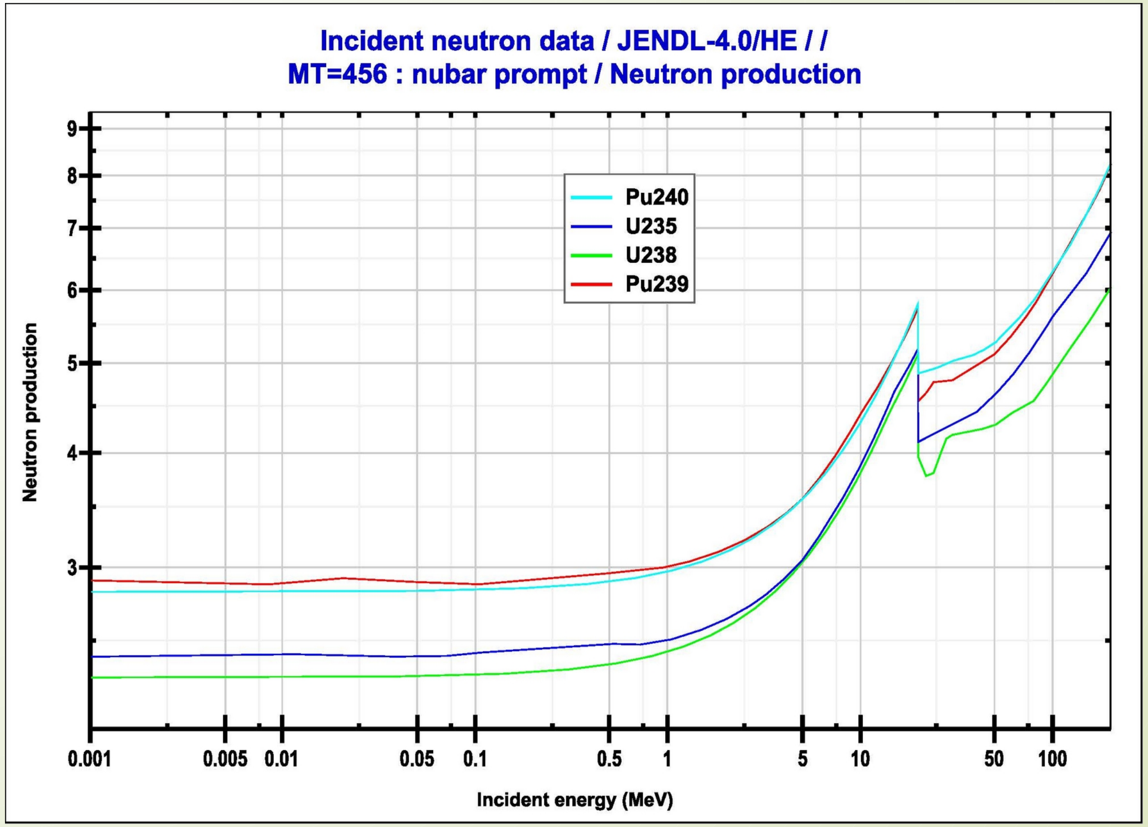


All ACE files with (n,f) reaction in TENDL2015 are with wrong cross sections (n,f) and (n,tot) in comparison with primary TENDL2015, NJOY generated wrong cross sections data above 20 MeV

The (n,tot) and (n,f)^{238}U cross sections for TENDL2015. The blue lines are extracted from the ACE file processed by NJOY99. The black lines illustrate the cross sections from the primary ENDF. The data is taken from the TENDL home page.

Errors in JENDL40he and TENDL2015 ACE and ENDF

The multiplicity in JENDL40he are wrong for ENDF and ACE. **The data is taken from NEA**



MCNP6 calculations

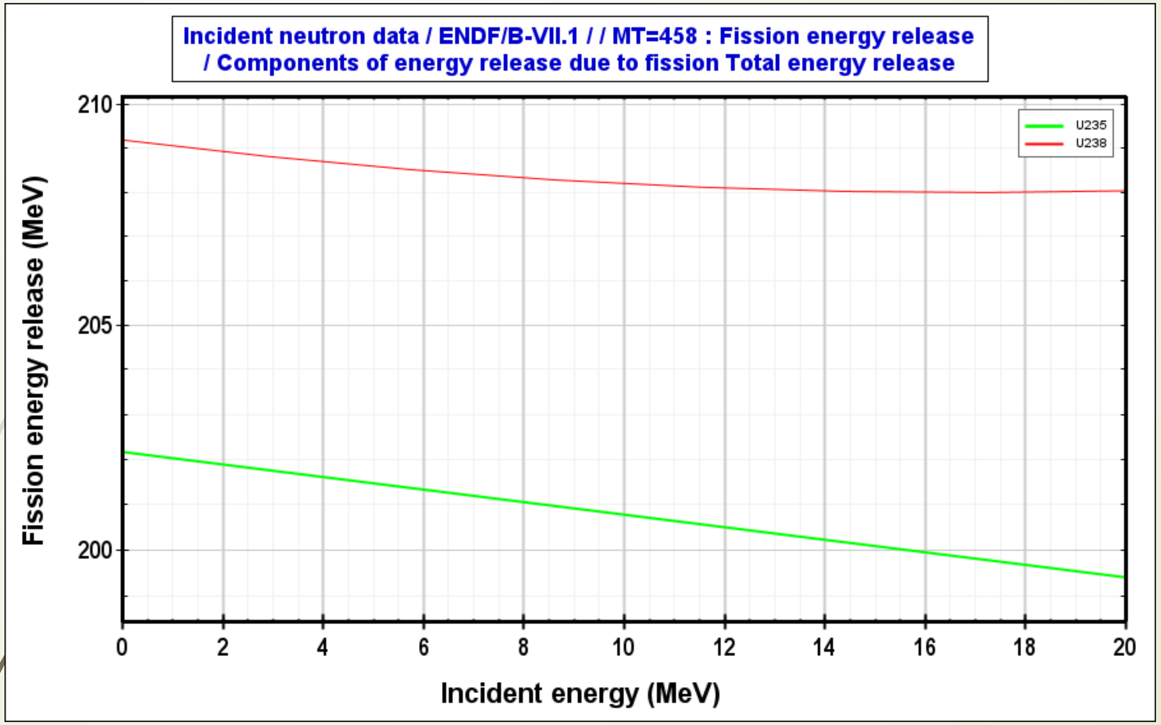
- F7 – tally it calculates the energy release due to fission induced by neutrons, where the (n,f) cross sections are available.

The reaction rate is calculated by $R_{(n,f)}=$

- The F6:N calculates the energy released by neutrons
- The F6+ calculates total energy release

The question is: How the energy release is calculated from high energy fission and spallation reactions?

Fission energy release as a function of incident neutron energy



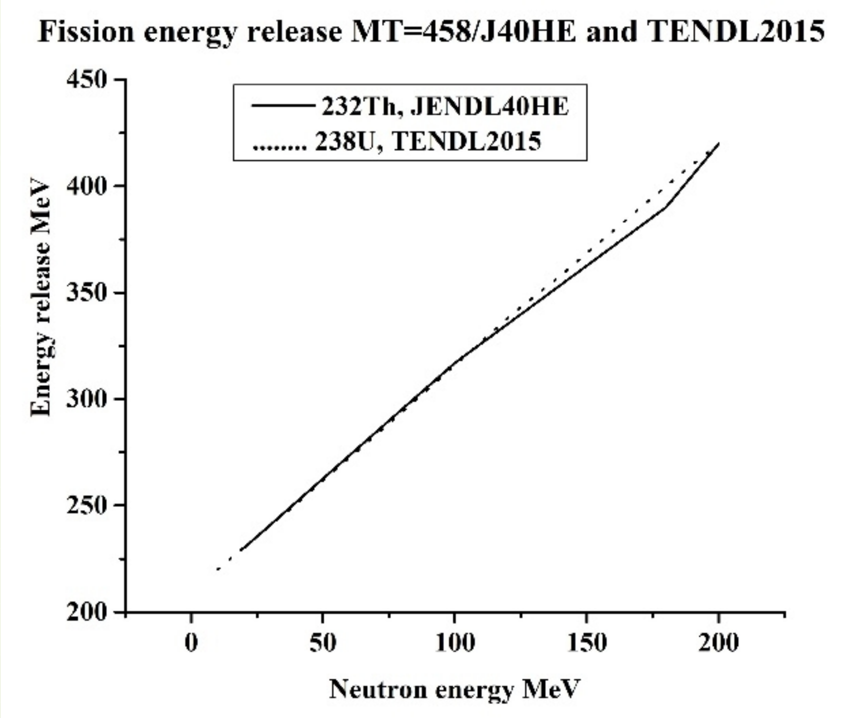


Figure 1. The figure shows the energy release per one fission for $^{235,238}U$ for extended libraries ENDF/B-VII.1 as a function of the incident neutron energy. The data is taken from NEA, JANIS.

Figure 2. The figure shows the energy release per one fission for ^{238}U and ^{232}Th for extended libraries TENDL2015 and JENDL40HE as a function of the incident neutron energy. The data is taken from NEA, JANIS.

Calculations for a volume 1 of the BURAN set up

	MeV	$(n,f)_{(20MeV)}$	$(n,f)_{(1GeV)}$	(n,γ)	E_{fiss}	E_{add}	E_f
ENDF-vi.2	20	8.19	9.7	12	1.58	0.68	1
endf/b-vii.0	30	7.4	9.11	12.2	1.51	0.523	0.9
endf71x	30	7.4	9	12.3	1.52	0.523	0.9
TENDl2017	30	7.2	9	10.9	1.32	0.546	0.83
TENDL2015	200	6.4	8.3	10.2	1.23	0.063	0.57
JENDL-40/he	200	7.3	9	11.9	1.47	0.063	0.69
JENDL-5	200	6.6	7,4	11.3	1.37	0.063	0.63
ADS-II	1000	6,3	7,6	10.6	1.31	0	0.58

In the first column are the nuclear data libraries, the second is the upper energy limit of the libraries, the next are the number of fissions induced by neutrons with energies up to E_n=20 and 1000 MeV, $(n,\gamma)^{238}U$ reactions are shown. E_{fiss} (MeVx10^3) is the fission deposition energy calculated by F7 tally, E_{add} (MeVx10^3) is added fission energy, E_f (MeVx10^3) is the ratio of the $(E_{fiss}+E_{add})_i$ / $(E_{fiss}+E_{add})_{ENDF-vi.2}$.

Calculations for a volume 3 of the BURAN set up

	MeV	$(n,f)_{(20MeV)}$	$(n,f)_{(1GeV)}$	(n,γ)	E_{fiss}	E_{add}	E_f
ENDF-vi.2	20	9.7	10.7	60	1.73	0.232	1
endf/b-vii.0	30	8.16	9.34	58	1.56	0.5	0.97
endf71x	30	8.2	9.36	58	1.56	0.355	0.98
TENDl2017	30	8.28	9.7	53.7	1.47	0.447	0.98
TENDL2015	200	6.94	9.57	4.95	1.32	0.023	0.69
JENDL-40/he	200	7.88	9.0	5.68	1.48	0.023	0.76
JENDL-5	200	6.8	8.3	50.6	1.23	0.023	0.64
ADS-II	1000	5,7	6.24	45	1.06	0	0.54

Integral Calculations for the BURAN set up

	MeV	$(n,f)_{(20MeV)}$	$(n,f)_{(1GeV)}$	(n,γ)	E_{fiss}	E_{add}	E_f	N_{tot}	N_{esc}
ENDF-vi.2	20	17.9	20.8	74	3.35	1.24	1.00	131	2.9
ENDF/b-vii.0	30	15.7	18.4	72	3.11	0.92	0.88	125	2.9
ENDF71x	30	15.4	17.4	72	3.12	0.92	0.88	125	2.9
TENDl2017	30	15.7	19	66	2.82	0.96	0.83	115	2.8
TENDL2015	200	13.5	18.1	61	2.58	0.08	0.58	106	2.8
JENDL-40/he	200	15.3	18.2	70	2.98	0.08	0.67	120	2.9
JENDL-5	200	13.6	15,9	68	2.63	0.08	0.59	107	2.7
ADS-II	1000	12,1	14	56	2.39	0	0.52	96	2.7

Main outcomes from the calculations

- The (n,f) reaction in the volume 1 and volume 3 is almost equal, but the mass of the v.3 is 30 times higher than v.1.
- In a volume 1 the (n,γ) reaction rate is five times less than in the volume 3.
- The total energy release and (n,γ) reaction calculated with ADS-II is 40%and 30% respectively less than these calculated by ENDF- v.2.
- The energy release due to spallation is not included.
- Increasing of the incident neutron energy of the neutron library underestimate neutron induced reactions and neutron production

Conclusions

- **The extended libraries and ACE files have to be analyzed in better way, due to unexpectable differences of neutron induced reactions in massive uranium target.**
- **The experimental and theoretical verification with massive uranium target have to be done**