



Uncertainty assessment methodologies applied to Tritium production in fusion lithium breeding blankets

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10th Kudowa Summer School
“Towards Fusion Energy”
June 14-18, 2011

Outline

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- Measurements of Tritium activity

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- Sensitivity/Uncertainty analysis
- Monte Carlo method

3. Nuclear Data Uncertainties

- ${}^7\text{Li}$ and ${}^6\text{Li}$

4. Uncertainty Results

- Measurements of tritium activity in HCLL TBM mock-up LiPb

5. Conclusion

1. Motivation. *Need of T production*

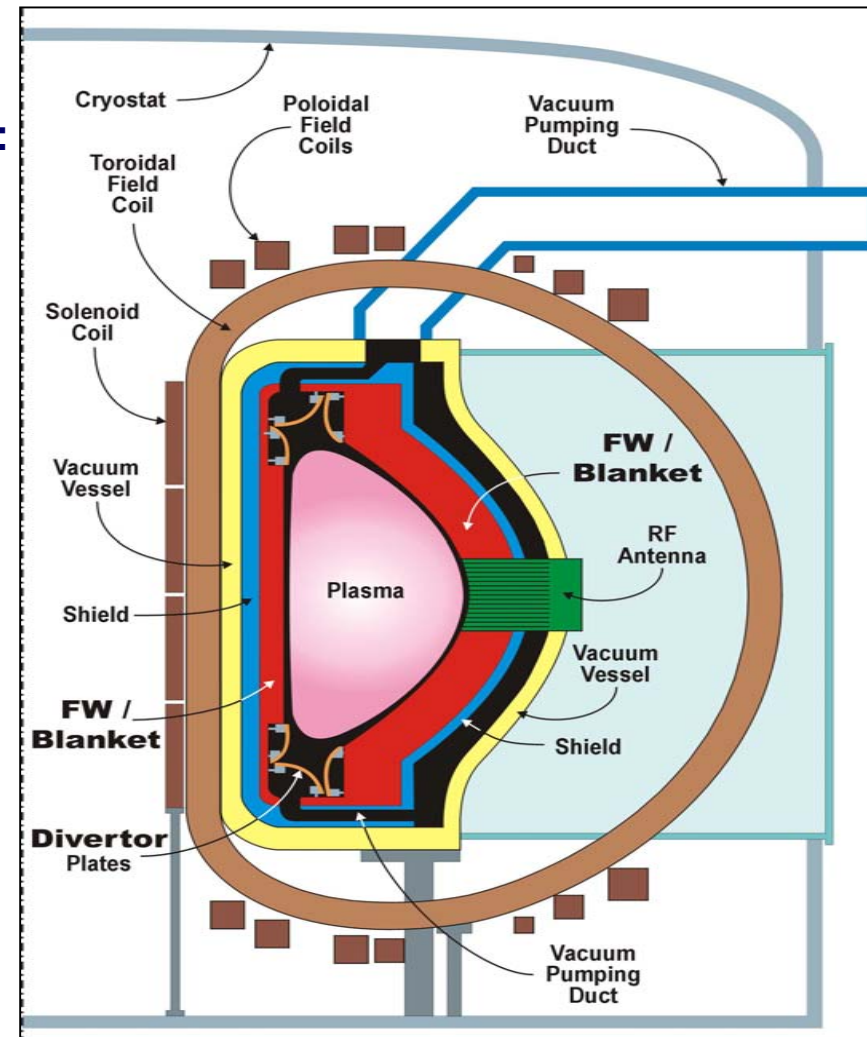
- Deuterium-tritium burning fusion systems need to be continuously fueled with:
 - a) Deuterium: available from natural water
 - b) Tritium: that has to be produced

- Within the reactor Tritium production occurs:



but a very low rate (1 Kg/year)

- Reactor core surroundings:
 - a) sustain a clean plasma domain
 - b) recover energy for exploitation
 - c) shield structures and personnel
 - d) breed the plasma with Tritium



1. Motivation. *Need of T production*

- It is possible to produce Tritium from the reactions



(that works with the high energy neutrons)



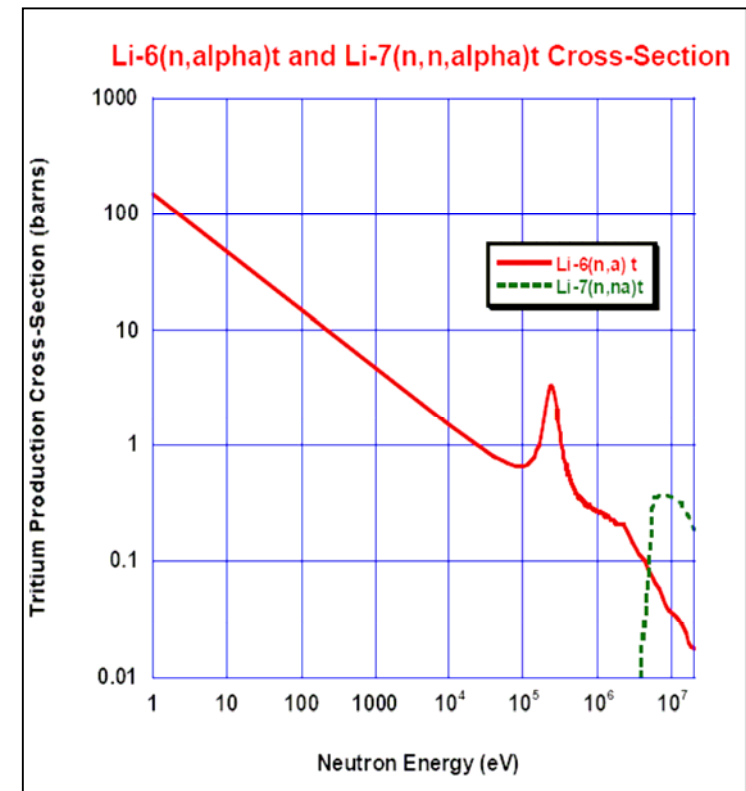
(low energy regions, decelerated neutrons)

- Tritium generation rate

$$G = \int_V \int_E \phi \rho \sigma$$

depends on neutron flux intensity, Li density and **Li cross section**

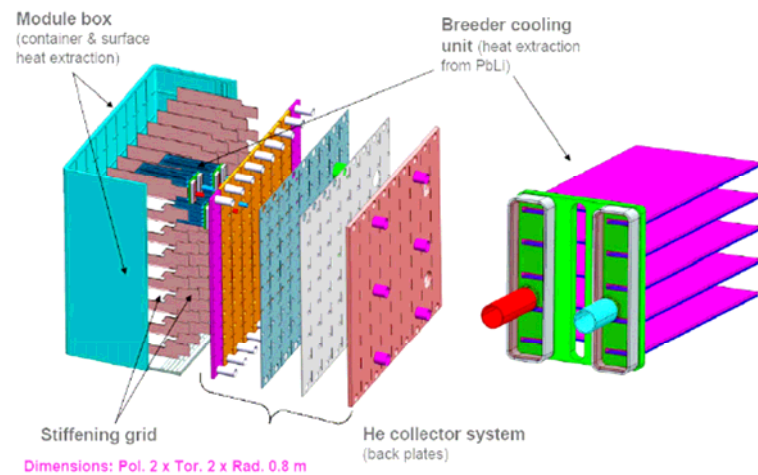
- Optimum tritium breeding requires
 - Increase the number of neutrons (neutron multipliers)
 - Increase the number of the slower neutrons (${}^6\text{Li} \sigma$)
 - Lithium 6 enrichments



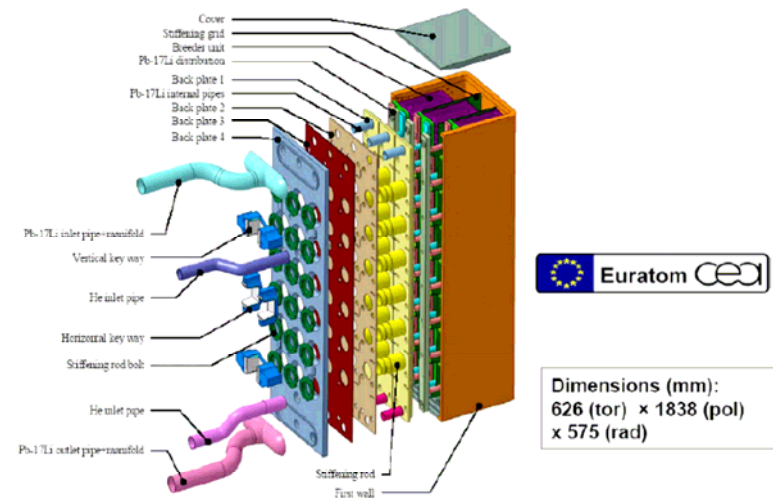
Natural mixture:
92.5 % ${}^7\text{Li}$, only 7.5 % ${}^6\text{Li}$

1. Motivation. *Neutronic objectives*

HCLL: Helium-Cooled Lithium-Lead



TBM: Test Blanket Module to be installed in ITER



Several test objectives of the TBM:

- Electromagnetic
- Neutronic

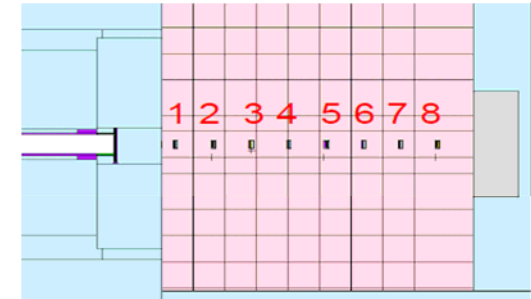
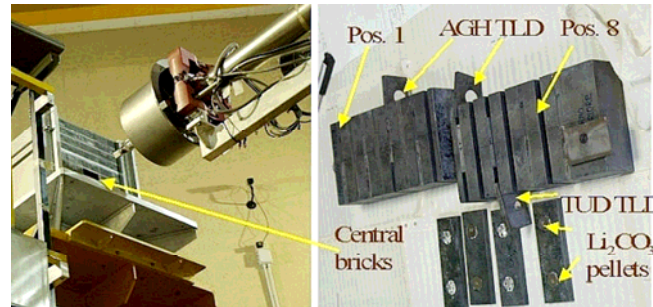
validation of the *capability of the neutronic codes* and *existing nuclear data to predict* the TBM nuclear response, including neutron fluxes and spectra, *the tritium production rate*, nuclear heat deposition, neutron multiplication and shielding efficiency.

- Thermo-mechanic and tritium control
- Integral

1. Motivation. *The Frascati experiment*

- **Neutronic**

validation of the capability of the neutronic codes and existing nuclear data to predict the tritium production rate

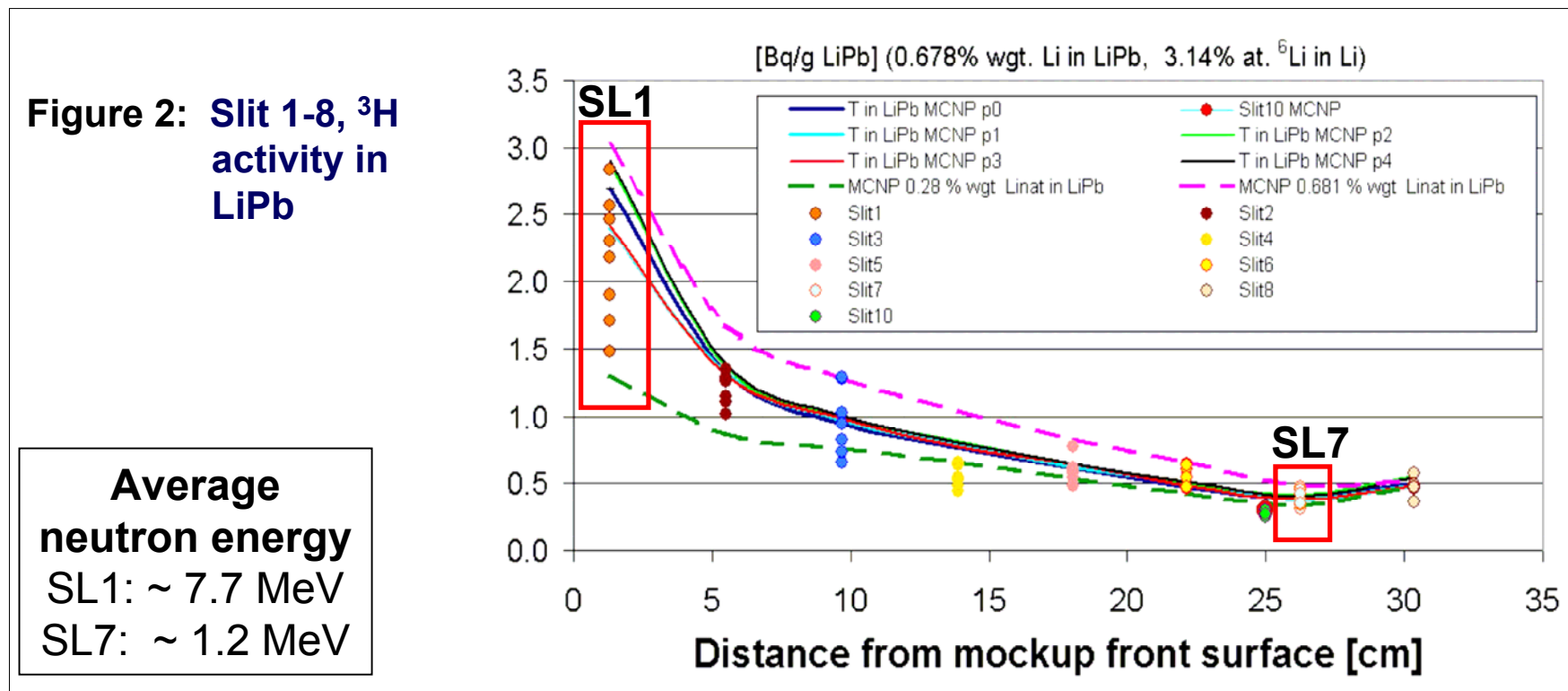


- At Frascati Neutron Generator Laboratory breeding blanket **mock-ups** are irradiated to study the tritium production variation with depth in LiPb samples under fusion condition neutron fluxes (14 MeV)
- We can take advantage of the experimental results to:
 - a) validate **transport codes** and prediction methodologies
 - b) sensitivity studies: tritium production **uncertainty assessment**. Main contributors
 - c) identify lacks and necessary **improvements of the nuclear data** involved in the tritium production

MEASUREMENTS vs MODELS {nuclear data & uncertainties}

1. Motivation. *Measurements of Tritium activity*

- **EFFDOC – 1113: “Measurements of tritium activity in HCLL TBM mock-up LiPb material irradiated in the Frascati experiment” (by W. W.Pohorecki) JEFF/EFF Meeting Paris, 31 May-2 June 2010**
- **T activity in LiPb mock-up material irradiated in Frascati: measurement and MCNP results.**



2. Error propagation techniques for activation

Goal: “to analyse how ND uncertainty is transmitted to N”

$$\boxed{\frac{d}{dt} N = AN} \quad \begin{matrix} N = (N_1, N_2, \dots) \\ \sigma = (\sigma_1, \sigma_2, \dots) \end{matrix} \quad \Rightarrow \quad N_i = N_i(\sigma)$$

1) Sensitivity / Uncertainty Analysis (S/U)

- ✚ Method based on the first order Taylor series to estimate uncertainty indices for each reaction cross section in a continuous irradiation scenario (***linear approximation***)

2) Monte Carlo Uncertainty Analysis (MC)

- ✚ To treat the global effect of all cross sections uncertainties in activation calculations, we have proposed an uncertainty analysis methodology based on Monte Carlo random sampling of the cross sections
- ✚ Assignment of a Probability Density Function (PDF) to each cross section

3. Nuclear Data Uncertainties (EAF/UN)

Review of available uncertainty cross-section data

→ Activation-oriented nuclear data libraries

✚ EAF2003/5/7/10-UN

Evaluated libraries from experiments and theoretical models

Cross sections, standard deviations, variances, covariances ...

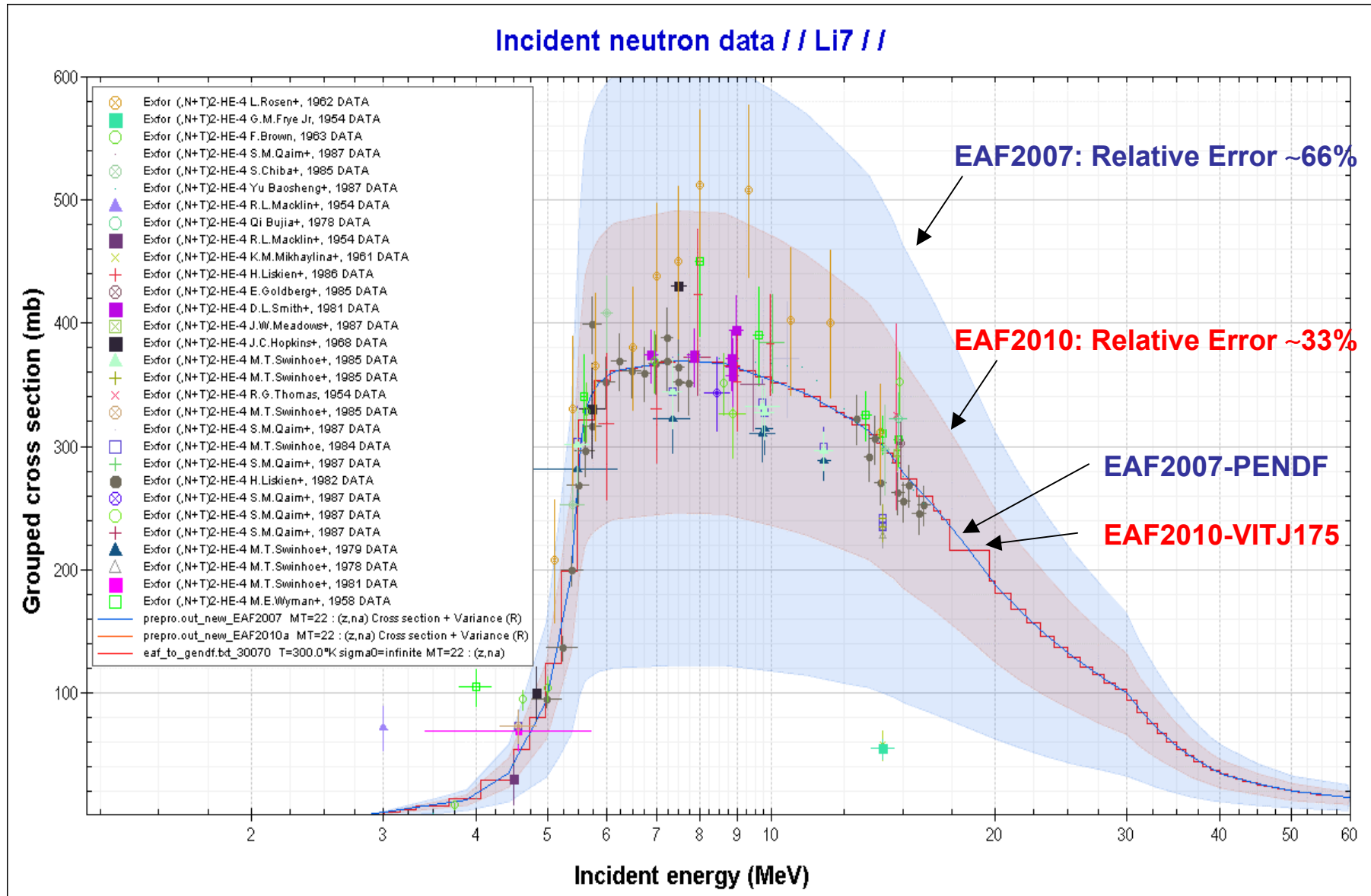
e.g.: EAF2007 Li⁷(n,na) T

LI-	7N,NA							30733	22	
3.00700E+3	6.9557E+00		0	0	0			1	30733	22
0.0000E+00	0.0000E+00		0	22	0			1	30733	22
0.0000E+00	0.0000E+00		0	1	8			4	30733	22
1.0000E-05	0.0000E+00	2.8213E+06	1.0000E+00	2.0000E+07	1.0000E+00			30733	22	
6.0000E+07	0.0000E+00							30733	22	

$$E_i \text{ (eV)} \quad \Delta_{I=1,EAF}^2 = (\sigma - \sigma_0) / \sigma_0 \quad E_{i+1} \text{ (eV)}$$

$$\text{(relative error, } \Delta) \sim \Delta_{I=1,EXP} = \Delta_{I=1,EAF} / 3$$

EAF 2010&2007 Uncertainties: ${}^7\text{Li}(n,T)$

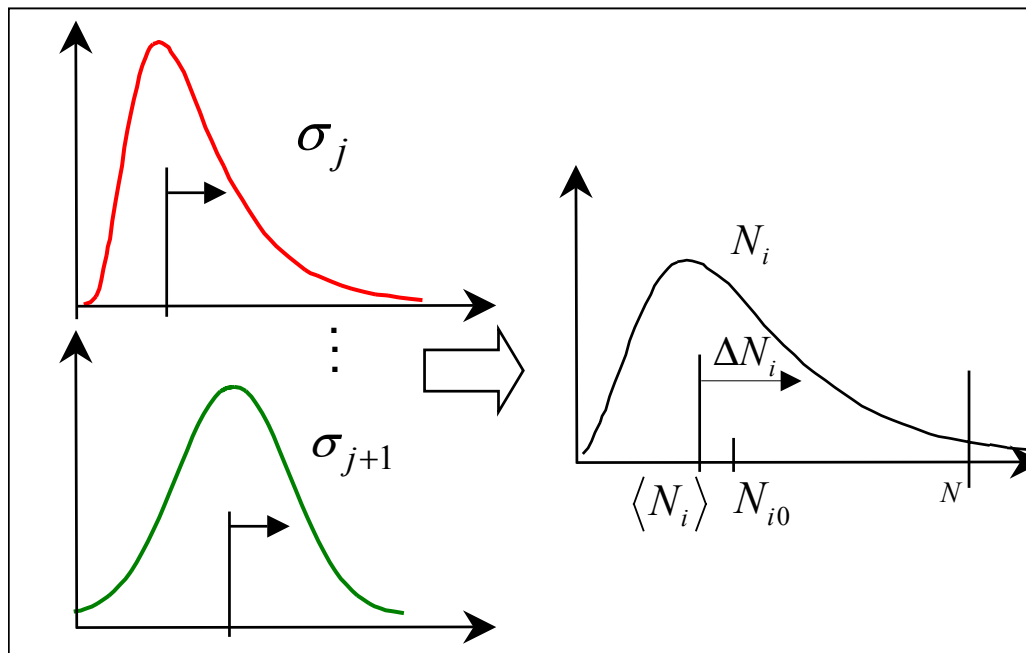


2. Error propagation techniques. Monte Carlo Method

- ✚ We use simultaneous random sampling of all the XS PDFs involved in the problem. PDF is assigned to each σ_j

- ✚ PDF assumed to be lognormal

$$\frac{d}{dt} N = AN$$



- ✚ From the sample of the random vector σ , $\sigma = (\sigma_1, \dots, \sigma_j, \dots, \sigma_m)$ the matrix \mathbf{A} is computed and the vector of nuclide quantities \mathbf{X} is obtained $N = (N_1, \dots, N_i, \dots, N_n)$
- ✚ Repeating the sequence, we obtain a sample of isotopic concentration vectors. The statistic estimators of the sample can be estimated
- ✚ Enables to investigate the global effect of the complete set of $\Delta\sigma$ on N

4. Uncertainty results of tritium activity in Frascati LiPb mock-up

Table 5: Tritium Uncertainty Prediction in SL1 and SL7 using EAF2007/UN

	SL1	SL7
	Depleted Li6 3.14% Li6 in Li	Depleted Li6 3.14% Li6 in Li
Total Bq (at shutdown)	3.47	0.28
Only due to Li	3.33	0.28
Only Li6	0.40	0.26
Only Li7	2.93	0.02
Sensitivity Coefficient: $\rho = (DN/N) / (DXS/XS)$ in %		
Li6(n,T)He4	0.12	0.91
Li7(n,na)T	0.84	0.09
F19(n,T)	0.04	
Mg25(n,T)	1.14E-06	
...		
F19(n,nT)	6.36E-03	
Sensitivity/Uncertainty (%) = $\rho \cdot \Delta$		
Li6(n,T)He4	0.38	3.03
Li7(n,na)T	56.21	5.76
F19(n,T)	0.70	
...		
F19(n,nT)	0.85	
Sensitivity/Uncertainty (%) = ($\rho \cdot \Delta$)	56.22	6.51
Uncertainty with Monte Carlo		
Mean value	4.27	0.29
Relative error (%)	67.03	8.77



- ρ : is the sensitivity coefficient for the tritium production
- Δ : is the corresponding relative error collapsed in 1 group
- the index " $\rho \Delta$ " that can be used to rank cross sections inducing the highest uncertainties

5. Conclusions








- Deviations in MCNP calculations of produced Tritium at high energies (~ 7 MeV) can be caused by ${}^7\text{Li}(n,\text{an})\text{T}$ cross section uncertainties.
- An experimental effort should be done in order to improve ${}^7\text{Li}$ tritium production nuclear data quality
- Tritium production rate calculations are not affected by these uncertainties due to the energy range in which the tritium production from ${}^7\text{Li}$ happens

6. References

For this work

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