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

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Outline

1. Motivation

- Need of Tritium production
- Neutronic objectives
- The Frascati experiment
- Measurements of Tritium activity

2. Error propagation techniques for activation

- Sensitivity/Uncertainty analysis
- Monte Carlo method

3. Nuclear Data Uncertainties

- ^{7}Li and ^{6}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:**

  $^{2}D + n \rightarrow T$

  but a very low rate (1 Kg/year)

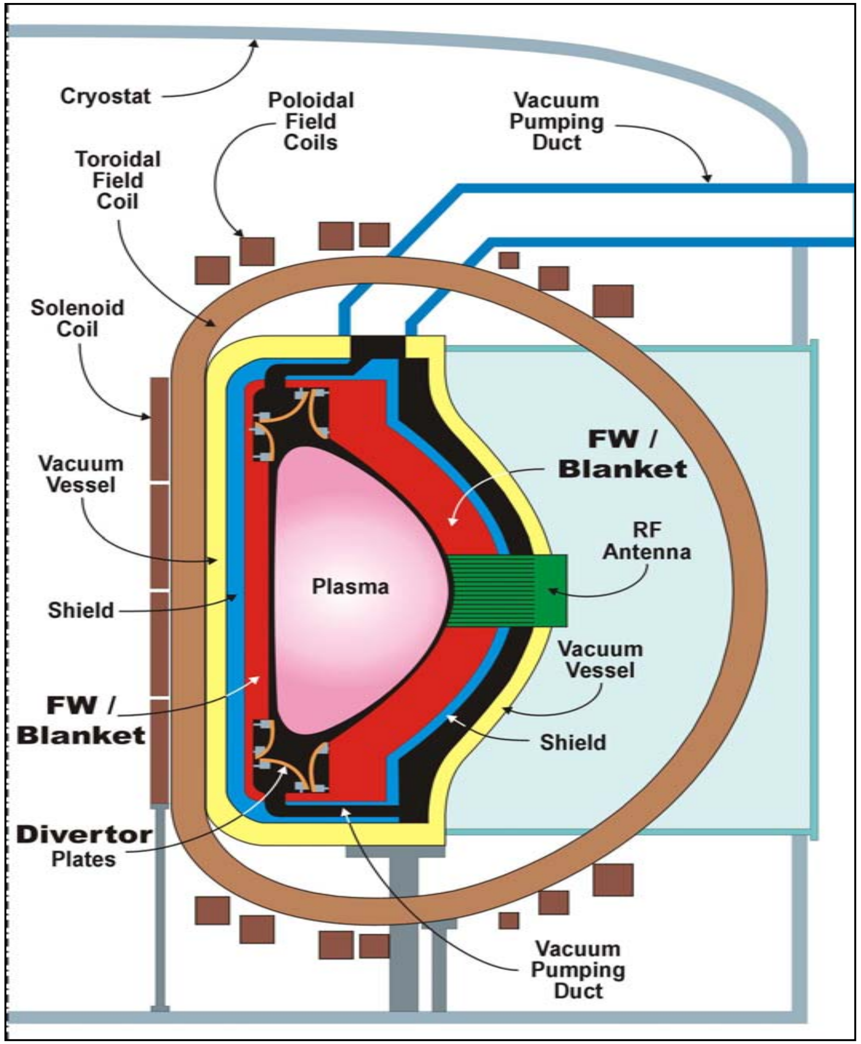
- **Reactor core surroundings:**

  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*

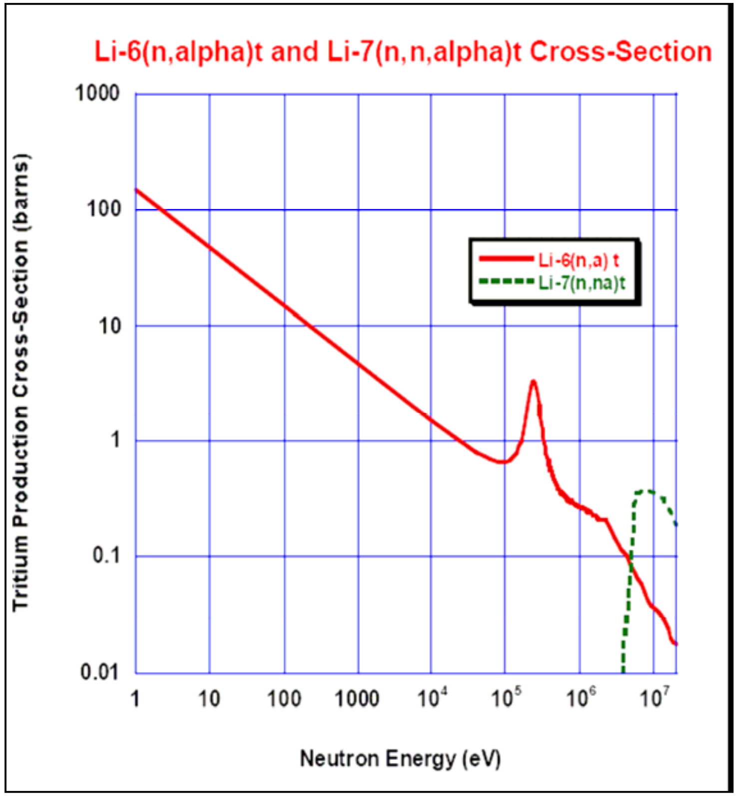
- **It is possible to produce Tritium from the reactions**

  $^7Li + n \rightarrow T + {}^4He + n - 2.8$ MeV

  (that works with the high energy neutrons)

  $^6Li + n \rightarrow T + {}^4He + 4.8$ MeV

  (low energy regions, decelerated neutrons)



- **Tritium generation rate**

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

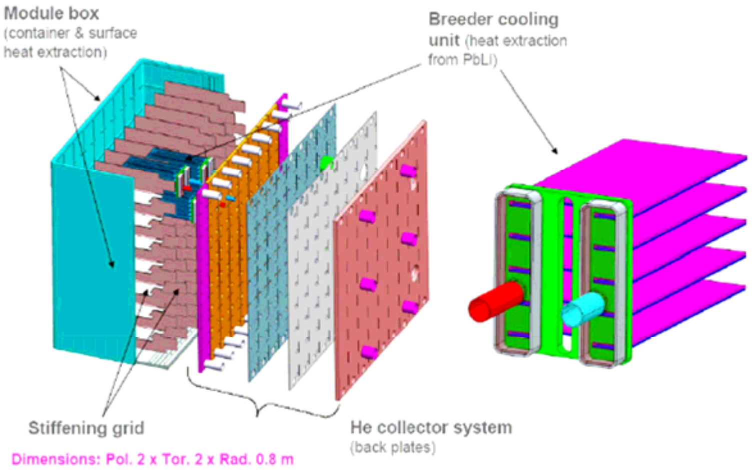
  depends on neutron flux intensity, Li density and **Li cross section**

- **Optimum tritium breeding requires**
  a) Increase the number of neutrons (neutron multipliers)
  b) Increase the number of the slower neutrons (^6Li σ)
  c) Lithium 6 enrichments

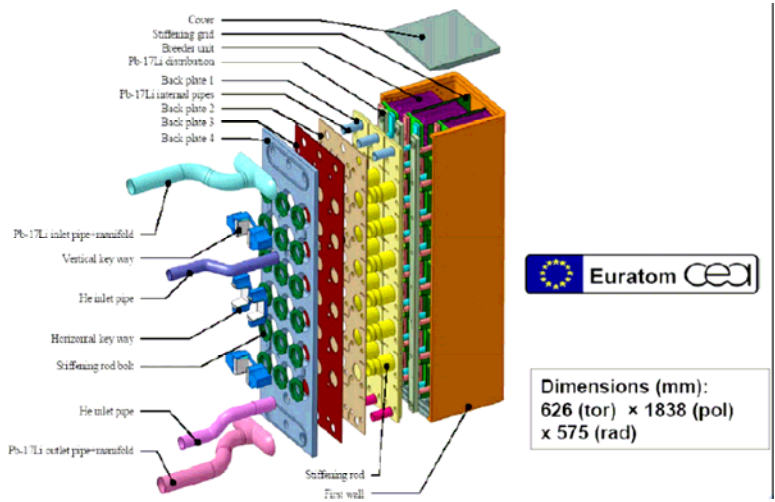
Natural mixture:
92.5 % ^7Li, only 7.5 % ^6Li

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**

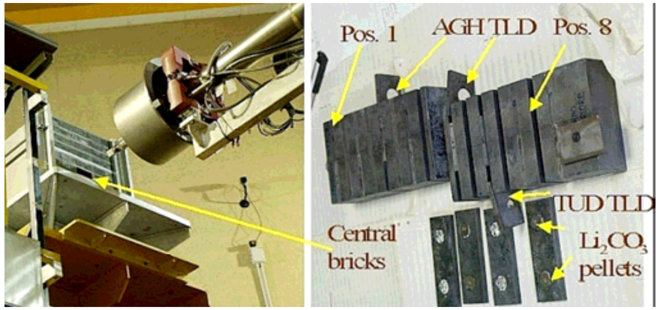
  validation of the ***capability of the neutronic codes*** and ***existing nuclear data to predict*** the TBM nuclear response, including neutron fluxes and spectra, ***the tritium production rate***, nuclear heat deposition, neutron multiplication and shielding efficiency.

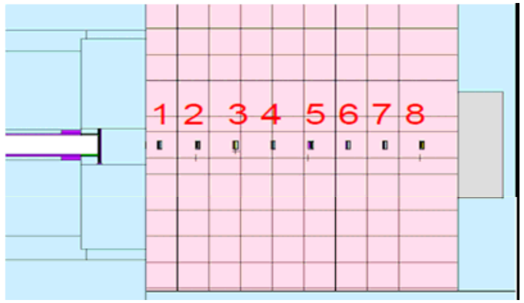
- Thermo-mechanic and tritium control
- Integral

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

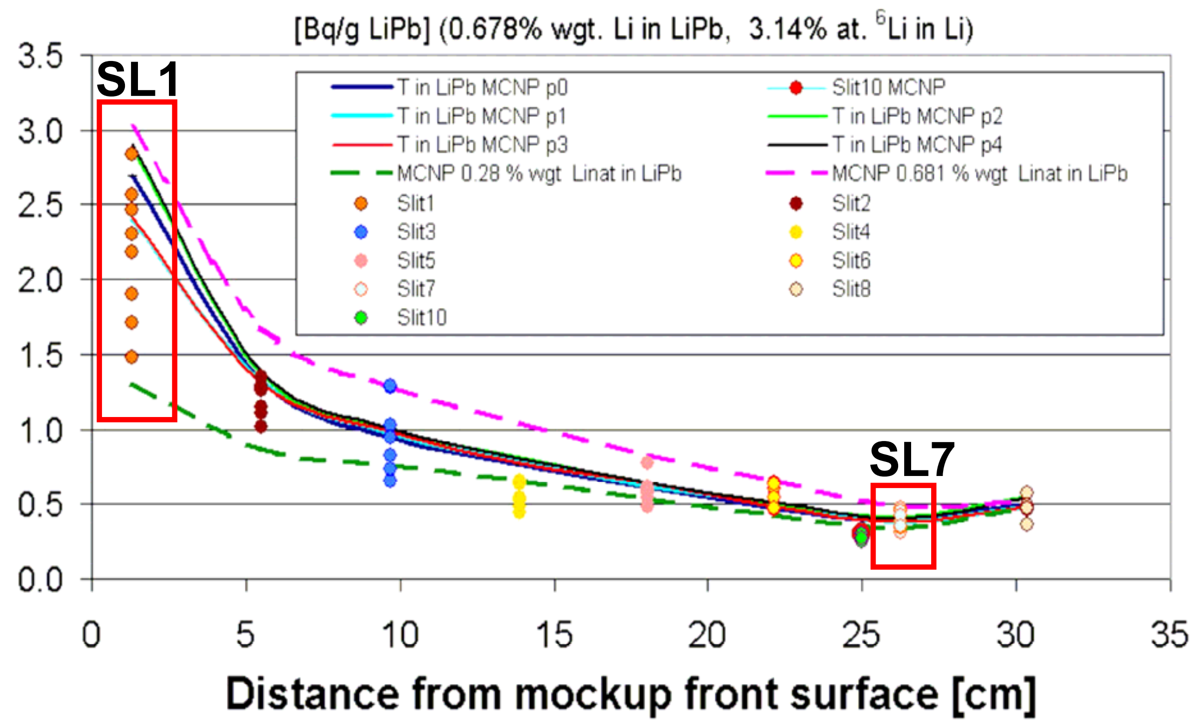
MEASUREMENTS vs MODELS {nuclear data & uncertainties}

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.**

Figure 2: Slit 1-8, ^{3}H activity in LiPb



Average neutron energy
SL1: ~ 7.7 MeV
SL7: ~ 1.2 MeV

2. Error propagation techniques for activation

Goal: "to analyse how ND uncertainty is transmitted to N"

$$\frac{d}{dt}N = AN \qquad N = (N_1, N_2, \ldots) \qquad \sigma = (\sigma_1, \sigma_2, \ldots) \qquad \Longrightarrow \qquad N_i = N_i(\sigma)$$

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

2. Error propagation techniques.
Sensitivity/Uncertainty Analysis

We assume only XS uncertainties:

$$N_i = N_i(\sigma, \not\lambda, \not\phi(\not E), \not N_0) \quad \Rightarrow \quad N_i(\sigma) \approx N_i(\sigma_0) + \sum_{j=1}^{m} \left[\frac{\partial N_i}{\partial \sigma_j}\right]_{\sigma_0} (\sigma_j - \sigma_{j0}) + \ldots$$

$$\frac{N_i(\sigma) - N_i(\sigma_0)}{N_i(\sigma_0)} \approx \sum_{j=1}^{m} \frac{\sigma_{j0}}{N_i(\sigma_0)} \left[\frac{\partial N_i}{\partial \sigma_j}\right]_{\sigma_0} \frac{(\sigma_j - \sigma_{j0})}{\sigma_{j0}}$$

e_i: Relative error in N_i due to changes in cross-sections

ρ_{ij}: Cross-section sensitivity coefficient (simulation codes)

ε_j: Relative error in cross-sections of each reaction j

$$e_i = \rho_{i1}\varepsilon_1 + \rho_{i2}\varepsilon_2 + \cdots + \rho_{im}\varepsilon_m$$

$$Var[e_i] = \rho_{i1}^2\Delta_1^2 + \rho_{i2}^2\Delta_2^2 + \cdots + \rho_{im}^2\Delta_m^2$$

$$Var[e_i] = \rho_i^T V \rho_i$$

$$\rho_i = (\rho_{i1}, \quad \rho_{i2}, \quad \cdots \quad \rho_{im})$$

$$Var(\varepsilon) = V$$

Information obtained processing ND
NJOY: ERROR, COVR and VIEWR

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 …

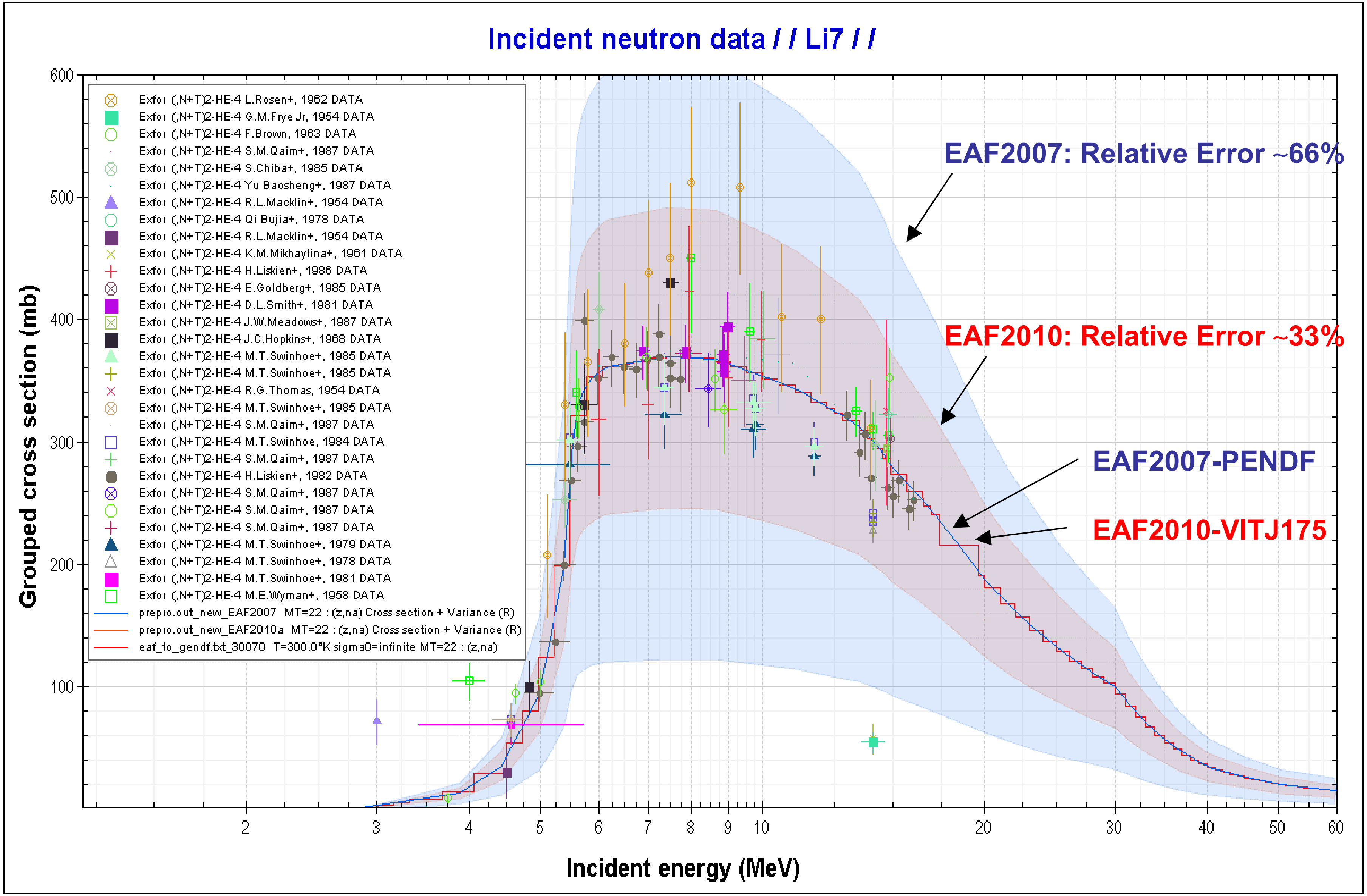
e.g.: EAF2007 Li^7(n,na) T

```
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 (eV) $\Delta^2_{I=1,EAF} = (\blacklozenge - \blacklozenge_0)/\blacklozenge_0$ E_{i+1}(eV)

(relative error, Δ)~ $\Delta_{I=1,EXP} = \Delta_{I=1,EAF}/3$

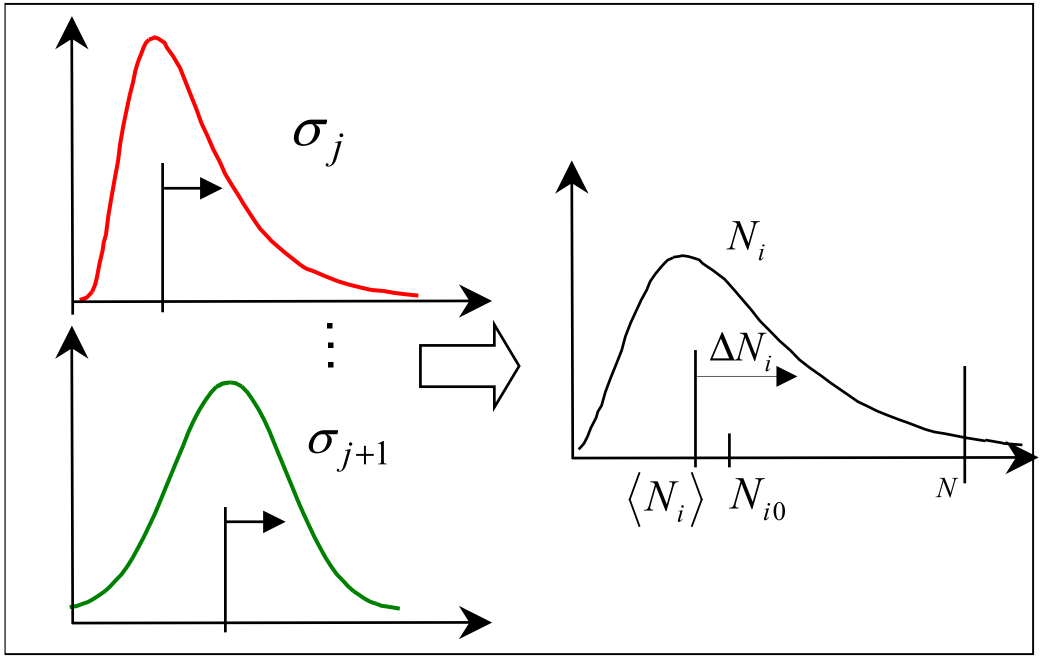
EAF 2010&2007 Uncertainties: ^{7}Li(n,T)



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, $\sigma = (\sigma_1 ..., \sigma_j ..., \sigma_m)$ the matrix **A** is computed and the vector of nuclide quantities ***X*** is obtained $N = (N_1 ..., N_i ..., N_n)$
- 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	
	Natural Abundance 7.25% Li6 in Li	Depleted Li6 3.14% Li6 in Li	Natural Abundance 7.25% Li6 in Li	Depleted Li6 3.14% Li6 in Li
Total Bq (at shutdown)	3.92	3.47	0.64	0.28
Only due to Li	3.78	3.33	0.64	0.28
Only Li6	0.96	0.40	0.62	0.26
Only Li7	2.82	2.93	0.02	0.02
Sensitivity Coefficiente: ρ = (DN/N) / (DXS/XS) in %				
Li6(n,T)He4	0.25	0.12	0.96	0.91
Li7(n,na)T	0.72	0.84	0.04	0.09
F19(n,T)		0.04		
Mg25(n,T)		1.14E-06		
…	…			
F19(n,nT)		6.36E-03		
Sensitivity/Uncertainty (%) = ρ*Δ				
Li6(n,T)He4	0.82	0.38	3.21	3.03
Li7(n,na)T	47.83	56.21	2.43	5.76
F19(n,T)		0.70		
…				
F19(n,nT)		0.85		
Sensitivity/Uncertainty (%)= (ρ*Δ)	47.84	**56.22**	4.03	**6.51**
Uncertainty with Monte Carlo				
Mean value	4.67	4.27	0.65	0.29
Relative error (%)	58.62	**67.03**	4.78	**8.77**

- ρ : is the sensitivity coefficient for the tritium production
- Δ : is the corresponding relative error collapsed in 1 group
- the index "ρΔ" 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}Li(n,an)T cross section uncertainties.

- An experimental effort should be done in order to improve ^{7}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}Li happens

6. References

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