Cosmogenic activation calculation of experiments with LAr target

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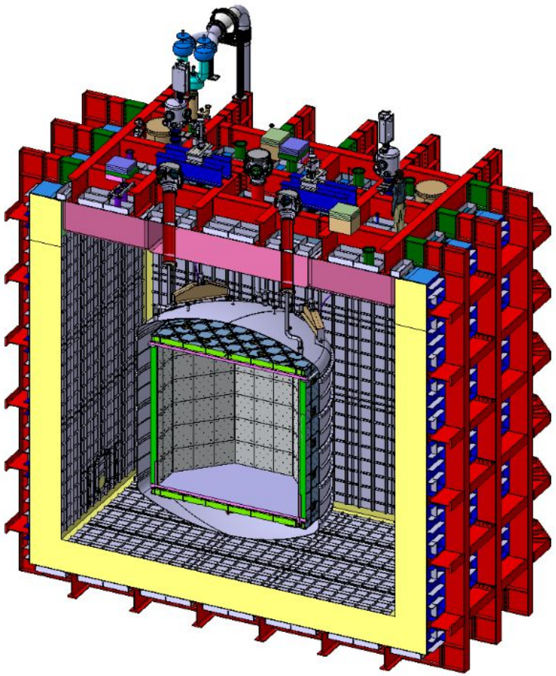
Rare event search experiments

- Rare event search experiments requires ultra low background conditions.
  - Deep underground laboratories with passive and active shields
  - Selection of radio pure materials.
  - Effective methods to discriminate signal and background.

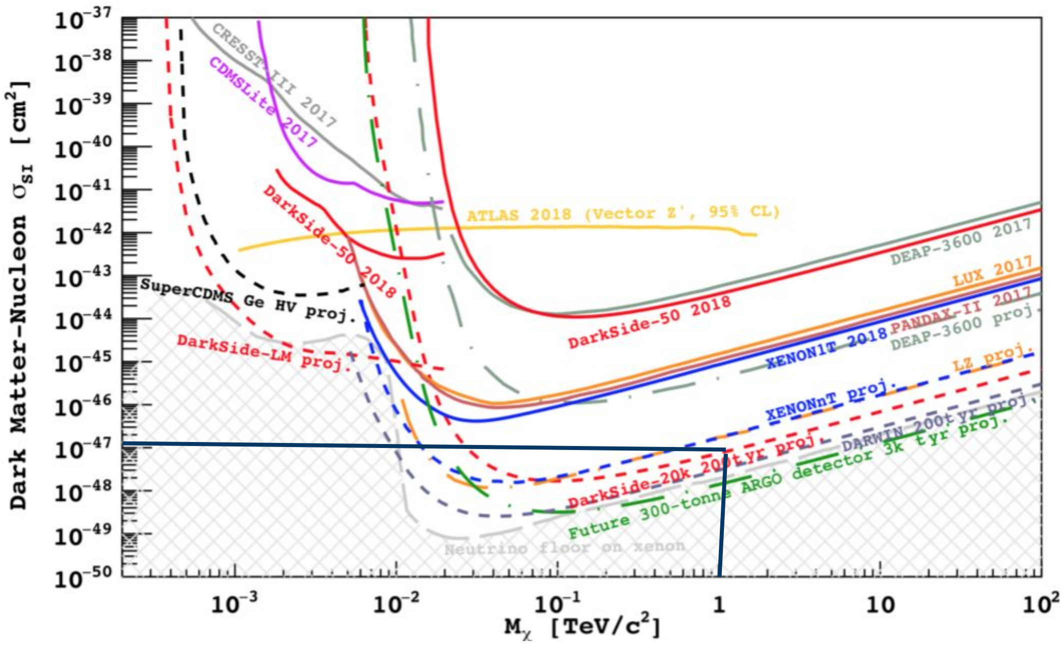
- The cosmogenic activation of detector materials while it is being stored or transported above ground can cause significant background.

- Estimation of the cosmogenic background is an essential step.

DARKSIDE-20K(DS-20K)



Schematic diagram of DS-20K



Expected spin-independent DM-nucleon scattering cross-section discovery sensitivity of current and future DM experiments

Liquid Argon target

S1 : scintillation signal

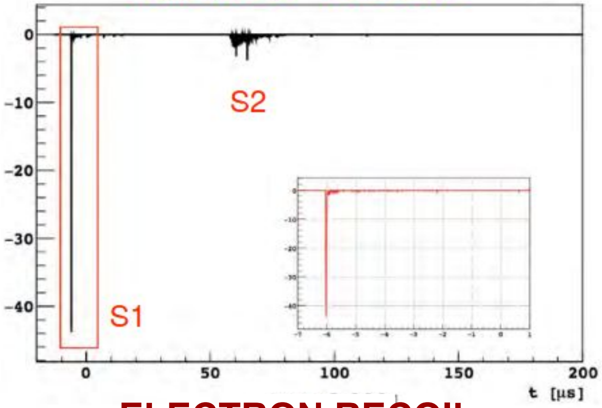
S2 : Ionisation Signal

- Has high ionization and scintillation yields

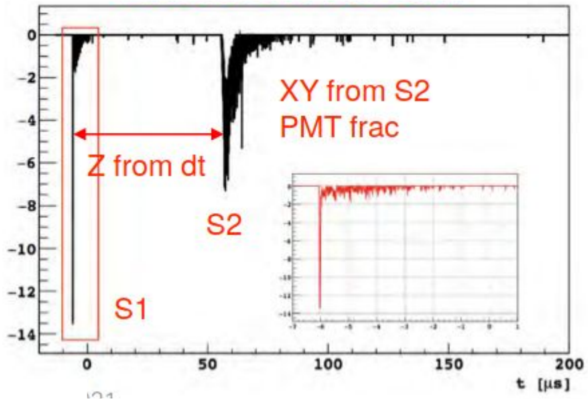
- Background rejection
  - Pulse shape Discrimination (PSD)
    - Fast decay time (Singlet) ~ **7 ns**
    - Slow decay time (Triplet) ~ **1600 ns**
    - Rejection power-10^8
  - S2/S1 Ratio-
    - $(S2/S1)_{ER} > (S2/S1)_{NR}$
    - Rejection power-10^2 to 10^3

-
- Radioactive isotopes
  - ^{39}Ar
    - Activity in Atmospheric Argon : 1 Bq/kg
    - Create a signal pile up as well as high data acquisition rates in the rare event search experiments.
  - ^{37}Ar , ^{42}Ar, ^{3}H

NUCLEAR RECOIL

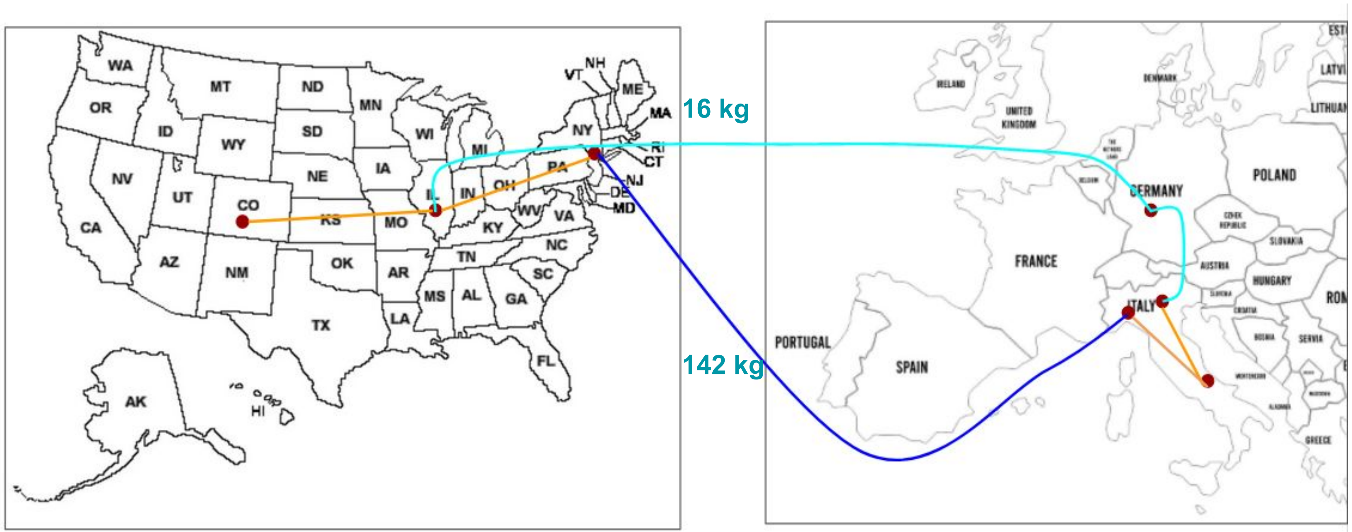


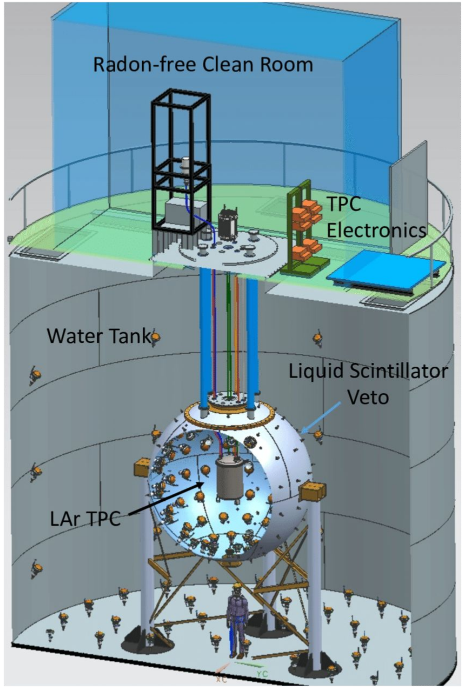
ELECTRON RECOIL



Activation Yield Calculation

- Estimate ^{37}Ar and ^{3}H activation yields.
- Validate against DarkSide-50
- Predict activation yields for DS-20k.
- DS-50 UAr was transported in two ways from Colorado to LNGS.





Schematic diagram of DS-50

^{37}Ar and ^{3}H

^{37}Ar

- **Decays by e^- capture**
- $T_{1/2}$=35 d
- Q-value =813.87 keV
- Main Production channels
  - $^{40}Ar(n,4n)^{37}Ar$
  - $^{36}Ar(n,\gamma)^{37}Ar$

^{3}H

- **β emitter**
- $T_{1/2}$=12.35 yr
- Q-value= 18.591 keV
- Fast neutron interaction of Ar isotopes produce ^{3}H.

Backgrounds from ^{37}Ar and ^{3}H

- **^{37}Ar**- electron capture on K (**2.83 keV**) and L1 (**0.28 keV**)[1].
- **^{3}H**- β emission(**18.59 keV**)

[1] https://doi.org/10.1103/PhysRevD.104.082005

Activation Rate & Induced Activity

- Induced activity is the total activity of a radionuclide during the exposure period.

$$R = N_{AR} \int F(E) * \sigma(E) \; dE$$

$$IA = R \left(1 - e^{-\lambda t_{exposure}} \right) e^{-\lambda t_{cooling}}$$

$t_{exposure}$: Time UAr is exposed in a fixed location.

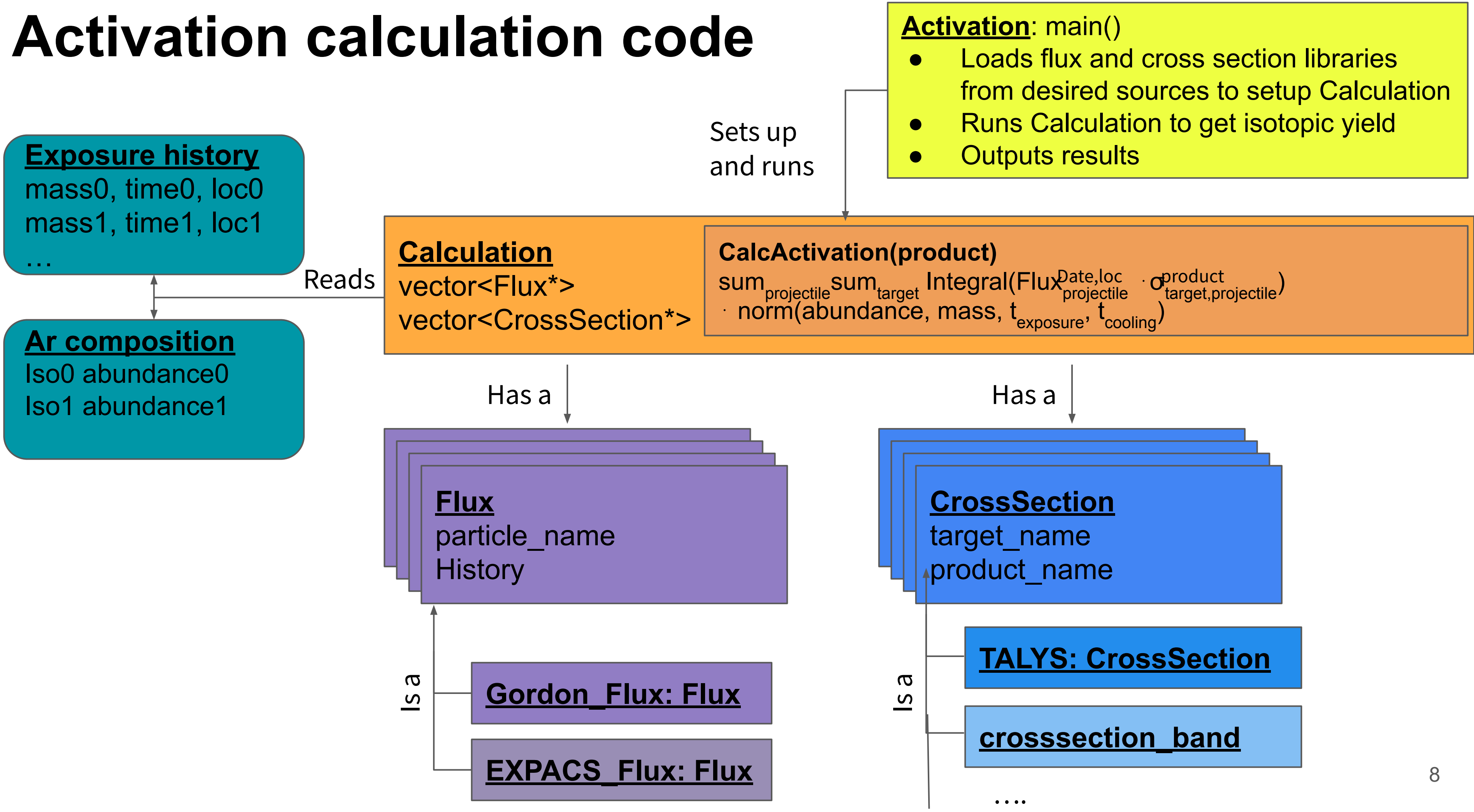
$t_{cooling}$: Time difference between the time when detector started running and time when the UAr exposed in a fixed location

f(E): Cosmic Ray flux

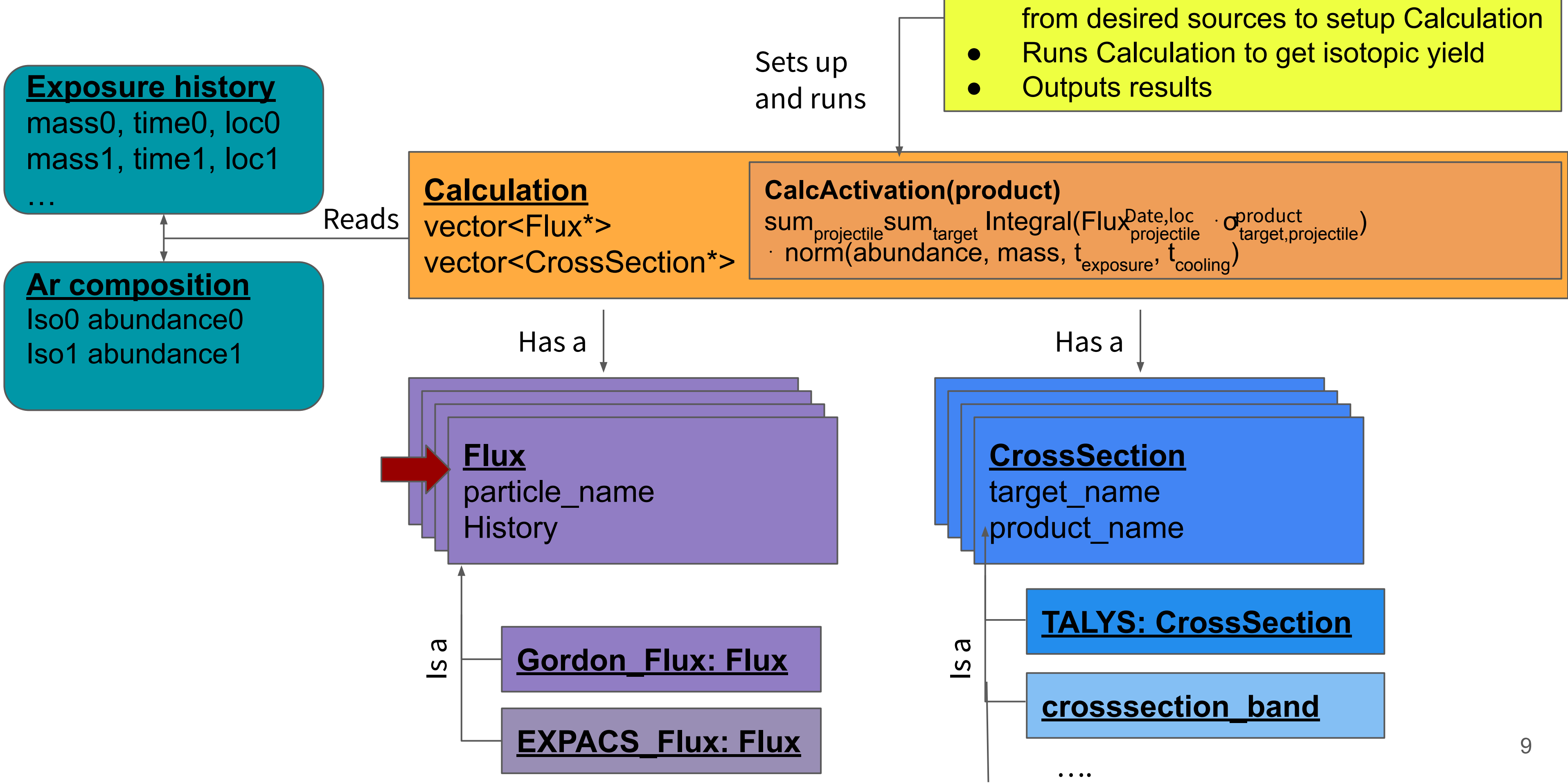
σ(E): Reaction cross-section

N_{AR}: Number of atoms in 1 kg of Ar

Activation calculation code



Activation calculation code



Cosmic ray Flux : EXPAC

- EXPAC is a software based on the PHITS based Analytical Radiation (PARMA) model.
- **PARMA**- An analytical model based on the MC simulation of the propagation of cosmic rays in the atmosphere performed by the **PHITS code**.
- Calculates the atmospheric cosmic-ray spectra of ions with charge up to 28 (Ni),n,p, μ±, e±, and γ.

- Input parameters →
  - ★ Location(Latitude, Longitude, Altitude)
  - ★ Time

For more info:https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0160390
https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0144679
http://phits.jaea.go.jp/expacs/

Cosmic ray Flux : Gordon Calculation

- The neutron flux and energy spectrum data from five ground-level measurements in North America are considered.
- An expression to scale the measured neutron flux to other locations has been developed.
- Neutron fluence rate spectrum at any location,

$$\frac{d\phi(E)}{dE} = \frac{d\phi_0(E)}{dE} F_{alt}(d)\, F_{BYSD}(R, d, I)$$

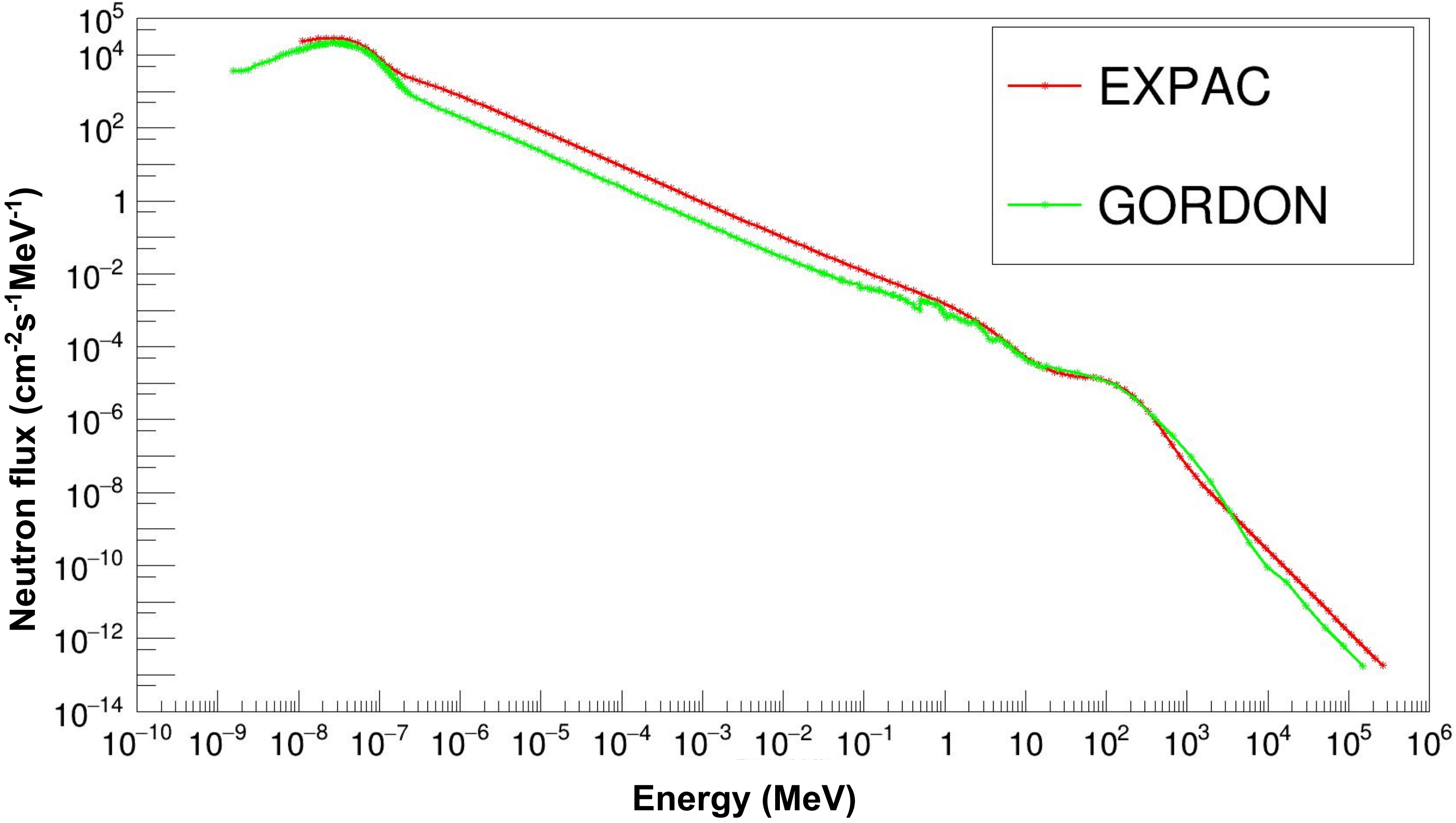
➔ **$d\phi_0$(E)/dE** : fluence rate spectrum at reference location.

➔ **F_{alt}(d)** : describes the dependence on altitude.

➔ **F_{BSYD}(Rc,d,I)** : describes the dependence on geomagnetic location and solar modulation (and also atmospheric depth)

Input Parameter : Location(Latitude, Longitude, Altitude)

EXPAC and Gordon Flux Distribution



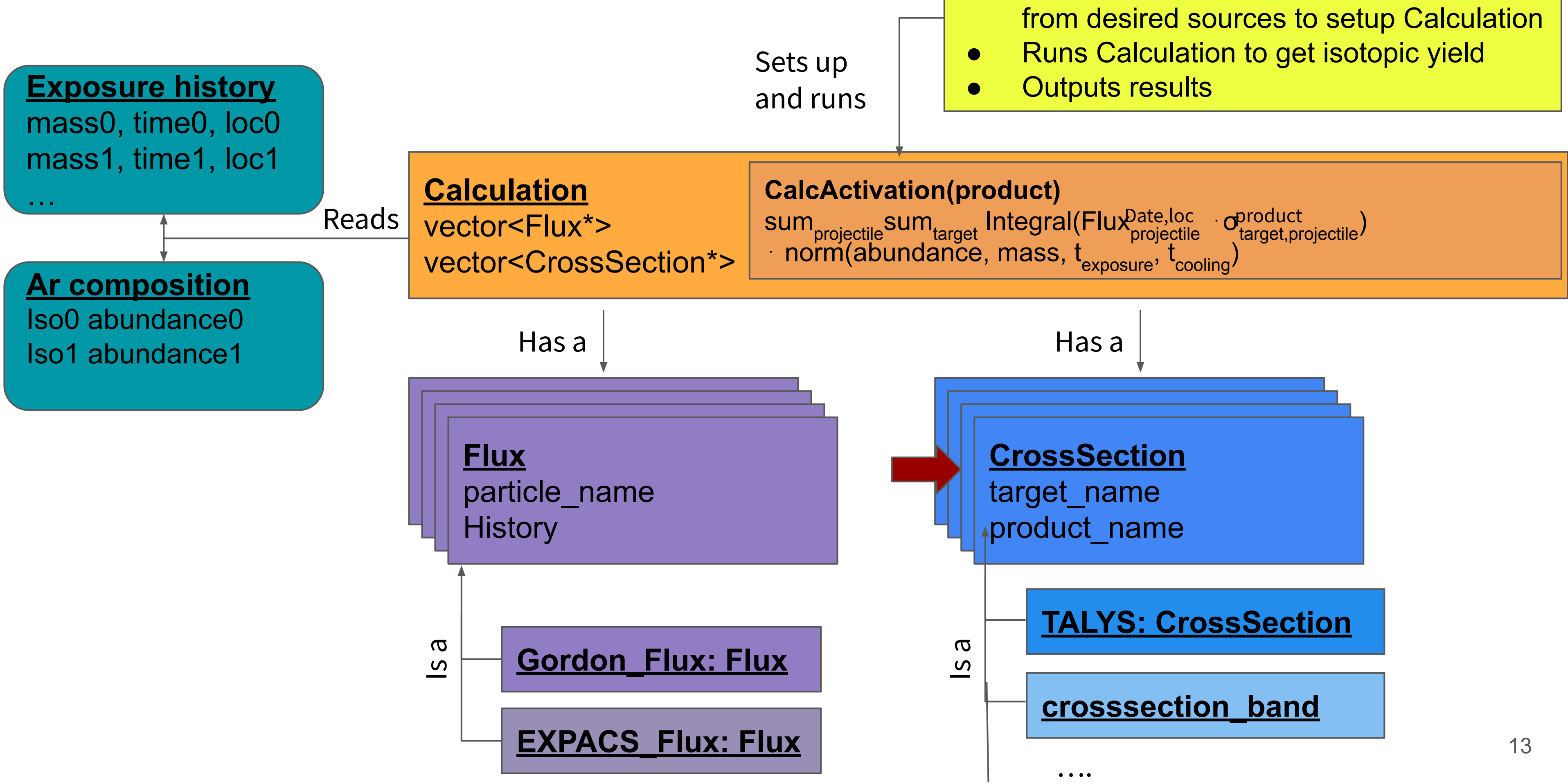
Altitude=0.0

Latitude=42.28

Longitude=48.18

Date: 14/01/2015

Activation calculation code



Cross-section Data

Projectiles: n, p , γ
Targets: ^{36}Ar, ^{38}Ar, ^{40}Ar

Major reaction channels

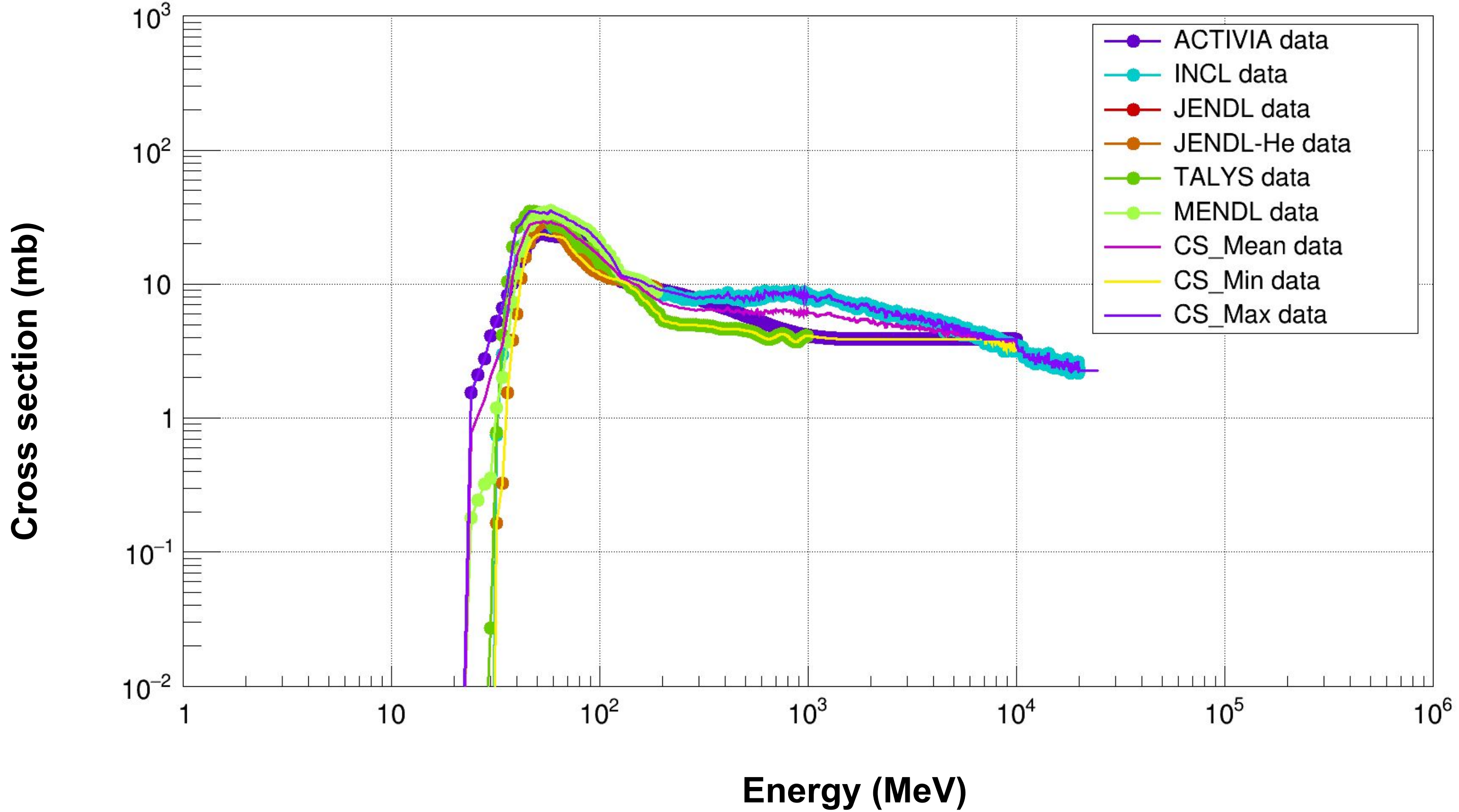
- $^{40}Ar(n,4n)^{37}Ar$
- $^{36}Ar(n,\gamma)^{37}Ar$
- $^{40}Ar(n,*)^{3}H$
- $^{36}Ar(n,*)^{3}H$
- $^{40}Ar(n,*)^{3}H$

Cross-section Libraries	
Simulations Used	**Databases Used**
❑ TALYS	❑ JENDL-He
❑ ACTIVIA	❑ JENDL
❑ INCL	❑ EXFOR
	❑ NNDC
	❑ MENDL
	❑ ENDF

CS_band- A subroutine created in the software to get maximum, minimum, and median values of reaction cross section. Used to find the cross section error band.

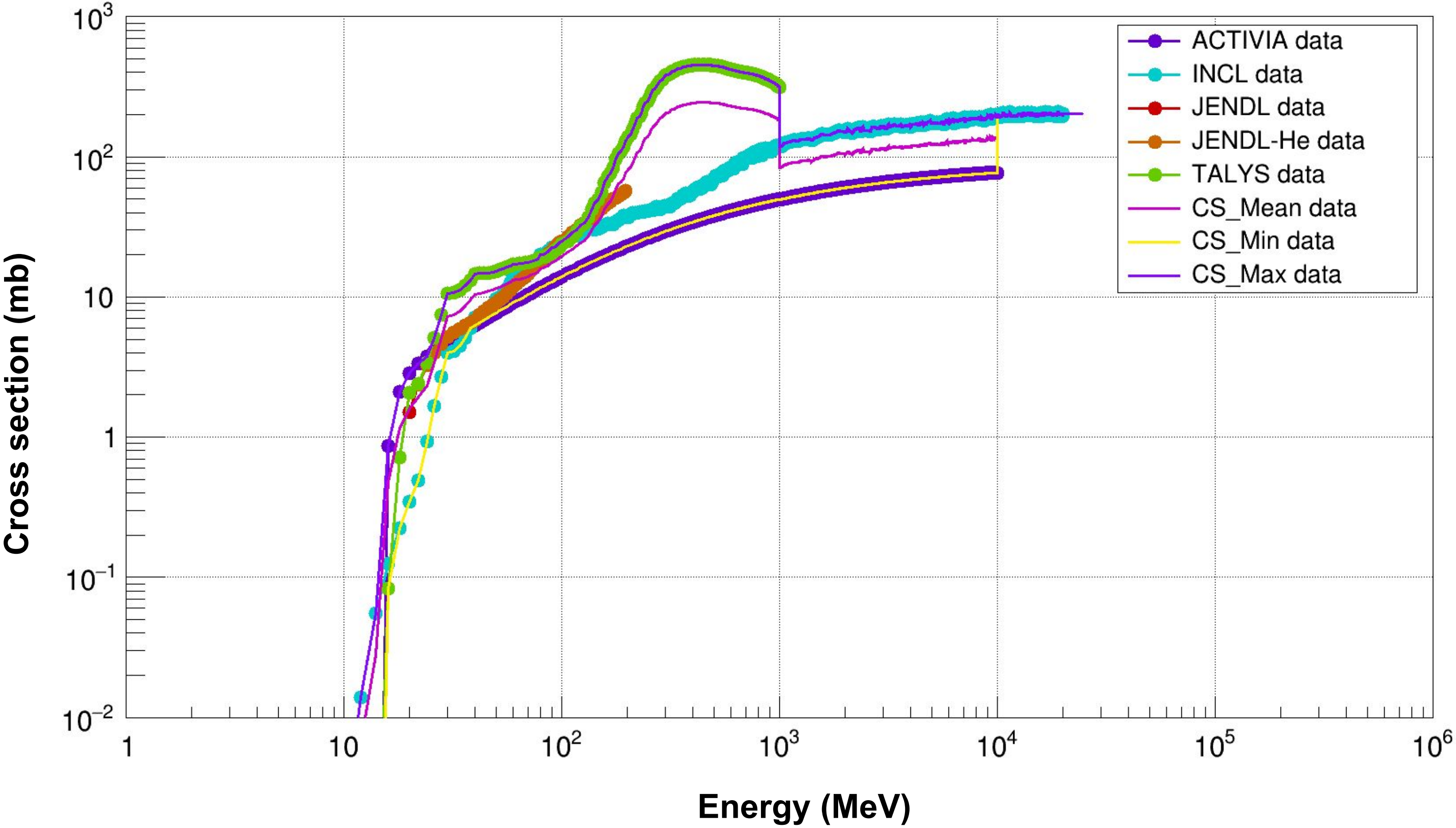
Different Cross section Libraries of $^{40}Ar(n,*)^{37}Ar$

After Scaling

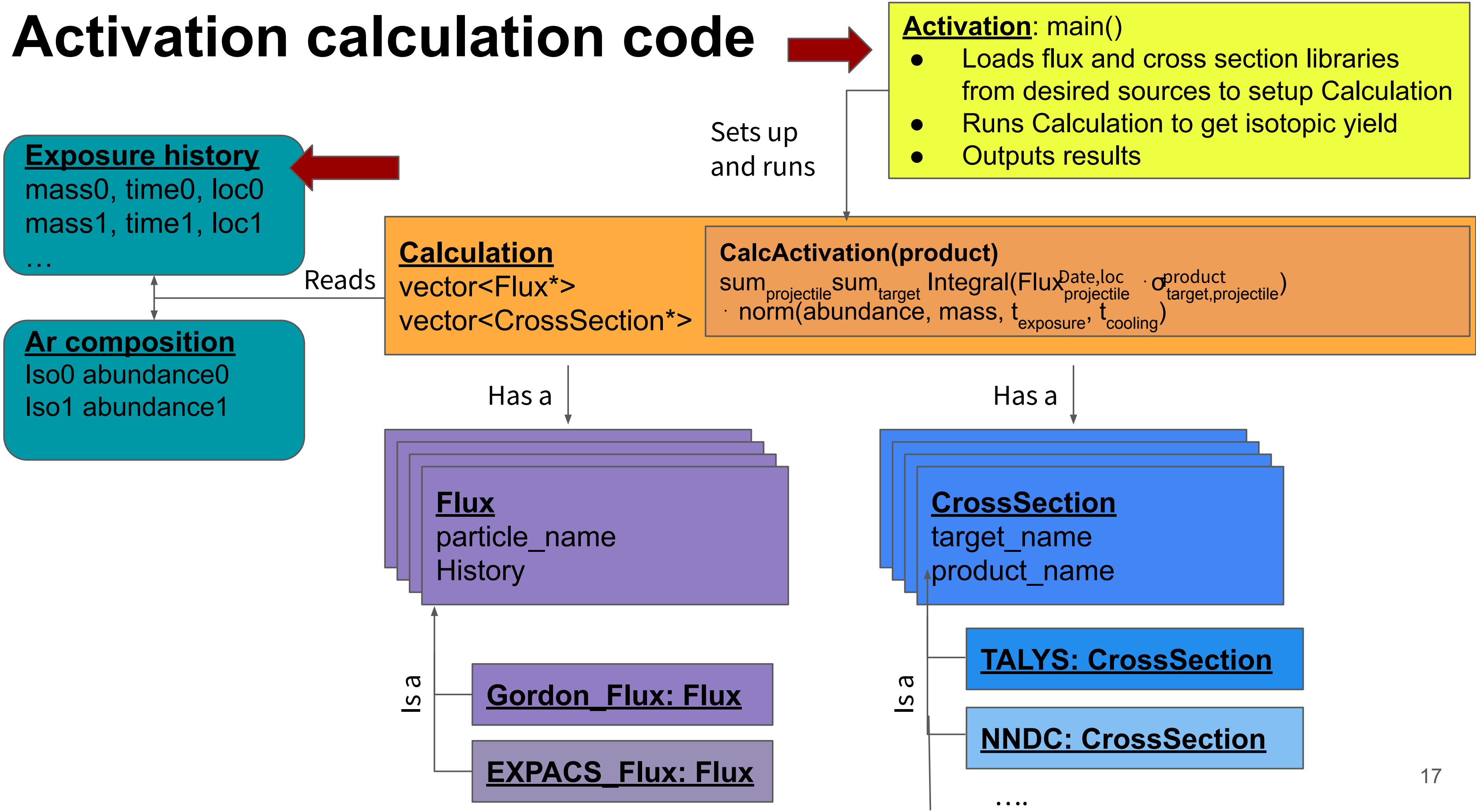


For scaling factors refer https://arxiv.org/abs/1902.09072

Different Cross section Libraries of $^{40}Ar(n,*)^3H$



Activation calculation code



Induced Activity from Activation Calculation Simulation

PRELIMINARY RESULTS

Reactions	Flight	Overseas
$^{40}Ar(n,*)^{37}Ar$	1.01 mBq/kg	0.18 mBq/kg
$^{38}Ar(n,*)^{37}Ar$	0.13 μBq/kg	0.02 μBq/kg
$^{36}Ar(n,*)^{37}Ar$	0.29 mBq/kg	3.09e-2 mBq/kg

Total Induced Activity

	Flight	Overseas
^{37}Ar	$1.7^{+0.38}_{-0.4}$ mBq/kg	$0.26^{+0.09}_{-0.09}$ mBq/kg
^{3}H	$0.14^{+0.11}_{-0.11}$ mBq/kg	$0.46^{+0.32}_{-0.34}$ mBq/kg

Conclusions

- ^{37}Ar is produced via fast and thermal neutron interaction of Argon isotopes, whereas ^{3}H is produced by the fast neutron interaction of Argon isotopes.

- The induced activity of ^{37}Ar at the flight level is greater than that of the overseas level. The half life of ^{37}Ar is shorter than the exposure time at overseas level.

Next Steps

- Include ^{39}Ar and ^{42}Ar reactions in the Activation Calculation package.
- Validate the results with DS-50 data with ^{37}Ar (Blind Analysis).
- Predict the cosmogenic activation of DS-20k.

Thank You

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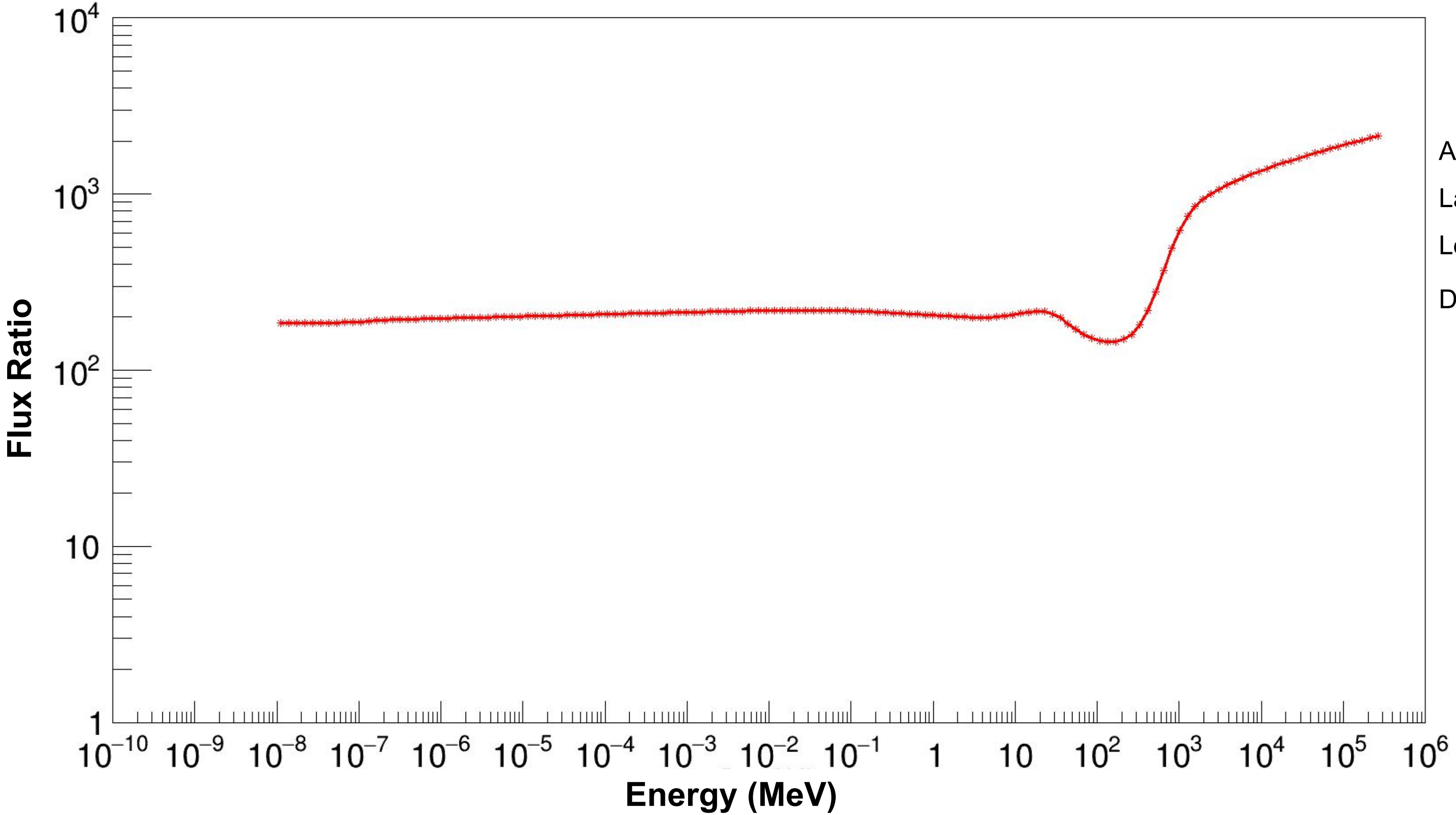
Dr. Iftikhar Ahmad, AstroCeNT
Dr. Brianne R Hackett, Pacific Northwest National Laboratory
Dr. Marco Rescigno, University of Roma

Backup slides

Flux Ratio between flight and overseas level



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Date: 14/01/2015