Radiological characterization of high-energy proton targets from the CERN-ISOLDE facility

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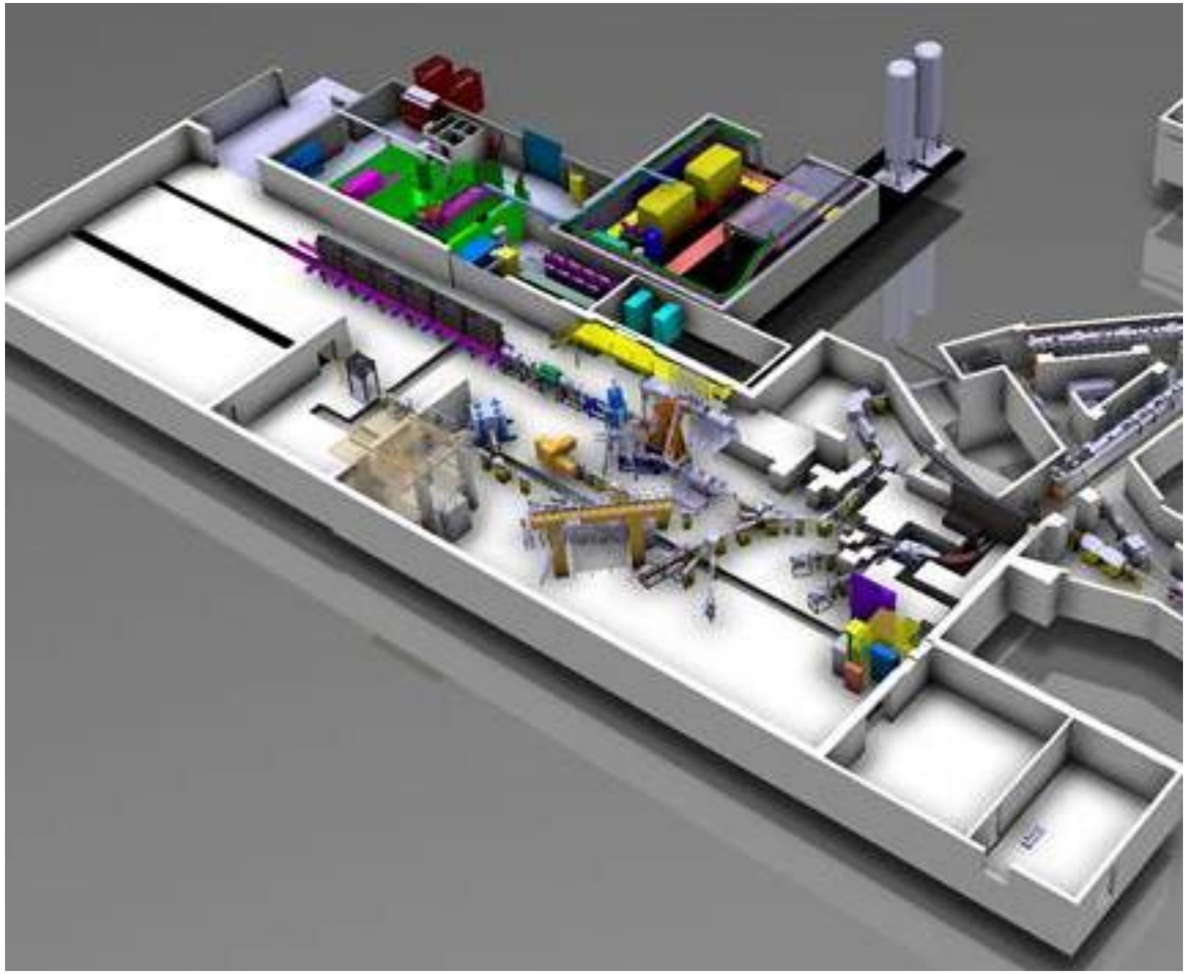
Contents

ISOLDE Facility

- The ISOLDE facility (Isotope mass Separator On-Line DEvice) at CERN is a unique source of beams of radioactive nuclides.

- It is used in a wide range of research domains.

- The radioactive nuclides are produced via spallation, fission and fragmentation reactions originating from a 1.4 GeV proton-beam that impinges on specifically designed thick targets.



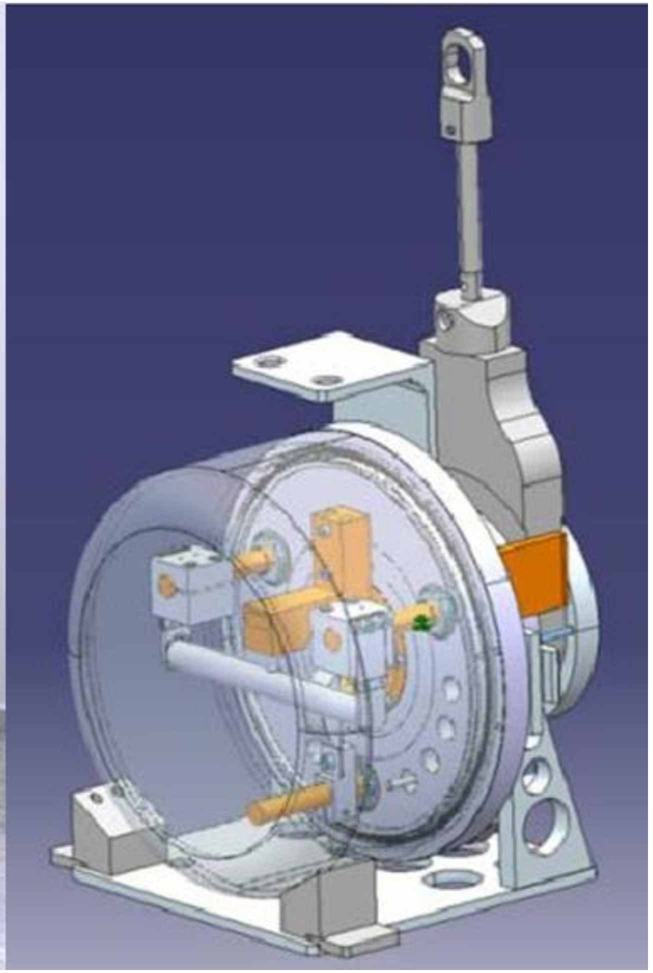
ISOLDE Targets

- **Target is a complex assembly that comprises the target core and its container, the ion source, the target base and the auxiliary components.**

- **40 different targets (targets material , ion sources and configuration) are generated irradiated every year.**

- **Different target configurations are required for the different physics experiments.**

- **Typical irradiation times are from few days to a couple of weeks.**



ISOLDE- Waste Production

- **After their irradiation, targets are stored for radioactive decay.**

- **Hundreds of irradiated targets are currently stored at CERN and a similar number is expected to be irradiated over the period 2022-2031.**

- **These targets will have to be dismantled and disposed of as radioactive waste in Switzerland.**

- **Therefore, the radiological characterization is a crucial step for their successful disposal.**

Challenges

- **There are many challenges associated with characterizing such radioactive waste**
- **These are mainly due to:**
  - Different target designs and characteristics (e.g. core materials)
  - Different irradiation configurations (e.g. direct/indirect irradiation)
  - Different irradiation histories (e.g. cooling times)
- **What did we do?**
  - Identifying the parameters relevant for the radiological characterisation
  - Calculating the fluence spectra using Fluka
  - Performing activation calculations using ActiWiz
  - Performing extensive statistical analysis of the results

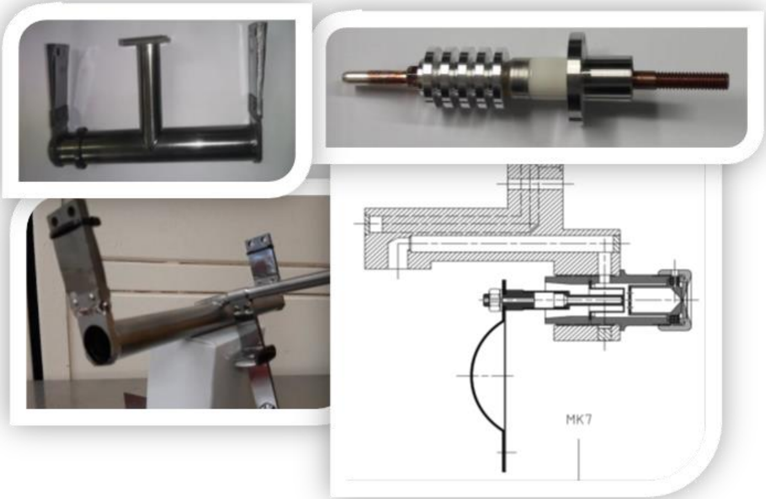
Challenges - Target characteristics

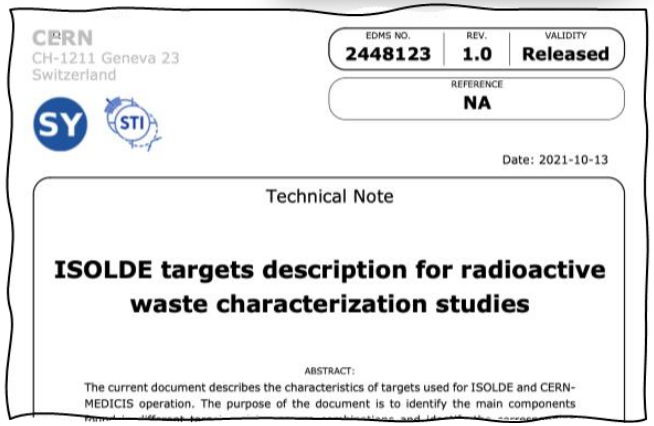
- **5 categories were identified to cover all the possible target designs.**

- **For each category, we calculated the total mass of each structural material (12 structural materials in total).**

- **For each of the 17 core materials, we retrieved the total mass and composition.**

- **For each material, either core or structural, we computed the average mass and standard deviation.**





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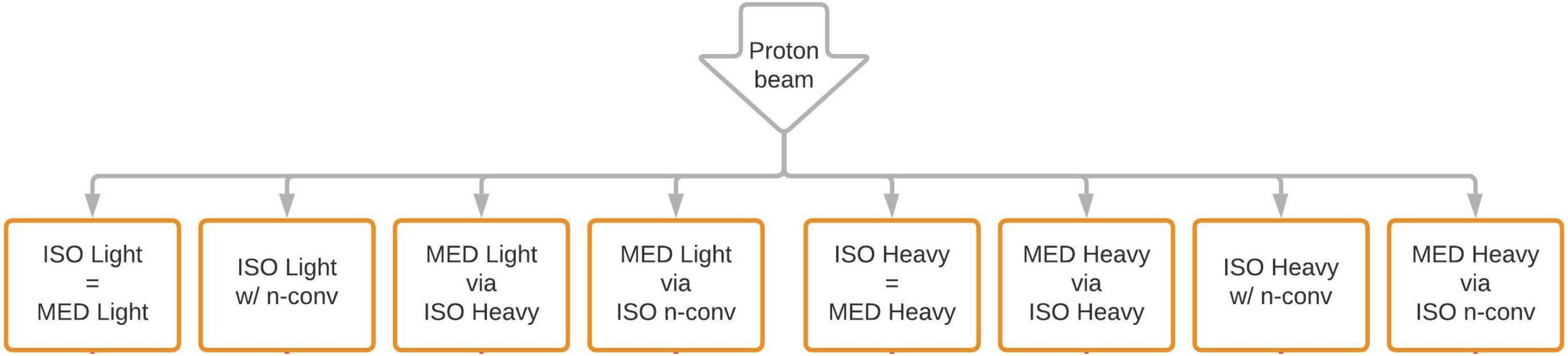
Technical Note

ISOLDE targets description for radioactive waste characterization studies

ABSTRACT:

The current document describes the characteristics of targets used for ISOLDE and CERN-MEDICIS operation. The purpose of the document is to identify the main components

Challenges - Irradiation configurations



8 irradiation configurations to simulate the activation of the structural materials using reference core materials:

- **Light: Tantalum**
- **Heavy: UC2C**

2 irradiation configurations to simulate the activation of the core materials:

- **Direct irradiation of each core material**
- **Irradiation via n-converter of each core material**

Estimation methodology – Calculation scheme

FLUKA simulations (Monte Carlo)

- **Input**: target geometry, main material compositions, irradiation parameters.
- **Output**: particle fluence spectra.

× **8+2 irradiation configurations**

ActiWiz Creator calculations

- **Input**: particle fluence spectra, exact material compositions, cooling times.
- **Output**: nuclide inventories, specific activities.

× **12+17 materials 25 cooling times**

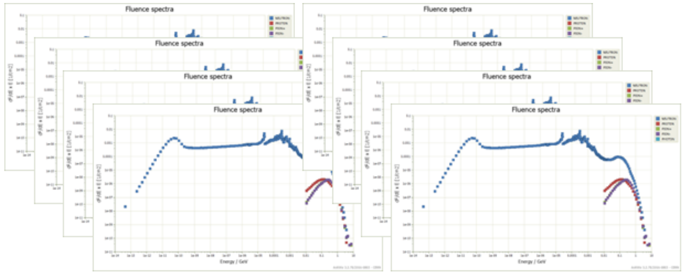
Statistical analysis

- **Input**: nuclide inventories, specific activities, protons on targets, material masses.
- **Output**: Min/Avg/Max total and specific activities with standard deviations.

× **~800 targets**

Estimation methodology – Example

- **Each ISOLDE-MEDICIS target contains 13.4 kg of Aluminium.**
- **It can be exposed to slightly 8 different particle spectra - 8 different irradiation configurations.**
- **We compute the nuclide inventories produced by each of the 8 different particle spectra for each cooling time.**
- **We compute the average nuclide inventory (given the previous 8) for each cooling time.**
- **We compute the average nuclide inventory for each target considering the target-specific number of received protons and the end-of-irradiation date.**



$$SA_i(mat, t, irr_c), \text{ for } i \in [1, N], c \in [1; C]$$

Representative nuclide inventory for Al, for a given cooling time, per received proton.

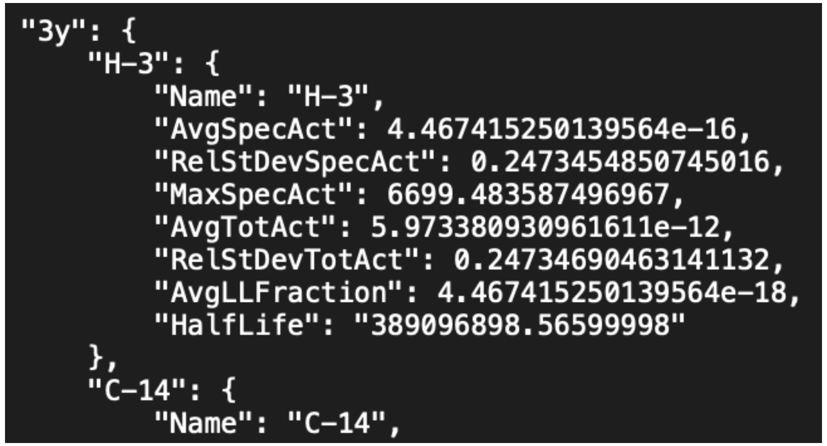
$$\overline{TA}_i(mat) = \sum_{k=1}^{K} \bar{A}_i(mat, t_k) \cdot POT_k \text{ , for } i \in [1, N]$$

General considerations

- **It is preferable to create a database with the extended ActiWiz results.**

- **JSON format provides an excellent, easy-to-read data structure for storing and processing the results.**

- **The combined use of FLUKA, ActiWiz Creator and Python (or C++, R, etc.) for the statistical analysis allows:**
  - Benefitting from each tool’s capabilities – modelling options, computational speed, analysis versatility.
  - Using each step’s output for other studies (e.g. using the FLUKA spectra for different AW calculations).



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Conclusions

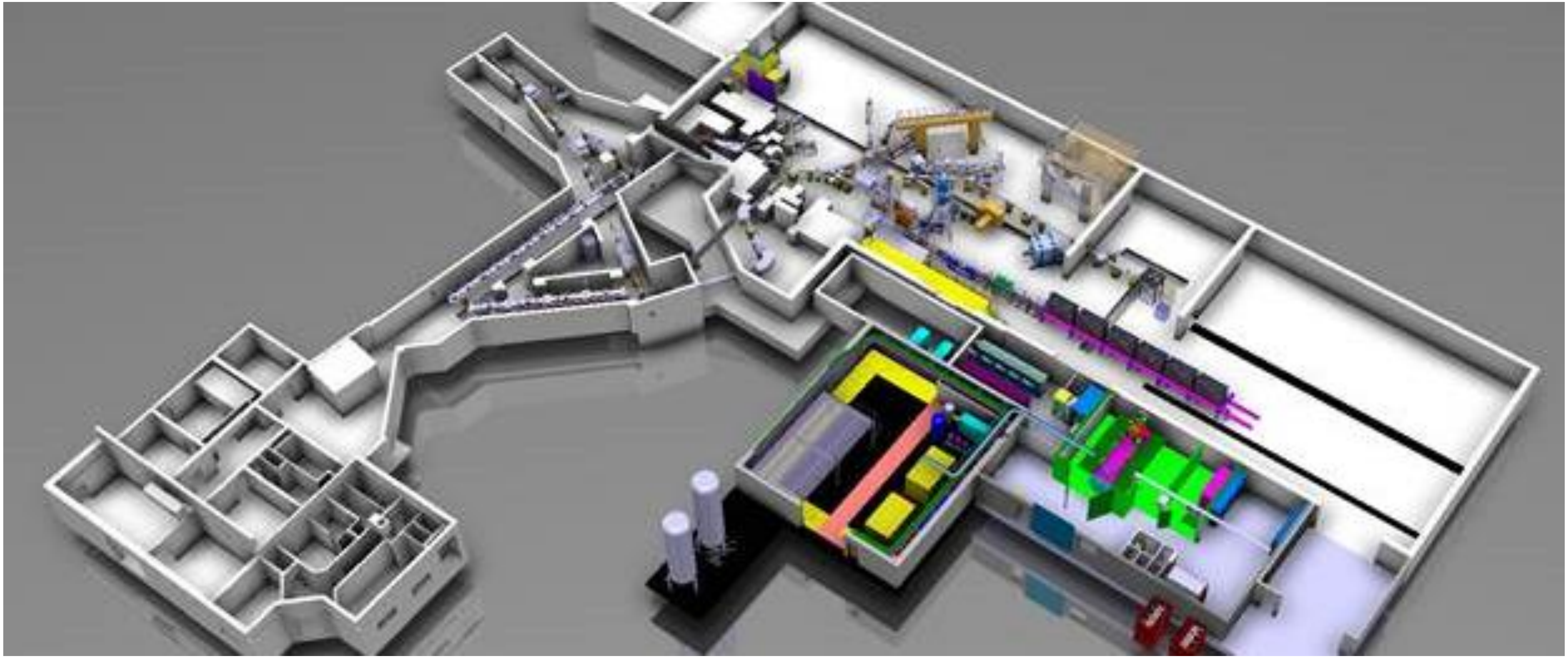
- **The structural and core materials are studied separately. 5 categories and 17 core materials were defined to cover the possible target designs.**

- **The estimation methodology**
  - Is comprised of 3 steps - FLUKA, ActiWiz, statistical analysis (Python),
  - Is designed to cover all the possible combinations of target designs, core materials, irradiation configurations, and cooling times.
  - Results in average nuclide inventories (total and specific activities) for each material considering the target-specific cooling time and number of primary protons.
  - Computes the standard deviation by considering the activity spread (produced by the irradiation configurations) and the mass spread.

- **ActiWiz was used to create a database rather than only the specific results required by the study.**

- **By combining Monte-Carlo (FLUKA) and analytical calculation (ActiWiz), and statistical analysis, one can manage to predict activities and scaling factors for extremely heterogeneous waste.**

Questions



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