Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DI LEGNARO

ADMIRAL

ISOLPHARM
SPES exotic beams for medicine

Laboratori Nazionali di Legnaro – INFN

IRIS (Isolpharm Radionuclide Impantation Station) development and simulations update

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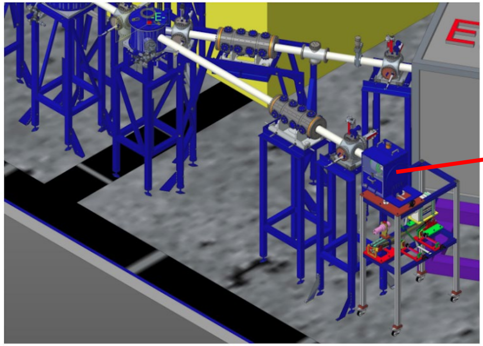
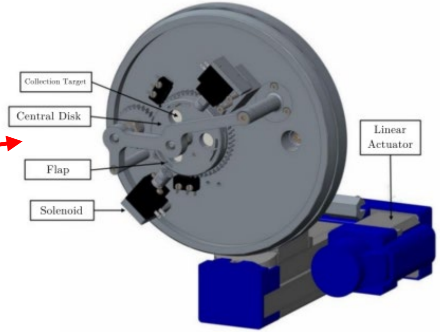
March 15th, 2024

Outline

I. Hardware development brief
II. Workflow of simulation study
III. Conclusion

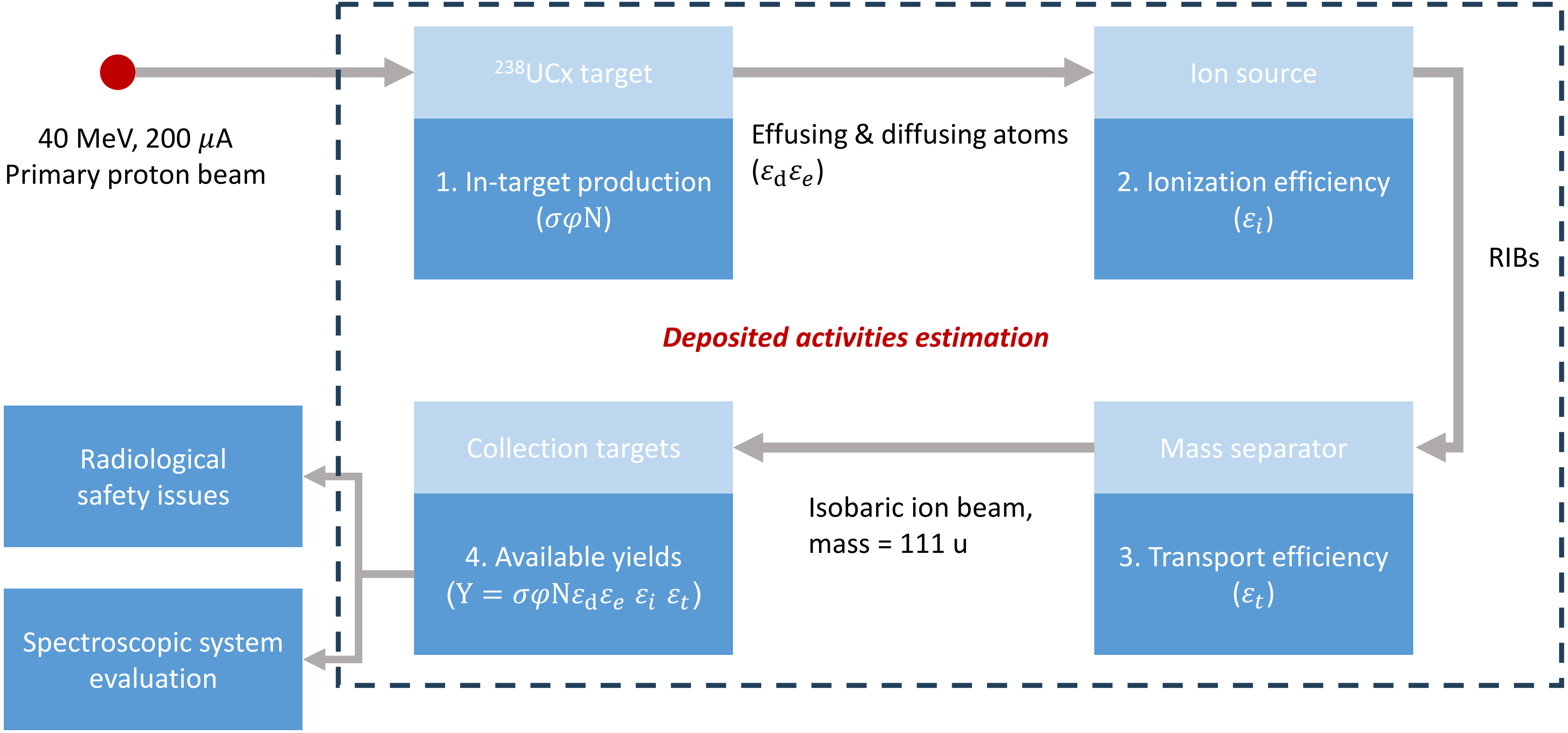
Hardware development brief





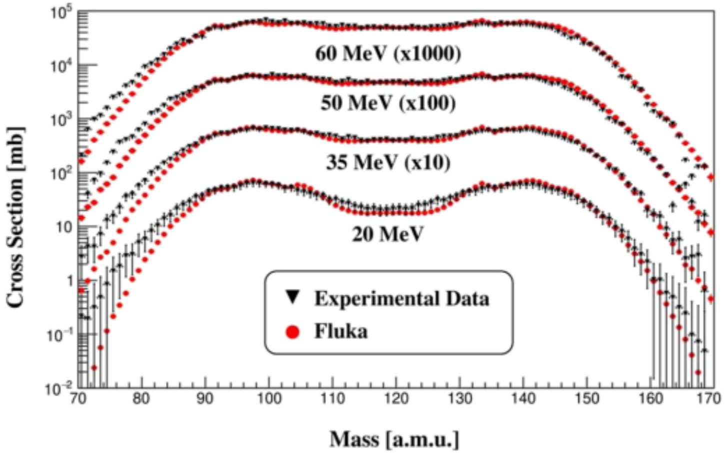
- Downstream of the SPES RIB line
- Handle the collection targets – Coupling with the beamline & subsequent movement for chemical processes
- Spectroscopic characterization – Online monitoring & EOB production measurement
- Being developed on the offline front-end in terms of electromechanical control and detection system

Workflow of simulation study

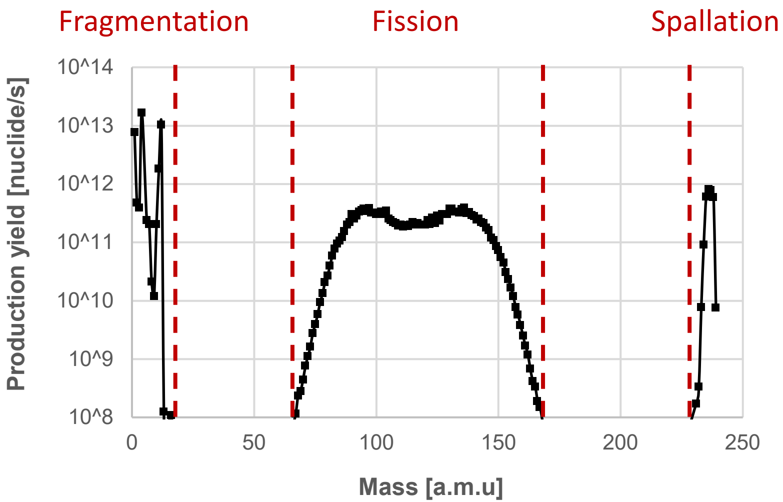


Workflow of simulation study

1. In-target production calculation



Comparison of ^{238}U proton-induced fission yields between FLUKA models and experimental data



Mass yield spectrum due to the primary proton beam interactions in the ^{238}UCx SPES target calculated with FLUKA 2023.3.3

Centofante, L., et al. "Study of the radioactive contamination of the ion source complex in the Selective Production of Exotic Species (SPES) facility." *Review of Scientific Instruments* 92.5 (2021).

Workflow of simulation study

Z	A	Isotope	Half-life	Half-life [s]	Volatile at 2000 ℃, 1e-5 mbar	In-target Production [nuclide/s/pr]	[nuclide/s/pr] merged	[nuclide/s]	Error %
40	110	110Zr	37.5ms	0.0375	0	9.00E-09	9.00E-09	1.13E+07	30.49
40	111	111Zr	24ms	0.024	0	2.00E-09	2.00E-09	2.50E+06	69.99
41	110	110Nb	82ms	0.082	0	1.40E-07	1.40E-07	1.75E+08	8.896
41	111	111Nb	54ms	0.054	0	4.20E-08	4.20E-08	5.25E+07	15.35
41	112	112Nb	33ms	0.033	0	1.40E-08	1.40E-08	1.75E+07	28.93
42	110	110Mo	0.296s	0.296	0	3.08E-06	3.08E-06	3.85E+09	1.789
42	111	111Mo	186ms	0.186	0	7.55E-07	7.55E-07	9.44E+08	3.747
42	112	112Mo	120ms	0.12	0	4.18E-07	4.18E-07	5.23E+08	4.518
43	110	110Tc	0.9s	0.9	0	2.07E-05	2.07E-05	2.59E+10	0.7812
43	111	111Tc	290ms	0.29	0	1.28E-05	1.28E-05	1.60E+10	0.6174
43	112	112Tc	271ms	0.271	0	4.45E-06	4.45E-06	5.56E+09	1.418
44	110	110Ru	12.04s	12.04	0	8.58E-05	8.58E-05	1.07E+11	0.3555
44	111	111Ru	2.12s	2.12	0	4.50E-05	4.50E-05	5.63E+10	0.4589
44	112	112Ru	1.75s	1.75	0	4.15E-05	4.15E-05	5.19E+10	0.4464
45	110	110Rh	3.35s	3.35	0	4.39E-05	4.39E-05	5.49E+10	0.499
45	111	111Rh	11s	11	0	7.83E-05	7.83E-05	9.79E+10	0.289
45	112	112Rh	3.6s	3.6	0	6.74E-05	6.74E-05	8.43E+10	0.4466
46	110	110Pd	STABLE	0	X	6.96E-06	6.96E-06	8.70E+09	1.248
46	111	111Pd	23.4m	1404	X	1.31E-05	1.33E-05	1.66E+10	0.96
46	112	112Pd	21.04h	75744	X	4.26E-05	4.26E-05	5.33E+10	0.4584
47	110	110Ag	24.56s	24.56	X	5.10E-08	6.30E-08	7.88E+07	13.28
47	111	111Ag	7.45d	643680	X	3.88E-07	6.92E-07	8.65E+08	6.362
47	112	112Ag	3.13h	11268	X	2.32E-06	2.32E-06	2.90E+09	2.2
48	111	111Cd	STABLE	0	X	2.00E-09	3.00E-09	3.75E+06	69.99
48	112	112Cd	STABLE	0	X	3.20E-08	3.20E-08	4.00E+07	15.31

Filter 1 – Half-life

Filter 2 – Volatility

Chosen ones

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Workflow of simulation study

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2. Ionization efficiency estimation

Plasma ion source

Test number	Measured ionization efficiency
#	%
1	10.54
2	8.91
3	16.17
4	11.88
5	8.8
6	4.18
7	6.85
8	15.63
9	14.83
10	14.62
Average	**11.24±4.07**

Tests 8–10: **15.03±0.53**

Laser ion source **≤14% RILIS@CERN**

3. Transport efficiency estimation

Calculation results of A = 150 u (safely compared to A = 111 u) :

- **WF (Wien Filter)** and **LRMS (Low Resolution Mass Spectrometer)** can individually remove **96.5%** and **99.99%** of isotopes with mass numbers close to 150.
- only **3.5E-4 %** of isotopes with A close to 150 contaminate the target, which could be neglected even in the case of mass number = 111.

Z	A	Isotope	In-target production	Ionization efficiency	Transport efficiency	Available yield
			[nuclide/s/pr] merged	%	%	[A]
46	111	111Pd	1.66E+10	15	99.99965	3.99E-10
46	112	112Pd	5.33E+10	15	3.50E-04	4.47E-15
47	110	110Ag	7.88E+07	15	3.50E-04	6.62E-18
47	111	111Ag	8.65E+08	15	99.99965	2.08E-11
47	112	112Ag	2.90E+09	15	3.50E-04	2.44E-16

Available yield of mass number = 111 **0.42 nA**

Ballan, Michele, et al. "Preliminary evaluation of the production of non-carrier added 111Ag as core of a therapeutic radiopharmaceutical in the framework of ISOLPHARM_Ag experiment." *Applied Radiation and Isotopes* 164 (2020): 109258.

Radiological safety issues

Benchmark between FLUKA and Phits results with monoisotopic source and simple geometry

↓

Build extended source (source.f) and detailed geometry of IRIS

↓

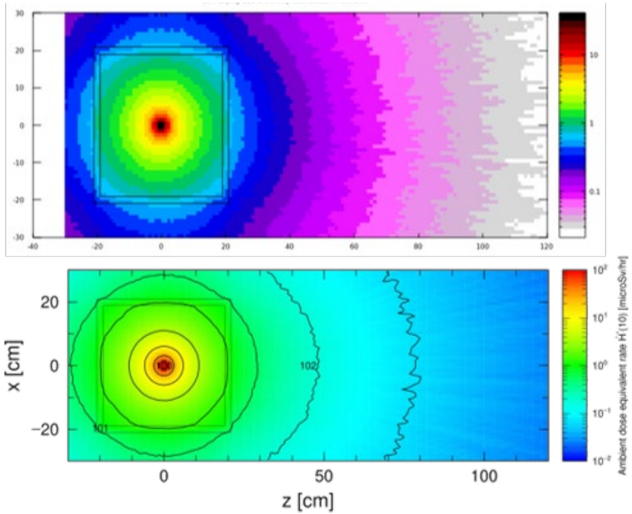
Apply time evolution information according to the real operation circles

↓

Evaluate the ambient dose equivalent rate at different times, provide guide to shielding of IRIS

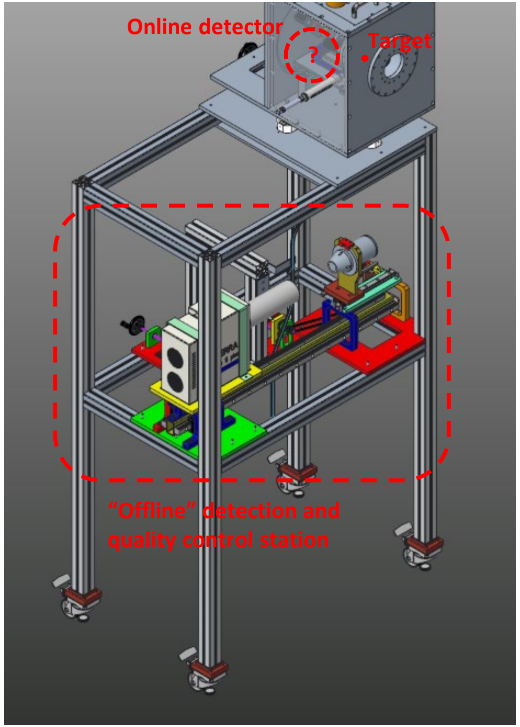
↓

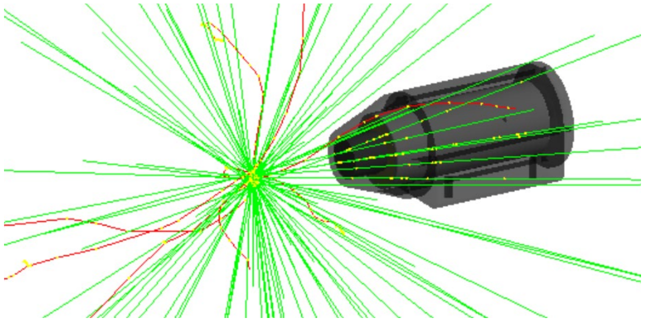
Evaluate the required shielding of the transportation container



- The relative difference of the dose equivalent rate in a sphere 1 m away from the target is ~ 16%.
- FLUKA is selected for following studies due to its capability of scoring at different times during and after production phase

Spectroscopic system evaluation





- Online (LBC) and Offline (LBC + HPGe) detection systems are studied in separate projects
- The detector response and the detection efficiency is studied with Geant4 on simulation side
- CADMesh is used to import detector and IRIS mechanical elements models into geometry
- StandardElectroMagnetic and G4RadioactiveDecay lists would be applied
- Simulation results will provide the guide to detectors place-ment and be used as bench-mark with experimental results

Conclusion

- A work flow is being developed for the case of estimating deposited activities of radionuclides of interest on collection targets installed in IRIS, different application scenarios may require different criteria.
- Starting from the estimated results, a few simulation studies can be performed to benefit the hardware development mutually, and used for benchmark in future tests.
- Considering the first-stage experiments arrangement of ISOLPHARM, Other targets (SiC, TiC, etc.) along with products of medical interest will be studied. The UCx target is chosen as the study case for its complexity in production.
- Preliminary results are supposed to be presented on SATIF-16 meeting.
- At this stage, a few issues are still to be discussed:
  - Lack of ionization efficiency data of some radionuclides of interest can be encountered;
  - Operation cycle and the sequence of collection targets handling need to be decided for simulation studies.