Study of Radioactive Mercury Observed at J-PARC Neutrino Target Station

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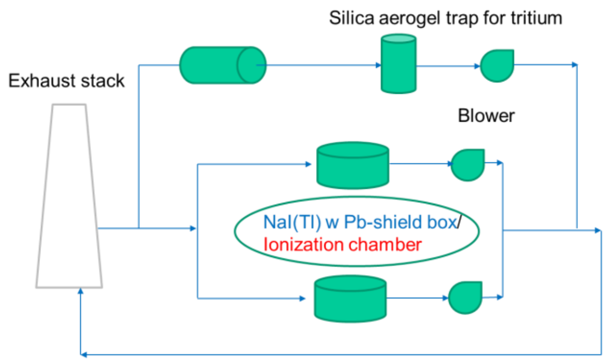
Radiological control

- At J-PARC, radiation levels and the radioactivity in the exhaust air and drainage water are monitored.



To measure activity without pause, gas monitors are duplicated

- Airborne activity in exhaust
  - Radioactive gas

    Ionization chamber or Plastic scintillator / NaI(Tl) with Pb shield

    For H-3, silica aerogel traps and liquid scintillator
  - Radioactive dust

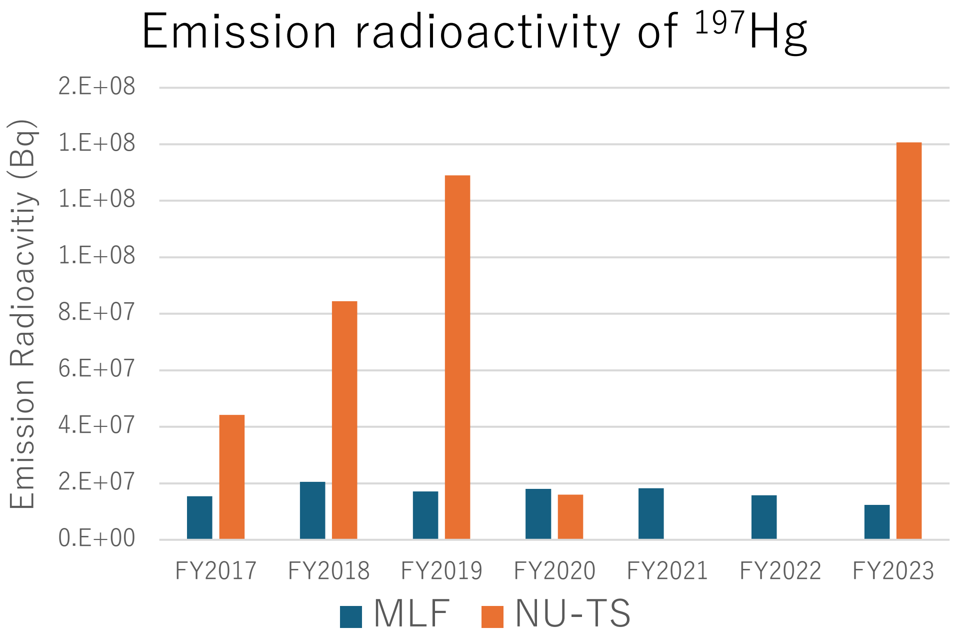
    Semi-conductor / GM or NaI(Tl) with filters

    Filters: A cellulose-glass fiber filter and a charcoal filter (for I, Hg etc.)
    replaced once a week and measured with Ge detector
- Activity in drain
  - Before drainage, radioactivity is measured with liquid scintillator and Ge detector

Radiomercury in J-PARC

Radiomercury (rad-Hg) is observed in exhaust air.

- MLFs have huge radioisotopes within the Hg spallation target but do not emit externally.
- NU buildings emit more rad-Hg than MLF.



Rad-Hg in the neutrino exp. facility

- Specific activity are much lower than the regulatory limits.
- It cannot be a barrier to Neutrino physics.
- However, its origin is unclear.

Reason to study rad-Hg

- MLF have a spallation neutron source with liquid mercury containing huge rad-Hg
- Necessary to show that the rad-Hg at the Neutrino exp. facility is not related to MLF origin.
- Responsibility for clarifying nuclide production mechanisms. (Japan-specific problems…?)

Outline

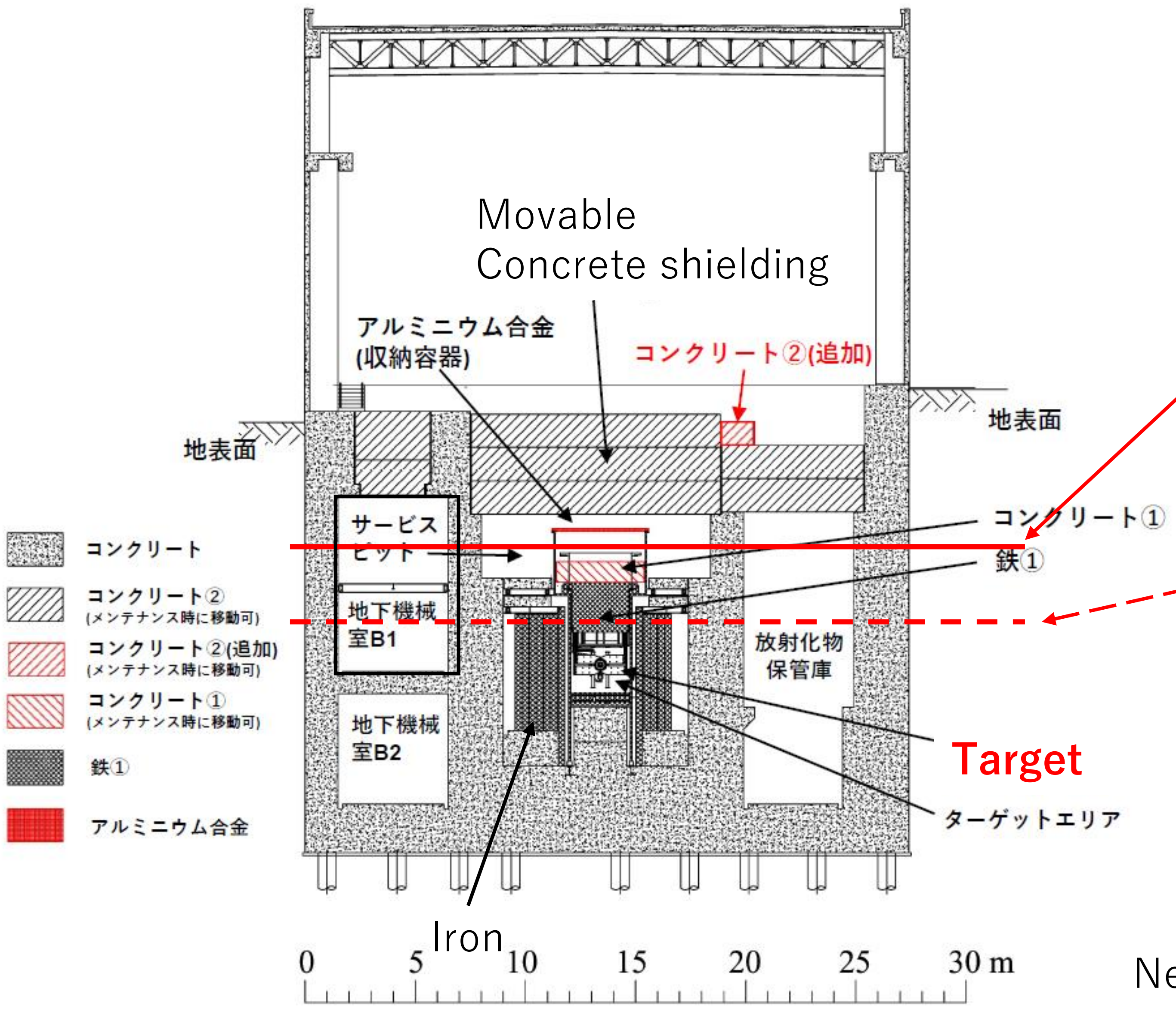
Deducing the source and production mechanism of rad-Hg

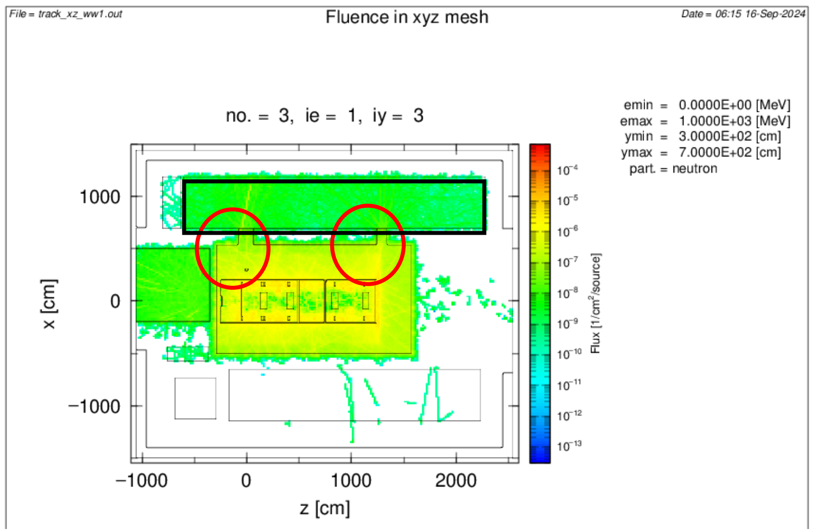
- Radiation environment at the neutrino TS?
- What is the target element producing radiomercury? What source?

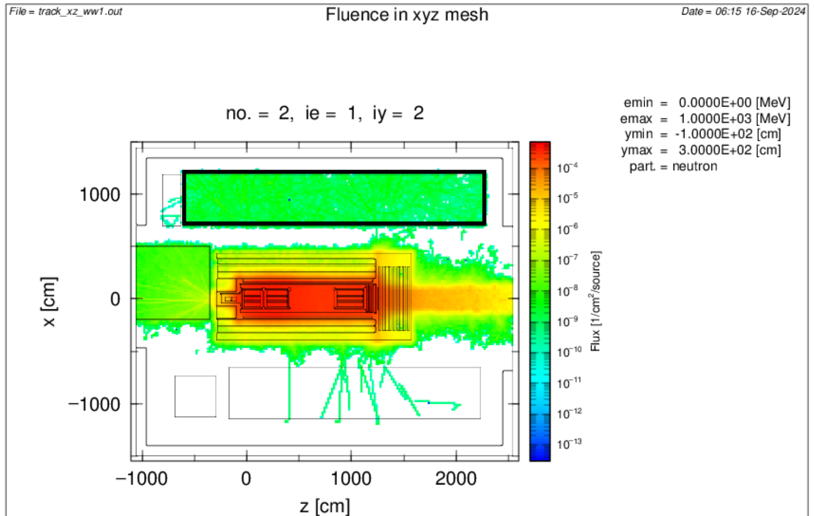
✓Experimentally collecting radiomercury with activated carbon (AC)
✓Radiation environment calculation with PHITS code
✓Model radioisotope yield calculation with PHITS code

Radiation environment of the neutrino experimental facility

Target Station Building, Neutrino Exp. Facility



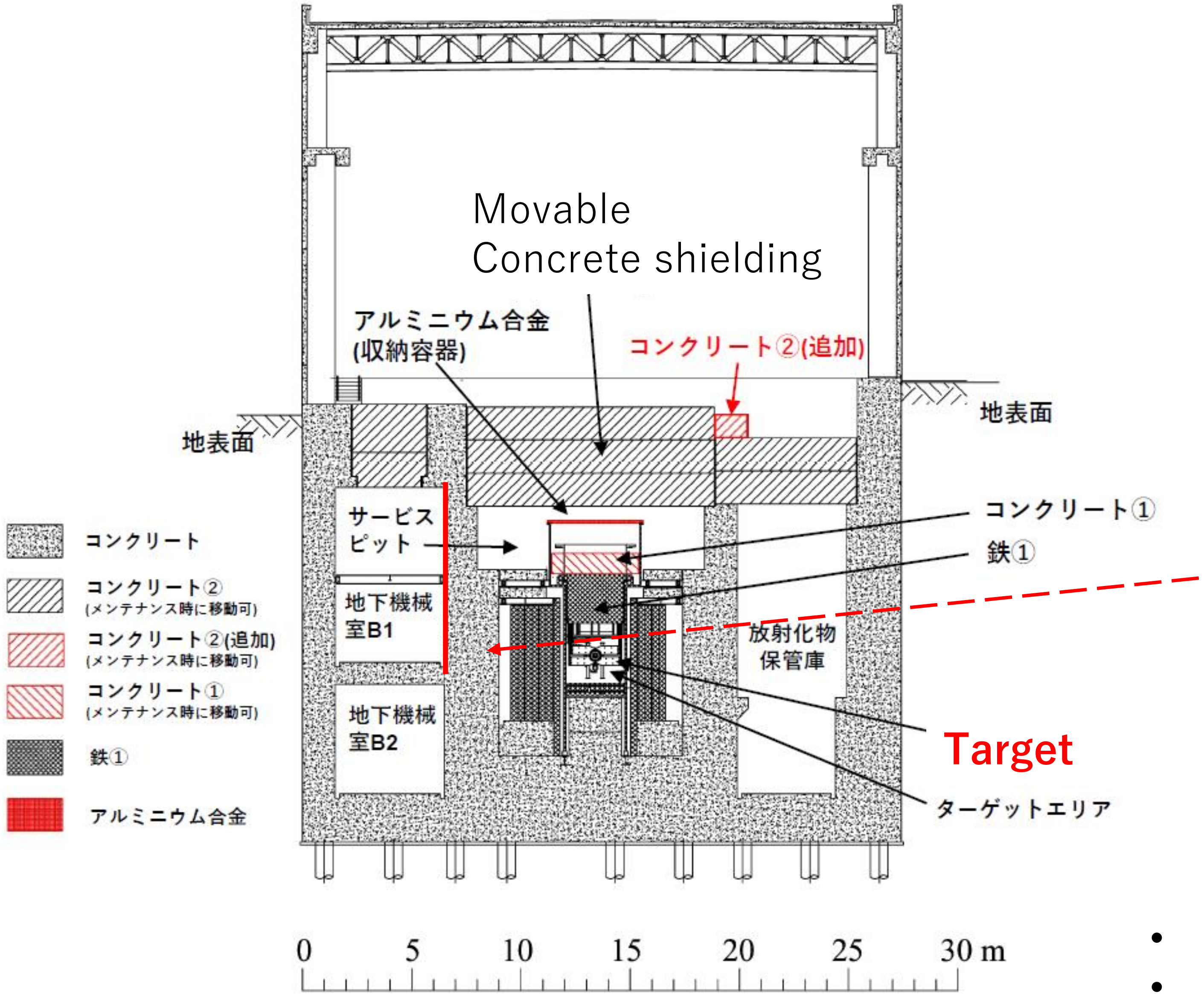


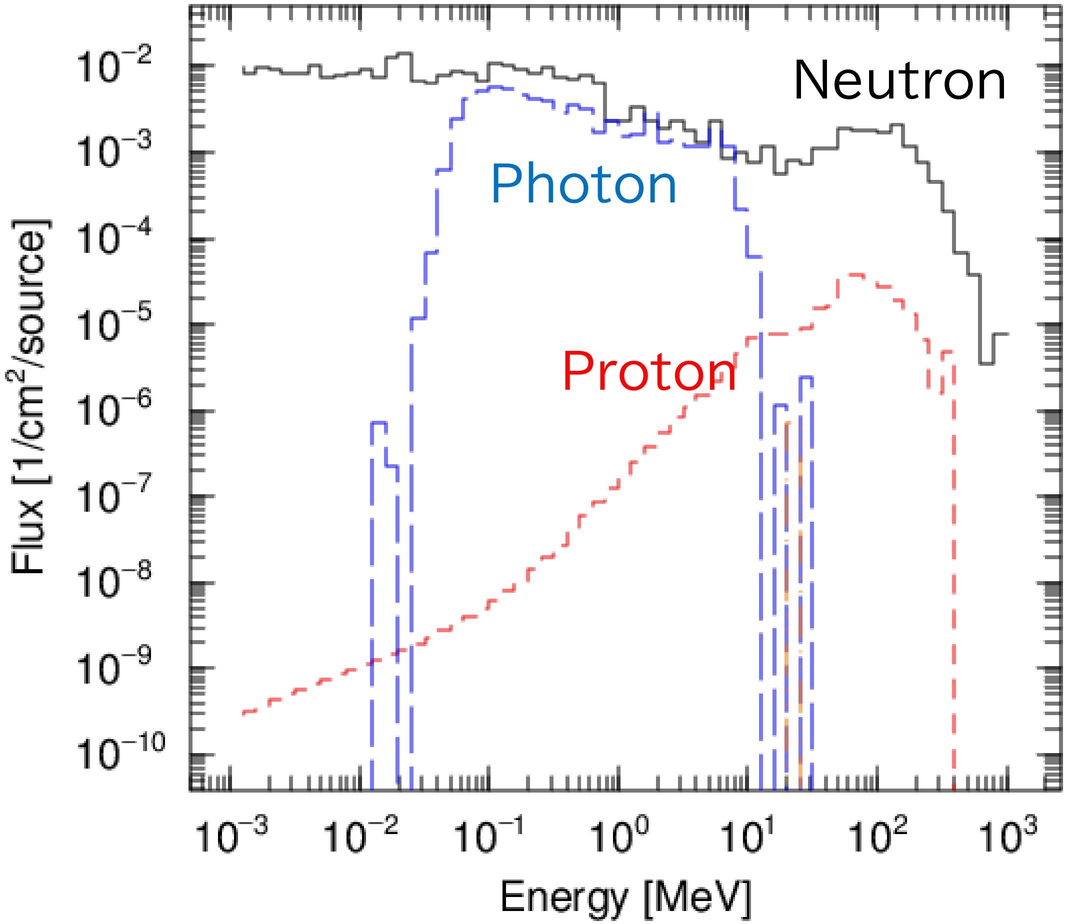


Calculated by Dr. E. Lee with PHITS

Neutrons fill the machinery room through two doors.

Target Station Building, Neutrino Exp. Facility





- Much protons and neutrons with 100-200 MeV
- In reality, lower energy due to the components.

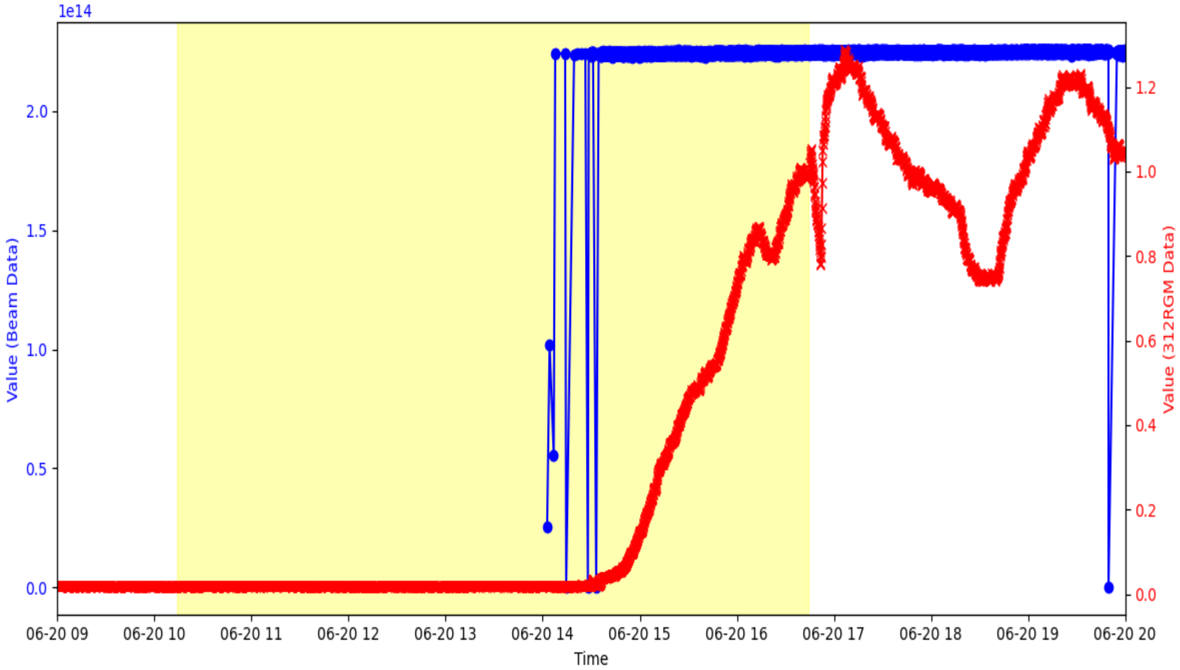
Collecting radiomercury with activated carbon cartridge

Air sampling

- Air sampling experiment was conducted in June 2024 operation.
- The air in the machinery room was collected for 134 min .at 100 L/min flow rate.
- Room gas monitors (ionization chamber) in the outside of interlocked area of Target Station were used.
- Activated carbon cartridges “CHC” (ADVANTEC), filter paper HE-40T (ADVANTEC, ø 60 mm) for dust filters were used.

Activated carbon cartridge (ADVANTEC)

Neutrino TS operation and radioactivity in RGM

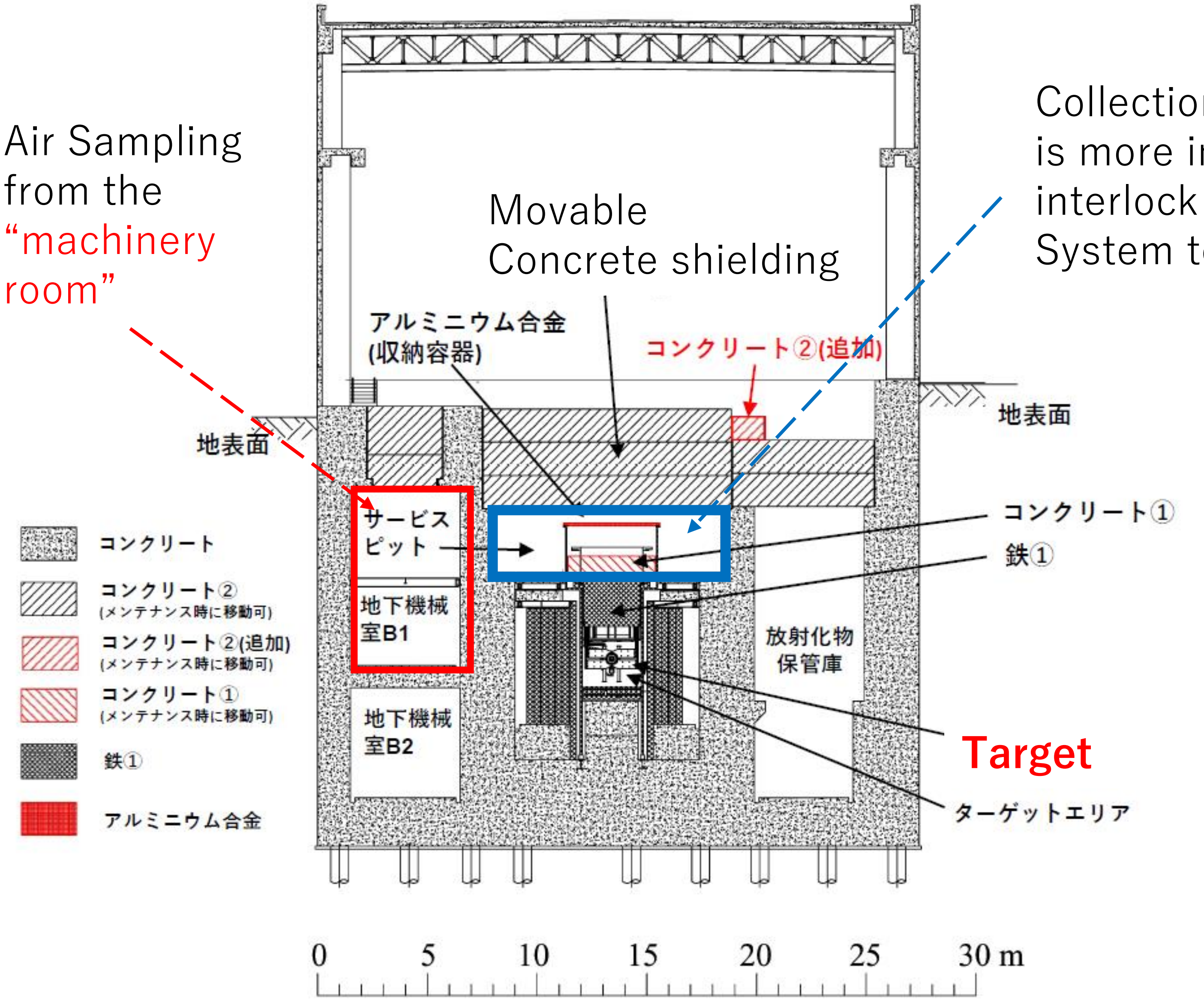


Air sampling

Air Sampling from the “machinery room”

Movable Concrete shielding

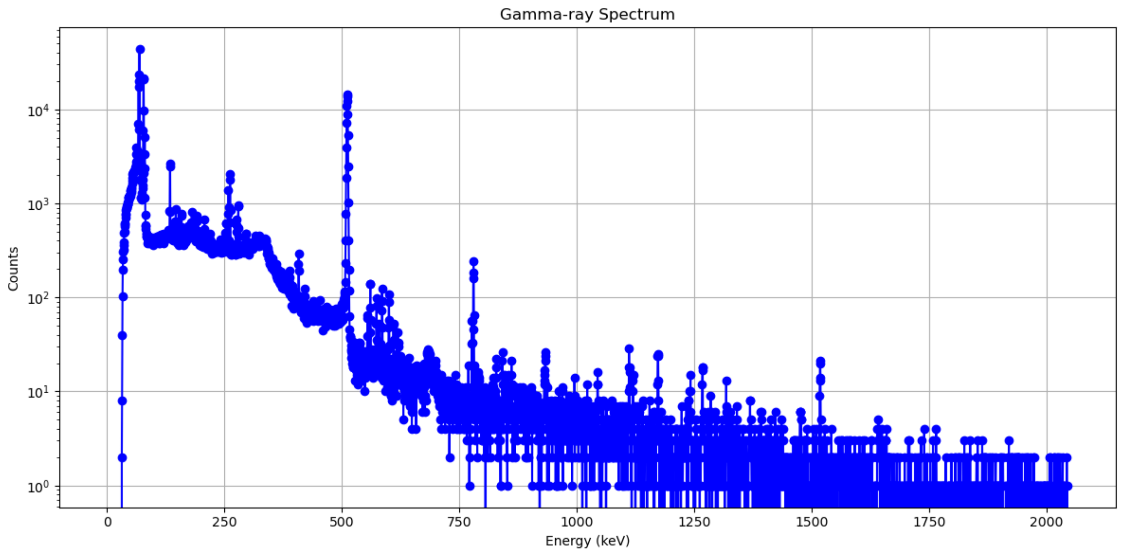
Collection of air from the service pit with high dose rate is more interesting, but the withdrawal of air outside the interlock area could activate the Personnel Protection System to stop beam operation.

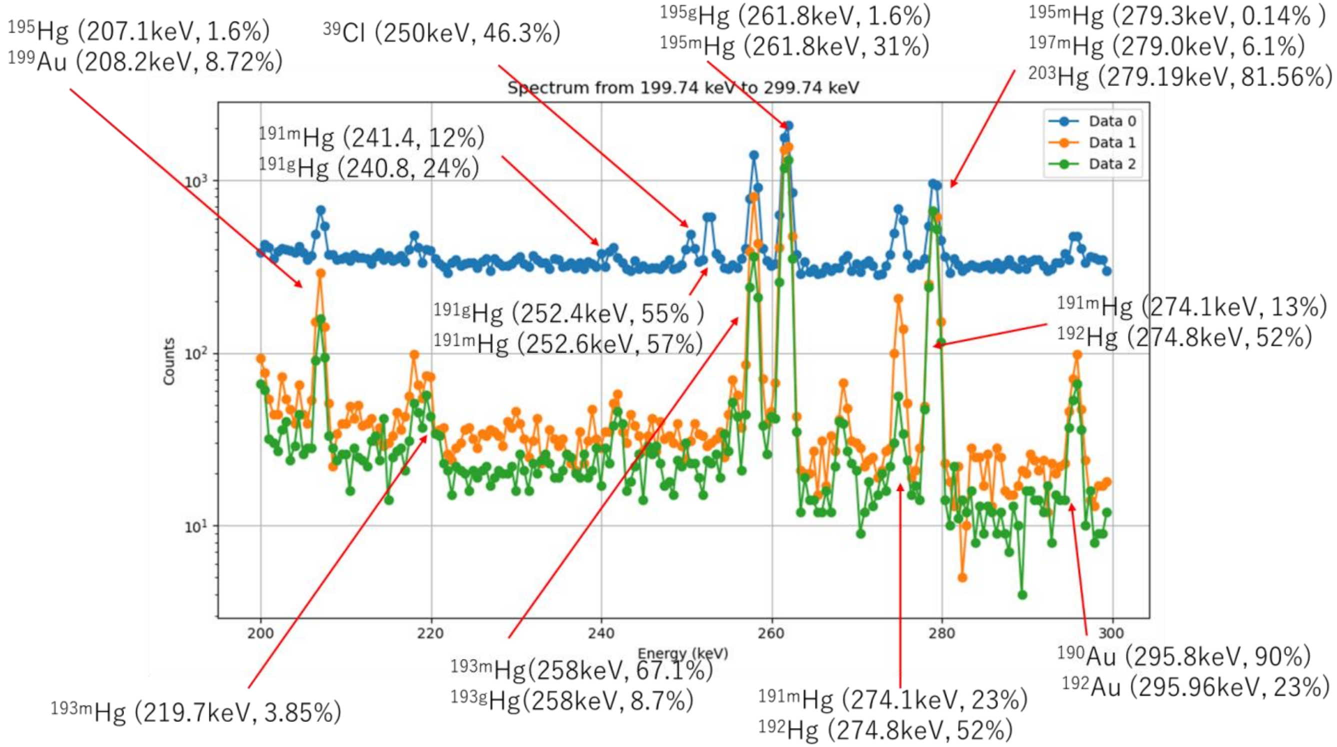


Gamma-ray analysis

- ✓ Sample was transported from the neutrino target station to the radiation measurement bldg.
- ✓ Gamma-ray measurement with Ge semiconductor detector.

Gamma-ray spectrum of CHC with rad-Hg





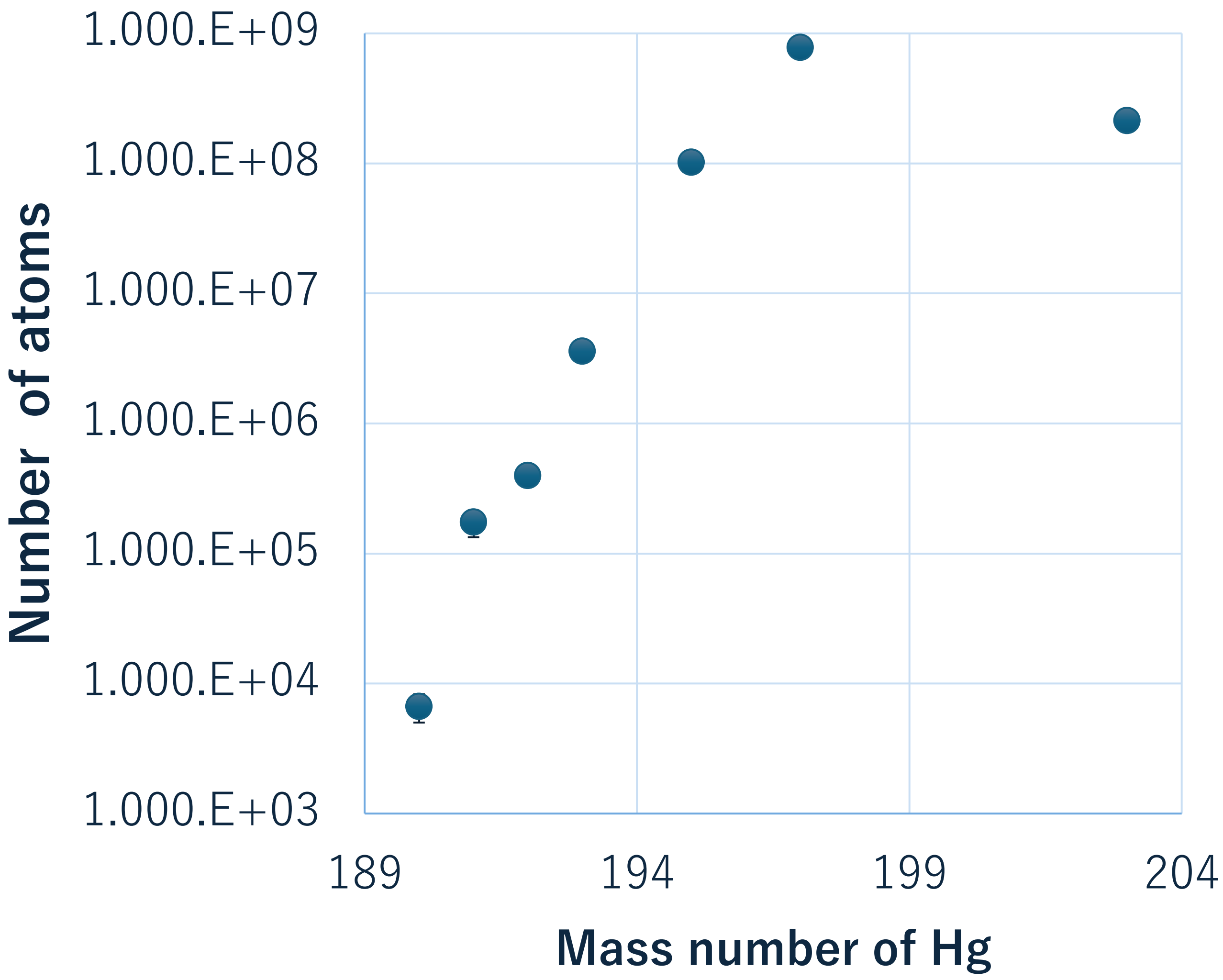
(Cooling Time: 2023 s, 19602s, 59786s)

Collection radiomercury in the machinery room

- ✓ Observed various rad-Hg isotope on an activated carbon filter.

Nuclide	Half-life (sec)	Activity (Bq)	err
Hg-190	1200	1.24.E+01	3.10.E+00
Hg-191g	2940	3.04.E+01	8.00.E+00
Hg-191m	3000	2.23.E+01	9.60.E+00
Hg-192	17460	3.90.E+01	3.40.E+00
Hg-193g	13680	2.80.E+01	1.23.E+01
Hg-193m	42480	5.23.E+01	5.60.E+00
Hg-195g	35640	8.05.E+02	7.36.E+01
Hg-195m	149760	2.92.E+02	2.38.E+01
Hg-197g	230904	2.28.E+03	2.90.E+02
Hg-197m	78480	2.08.E+02	4.80.E+00
Hg-203	4025376	4.54.E+01	2.00.E-01

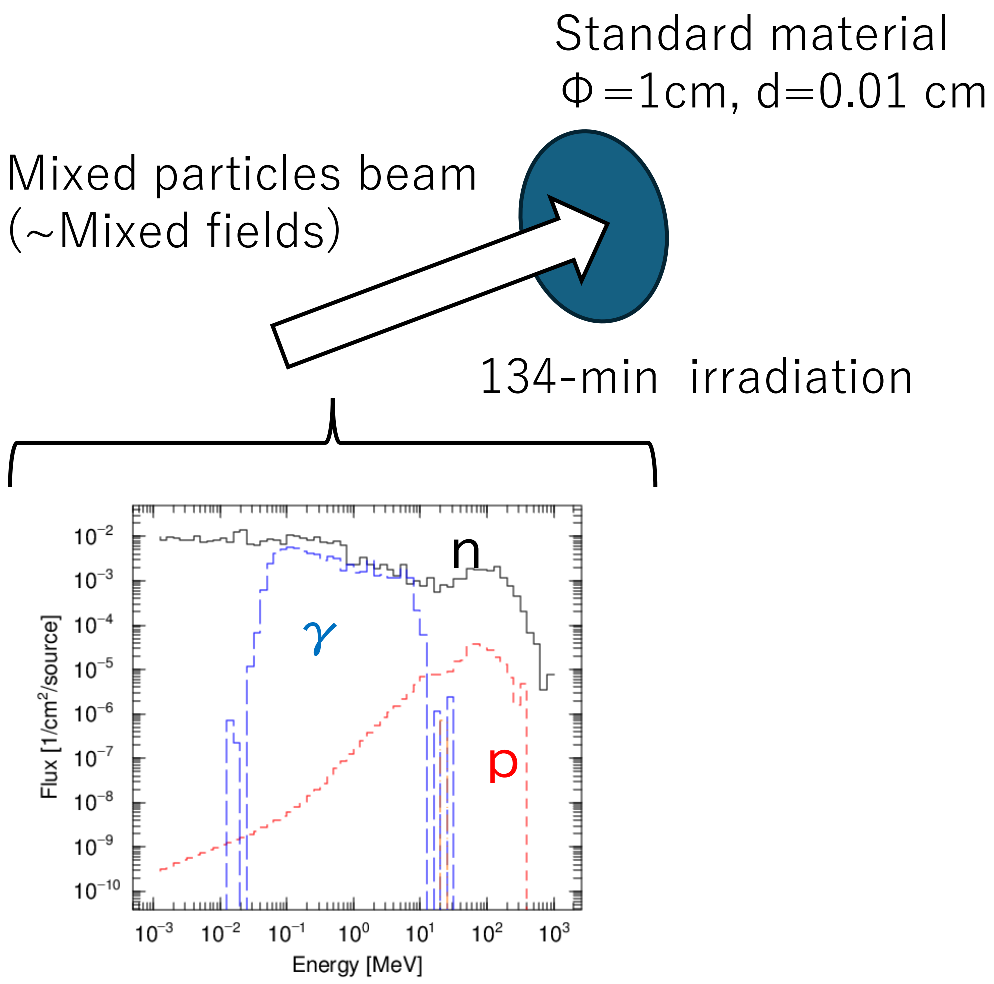
(At the end of collection)

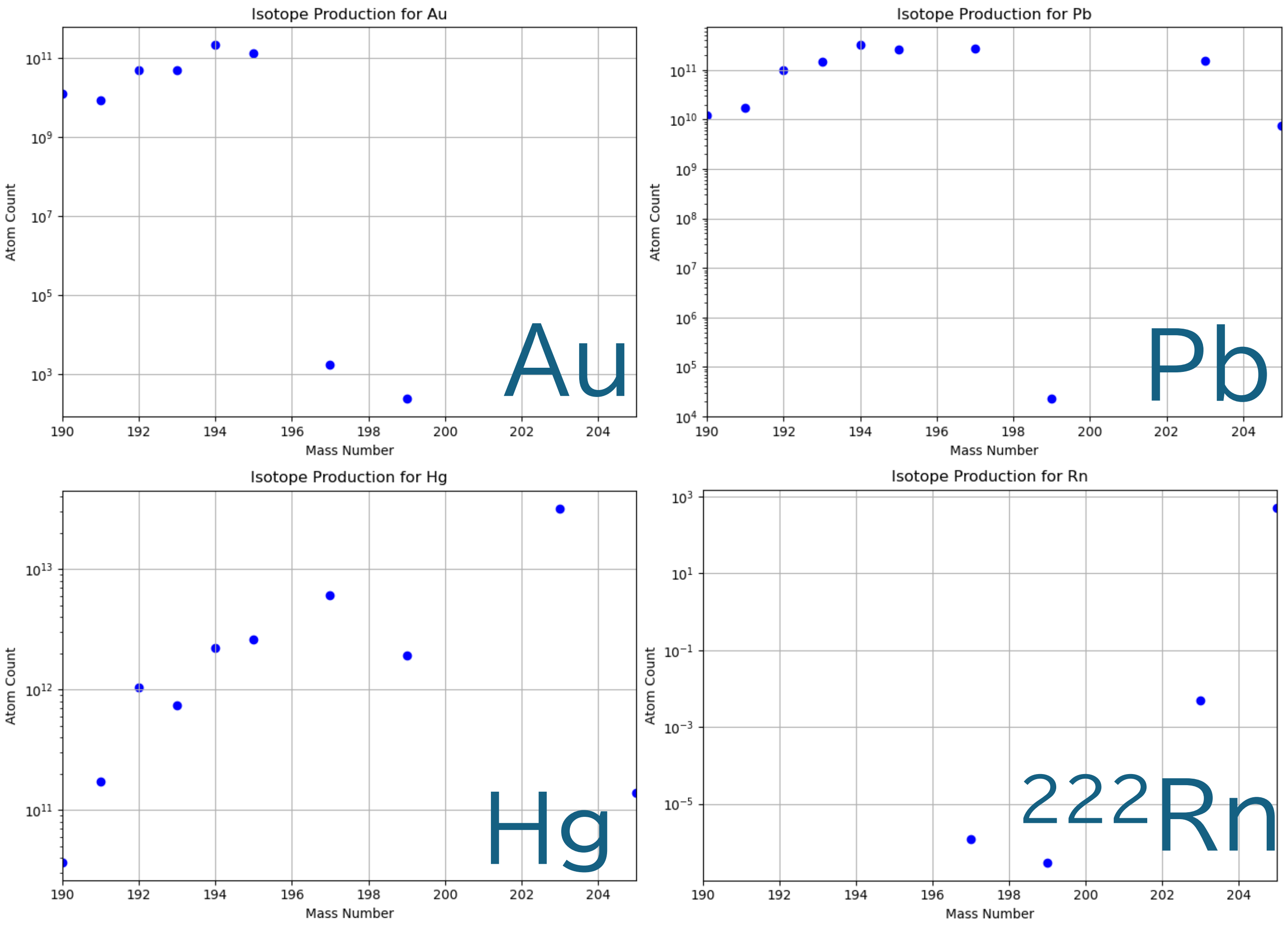


Comparison with model nuclear reaction calculation by PHITS

Model isotope production calculation

- ✓ Model calculations were conducted to deduce the "target material" producing rad-Hg.



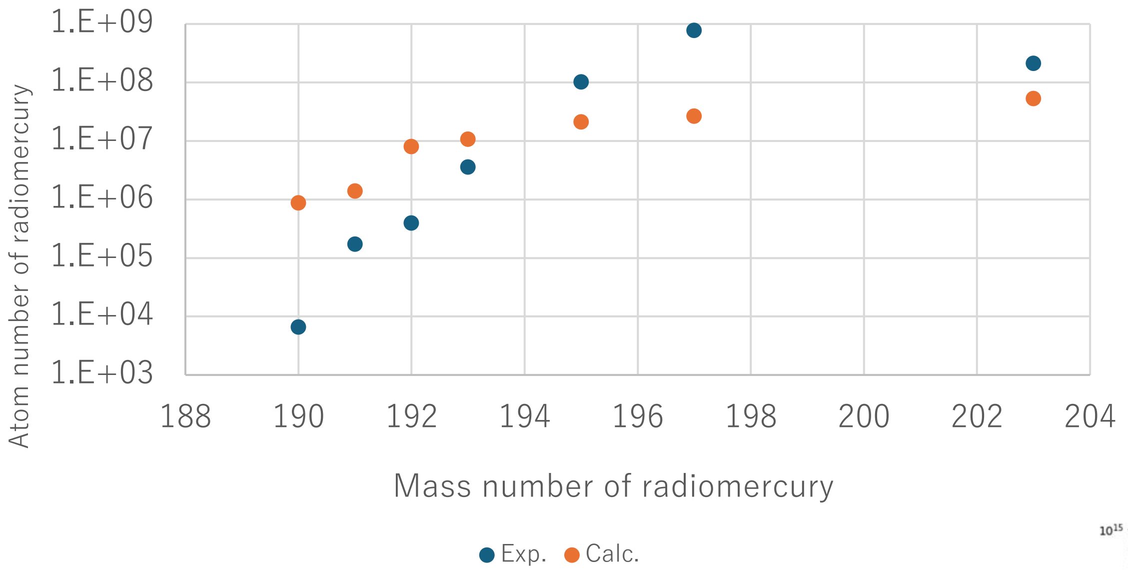


- Au target does not produce higher A rad-Hg
- Rn targets do not produce lower A rad-Hg
- Hg and Pb targets produce rad-Hg with broad A

Estimation of rad-Hg produce

In terms of isotopic distribution, source of rad-Hg supposed to be Hg or Pb.
As sources, naturally present Hg (1.7 ng/m^3) and Pb (73 ng/m^3) in air are good candidate.

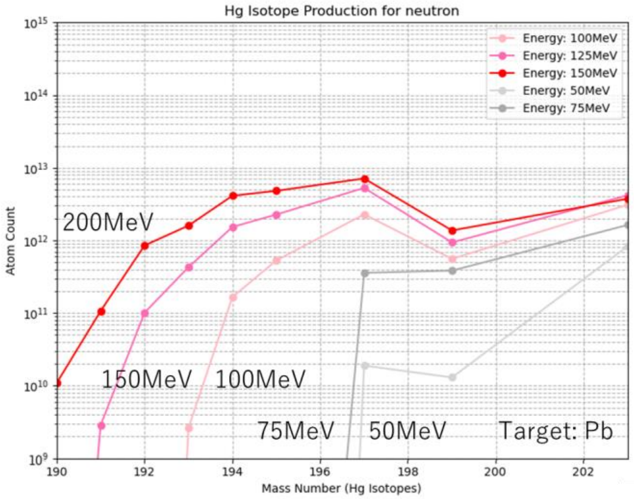
Radiomercury in the air extracted from the machinery room ($V = 13.4\ m^3$)



Possible discrepancies between experimental and calculation data;

- A = 197-203: Calc. underestimates by not considering thermal neutrons
- A = 190-197: Calc. overestimates due to not considering degrade of 100-200 MeV neutron/proton

➢ We are planning actual measurements of the radiation field in the machinery room



Summary

- J-PARC neutrino experimental facility emits much less rad-Hg than the regulation value.
- We are trying to estimate its origin as an accountability of the J-PARC safety division.

- Based on experimental radioactivity measurements and PHITS calculations, it is semi-quantitatively estimated that the source is probably naturally-present mercury and lead in the air.
- The accelerators upgrade has resulted in background observations of nuclides that were not previously observed.
- Rad-Hg in the neutrino facility would not be related to the MLF.

- Actual measurements of the mixed particle field in the machinery room are expected to verify the hypothesis.