Characterization of the nTOF Radioactive Waste

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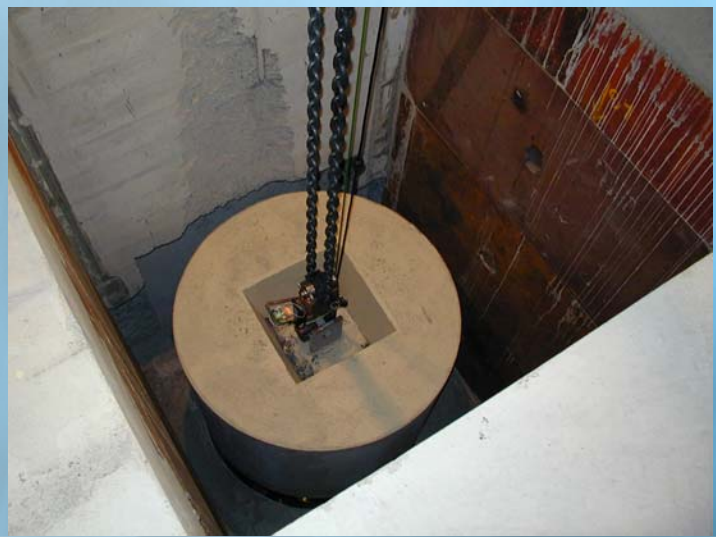
Overview

- **FLUKA Calculation Details & Method**
  - Geometry, beam details, irradiation & cooling times
  - Relevant quantities
- **Results**
  - Target with pure composition
  - First estimate for detailed composition
  - Respective inherent uncertainties
- **New target**
  - General design goals

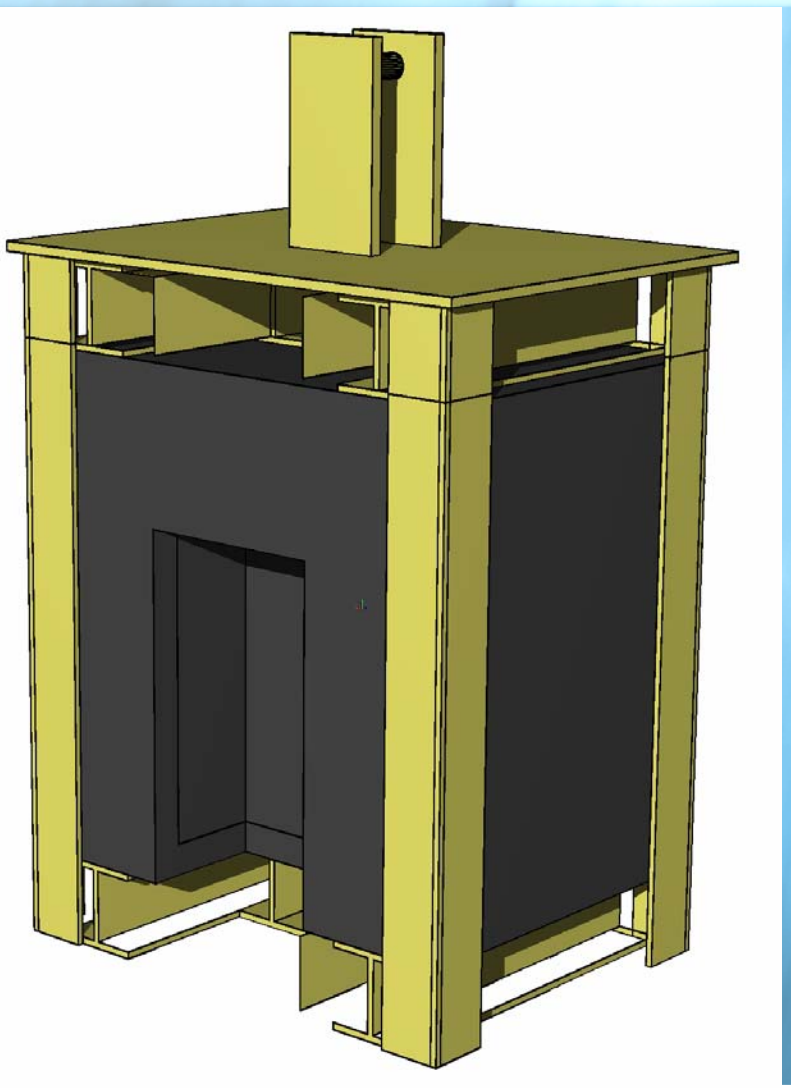
The Target…



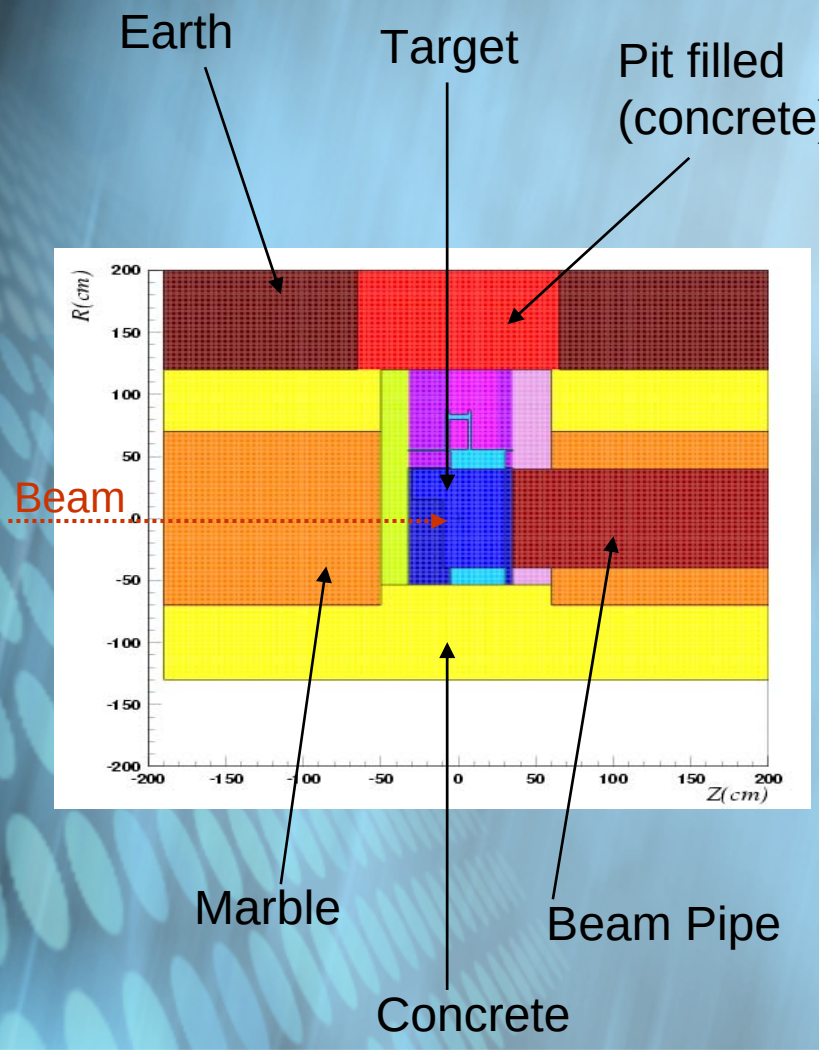
FLUKA Calculations

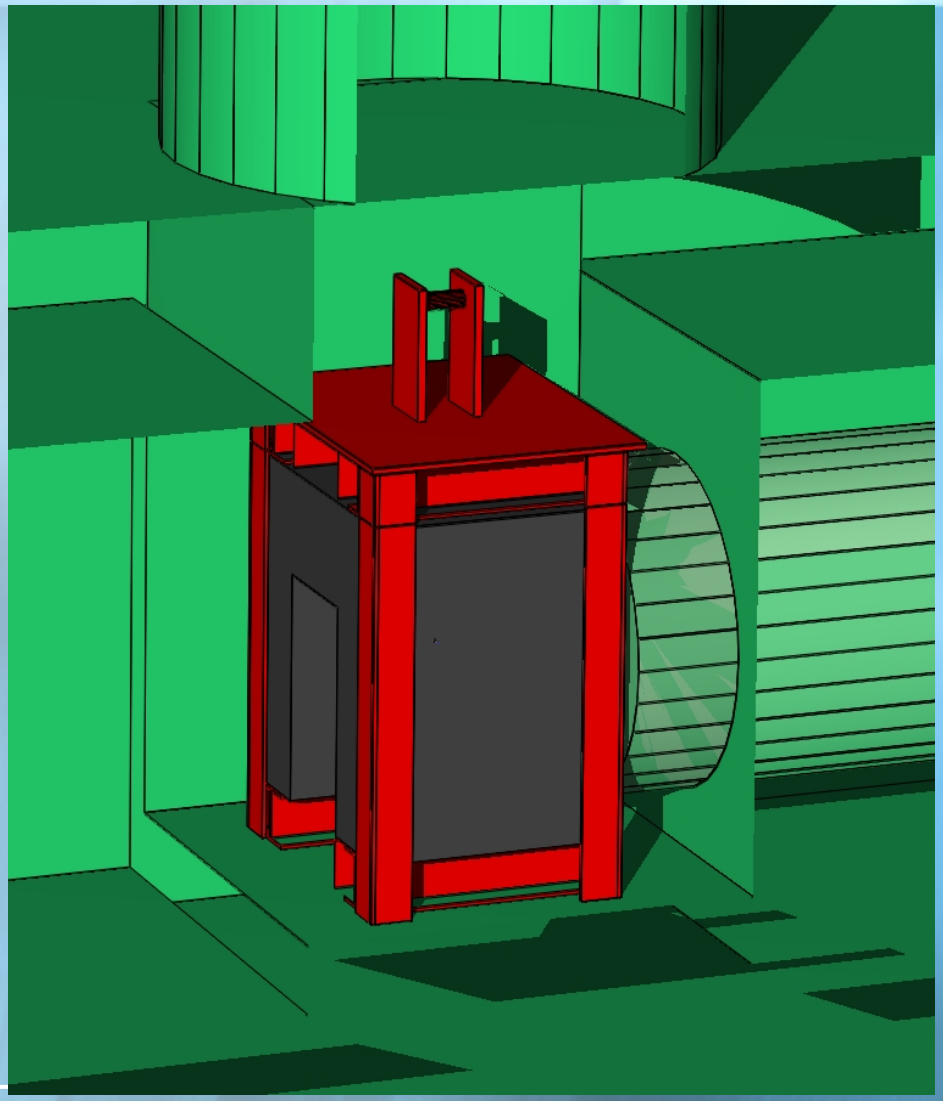
- **Detailed geometry**
  - target and support, surrounding structure (shielding, cooling basin,…)
  - downstream tunnel structure
- **Beam & Irradiation Parameters**
  - Irradiation time: 6 months/year
  - Proton intensity: $5x7x10^{12}$ p/supercycle
  - Protons on target: $3.2x10^{19}$ p/year
    ($1.3x10^{19}$ p/year)
- **Activation of target**
  - specific and total activity as well as expression of the first as multiple of the exemption limits

Geometry Details

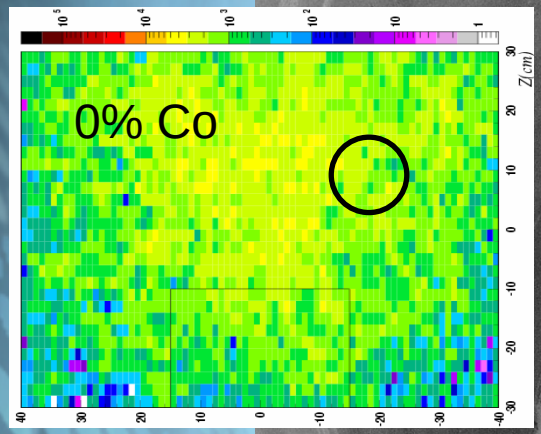


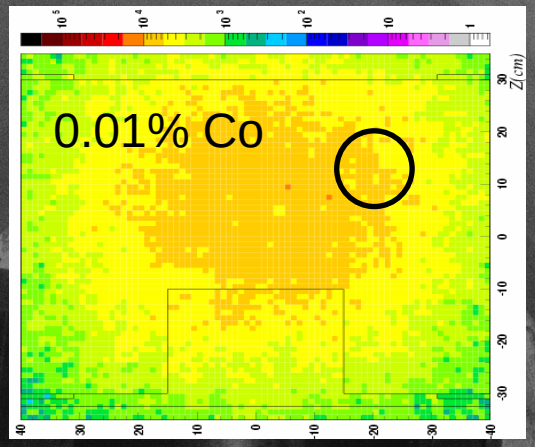
Target in the Pit

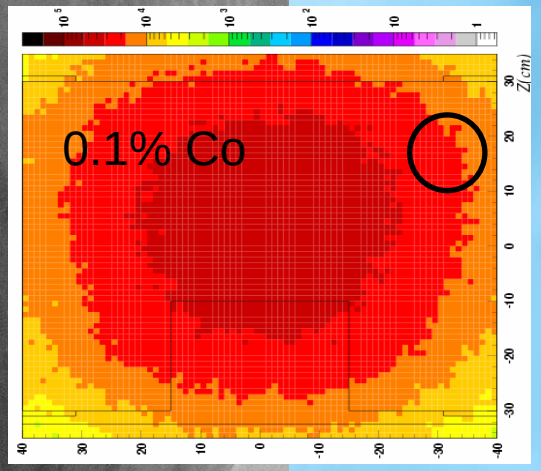




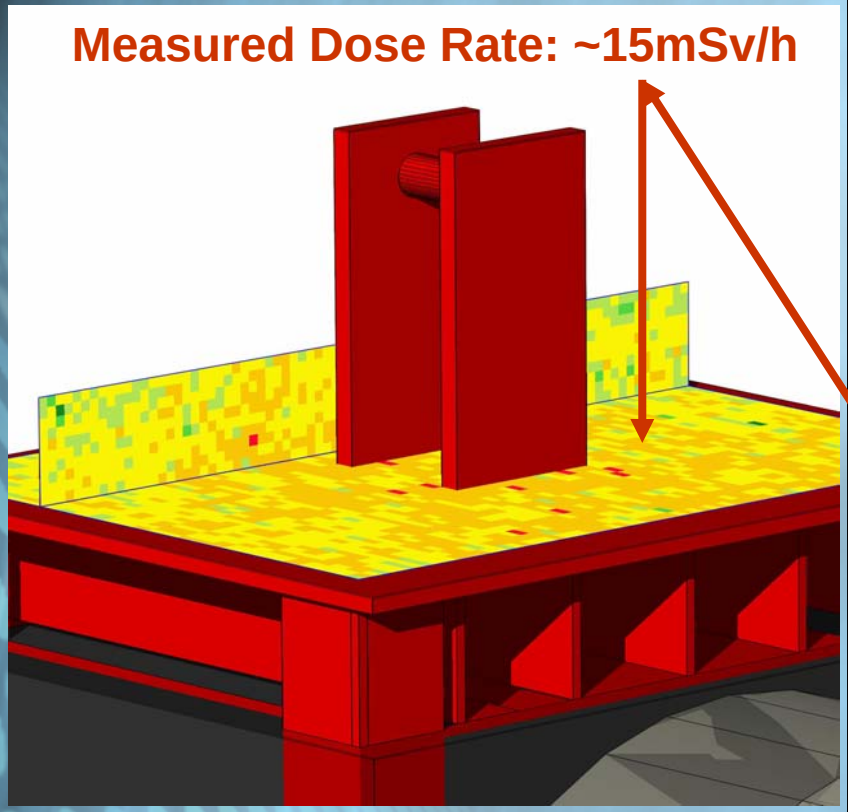
Target - Residual Dose Rate

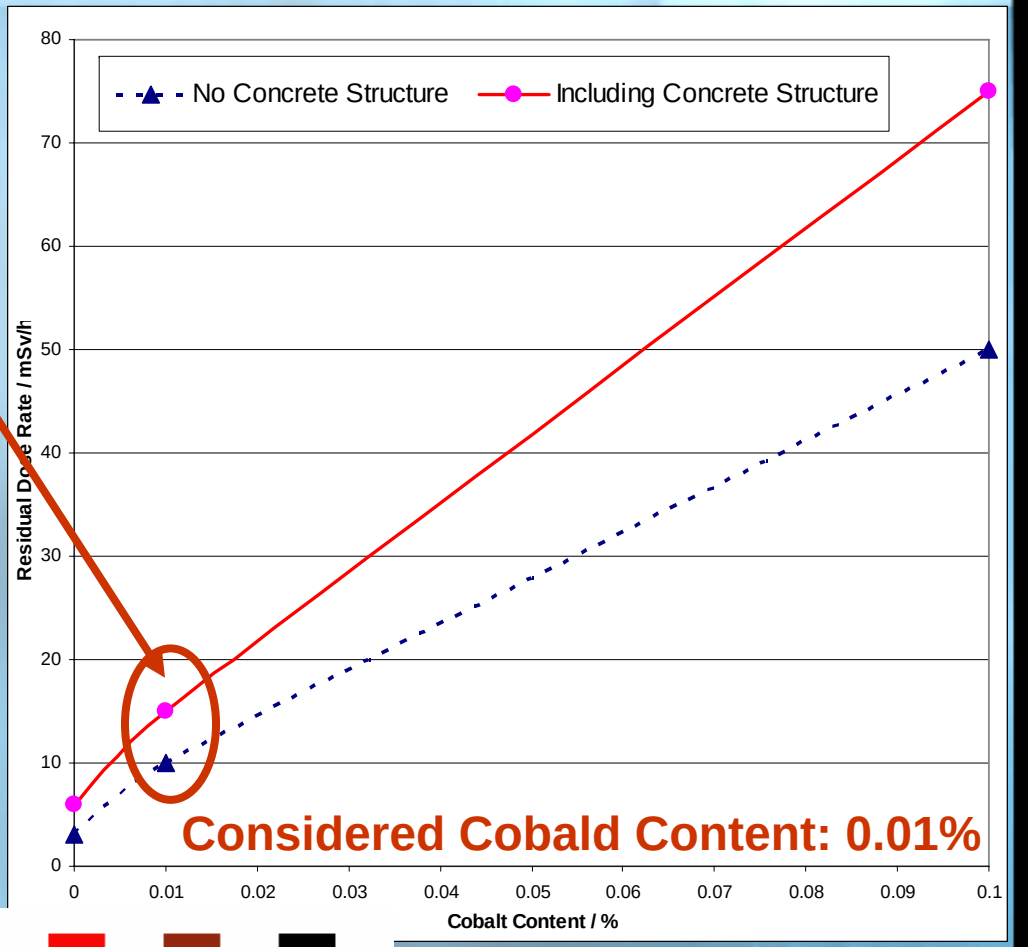


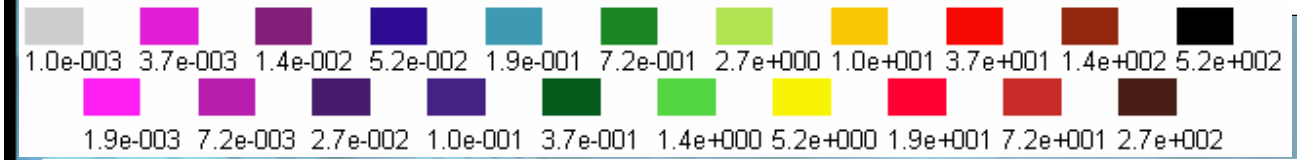




Residual Dose Rate Calculations







Radioactive Waste

- **Nuclide inventory**
  - specific and total activity
  - content of alpha emitters
- **Elimination pathway**
  - temporary, intermediate & final storage
  - acceptance by NAGRA/PSI
    - maximum alpha content, residual dose rate
- **Transport**
  - class A
    - contamination, residual dose rate, container

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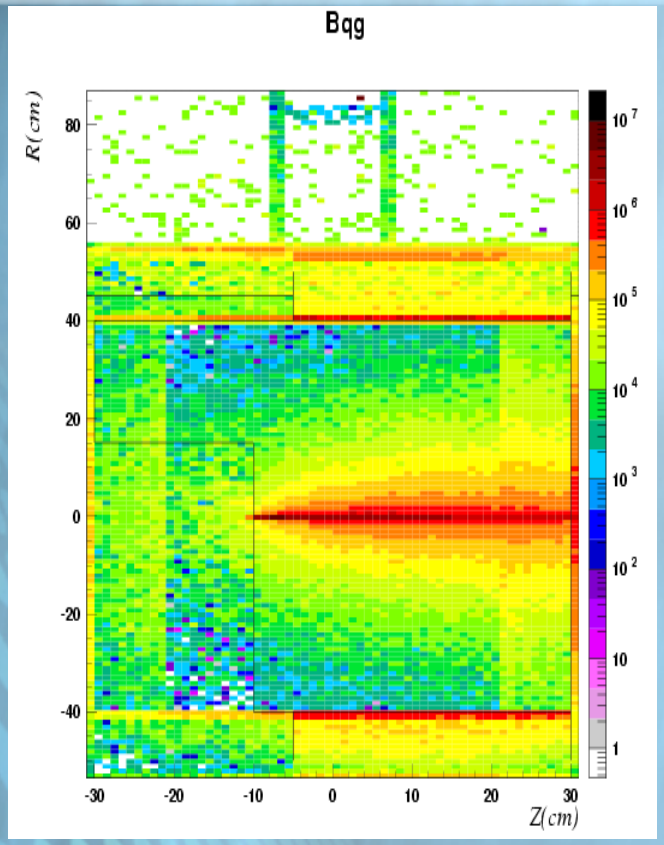
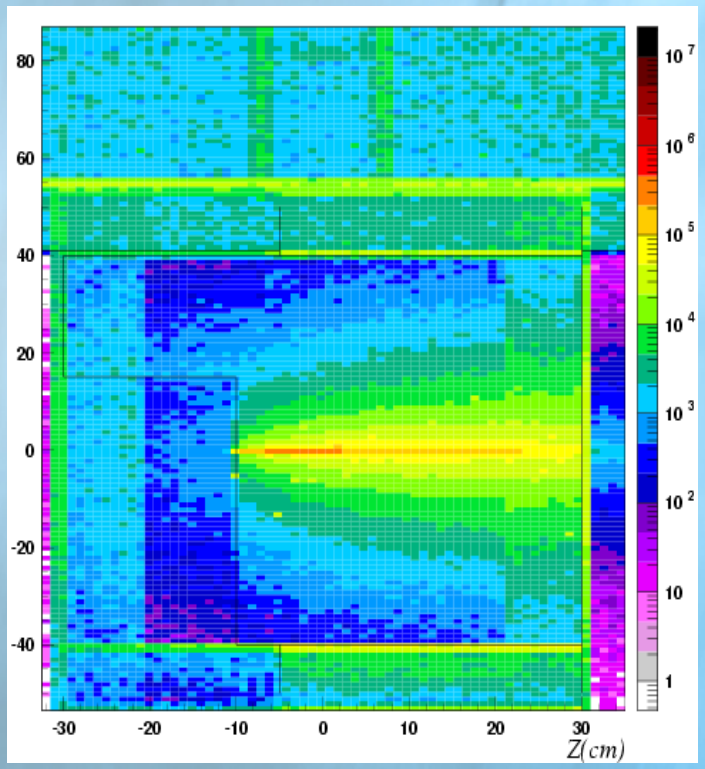
Target Disposal – Waste Study





- Specific activity (Bq/g)
- Specific activity (Multiples of LE)

→ **Nuclide Vector**

Nuclide Vector

- The FLUKA study is based on the **entire nToF operation period** (2001-2004)
- **Several cooling times** were calculated; shown results refer to Mai 2006
- Target assumed to be **pure lead**

Stainless Steel Frame

Isotope	T 1/2 [s]	Specific Activity [Bq/g]	Exemption Limit (LE) [Bg/g]	Multiples of LE
^{60}Co	1.662×10^{8}	1.835×10^{4}	1	18350
^{55}Fe	8.609×10^{7}	4.896×10^{5}	30	14323.3
^{54}Mn	2.697×10^{7}	1.001×10^{4}	10	948.8
^{63}Ni	3.157×10^{9}	2.071×10^{4}	70	151
^{57}Co	2.348×10^{7}	3.015×10^{3}	50	34.44
^{49}V	2.920×10^{7}	3.206×10^{3}	600	4.54

Lead Target (pure Pb)

Isotope	T 1/2 [s]	Specific Activity [Bq/g]	Exemption Limit (LE) [Bg/g]	Multiples of LE
^{204}Tl	1.192×10^{8}	3.050×10^{4}	8	3812
^{194}Hg	1.640×10^{10}	2.812×10^{2}	0.2	1406
^{60}Co	1.662×10^{8}	2.553×10^{2}	1	255.3
^{172}Lu	5.789×10^{5}	1.744×10^{3}	8	218
^{195}Au	1.608×10^{7}	8.290×10^{3}	40	207.25
^{172}Hf	5.897×10^{7}	1.727×10^{3}	10	172.7
^{106}Ru	3.228×10^{7}	1.596×10^{2}	1	159.6
^{106}Rh	2.980×10^{1}	1.596×10^{2}	1	159.6
^{3}H	3.888×10^{8}	1.915×10^{4}	200	95.75
^{207}Bi	9.950×10^{8}	6.609×10^{2}	8	82.61
^{109}Cd	3.997×10^{7}	3.746×10^{2}	5	74.92
^{173}Lu	4.320×10^{7}	1.638×10^{3}	40	40.95
^{65}Zn	2.110×10^{7}	1.167×10^{2}	3	38.9
^{133}Ba	3.318×10^{8}	2.108×10^{2}	10	21.08
^{101}Rh	1.041×10^{8}	3.371×10^{2}	20	16.855
^{54}Mn	2.697×10^{7}	1.522×10^{2}	10	15.22
^{179}Ta	5.645×10^{7}	3.029×10^{3}	200	15.145
^{194}Au	1.369×10^{5}	2.812×10^{2}	20	14.06
^{88}Y	9.215×10^{6}	1.044×10^{2}	8	13.05
^{193}Pt	1.577×10^{9}	3.344×10^{3}	300	11.14
^{185}Os	8.087×10^{6}	1.812×10^{2}	20	9.06
^{145}Sm	2.938×10^{7}	3.101×10^{2}	50	6.202
^{55}Fe	8.609×10^{7}	1.620×10^{2}	30	5.4
^{143}Pm	2.290×10^{7}	2.013×10^{2}	40	5.0325
^{153}Gd	2.087×10^{7}	1.619×10^{2}	40	4.0475
^{181}W	1.047×10^{7}	3.311×10^{2}	100	3.311
^{145}Pm	5.582×10^{8}	1.414×10^{2}	90	1.57
^{159}Dy	1.248×10^{7}	1.025×10^{2}	100	1.025
^{49}V	2.920×10^{7}	8.028×10^{1}	600	0.1338
^{85}Kr	3.392×10^{8}	7.711×10^{1}	1×10^{4} *	7.711×10^{-3}

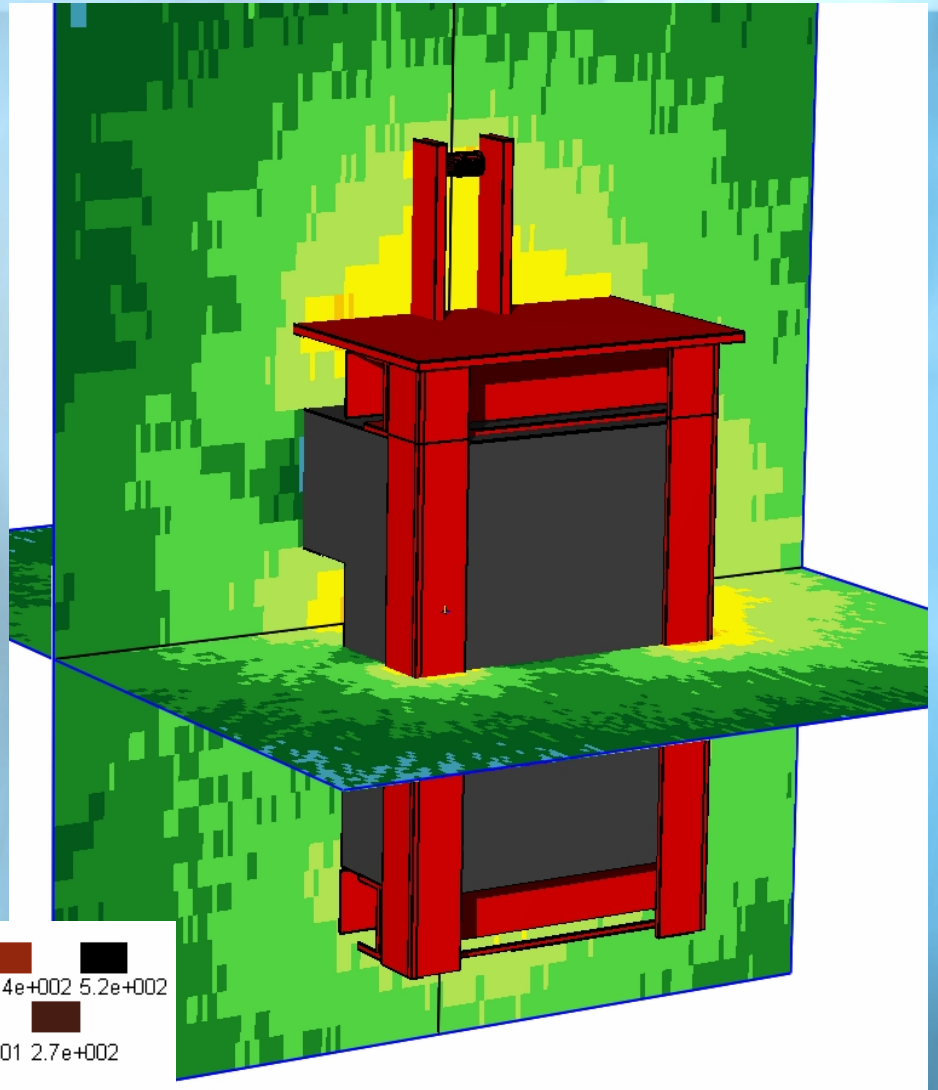
Nuclide Vector

- **First estimate for detailed composition** (NAGRA)
- **Simplified geometry**, high statistical uncertainties
- **Low-alpha content**
  - **~2 Bq/g** specific alpha activity (<10kBq/g)
  - **~1 MBq** total activity
- **To be confirmed by detailed FLUKA calculations**

Isotope	a [Bq/g]	A [Bq]
^{206}Po	2.21E-20	9.64E-15
^{208}Po	**6.98E-01**	**3.04E+05**
^{210}Po	**5.68E-01**	**2.48E+05**
^{211}Po	4.24E-08	1.85E-02
^{212}Po	9.34E-02	4.07E+04
^{213}Po	1.19E-04	5.18E+01
^{214}Po	9.43E-05	4.11E+01
^{215}Po	1.52E-05	6.60E+00
^{216}Po	**1.45E-01**	**6.34E+04**
^{218}Po	9.43E-05	4.11E+01
^{215}At	3.48E-11	1.52E-05
^{217}At	1.22E-04	5.30E+01
^{218}At	1.89E-08	8.26E-03
^{219}At	1.30E-11	5.64E-06
^{217}Rn	1.33E-07	5.80E-02
^{218}Rn	1.89E-11	8.26E-06
^{219}Rn	1.52E-05	6.60E+00
^{220}Rn	**1.45E-01**	**6.34E+04**
^{222}Rn	9.43E-05	4.11E+01
^{221}Fr	1.22E-04	5.30E+01
^{223}Fr	2.16E-07	9.41E-02
^{221}Ra	1.22E-07	5.30E-02
^{223}Ra	1.52E-05	6.60E+00
^{224}Ra	**1.45E-01**	**6.34E+04**
^{226}Ra	9.43E-05	4.11E+01
^{225}Ac	1.22E-04	5.30E+01
^{227}Ac	1.57E-05	6.84E+00
^{228}Ac	1.55E-08	6.76E-03
^{227}Th	1.52E-05	6.60E+00
^{228}Th	**1.44E-01**	**6.30E+04**
^{229}Th	1.22E-04	5.30E+01
^{230}Th	4.71E-05	2.05E+01
^{232}Th	4.08E-03	1.78E+03
^{234}Th	1.53E-07	6.68E-02
^{231}Pa	1.56E-04	6.80E+01
^{234}Pa	1.99E-10	8.68E-05
^{231}U	1.11E-45	4.84E-40
^{233}U	5.29E-04	2.30E+02
^{234}U	3.64E-06	1.59E+00
^{235}U	1.11E-03	2.41E+02
^{236}U	9.34E-08	4.07E-02
^{238}U	1.24E-02	5.42E+03
^{239}Pu	3.08E-03	1.34E+03
sum	**1.96E+00**	**8.55E+05**

Residual Dose Rate Maps

- **3D residual dose rate maps** are available for various cooling times
- **Hotspots** are located at the entry and exit point of the beam as well as around the stainless steel support

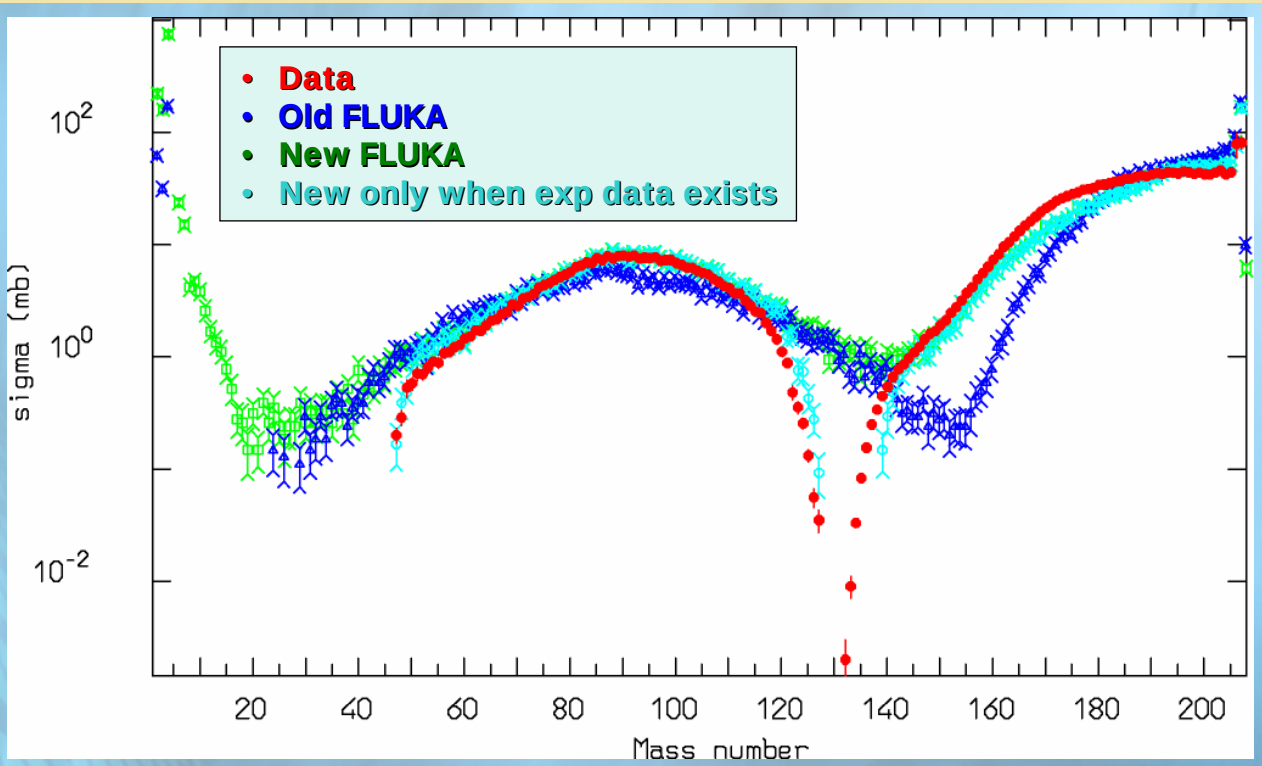


Related Uncertainties

- **Chemical Composition**
  - accurately known for the Pb (*e.g.*, 19ppm Bi)
  - for Steel: “known” from benchmark experiments, confirmed by dose rate measurement and finally to be confirmed during the target removal
- **Irradiation History**
  - beam intensity and irradiation time profile is accurately known
- **Geometry**
  - implemented in a very detailed way
- **Statistical Uncertainty of MC Calculation**
  - good statistics for pure lead case
  - important uncertainties for estimate of the alpha content
  - to be improved with a more detailed calculation
- **FLUKA Models – Activation/Residual DR**
  - well benchmarked for low-mass materials at CERF
  - recent comparison for high mass isotopes show a very good overall agreement (see next slide)

Related Uncertainties

1 A GeV ^{208}Pb + p reactions Nucl. Phys. A 686 (2001) 481-524



- One expects an accurate characterization of the nuclide vector for nToF

Target Disposal – Conclusion

- **Characterization of the nuclide vector**
  Specific activities, total activity, residual dose rate (for different cooling times)
  - detailed calculation and good statistics for pure target
  - first estimate for detailed composition
  - including alpha emitters (showing low levels)
  - additional measurements during the target removal
- **Transport**
  should be performed as Class-A
  - final activation levels are checked
  - hot spots of target can be shielded
- **Possible elimination pathway**
  all necessary quantities are prepared
  - coordinated by NAGRA, to be sent to PSI
  - details currently prepared (more in the talk of L. Ulrici)

New Target Design Constraints

- **Target Design**
  - not in direct contact with the cooling water
  - optimized smaller dimensions
    - less material
    - minimizes radioactive waste production
    - however, leads to higher contact dose rates
      - *compensated by a respective target container*
- **Update of FLUKA calculations**
  - nuclide inventory
  - residual dose rates
  - handling procedures
- **Inspection of old target** is necessary for the final verification
  - measurements of specific activity and residual dose rates