Dose Rates, Radio Isotope Inventories and Air Activation

RP Calculations & Impact on Design and Upgrade

Activation, Handling, Ventilation

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Introduction

Calculation Input to RP Classification

Relevant for Personnel and Environment

- Activation
  - Components & Handling (+ Nuclide Vector)
  - Cooling Water
  - Air Activation
- Dose Rates & Shielding Design
- Contamination Risk (including Alpha Emitters)

Iteration based on the previously defined RP Classifications

Project Phase	Calculations	Procedures	Measurements
New Target Conceptual Design	- Feasibility - Determination of Technical Constraints - Determination of Safety Constraints	- Quality assurance	- Model Development & Benchmark
Technical Design	- Design Calculation: + Engineering o material damage & fatigue o cooling o handling + Facility o shielding layout o activation of water o activation of air + Safety (e.g., handling) o residual dose rates	- Operational Procedures - Safety Procedures - Handling Procedures	- Benchmark (test measurements) - Point-Zero - Material damage and or fatigue
Operation	- Refined calculations of 'as-is' situation - Respective evaluation	- Monitoring - Refinement of Intervention Procedures - Intervention Planning	- Commissioning o engineering parameters o activation of cooling water o activation of air o activation levels of the facility - Monitoring of the above
Existing Target Dismantling & Disposal	- Final nuclide vector - Residual dose rates *(based on real operation)*	- Organisation of Disposal + handling + container + transport - Dismantling of Facility	- Evaluation: o residual dose rates o contamination check o GS of target (mobile) o GS of samples

Overview

- **Introduction**
  - Required specifications
  - FLUKA calculations
- **FLUKA calculations for Radiation Protection Characterization**
  - Existing target activation (Radioactive Waste, Handling)
  - New Target Design Options (Engineering Design, Waste, Handling,)
  - Ventilation
- **Target Cooling Circuit**
  - Contamination
  - Corrosion
  - Consequences
- **Conclusion**

Required Specifications

- **RW specifications for the nToF target disposal**
  - Specific and total activities
  - Alpha emitters
  - Residual dose rates around the storage container
  - Contamination
- **Target handling**
  - Residual dose rates around the existing target
  - Procedures and dose planning
- **New Target design**
  - Impact on radionuclide vector
  - Residual dose rates & handling

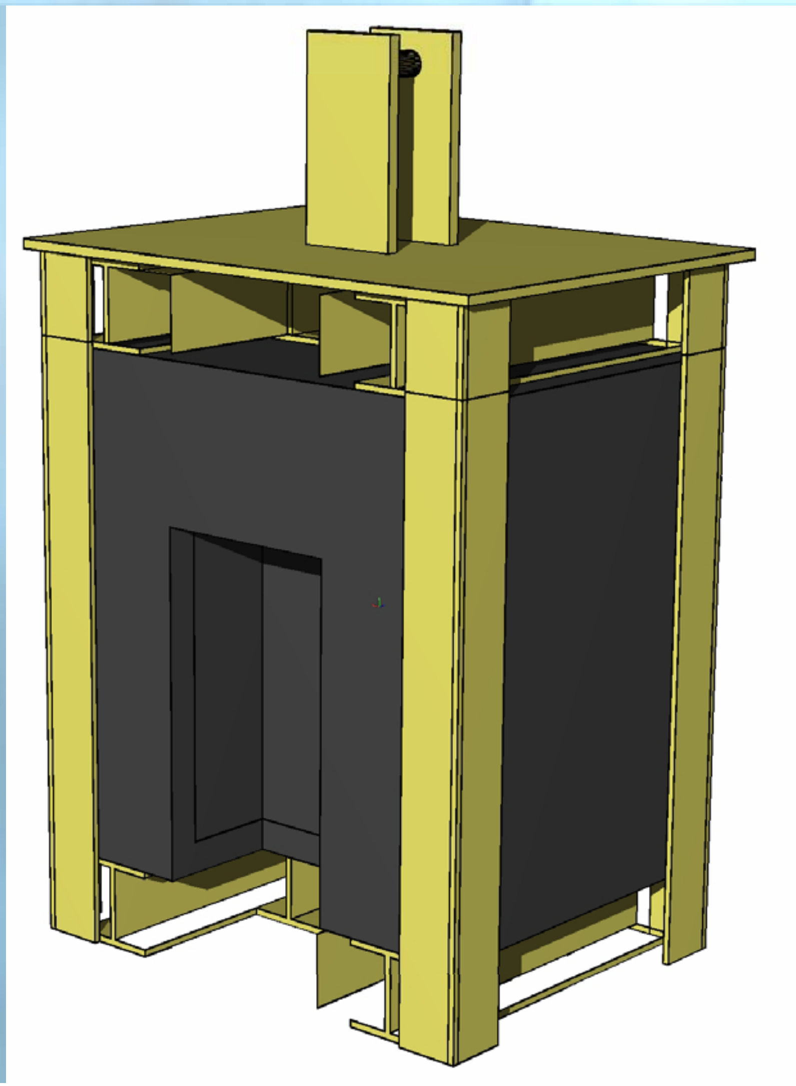
Required Specifications

- **Ventilation requirements**
  - Radioisotope production
  - Different operational scenarios
  - Dose to the critical group
- **Cooling System & Implications**
  - Contamination: facts/hypotheses
    - Inspection
    - Possible Repair
  - Corrosion: facts/hypotheses
    - Inspection
    - Possible Repair
  - Intervention scenario
    - Handling, Inspection, Repair
    - Planning & Optimization

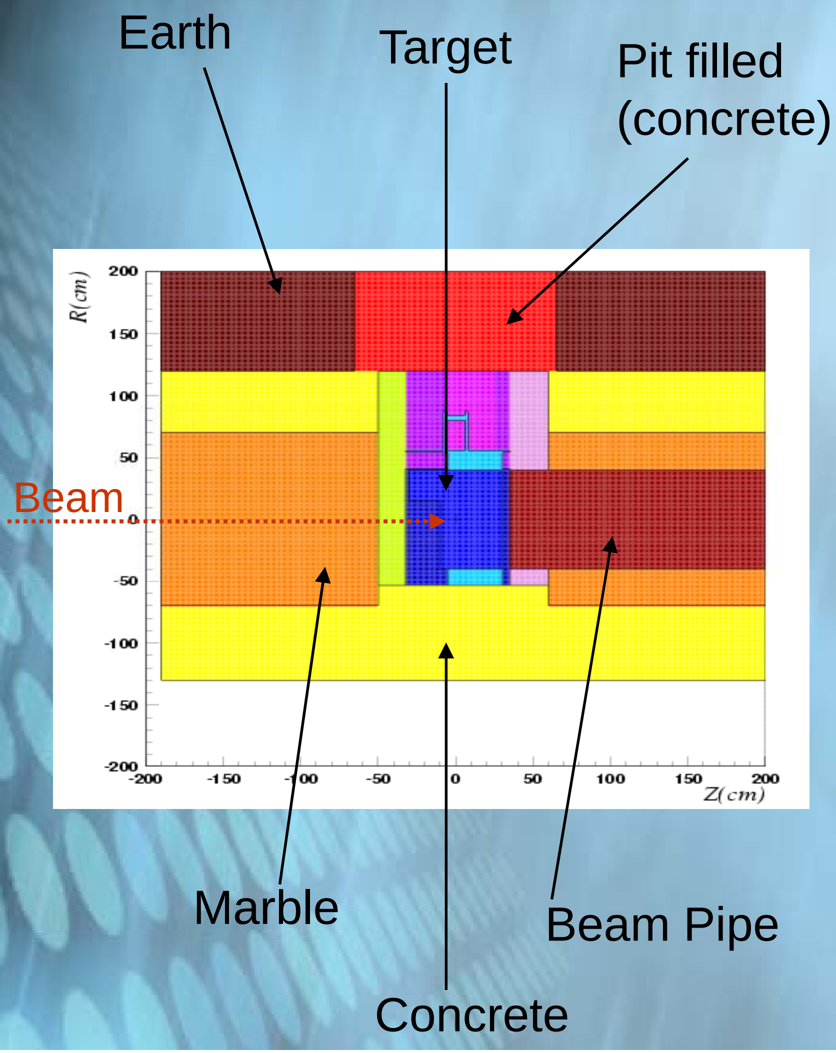
FLUKA Calculations

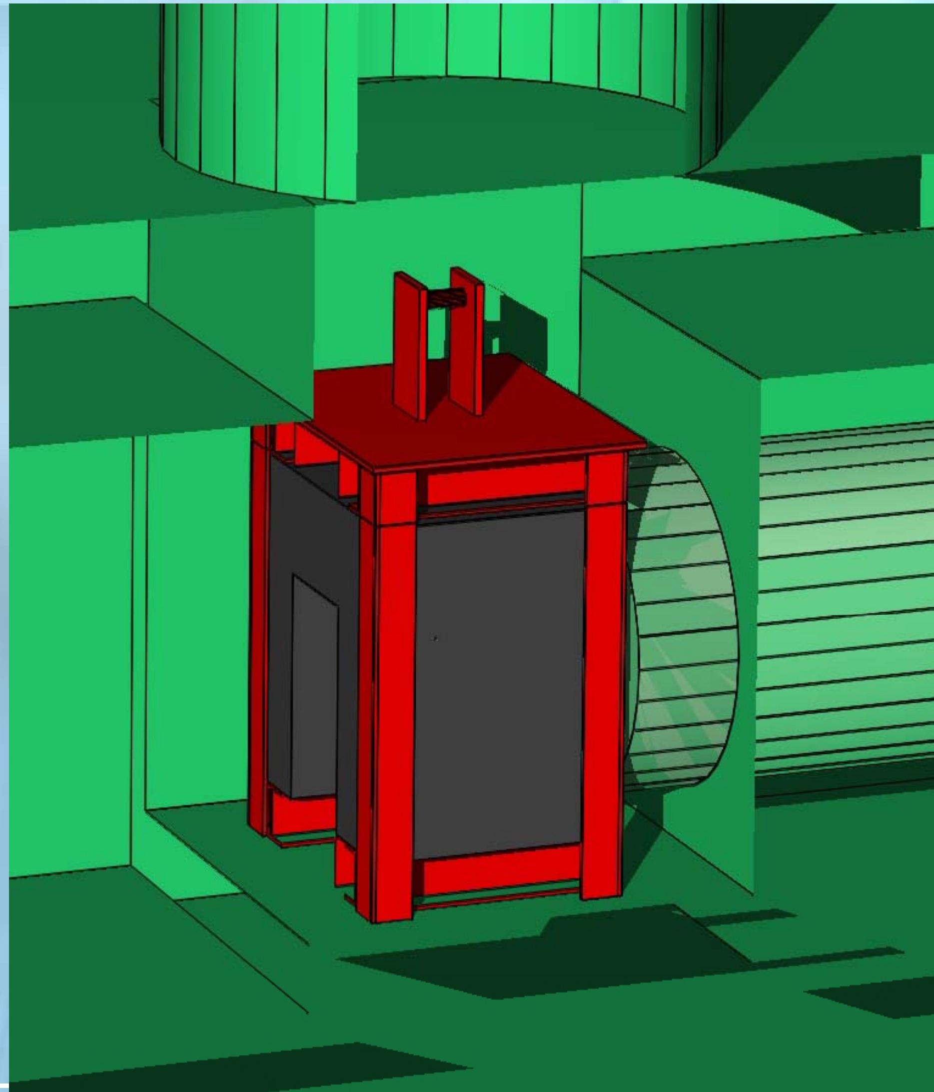
- **Geometry Implementation**
  - the simulation includes a detailed layout and design, for both the target and the tunnel up to the experimental area
- **New Design Options**
  - flexibility to change design parameters and estimate respective influences
- **Detailed Estimates concerning**
  - *neutron fluences (physics) [Y. Kadi]*
  - *energy deposition (engineering design) [Y. Kadi]*
  - isotope production (radioactive waste, air activation)
  - residual dose rates (handling, waste)
- **Accuracy**
  - well benchmarked code in all required fields

Geometry Details



Target in the Pit

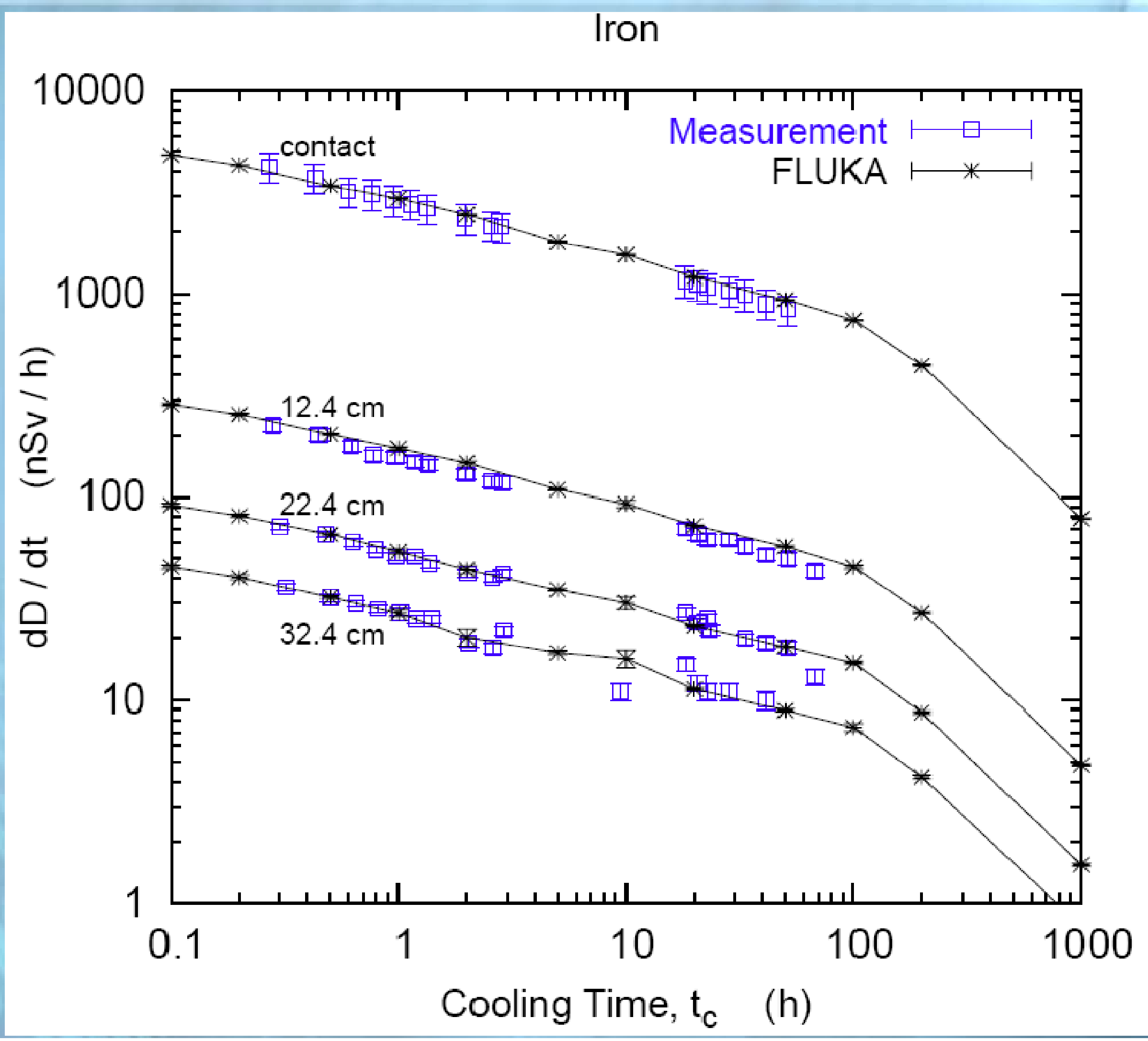




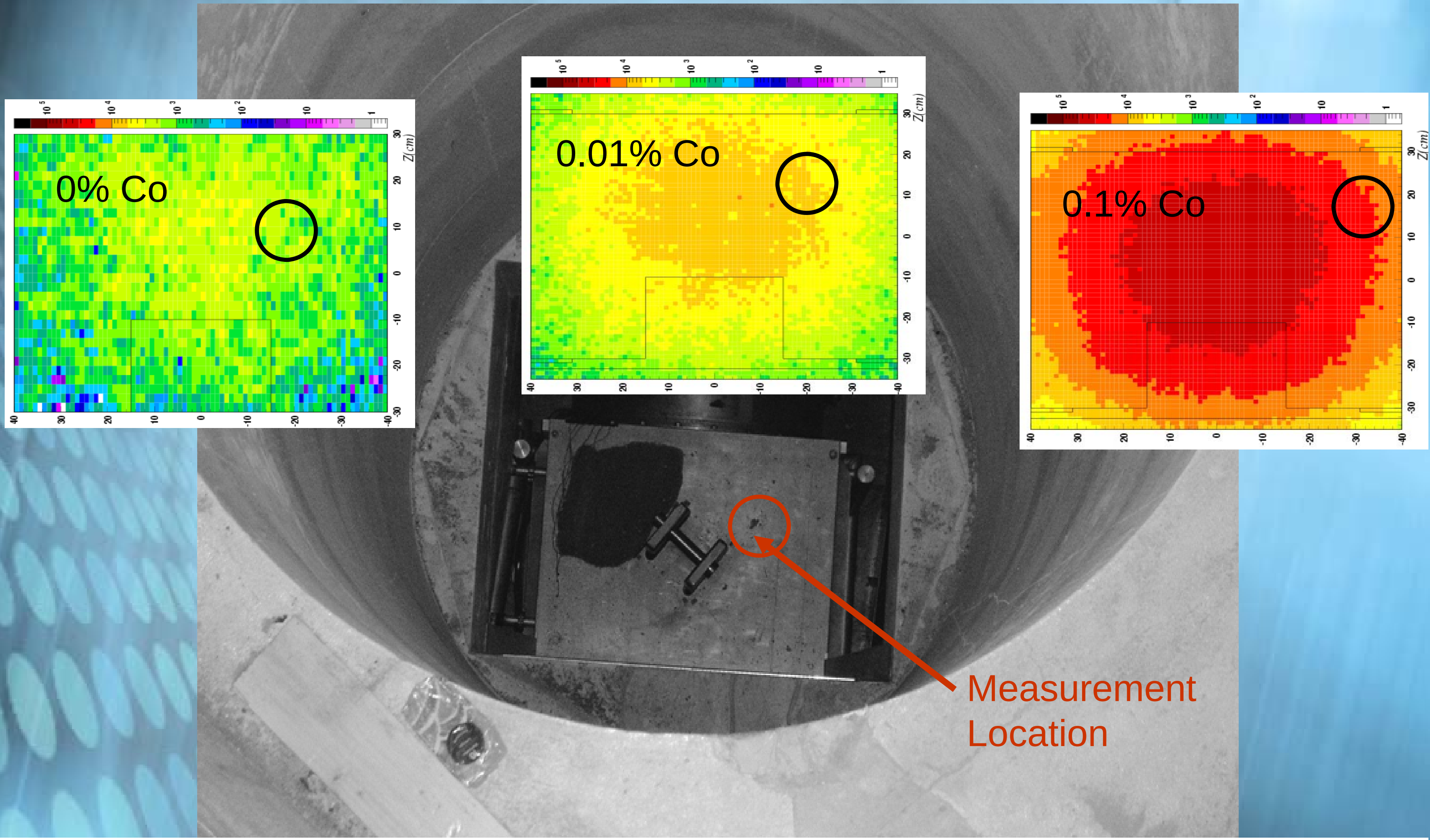
Important Input Parameters

- **Chemical Composition**
  - accurately known for the used lead (*e.g.*, 19ppm Bi)
  - for steel: variation “known” from benchmark experiments carried out at CERN, “confirmed” by preliminary dose rate measurement and finally to be evaluated during the target removal
- **Irradiation History**
  - beam intensity and irradiation time profile is accurately known
- **Geometry**
  - implemented in a very detailed way
- **MC Calculation**
  - extensive calculations (computer cluster), statistics is better than the systematic error
- **FLUKA Models – Activation/Residual DR**
  - well benchmarked for low/medium-mass materials at CERF
  - recent comparison for high mass isotopes show a very good overall agreement

Residual Dose Rates - Benchmark

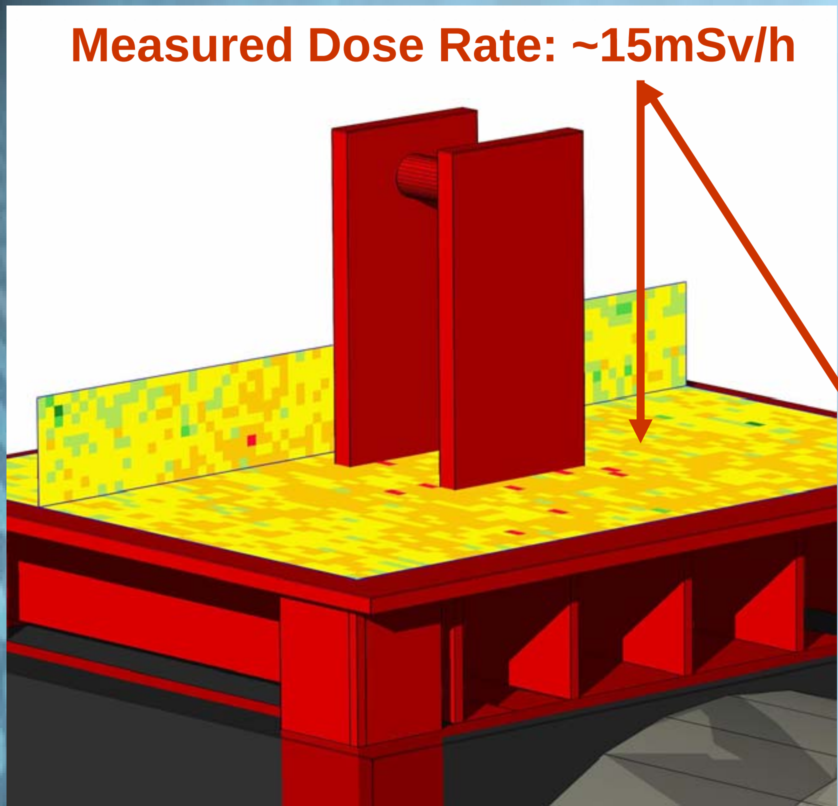


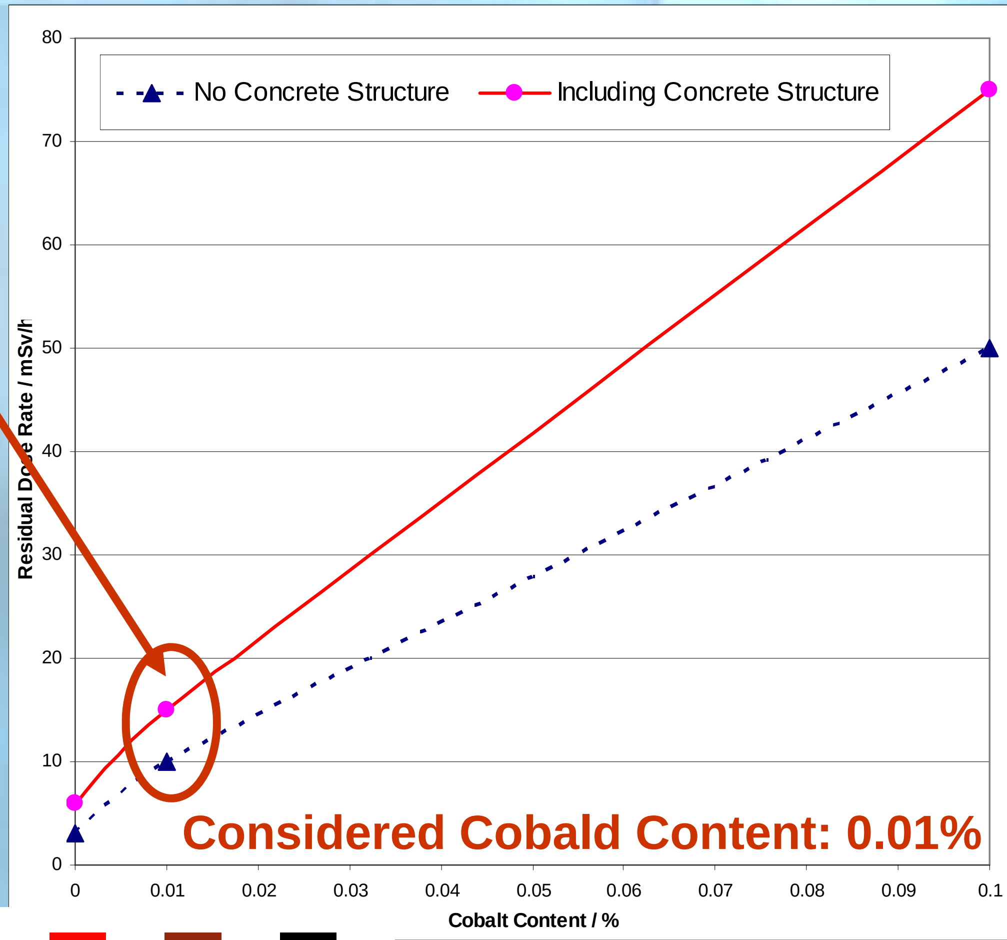
Target - Residual Dose Rate vs. Co Content



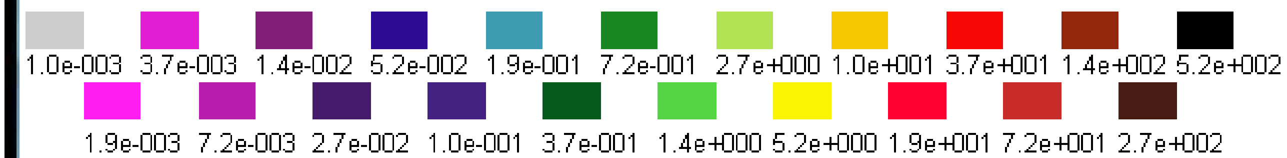
Residual Dose Rate Calculations

Measured Dose Rate: ~15mSv/h





Considered Cobald Content: 0.01%



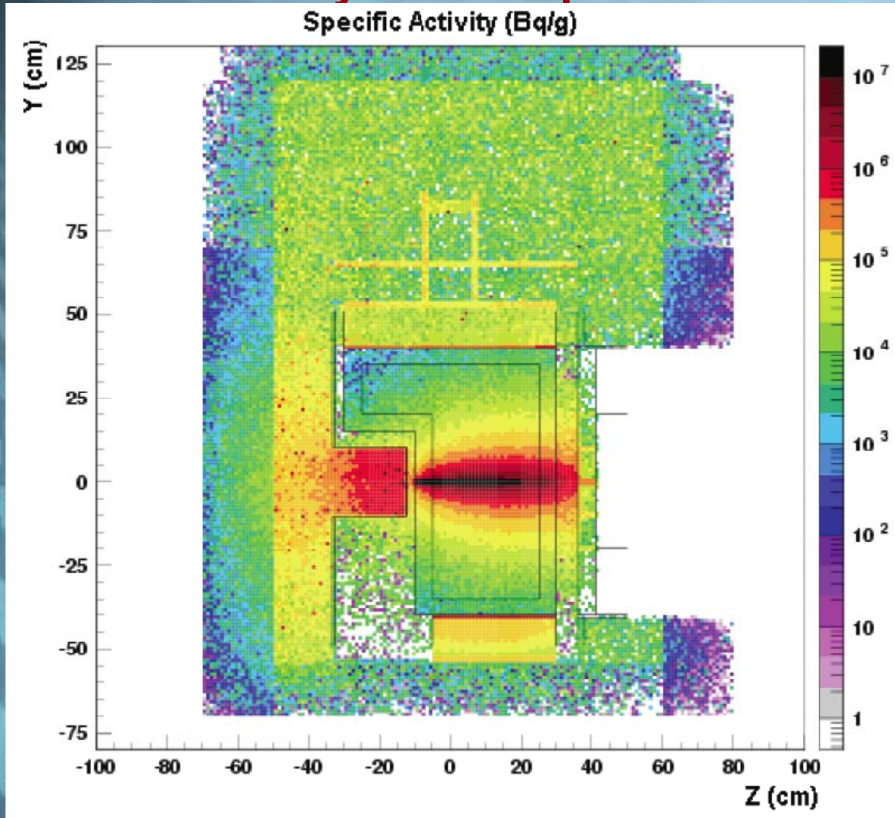
Isotope Production Waste Disposal

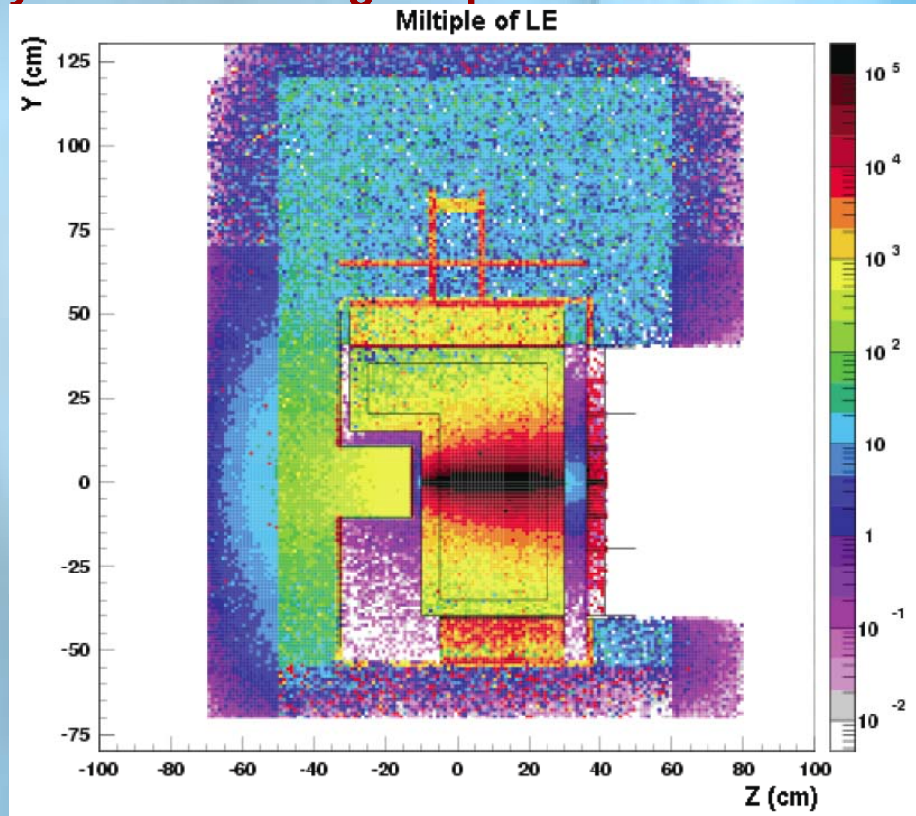
Existing Lead Target

- **Detailed geometry**
  - target and support, surrounding structure downstream tunnel structure
- **Beam & Irradiation Parameters**
  - Irradiation time: 6 months/year [2001-2004]
  - Proton intensity: $7x10^{12}$ p/pulse - ~1 pulses/2.4s
  - Protons on target: real average: $1.3x10^{19}$ p/year (maximum: $3.2x10^{19}$ p/year)
- **Activation of target**
  - specific and total activity as well as expression of the first as multiple of the respective exemption limit
  - residual dose rates around the target
  - nuclide vector for waste disposal
  - time evolution of main parameters

… in terms of Exemption Limits

after 4 years of operations and 3 years of cooling: September 2007

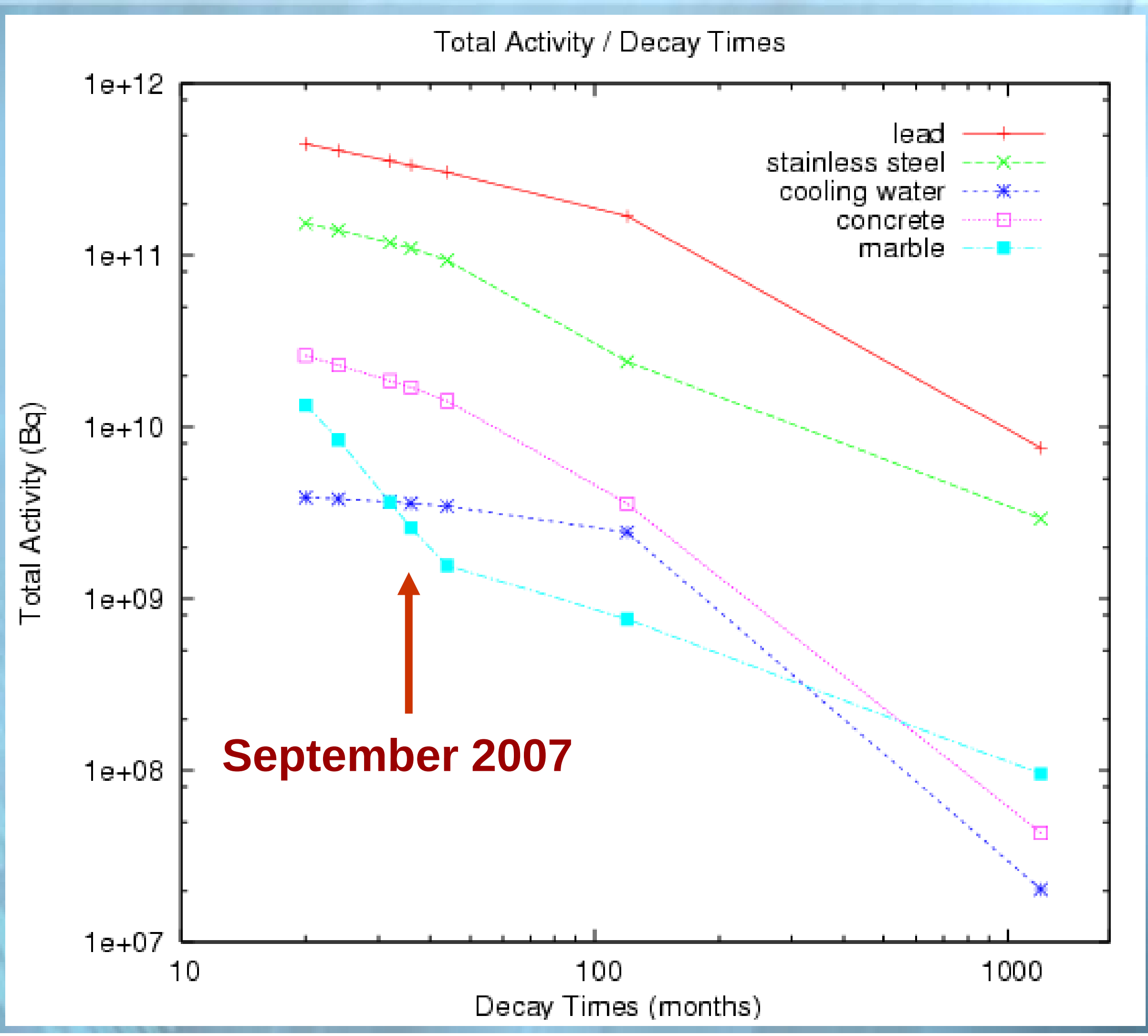




- Specific activity (Bq/g)
- Specific activity (Multiples of LE)

→ **Nuclide Vector**

Time Dependence - Total Activity



Nuclide Vector

after 4 years of operations and 3 years of cooling: September 2007

- **non α-emitting**
- Most abundant in terms of the Exemption limit (LE)

Steel Support

Isotope	Halflife (s)	Specific Activity (Bq/g)	Exemption Limit LE (Bq/g)	Multiples of LE	Total Activity (Bq)
^{60}Co	1.66E+08	1.31E+04	1	13149	4.31E+09
^{55}Fe	8.64E+07	3.00E+05	30	9996	9.82E+10
^{54}Mn	2.70E+07	2.99E+03	10	299	9.79E+08
^{63}Ni	3.16E+09	1.73E+04	70	247	5.67E+09
^{57}Co	2.35E+07	7.65E+02	50	15	2.51E+08
^{22}Na	8.21E+07	1.95E+01	3	6	6.37E+06
^{3}H	3.89E+08	6.30E+02	200	3	2.06E+08
^{44}Ti	1.89E+09	5.29E+00	2	3	1.73E+06
^{49}V	2.84E+07	1.11E+03	600	2	3.63E+08
^{59}Ni	2.40E+12	1.46E+02	200	1	4.78E+07
^{45}Ca	1.41E+07	1.95E+00	10	0.2	6.37E+05
^{44}Sc	1.43E+04	5.29E+00	30	0.2	1.73E+06
	TOTAL:	3.36E+05			1.10E+11

Lead Target

Isotope	Halflife (s)	Specific Activity (Bq/g)	Exemption Limit LE (Bq/g)	Multiples of LE	Total Activity (Bq)
^{204}Tl	1.19E+08	2.27E+04	8.0	2841	9.05E+10
^{194}Hg	1.40E+10	3.02E+02	0.2	1509	1.20E+09
^{60}Co	1.66E+08	3.21E+02	1.0	321	1.28E+09
^{3}H	3.89E+08	5.48E+04	200.0	274	2.18E+11
^{207}Bi	1.04E+09	1.82E+03	8.0	227	7.24E+09
^{172}Lu	5.79E+05	1.29E+03	8.0	161	5.12E+09
^{172}Hf	5.90E+07	1.27E+03	10.0	127	5.07E+09
^{90}Sr	9.12E+08	1.91E+01	0.4	48	7.59E+07
^{195}Au	1.61E+07	1.56E+03	40.0	39	6.22E+09
^{109}Cd	3.99E+07	1.54E+02	5.0	31	6.13E+08
^{173}Lu	4.32E+07	1.01E+03	40.0	25	4.02E+09
^{65}Zn	2.11E+07	6.28E+01	3.0	21	2.50E+08
^{202}Pb	1.66E+12	1.58E+01	1.0	16	6.31E+07
^{194}Au	1.37E+05	3.02E+02	20.0	15	1.20E+09
^{101}Rh	1.04E+08	2.72E+02	20.0	14	1.08E+09
^{54}Mn	2.70E+07	1.27E+02	10.0	13	5.08E+08
^{193}Pt	1.58E+09	3.48E+03	300.0	12	1.39E+10
^{179}Ta	5.74E+07	2.02E+03	200.0	10	8.03E+09
^{55}Fe	8.64E+07	2.76E+02	30.0	9	1.10E+09
^{106}Ru	3.23E+07	9.19E+00	1.0	9	3.66E+07
^{106}Rh	2.98E+01	9.19E+00	1.0	9	3.66E+07
^{133}Ba	3.32E+08	6.11E+01	10.0	6	2.43E+08
^{134}Cs	6.52E+07	2.97E+00	0.5	6	1.18E+07
	TOTAL:	9.30E+04			3.70E+11

Nuclide Vector

after 4 years of operations and 3 years of cooling: September 2007

- **α-emitting**
- Most abundant in terms of the Exemption limit
- Significantly smaller than the PSI reference value for a specific activity of ~ 20kBq/g (<<ATA)

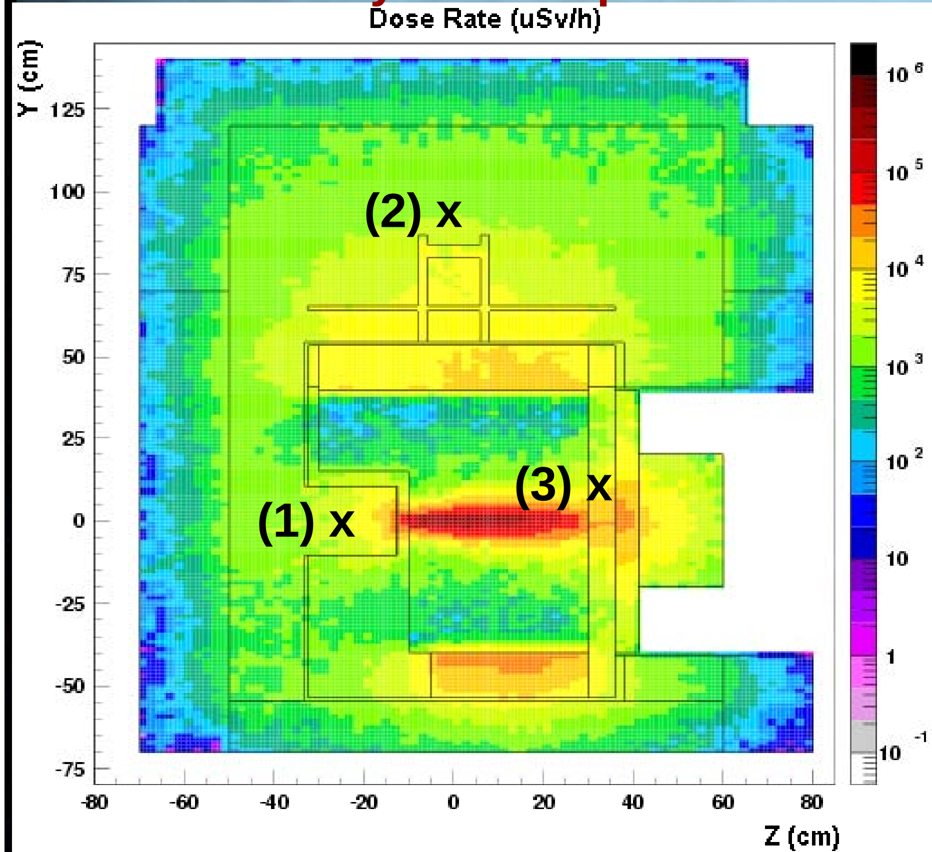
Lead Target

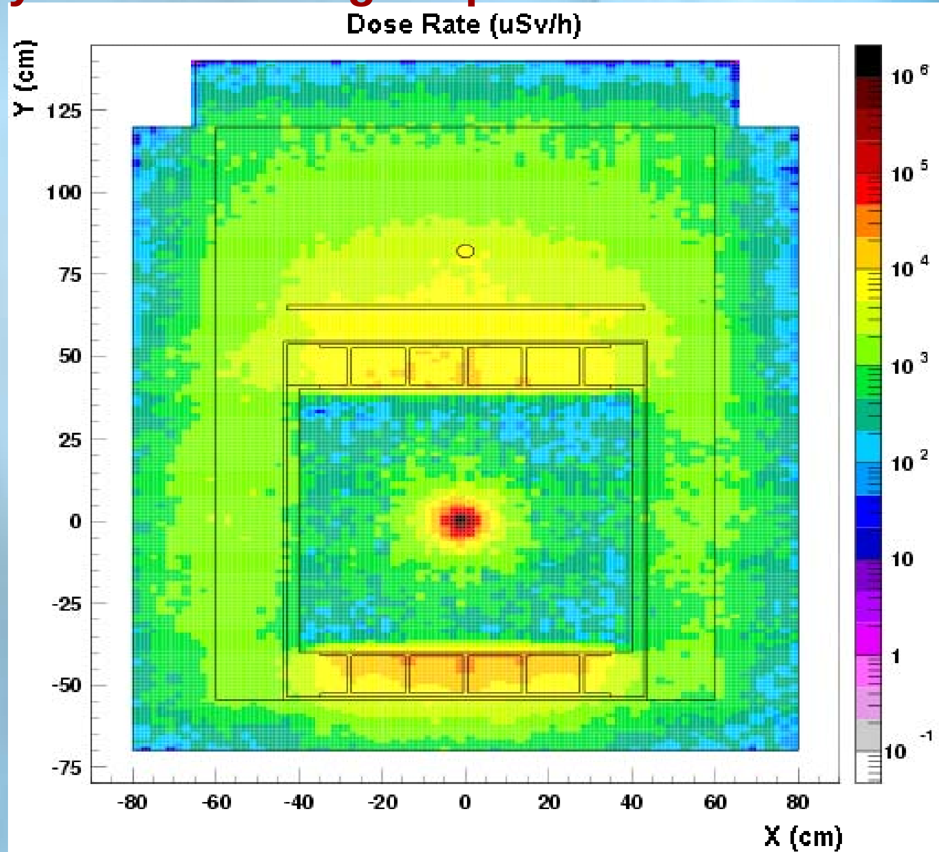
Isotope	Halflife (s)	Specific Activity (Bq/g)	Exemption Limit LE (Bq/g)	Multiples of LE	Total Activity (Bq)
^{148}Gd	2.24E+09	2.95E+01	0.2	147	1.17E+08
^{208}Po	9.15E+07	6.97E-02	0.01	7	2.77E+05
^{210}Po	1.20E+07	8.10E-02	0.04	2	3.22E+05
^{145}Pm	5.59E+08	7.32E+01	90	1	2.92E+08
^{209}Po	3.22E+09	1.04E-03	0.01	0.1	4.16E+03
^{151}Gd	1.07E+07	3.13E+00	50	0.1	1.25E+07
^{146}Sm	3.25E+15	1.99E-05	0.2	0	7.92E+01
^{148}Eu	4.71E+06	2.97E-05	8	0	1.18E+02
^{190}Pt	2.05E+19	1.35E-07	1	0	5.36E-01
^{147}Sm	3.35E+18	1.75E-08	0.2	0	6.98E-02
^{152}Gd	3.41E+21	1.87E-11	0.2	0	7.46E-05
^{147}Eu	2.08E+06	1.54E-11	20	0	6.15E-05
^{188}Pt	8.81E+05	5.57E-29	10	0	2.22E-22
^{149}Gd	8.02E+05	2.56E-33	20	0	1.02E-26
^{206}Po	7.60E+05	4.86E-39	0.08	0	1.94E-32
^{154}Dy	9.47E+13	8.92E-04	0	0	3.55E+03
^{150}Gd	5.65E+13	1.04E-03	0	0	4.15E+03
	TOTAL:	**1.06E+02**			**4.22E+08**

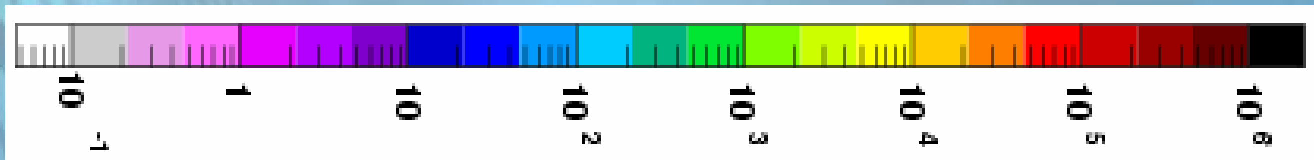
Residual Dose Rates

Residual Dose Rate (μSv/h)

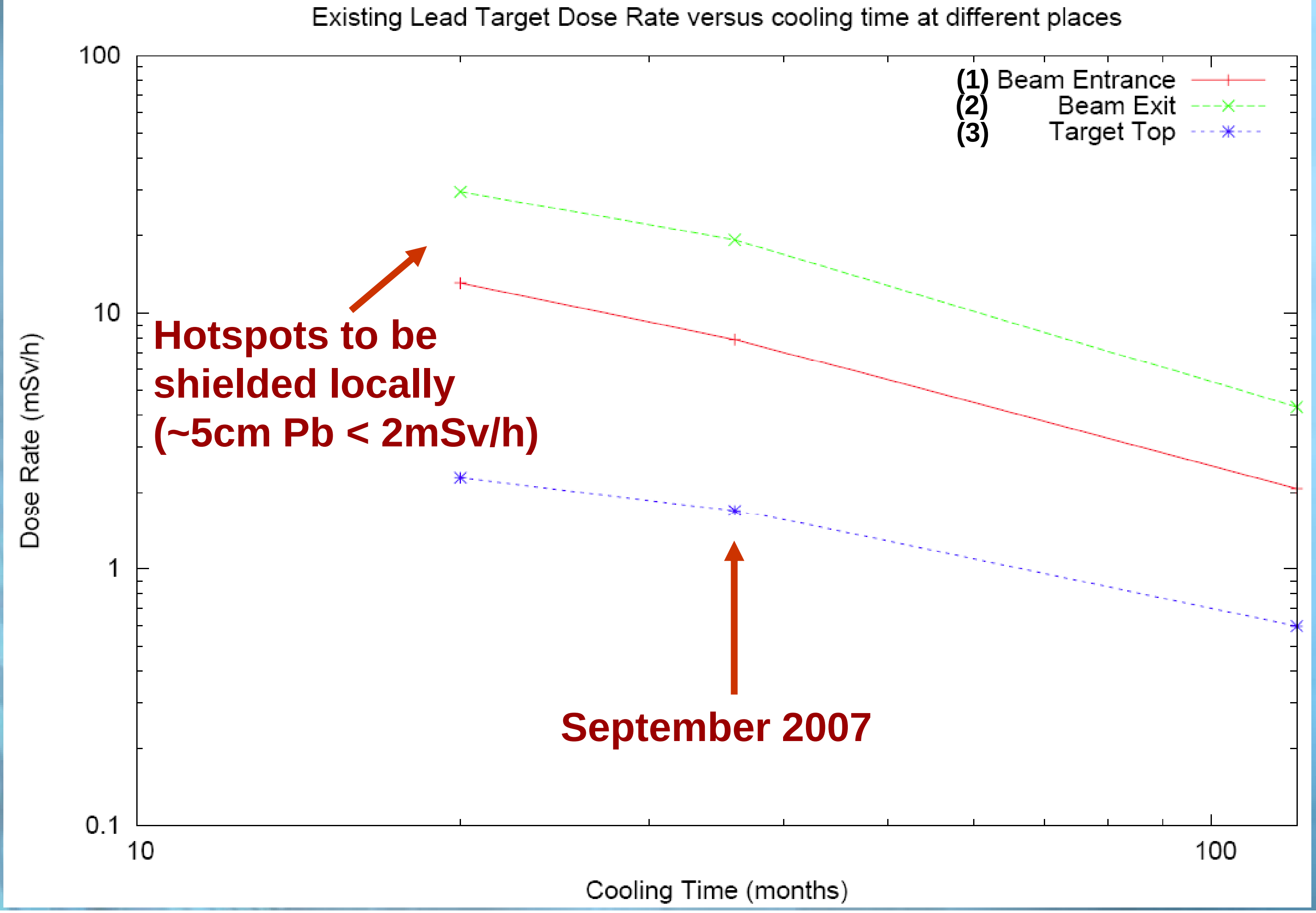
after 4 years of operations and 3 years of cooling: September 2007







Time Dependence – Dose Rates



Target Disposal – Conclusion

- **Characterization of the nuclide vector**
  Specific activities, total activity, residual dose rate (for different cooling times)
  - detailed calculation and good statistics
  - including alpha emitters (showing low levels)
  - dose rate + gamma spectroscopy measurement
  - contamination measurement on Al, SS, Pb
- **Transport**
  might be performed as Class-A
  - final activation levels are checked
  - hotspots of target can be shielded locally
- **Possible elimination pathway**
  all necessary input is available
  - coordinated by RP & NAGRA, to be sent to PSI

New Target Design Options

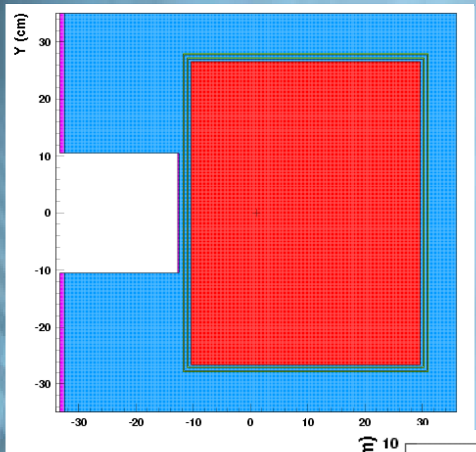
New Target Design Options

Target Type	Shape	Lateral Dimensions	Length	Comments
Pb	Cubic	80 x 80 cm	60 cm	Existing Target
Pb	Cubic	80 x 80 cm	60 cm	New Cladded
Pb	Cylindrical	53 cm Ø	40 cm	MiniPool Solution
Ta	Cylindrical	30 cm Ø	30 cm	Sliced Ta Disks
Ta + Pb	Cyl + Cub	Ta: 20 cm Ø Pb: 55 cm Ø	Ta: 25 cm Pb: 40 cm	Hybrid Solution

- Several configurations were studied:
- Pure Lead
  - Existing target (or cladedd)
  - Mini-pool solution to avoid
    the direct contact between the target and the cooling water
- Tantalum
  - Tantalum solution to withstand higher mechanical stresses and may solve the contamination issue without need for cladding
- Hybrid
  - Combination between lead and tantalum

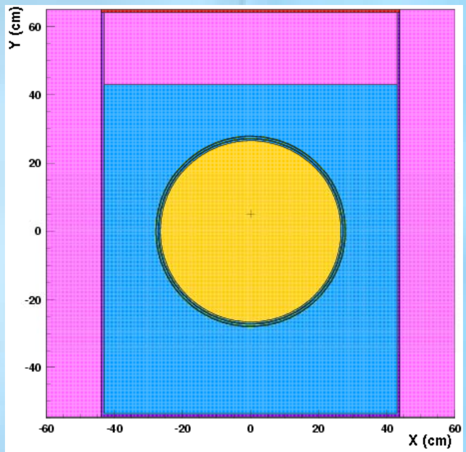
Pb Cylinder With Mini-Pool Solution

Side view

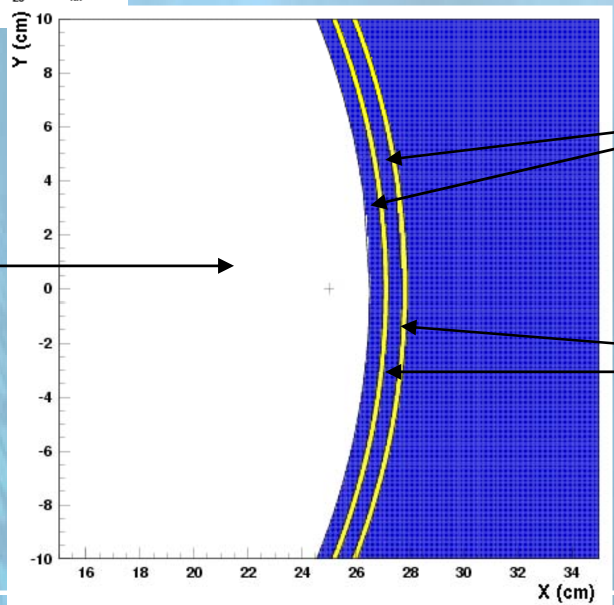


- Length: 40 cm
- Diameter: 53 cm

Front view



Lead

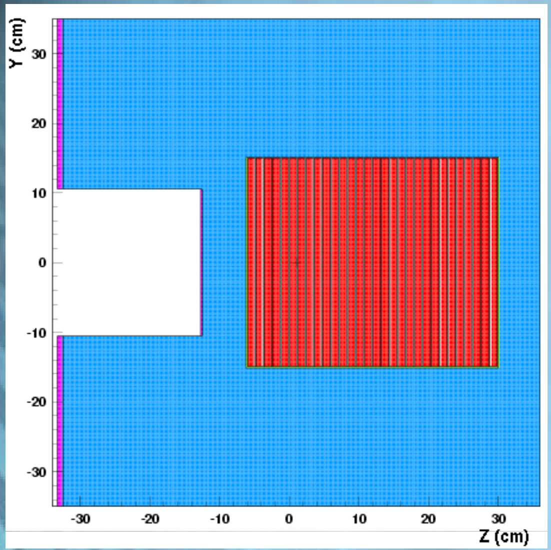


2 × 0.5 cm
Mini-pool thickness

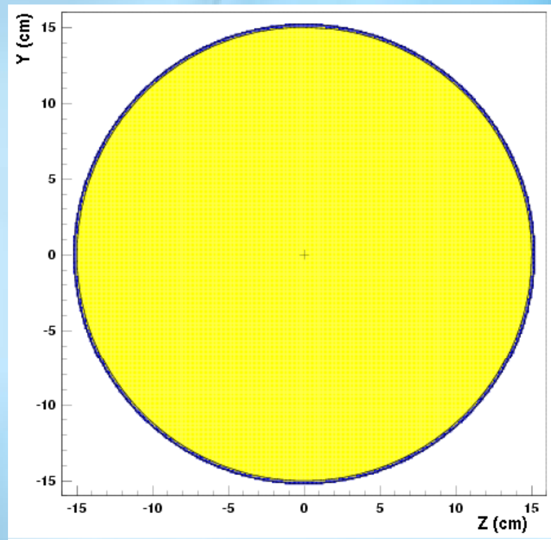
2 × 0.5 cm
Aluminum
container thickness

Sliced Ta Cylinder (Air) + Al cladding

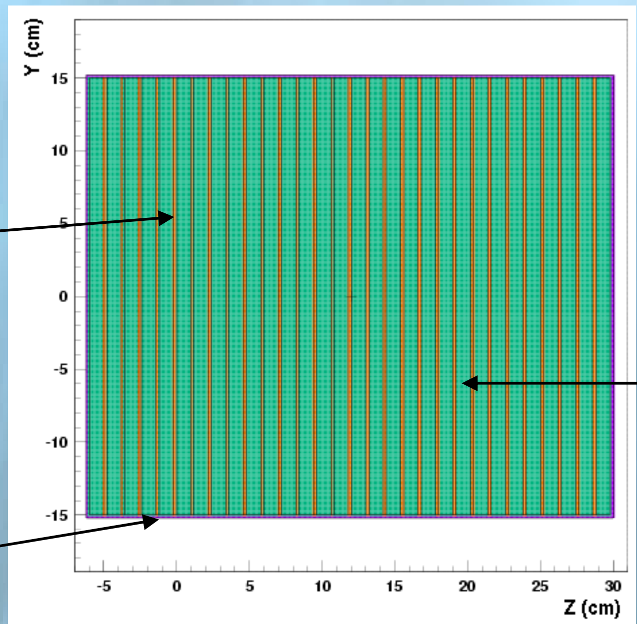
Side view



Front view



- Length: 30 cm
- Diameter: 30 cm



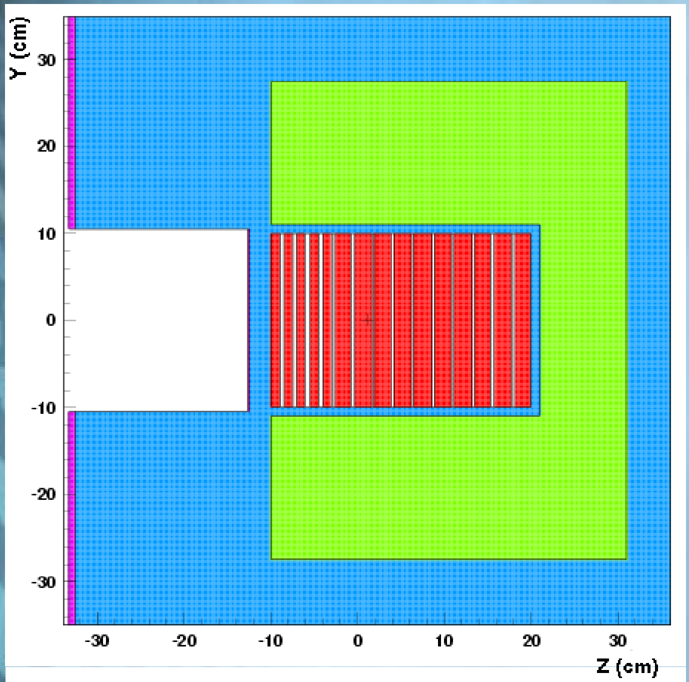
0.2 cm
air thickness

1 cm
tantalum thickness

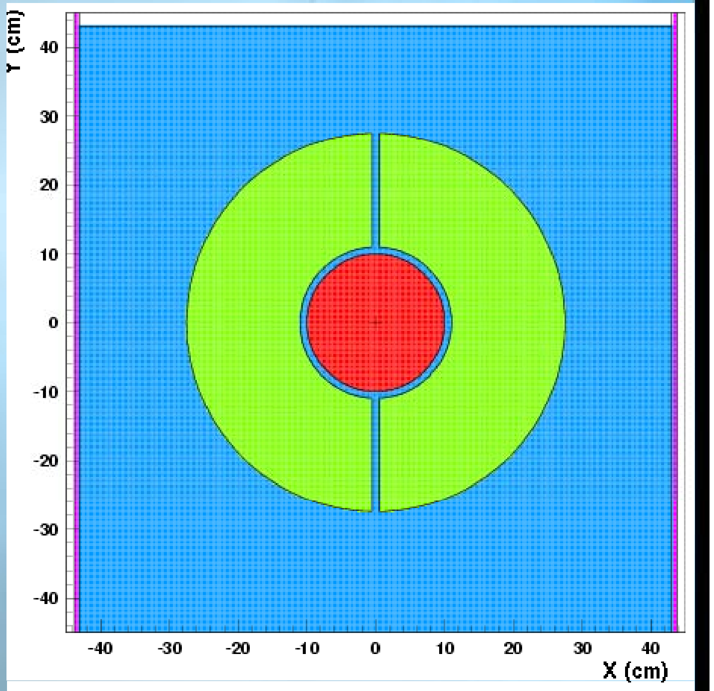
0.2 cm
Al cladding
thickness

Sliced Ta + Lead + Cooling System

Side view



Front view



→ Tantalum:

- Length: 25 cm
- Diameter: 20 cm

→ Lead:

- Length: 40 cm
- Diameter: 55 cm

→ Water:

- Thickness: 1 cm

Pb – Ta: Nuclide Vector

after 4 years of operations and 3 years of cooling: September 2007

Lead Target Solution				Tantalum Target Solution			
Isotope	Halflife (s)	Specific Activity (Bq/g)	Total Activity (Bq)	Isotope	Halflife (s)	Specific Activity (Bq/g)	Total Activity (Bq)
^{204}Tl	1.19E+08	2.27E+04	9.05E+10	^{172}Lu	5.79E+05	4.18E+05	1.48E+11
^{194}Hg	1.40E+10	3.02E+02	1.20E+09	^{182}Ta	9.89E+06	3.02E+05	1.07E+11
^{60}Co	1.66E+08	3.21E+02	1.28E+09	^{172}Hf	5.90E+07	4.14E+05	1.46E+11
^{3}H	3.89E+08	5.48E+04	2.18E+11	^{148}Gd	2.24E+09	3.29E+03	1.16E+09
^{207}Bi	1.04E+09	1.82E+03	7.24E+09	^{179}Ta	5.74E+07	2.43E+06	8.59E+11
^{172}Lu	5.79E+05	1.29E+03	5.12E+09	^{173}Lu	4.32E+07	4.49E+05	1.59E+11
^{172}Hf	5.90E+07	1.27E+03	5.07E+09	^{3}H	3.89E+08	5.64E+05	1.99E+11
	TOTAL:	**9.30E+04**	**3.70E+11**		TOTAL:	**4.70E+06**	**1.66E+12**

- Tantalum results in about a **factor of 4 higher total activity**
- Having much less mass and being concentrated around the beam core part, this results in a factor of ~50 higher specific activity

Cooling Water - Comparison

after 4 years of operations and 3 years of cooling: September 2007

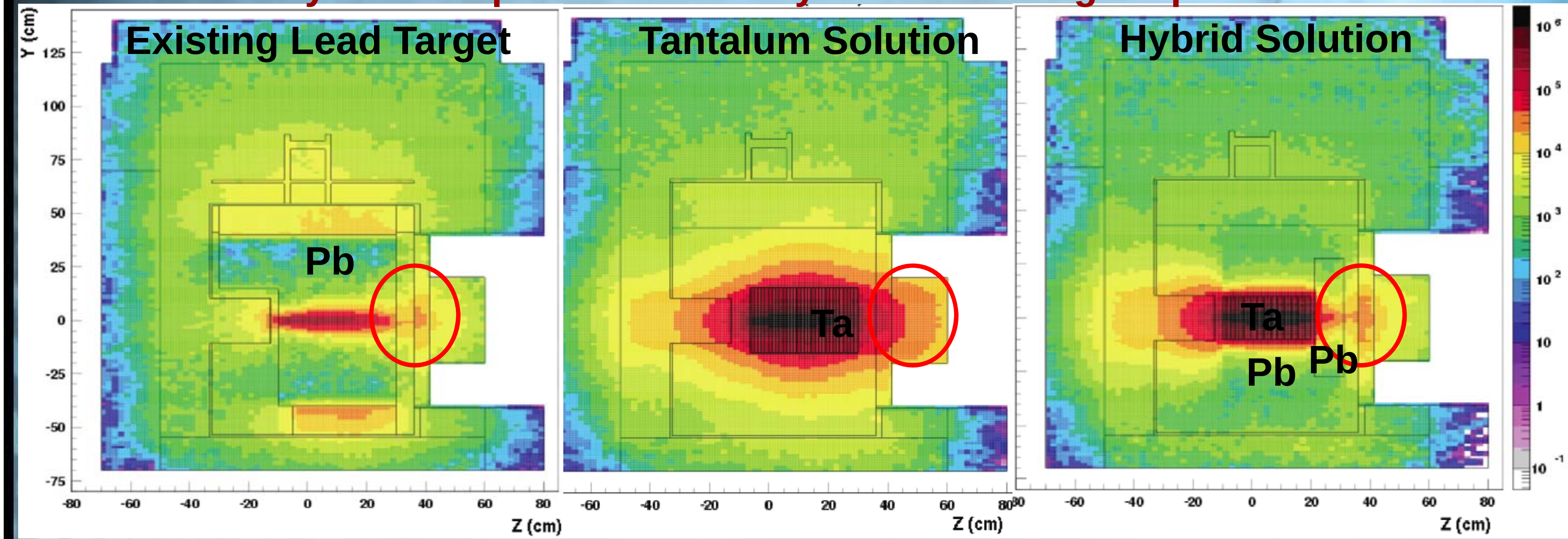
- The **tritium content** being the main element of the cooling water nuclide vector, shows changes of **up to a factor three** depending on the target solution
- In case of the **hybrid solution the increase is less than a factor of two**

Target Configuration	Total Activity (Bq)	Specific Activity (Bq/g)
Existing Lead Target	3.61E+09	4.51E+03
Lead cylinder with Mini-Pool	5.29E+09	6.61E+03
Sliced Tantalum Cylinder with Aluminum Cladding	1.07E+10	1.34E+04
Small Tantalum Cylinder Surrounded by Lead	1.01E+10	1.26E+04
Sliced Tantalum Cylinder Surrounded by Lead with Cooling Water Passages	5.21E+09	6.51E+03

- A possible **wash-out of isotopes** stemming from the pipes or the target (cladding) is **not considered**. Always being present, they will however be **captured in the filters**.

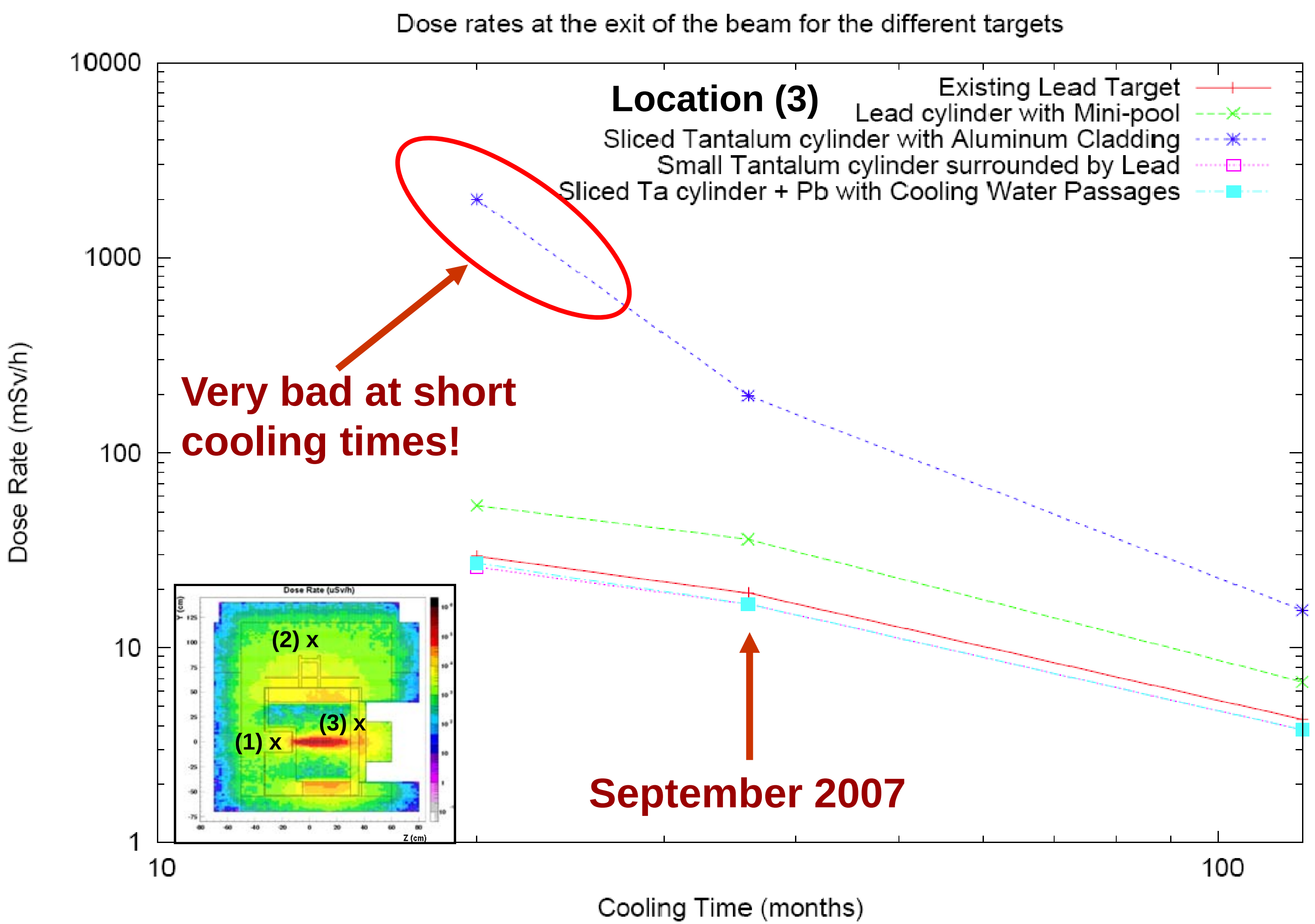
Pb – Ta: Residual Dose Rates

after 4 years of operations and 3 years of cooling: September 2007



- **Pure Tantalum** solution results in **important residual dose rates** towards the **beam exit**
- A possible **hybrid solution** leads to **acceptable residual dose rates** at the exit side
- The **hotspot at the entrance side** could be easily covered with a **lead plug** as soon as the target is removed

Comparison - Residual Dose Rates



Target Nuclide Vector - Comparison

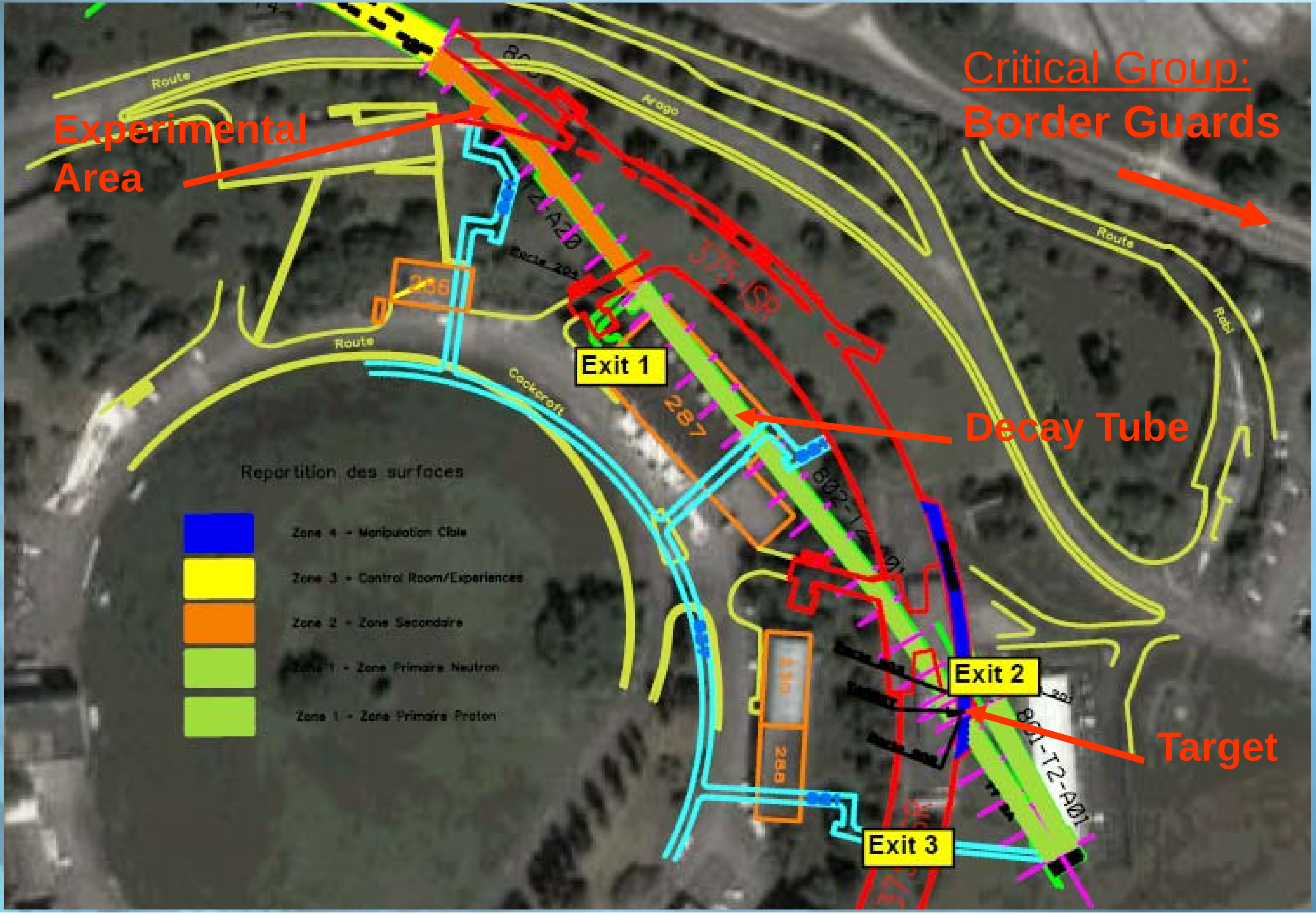
after 4 years of operations and 3 years of cooling: September 2007

Target Configuration	Total Activity (Bq)		Specific Activity (Bq/g)		Most Abundant Isotope (Multiple of LE, Total and Specific Activity)		Dose Rate (@10cm) for three different locations (mSv/h)		
	Lead	Tantalum	Lead	Tantalum	Lead	Tantalum	Proton Beam Entrance	Exit Proton Beam	Target Top
Existing Lead Target	3.7×10^{11} α: 4.2×10^{8}		9.3×10^{4} α: 1.0×10^{2}		^{204}Tl / 2841.17 9.0×10^{10} Bq 2.3×10^{4} Bq/g		~ 20	~ 20	~ 5
Lead cylinder with Mini-Pool	3.3×10^{11} α: 1.6×10^{9}		3.3×10^{5} α: 1.6×10^{3}		^{204}Tl / 10308.37 8.3×10^{10} Bq 8.2×10^{4} Bq/g		~ 30	~ 35	~ 2
Sliced Tantalum Cylinder with Aluminum Cladding		1.6×10^{12}		4.5×10^{6}		^{172}Lu / 52263.77 1.4E+11 Bq 4.2E+05 Bq/g	~ 70	~ 200	~ 2
Small Tantalum Cylinder Surrounded by Lead	2.1×10^{11} α: 7.9×10^{8}	7.4×10^{11}	2.0×10^{5} α: 7.7×10^{2}	9.4×10^{6}	^{204}Tl / 7628.22 6.2×10^{10} Bq 6.0×10^{4} Bq/g	^{172}Lu / 109693.7 6.5×10^{10} Bq 8.7×10^{5} Bq/g	~ 100	~ 20	~ 1
Sliced Tantalum Cylinder Surrounded by Lead with Cooling Water Passages	1.0×10^{11} α: 2.7×10^{8}	1.1×10^{12}	1.7×10^{5} α: 4.8×10^{2}	8.4×10^{6}	^{204}Tl / 8656.9 3.9×10^{10} Bq 6.8×10^{4} Bq/g	^{172}Lu / 98623.7 1.0×10^{11} Bq 7.8×10^{5} Bq/g	~ 100	~ 20	~ 1

- **Tantalum** leads to significant **higher isotope production**
- **Tantalum** shows important **residual dose rates** at both the proton beam entry and exit
- The latter can be **overcome by a hybrid solution**
- Both, **the existing and the hybrid target** seem to be a **possible solution**

Air Activation & Ventilation

Critical Groups



Air Activation - Assumptions

- **General:**
  - Facility operation time: 6 months
  - Air volume considered for activation: $600m^3$
  - Air volume considered for decay: $120m^3$
  - **No dilution**
  - Dose to Public: annual dose based on long-term dose conversion factors (P. Vojtyla)
  - Dose to Personnel: dose rate due to direct exposure (conversion factors from the Swiss and French legislation)
- **Possible Ventilation System:**
  - Ventilation speed: $5000m^3/h$
  - Enclosed Case: Waiting time before access: 1 day

Annual Dose Calculation

- **FLUKA simulations** to calculate the isotope production yield (39 different isotopes considered)
- **Exposure of personnel (access to nToF area)**
  - **Dose conversion coefficients** based on the Swiss and French legislation
- **Dose to the public (outside CERN)**
  - Definition of critical groups (border guards)
  - Calculation of dose conversion coefficients (P. Vojtyla) based on environmental models
- **Different ventilation scenarios**
  - Existing situation
  - Continuous ventilation (laminar flow)
  - Enclosed area and flush before access (full mixing)

Studied Options

- Isotope production term is "transported" according to the **assumed ventilation scenario**
- Assumptions for **exposure**:
  - personnel: direct (full) exposure at the pit
  - critical group: specific dose conversion factors
- **Continuous ventilation system**
  - laminar flow to the pit
  - ventilation speed of 5000 m^3/h
- **Enclosed ventilation system**
  - full mixing in the cavern
  - one day waiting time before flush (before access)
  - ventilation speed of 5000 m^3/h
  - direct exposure happens during full air exchange

Ventilation System - Comparison

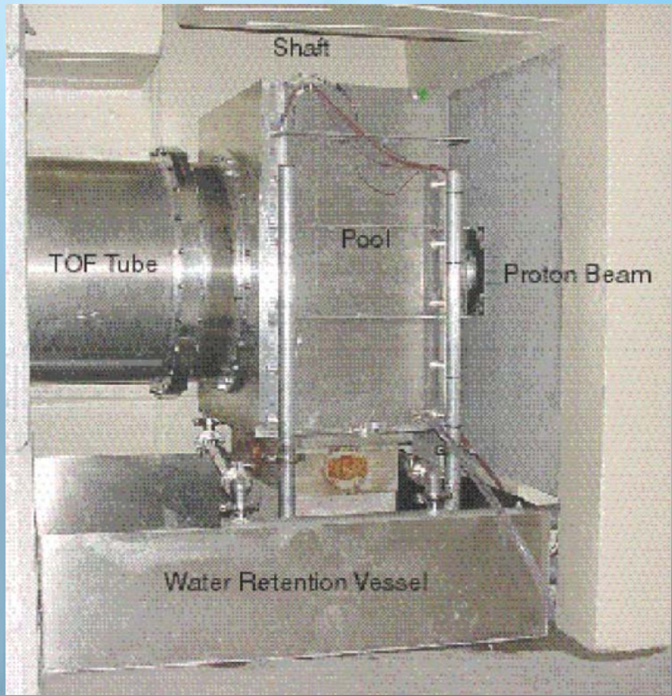
Ventilation Scenario	Personnel			Public	
	Maximum Dose Rate	Maximum Total Dose	Most Abundant Isotopes	Maximum Annual Dose	Most Abundant Isotopes
Continuous	**~90 uSv/h**	not applicable	~45% **N^{13}** (~10 minutes) ~40% **O^{15}** (~2 minuts) ~10% **Ar^{41}** (~2 hours)	**1.2 uSv**	~30% **C^{11}** (~20 minutes) ~40% **N^{13}** (~10 minutes) ~20% **Ar^{41}** (~2 hours)
Enclosed + Flush	~120 uSv/h	**14 uSv**	~10% **Be^{7}** (~53 days) ~80% **P^{32}** (~14 days)	**0.01 uSv**	~90% **Be^{7}** (~53 days)

- All calculations consider **strict conservative assumptions**
- **Continuous ventilation** leads to a maximum annual dose to the public of **~1 μSv**
- An **enclosed scenario** with flush before access would **reduce the dose to the public by a factor of 100** with a maximum exposure of personnel up to a total dose of **~15 μSv** (however under unrealistic assumptions)
- The **continuous ventilation scenario is highly depending on the chosen ventilation speed** (main contributing isotopes)

Cooling System

Target Cooling - Contamination

- **Facts/Hypotheses**
  - *Origin -> **Many Hypotheses** as outlined before*
  - Level of contamination only estimated, deposits exist, based on dose rate measured above and below
  - Contamination: contained or soluble?
- **Options**
  - accept contamination and continue running with existing circuit
  - accept contamination and upgrade certain parts of the cooling circuit
  - decontamination/replacement
- **Foreseen Measurements**
  - Visual inspection (partly remote)
  - Contamination sample
  - Pictures & Macro-Pictures

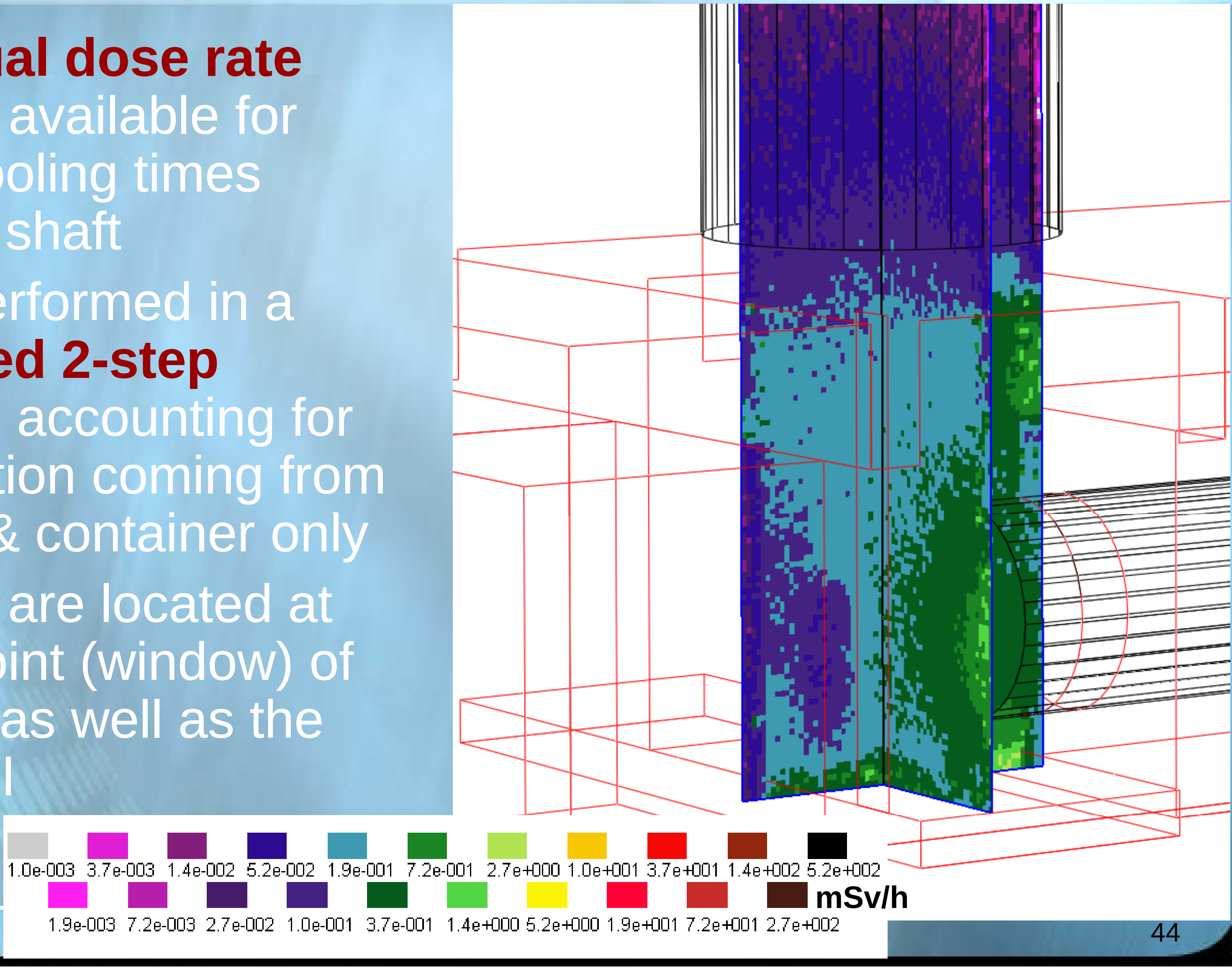


Intervention Scenarios

- **Planned (individual/collective dose)**
  - Sand removal (~20 μSv)
  - Taking of pictures (~20 μSv)
  - Taking of samples (~80 μSv)
- **Corrosion Inspection (Endoscopy)**
  - Previous visual inspection and detailed intervention planning
  - Person needs to be lowered into the target shaft
  - Attached to the crane with safety passage
  - Mock-up training and time optimization
- **If major Corrosion is observed Replacement of Pipes inside the Shielding**
  - Dismantling of most of the shielding
  - Localized residual dose rates (hotspots) as well as generally high values with respect to the needed long intervention
  - Estimated time for full intervention: 6 months, 3 persons

Residual Activation in the Shaft

- **3D residual dose rate maps** are available for various cooling times inside the shaft
- Can be performed in a **specialized 2-step approach** accounting for the activation coming from the walls & container only
- **Hotspots** are located at the exit point (window) of the beam as well as the lateral wall



Dose Planning: Corrosion Inspection

- **Preliminary estimates**
  - Average dose rate in the shaft: ~50 μSv/h
  - Expected hot spots: ~250 μSv/h
  - Intervention time in the shaft: 5 minutes
  - Intervention time close to hot spots: 2 minutes
  - Needed minimum safety factor: 2 (Time) x 2 (Dose Rates)
  - Estimated maximum individual dose: ~50 μSv
- **Requirements (details to be refined)**
  - Work in contaminated area
    - protection clothing, respiratory mask (filter), preparation of mobile SAS
  - Careful intervention planning, optimization, mock-up training
  - Monitoring during the intervention with pre-defined thresholds to stop the work

Replacement of the Cooling Circuit

- **Preliminary estimates**
  - Average dose rate in the area: ~5 - 10 μSv/h
  - Average dose rate close to the tank: ~50 - 100 μSv/h
  - Expected hot spots: ~0.5 - 1 mSv/h
  - Estimated individual dose (preliminary): ~1 mSv
  - Estimated collective dose (preliminary): ~3 mSv
- **Requirements**
  - long intervention asking for detailed optimization even for parts with low residual dose rates
  - many requirements see partly before

Conclusion

RP Calculation - Summary

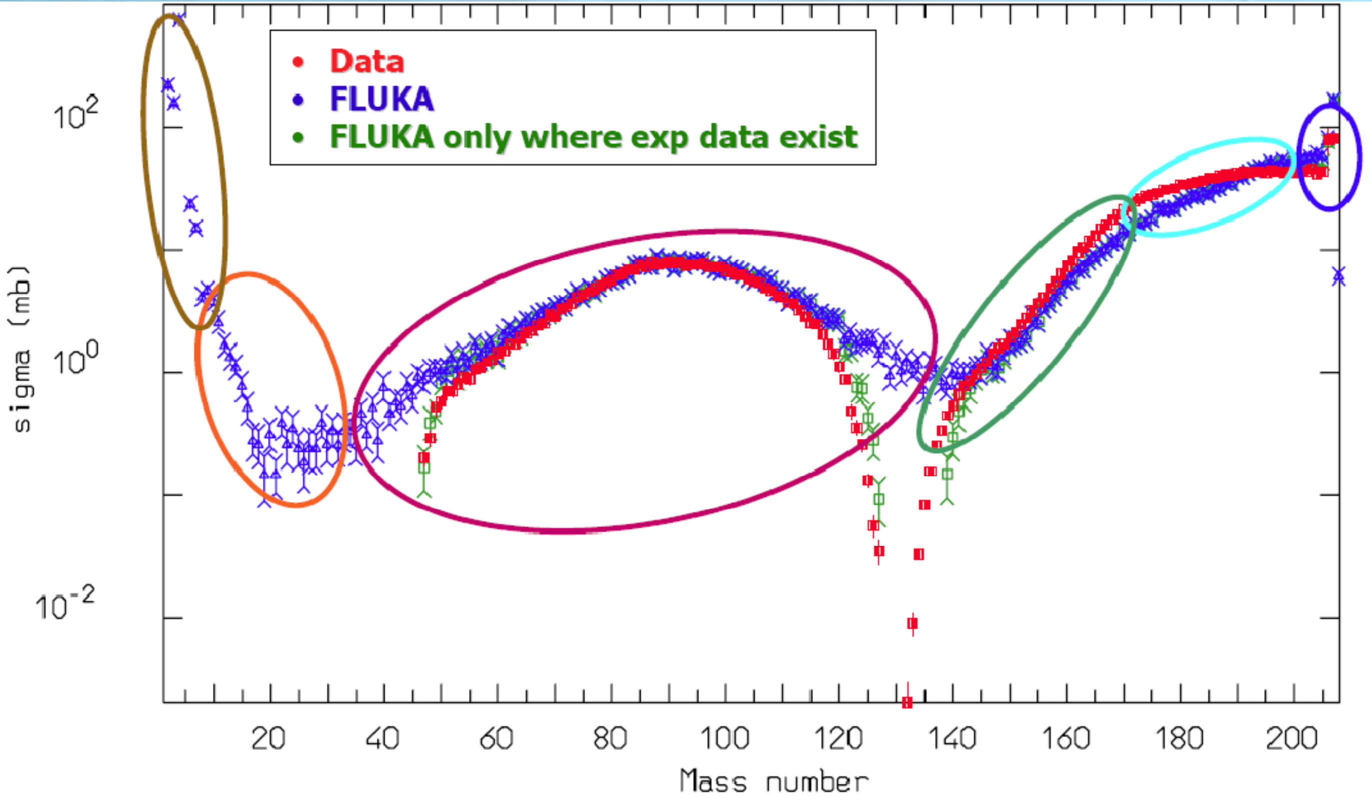
- **Needed input for existing target disposal**
  - all available
  - final report in preparation
  - delay: no
  - resources: no
- **Existing target handling**
  - all needed input available
  - procedures prepared
  - additional inspection needed (cooling system)
  - delay: no
  - resources: 0.5 FTE month
- **New Target design**
  - preliminary designs studied
  - physics included
  - engeneering design needed
- **Ventilation requirements**
  - all input available
  - different options studied
  - final report in preparation
  - delay: no
  - resources: no
- **Cooling System & Implications**
  - Measurements needed
  - Possible interventions
  - Refined intervention scenarios needed
  - delay: 1-2 weeks
  - resources: 0.5 FTE month

- delay: 2+ months
- resources: 2+ FTE months

Supporting Material

Isotope Production - Benchmark

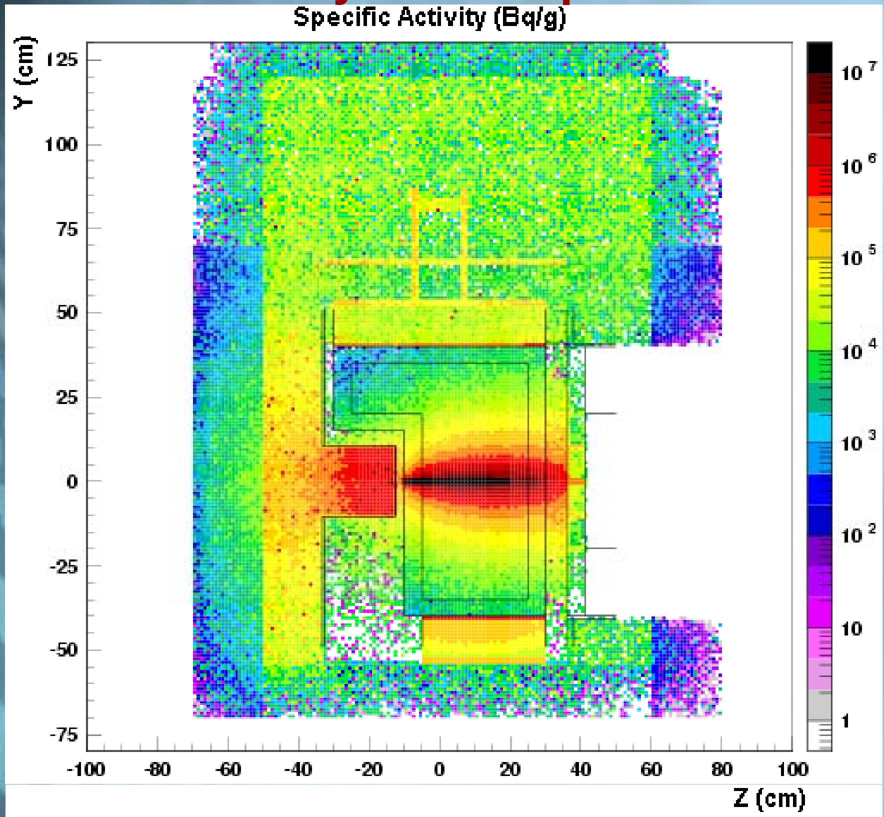
1 A GeV ^{208}Pb + p reactions Nucl. Phys. A 686 (2001) 481-524

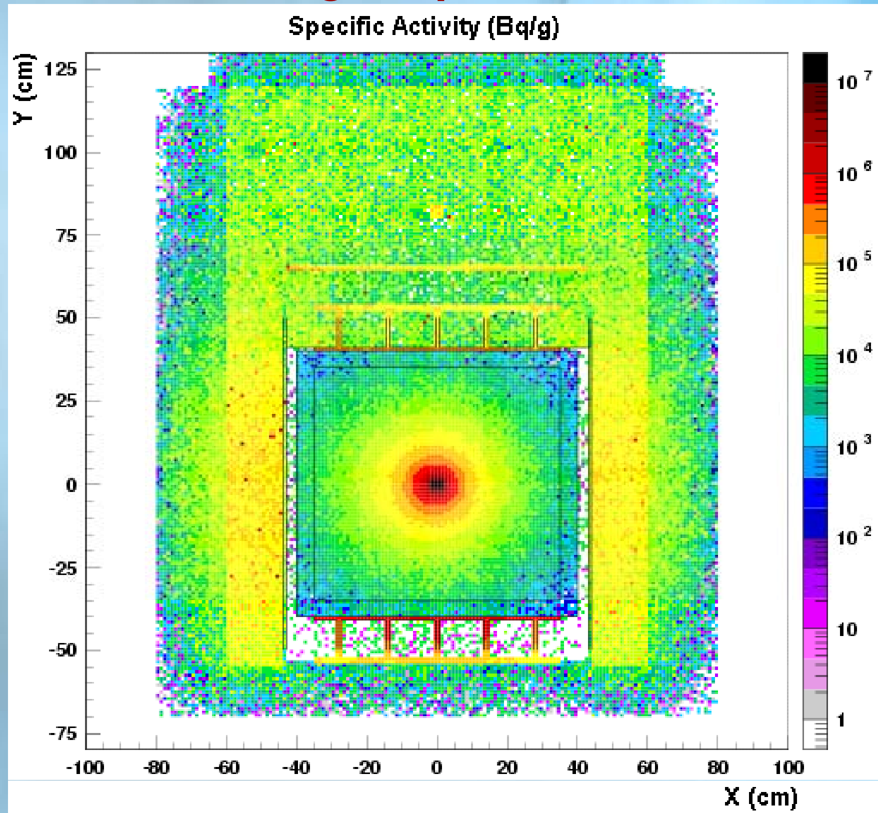


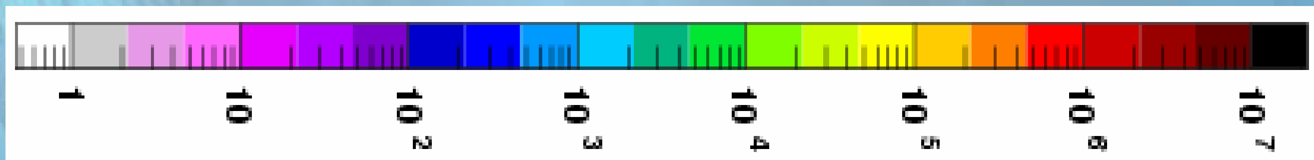
- **One expects an accurate characterization of the nuclide vector for nToF, well below the required accuracy**

Specific Activity (Bq/g)

after 4 years of operations and 3 years of cooling: September 2007

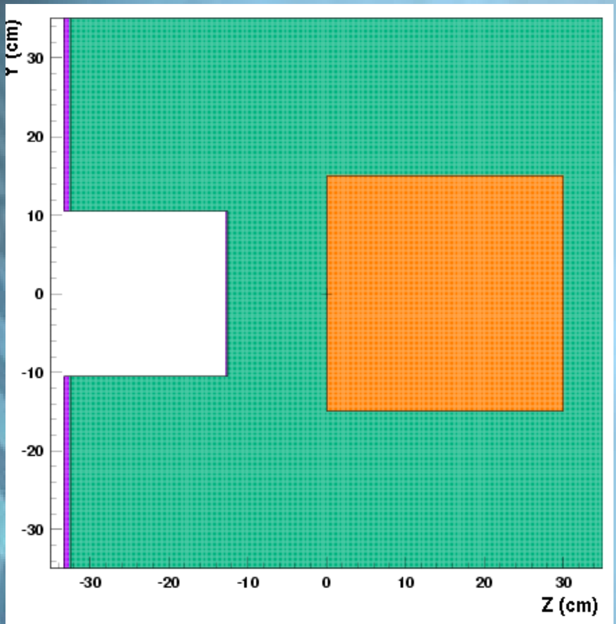






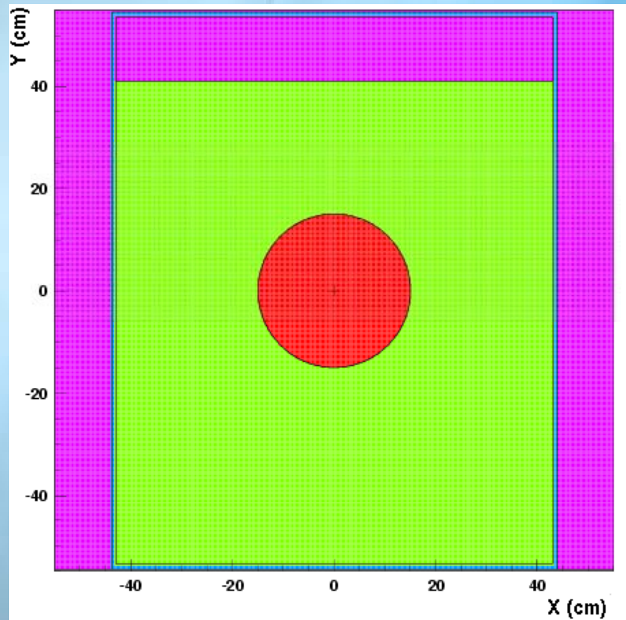
Tantalum cylinder

Side view



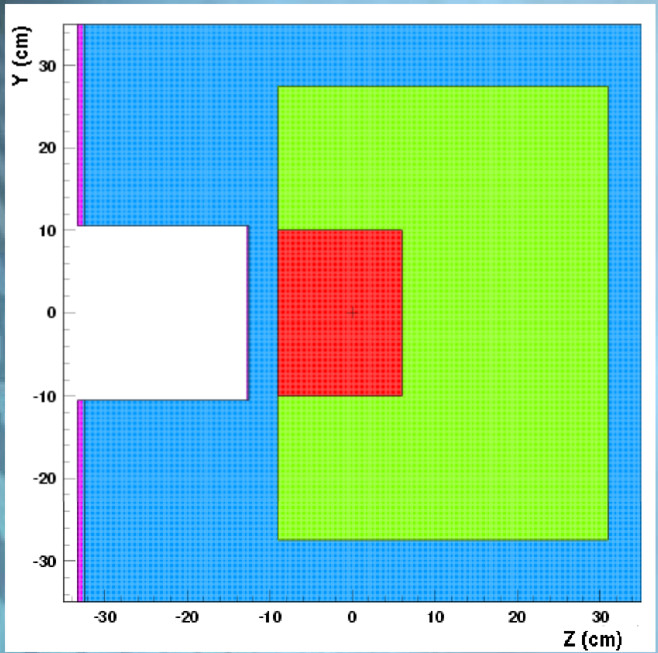
- Length: 30 cm
- Diameter: 30 cm

Front view



Short Ta Cylinder Surrounded by Lead

Side view



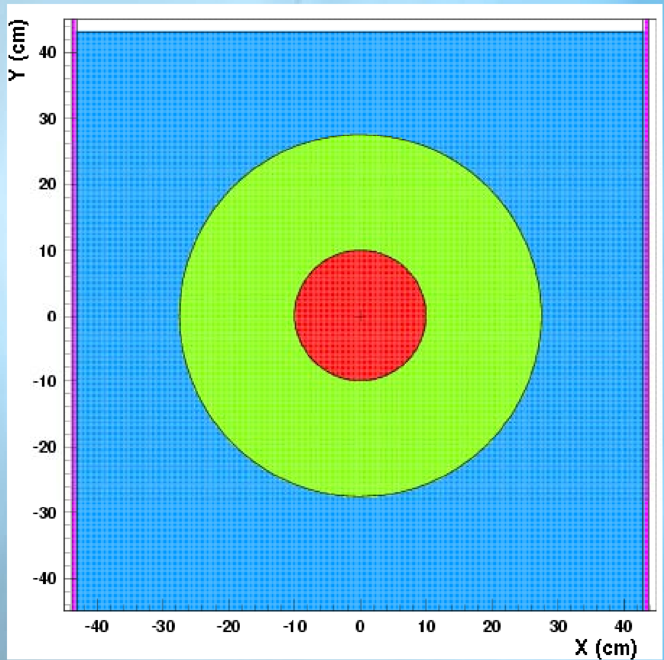
→ Tantalum:

- Length: 15 cm
- Diameter: 20 cm

→ Lead:

- Length: 40 cm
- Diameter: 55 cm

Front view



Continuous Ventilation Design

Direct Exposure (Personal along the Air)
Dose to public (critical group)

Isotope		Production [#Of_Isotopes per total Volume and second]				a_i Specific Activity [Bq/m3]	Inhalation Conversion Coefficients [Sv/Bq]	Dose Rate Maximal [µSv/h]	rel. Contr. [%]	Total Release [Bq]	Critical Group Conversion Coefficients EXIT 3 [Sv/Bq]	Dose to 'Critical Group' [uSv]	rel. Contr. [%]
H-3	12.35 y	4.20E+08	+/-	0.40	%	5.37E-01	1.80E-11	1.16E-05	0.00	1.16E+07	1.82E-19	2.11E-06	0.00
Be-7	53.3 d	1.40E+08	+/-	0.50	%	1.52E+01	4.80E-11	8.75E-04	0.00	3.28E+08	7.47E-17	2.45E-02	2.01
Be-10	1.6E6 y	1.80E+08	+/-	0.60	%	1.87E-06	3.20E-08	7.19E-08	0.00	4.04E+01	4.53E-16	1.83E-08	0.00
C-11	20.38 m	3.20E+08	+/-	0.60	%	1.12E+05	2.52E-11	3.39E+00	3.92	2.42E+12	1.42E-19	3.44E-01	28.20
C-14	5730.0 y	2.70E+11	+/-	0.40	%	7.49E-01	6.20E-12	5.57E-06	0.00	1.62E+07	2.72E-17	4.40E-04	0.04
N-13	9.965 m	4.50E+08	+/-	0.40	%	2.67E+05	1.19E-10	3.81E+01	44.05	5.76E+12	8.32E-20	4.79E-01	39.32
O-14	71.0 s	2.10E+07	+/-	1.20	%	1.48E+04		0.00E+00	0.00	3.20E+11	1.301E-20	4.17E-03	0.34
O-15	122.24 s	2.60E+08	+/-	0.50	%	2.41E+05	1.19E-10	3.45E+01	39.87	5.21E+12	9.33E-21	4.86E-02	3.99
O-19	27.1 s	1.50E+04	+/-	1.50	%	2.72E+00		0.00E+00	0.00	5.88E+07	6.7E-22	3.94E-08	0.00
F-18	109.77 m	3.40E+05	+/-	1.10	%	2.49E+01	9.30E-11	2.78E-03	0.00	5.38E+08	2.63E-18	1.41E-03	0.12
Ne-23	28.0 s	3.80E+04	+/-	1.30	%	1.25E+01		0.00E+00	0.00	2.71E+08	2.315E-22	6.27E-08	0.00
Ne-24	3.38 m	8.00E+03	+/-	1.40	%	7.67E+00		0.00E+00	0.00	1.66E+08	1.108E-20	1.84E-06	0.00
Na-22	2.602 y	1.20E+05	+/-	1.00	%	7.30E-04	2.00E-09	1.75E-06	0.00	1.58E+04	3.16E-14	4.98E-04	0.04
Na-24	15.0 h	1.80E+05	+/-	0.90	%	1.66E+00	5.30E-10	1.05E-03	0.00	3.58E+07	6.78E-17	2.43E-03	0.20
Na-25	60.0 s	6.90E+04	+/-	1.10	%	4.14E+01		0.00E+00	0.00	8.95E+08	1.606E-21	1.44E-06	0.00
Mg-27	9.5 m	1.00E+05	+/-	1.00	%	6.13E+01		0.00E+00	0.00	1.32E+09	2.29E-18	3.04E-03	0.25
Mg-28	20.91 h	3.90E+04	+/-	0.70	%	2.59E-01	1.70E-09	5.28E-04	0.00	5.59E+06	5.78E-17	3.23E-04	0.03
Al-26	7.2E5 y	1.70E+05	+/-	0.90	%	3.69E-09	1.80E-08	7.97E-11	0.00	7.97E-02	3.77E-13	3.00E-08	0.00
Al-28	2.24 m	4.60E+05	+/-	0.70	%	4.35E+02	1.39E-09	7.26E-01	0.84	9.40E+09	3.21E-19	3.02E-03	0.25
Al-29	6.6 m	2.10E+05	+/-	0.80	%	1.61E+02		0.00E+00	0.00	3.48E+09	1.133E-19	3.94E-04	0.03
Si-31	157.3 m	2.90E+05	+/-	0.50	%	1.51E+01	1.10E-10	1.99E-03	0.00	3.25E+08	6.41E-19	2.08E-04	0.02
Si-32	450.0 y	1.70E+05	+/-	0.50	%	1.57E-05	2.78E-07	5.24E-06	0.00	3.39E+02	8.99E-16	3.05E-07	0.00
P-30	2.499 m	1.30E+05	+/-	0.70	%	1.26E+02		0.00E+00	0.00	2.71E+09	3.43E-20	9.30E-05	0.01
P-32	14.29 d	1.60E+06	+/-	0.50	%	6.65E-01	3.20E-08	2.55E-02	0.03	1.44E+07	9.56E-17	1.37E-03	0.11
P-33	25.4 d	2.60E+06	+/-	0.40	%	5.90E-01	1.40E-09	9.91E-04	0.00	1.27E+07	2.06E-17	2.62E-04	0.02
P-35	47.4 s	2.20E+05	+/-	0.30	%	1.02E+02		0.00E+00	0.00	2.21E+09	2.20E-19	4.85E-04	0.04
S-35	87.44 d	2.60E+06	+/-	0.40	%	1.71E-01	1.10E-10	2.25E-05	0.00	3.69E+06	1.97E-17	7.25E-05	0.01
S-37	5.06 m	7.60E+05	+/-	0.60	%	6.55E+02		0.00E+00	0.00	1.41E+10	1.373E-19	1.94E-03	0.16
S-38	2.87 h	4.90E+05	+/-	0.40	%	2.39E+01		0.00E+00	0.00	5.17E+08	5.36E-18	2.77E-03	0.23
Cl-34	32.0 m	8.20E+04	+/-	0.60	%	6.26E-16		0.00E+00	0.00	1.35E-08	0	0.00E+00	0.00
Cl-36	3.0E5 y	6.50E+06	+/-	0.50	%	3.41E-07	6.90E-09	2.83E-09	0.00	7.38E+00	1.36E-14	1.00E-07	0.00
Cl-38	37.21 m	5.20E+06	+/-	0.40	%	1.07E+03	7.30E-11	9.40E-02	0.11	2.32E+10	1.33E-18	3.08E-02	2.53
Cl-39	55.6 m	8.70E+06	+/-	0.40	%	1.24E+03	7.60E-11	1.13E-01	0.13	2.67E+10	1.85E-18	4.93E-02	4.05
Cl-40	1.4 m	1.40E+06	+/-	0.60	%	1.09E+03		0.00E+00	0.00	2.35E+10	2.306E-20	5.41E-04	0.04
Ar-37	35.02 d	2.00E+07	+/-	0.30	%	3.33E+00	1.42E-16	5.68E-10	0.00	7.19E+07	4.69E-25	3.37E-11	0.00
Ar-39	269.0 y	3.30E+07	+/-	1.10	%	1.94E-03	3.82E-13	8.88E-10	0.00	4.19E+04	1.782E-21	7.46E-11	0.00
Ar-41	1.827 h	5.90E+08	+/-	0.40	%	4.32E+04	1.84E-10	9.54E+00	11.04	9.34E+11	2.338E-19	2.18E-01	17.91
K-38	7.636 m	6.30E+04	+/-	2.40	%	4.41E+01	1.19E-10	6.30E-03	0.01	9.53E+08	8.38E-19	7.98E-04	0.07
K-40	1.3E9 y	3.00E+05	+/-	2.90	%	3.72E-12	3.00E-09	1.34E-14	0.00	8.03E-05	4.09E-14	3.29E-12	0.00
						683298.38		86.49	uSv/h	1.48E+13		1.219	uSv

dose conversion coefficients (P. Vojtyla)

Enclosed Ventilation Design

Direct Exposure (Personal along the Air)
Dose to public (critical group)

Isotope		Production [#Of_Isotopes per total Volume and second]				a_i Specific Activity [Bq/m3]	Inhalation Conversion Coefficients [Sv/Bq]	Dose Rate Maximal [µSv/h]	rel. Contr. [%]	Total Release [Bq]	Critical Group Conversion Coefficients EXIT 3 [Sv/Bq]	Dose to 'Critical Group' [uSv]	rel. Contr. [%]
H-3	12.35 y	4.20E+08	+/-	0.40	%	1.91E+04	1.80E-11	4.12E-01	0.35	1.14E+07	1.82E-19	2.08E-06	0.02
Be-7	53.3 d	1.40E+08	+/-	0.50	%	2.08E+05	4.80E-11	1.20E+01	10.17	1.25E+08	7.47E-17	9.33E-03	89.03
Be-10	1.6E6 y	1.80E+08	+/-	0.60	%	6.74E-02	3.20E-08	2.59E-03	0.00	4.04E+01	4.53E-16	1.83E-08	0.00
C-11	20.38 m	3.20E+08	+/-	0.60	%	1.13E-16	2.52E-11	3.42E-21	0.00	6.78E-14	1.42E-19	9.62E-27	0.00
C-14	5730.0 y	2.70E+11	+/-	0.40	%	2.69E+04	6.20E-12	2.00E-01	0.17	1.62E+07	2.72E-17	4.40E-04	4.20
N-13	9.965 m	4.50E+08	+/-	0.40	%	3.36E-38	1.19E-10	4.80E-42	0.00	2.02E-35	8.32E-20	1.68E-48	0.00
O-14	71.0 s	2.10E+07	+/-	1.20	%	0.00E+00		0.00E+00	0.00	0.00E+00	1.301E-20	0.00E+00	0.00
O-15	122.24 s	2.60E+08	+/-	0.50	%	7.86E-212	1.19E-10	1.12E-215	0.00	4.71E-209	9.33E-21	4.40E-223	0.00
O-19	27.1 s	1.50E+04	+/-	1.50	%	0.00E+00		0.00E+00	0.00	0.00E+00	6.7E-22	0.00E+00	0.00
F-18	109.77 m	3.40E+05	+/-	1.10	%	6.49E-02	9.30E-11	7.25E-06	0.00	3.90E+01	2.63E-18	1.02E-10	0.00
Ne-23	28.0 s	3.80E+04	+/-	1.30	%	0.00E+00		0.00E+00	0.00	0.00E+00	2.315E-22	0.00E+00	0.00
Ne-24	3.38 m	8.00E+03	+/-	1.40	%	1.20E-129		0.00E+00	0.00	7.21E-127	1.108E-20	7.99E-141	0.00
Na-22	2.602 y	1.20E+05	+/-	1.00	%	2.46E+01	2.00E-09	5.91E-02	0.05	1.48E+04	3.16E-14	4.67E-04	4.45
Na-24	15.0 h	1.80E+05	+/-	0.90	%	9.90E+01	5.30E-10	6.29E-02	0.05	5.94E+04	6.78E-17	4.03E-06	0.04
Na-25	60.0 s	6.90E+04	+/-	1.10	%	0.00E+00		0.00E+00	0.00	0.00E+00	1.606E-21	0.00E+00	0.00
Mg-27	9.5 m	1.00E+05	+/-	1.00	%	3.91E-44		0.00E+00	0.00	2.35E-41	2.29E-18	5.38E-53	0.00
Mg-28	20.91 h	3.90E+04	+/-	0.70	%	2.93E+01	1.70E-09	5.97E-02	0.05	1.76E+04	5.78E-17	1.01E-06	0.01
Al-26	7.2E5 y	1.70E+05	+/-	0.90	%	1.33E-04	1.80E-08	2.87E-06	0.00	7.97E-02	3.77E-13	3.00E-08	0.00
Al-28	2.24 m	4.60E+05	+/-	0.70	%	6.54E-198	1.39E-09	1.09E-200	0.00	3.92E-195	3.21E-19	1.26E-207	0.00
Al-29	6.6 m	2.10E+05	+/-	0.80	%	7.15E-65		0.00E+00	0.00	4.29E-62	1.133E-19	4.86E-75	0.00
Si-31	157.3 m	2.90E+05	+/-	0.50	%	8.27E-01	1.10E-10	1.09E-04	0.00	4.96E+02	6.41E-19	3.18E-10	0.00
Si-32	450.0 y	1.70E+05	+/-	0.50	%	5.65E-01	2.78E-07	1.88E-01	0.16	3.39E+02	8.99E-16	3.05E-07	0.00
P-30	2.499 m	1.30E+05	+/-	0.70	%	8.76E-172		0.00E+00	0.00	5.26E-169	3.43E-20	1.80E-182	0.00
P-32	14.29 d	1.60E+06	+/-	0.50	%	2.54E+03	3.20E-08	9.74E+01	82.64	1.52E+06	9.56E-17	1.45E-04	1.39
P-33	25.4 d	2.60E+06	+/-	0.40	%	4.19E+03	1.40E-09	7.03E+00	5.97	2.51E+06	2.06E-17	5.16E-05	0.49
P-35	47.4 s	2.20E+05	+/-	0.30	%	0.00E+00		0.00E+00	0.00	0.00E+00	2.20E-19	0.00E+00	0.00
S-35	87.44 d	2.60E+06	+/-	0.40	%	3.26E+03	1.10E-10	4.30E-01	0.36	1.96E+06	1.97E-17	3.84E-05	0.37
S-37	5.06 m	7.60E+05	+/-	0.60	%	2.55E-84		0.00E+00	0.00	1.53E-81	1.373E-19	2.10E-94	0.00
S-38	2.87 h	4.90E+05	+/-	0.40	%	2.05E+00		0.00E+00	0.00	1.23E+03	5.36E-18	6.58E-09	0.00
Cl-34	32.0 m	8.20E+04	+/-	0.60	%	0.00E+00		0.00E+00	0.00	0.00E+00	0	0.00E+00	0.00
Cl-36	3.0E5 y	6.50E+06	+/-	0.50	%	1.23E-02	6.90E-09	1.02E-04	0.00	7.38E+00	1.36E-14	1.00E-07	0.00
Cl-38	37.21 m	5.20E+06	+/-	0.40	%	1.30E-08	7.30E-11	1.14E-12	0.00	7.83E-06	1.33E-18	1.04E-17	0.00
Cl-39	55.6 m	8.70E+06	+/-	0.40	%	1.90E-04	7.60E-11	1.74E-08	0.00	1.14E-01	1.85E-18	2.11E-13	0.00
Cl-40	1.4 m	1.40E+06	+/-	0.60	%	0.00E+00		0.00E+00	0.00	0.00E+00	2.306E-20	0.00E+00	0.00
Ar-37	35.02 d	2.00E+07	+/-	0.30	%	3.18E+04	1.42E-16	5.43E-06	0.00	1.91E+07	4.69E-25	8.94E-12	0.00
Ar-39	269.0 y	3.30E+07	+/-	1.10	%	6.97E+01	3.82E-13	3.19E-05	0.00	4.18E+04	1.782E-21	7.45E-11	0.00
Ar-41	1.827 h	5.90E+08	+/-	0.40	%	1.13E+02	1.84E-10	2.49E-02	0.02	6.76E+04	2.338E-19	1.58E-08	0.00
K-38	7.636 m	6.30E+04	+/-	2.40	%	3.02E-55	1.19E-10	4.31E-59	0.00	1.81E-52	8.38E-19	1.52E-64	0.00
K-40	1.3E9 y	3.00E+05	+/-	2.90	%	1.35E-07	3.00E-09	4.85E-10	0.00	8.08E-05	4.09E-14	3.31E-12	0.00
							Total:	117.87	uSv/h	1.78E+08		0.010	uSv
						Integrated (tot. Volume):		14.14	uSv				

dose conversion coefficients (P. Vojtyla)

Envisaged Ventilation System Options

Configuration	Direct Exposure at "Pit": Maximum Dose Rate [uSv/h]						Maximum Total Dose [uSv]	Release to Critical Group: Total Release [Bq]	Total Dose [uSv]				
	Total	Be7 [%]	N13 [%]	O15 [%]	P32 [%]	Ar41 [%]			Total	Be7 [%]	C11 [%]	N13 [%]	Ar41 [%]
No additional shielding Laminar Flow	**327**	0.0	44.0	44.6	0.0	5.4		5.79E+13	**4.447**	2.6	33.8	40.7	9.2
No additional shielding Enclosed	**557**	10.1	0.0	0.0	83.0	0.0	**67**	7.37E+08	**0.049**	90.3	0.0	0.0	0.0
Additional Shielding 1 Laminar Flow	**86**	0.0	44.1	39.9	0.0	11.0		1.48E+13	**1.219**	2.0	28.2	39.3	17.9
Additional Shielding 1 Enclosed	**118**	10.2	0.0	0.0	82.6	0.0	**14**	1.78E+08	**0.010**	89.0	0.0	0.0	0.0
Additional Shielding 2 Laminar Flow	**66**	0.0	43.8	38.4	0.0	13.1		1.11E+13	**0.938**	1.8	26.3	38.6	20.9
Additional Shielding 2 Enclosed	**82**	10.4	0.0	0.0	82.0	0.0	**10**	1.33E+08	**0.007**	88.4	0.0	0.0	0.0

Standard Ventilation

Parameters for Laminar Flow

A:	12	12	m2
l:	60	200	m
Active Length:	50	50	m
Vtot:	**720.0**	720	**m3**
Vdecay:	**120.0**	120.0	**m3**
Virr:	**600.0**	600	**m3**
v:	**5000.00**	150	**m3/h**
T_irr;	**432.0**	432	**s**
T_d:	**86.4**	86.4	**s**
Oper. Time:	**4320.0**	4320	**h**
A-Vrate:	**1.2**		**m3/h**

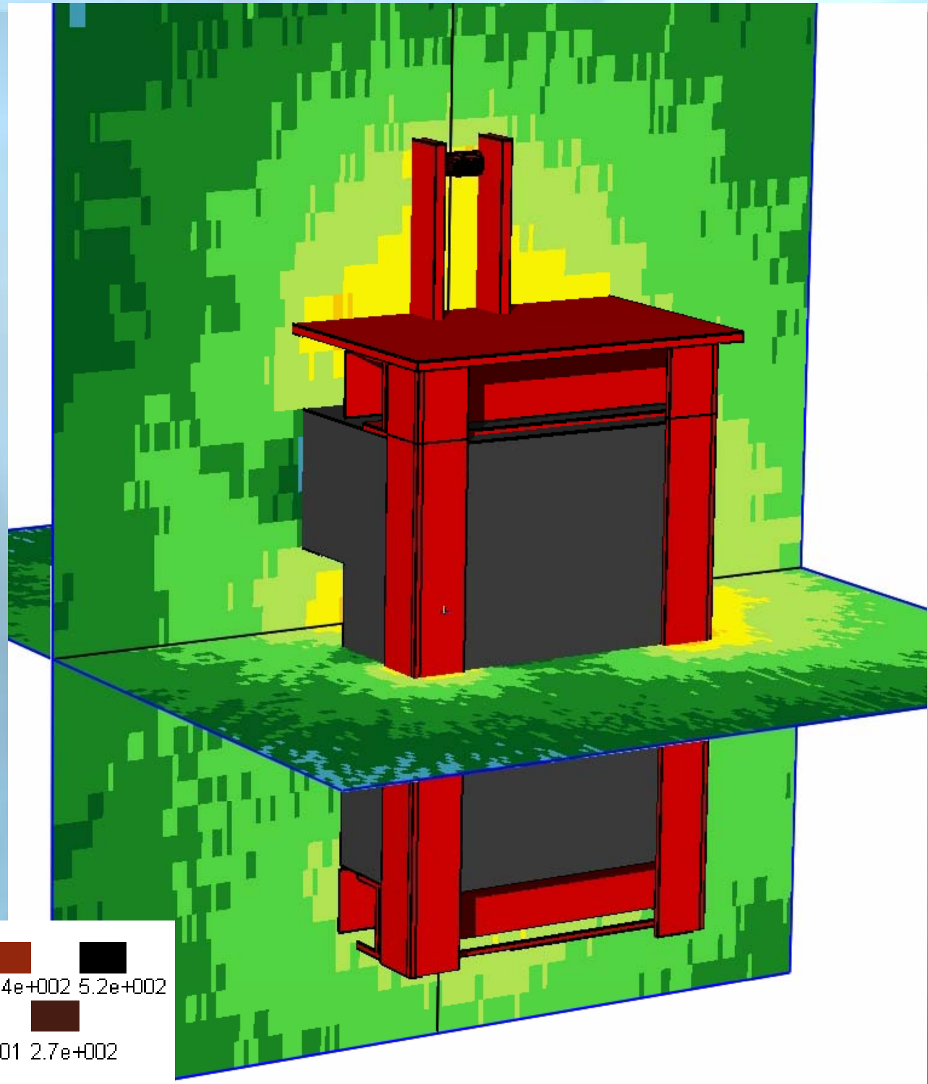
Parameters for Enclosed Case

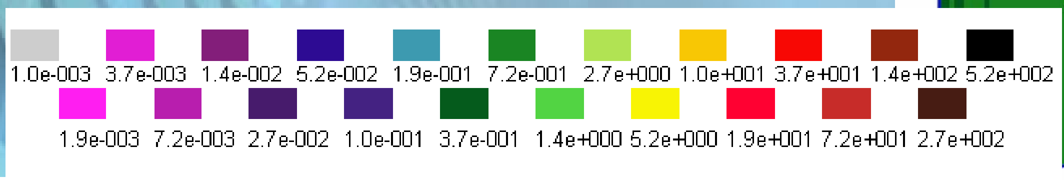
A:	12		m2
l:	200		m
Active Length:	50		m
V:	2400.0	2400	m3
Virr:	**600.0**	600	**m3**
v:	**5000.00**	500	**m3/h**
T_irr;	**15552000.0**	15552000	**s**
T_d:	**86400.0**	3600	**s**
Oper. Time:	**0.1**	4320	**h**
A-Vrate:	**1.2**		**m3/h**

- Dose to public: ~1 µSv (laminar), <0.1 µSv (enclosed)
- Dose to personnel:
  - ~86 µSv/h (laminar flow, continuous ventilation)
  - ~15 µSv (enclosed configuration, per flush) – P^{32}, Be^{7}

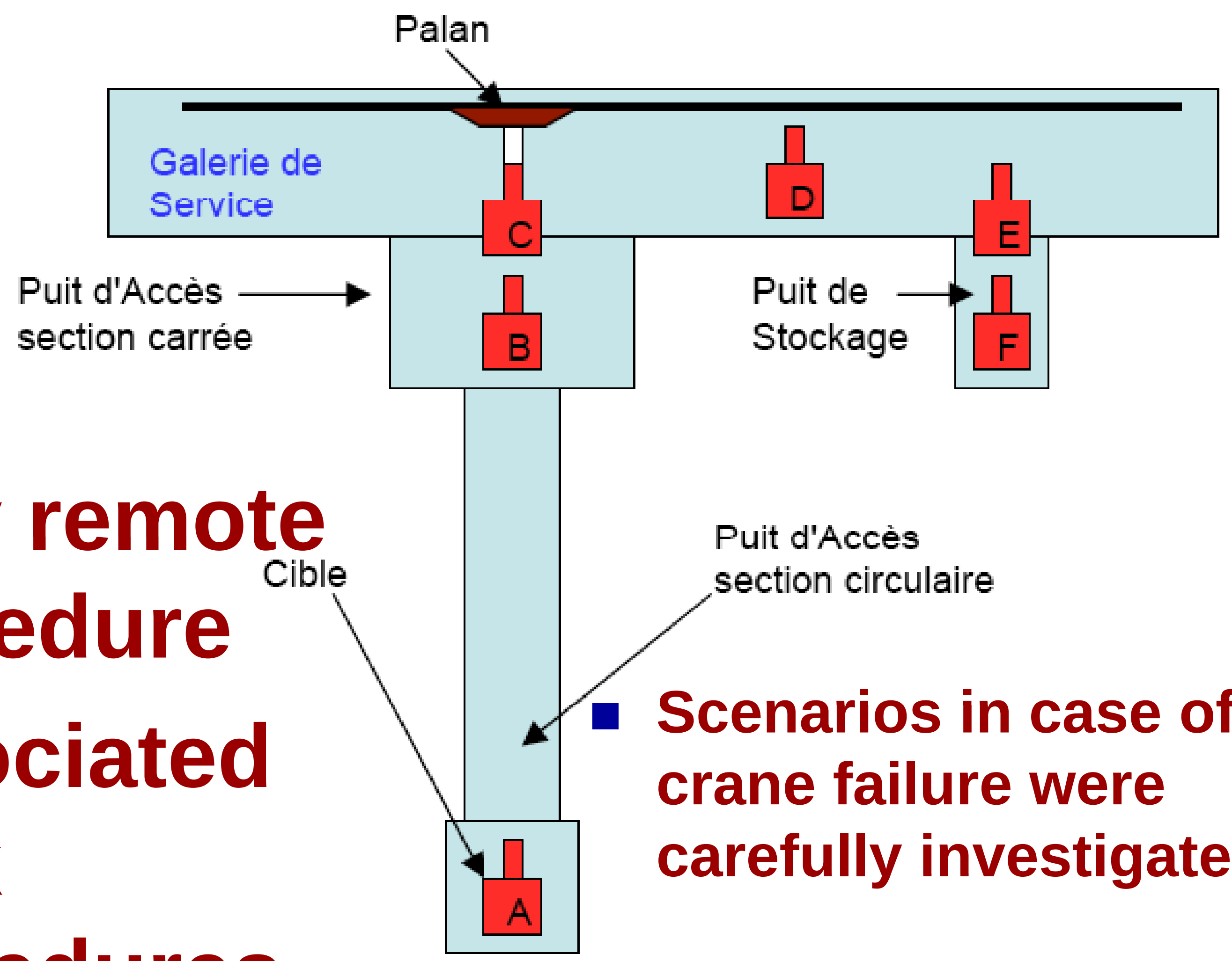
Residual Dose Rate Maps

- **3D residual dose rate maps** are available for various cooling times
- Can be performed in a **specialized 2-step approach** accounting for the target only
- **Hotspots** are located at the entry and exit point of the beam as well as around the stainless steel support





Target Removal Procedure

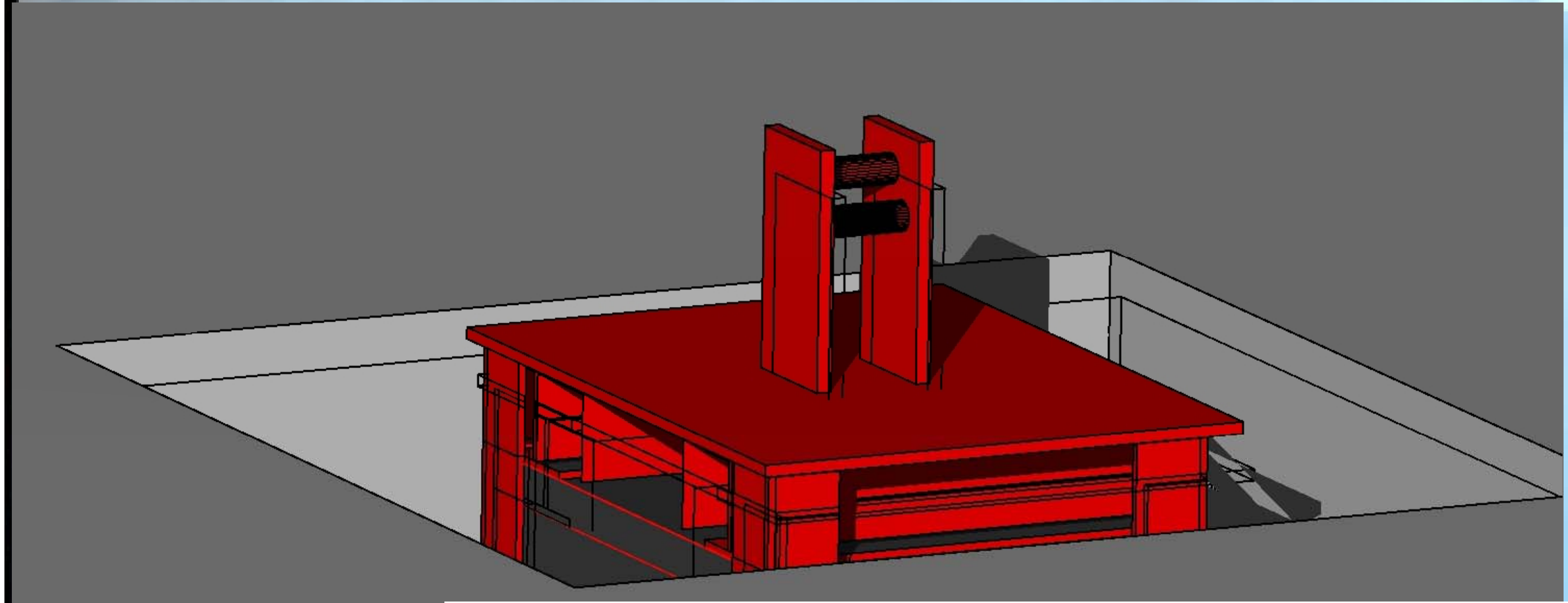


- **Fully remote procedure**
- **Associated work procedures**

- **Scenarios in case of crane failure were carefully investigated**

Example: Removal of Sand

Removal of Sand



1. Préparation de l'intervention avant l'ouverture du puit (dernier bouchon)
   - alimentation électrique
   - aspirateur avec bac et filtre neufs
   - tenue complète contamination niveau XXX (procédure à référencer)
2. Levage de la cible jusqu'au niveau du sol de la galerie de service
3. La position de la personne est assumée comme 100 cm au dessus du niveau de couvercle avec une distance de 150cm par rapport le centre de l'accroche.
4. Estimation de débit de dose (FLUKA): 200 μSv/h
5. Temps estime nécessaire pour le nettoyage : ~5min
6. Dose individuel et collective : ~20 μSv

Specifications - Summary

- **Needed input for target disposal**
  - Specific and total activities
  - Alpha emitters
  - Residual dose rates around the storage container
  - Contamination
- **Target handling**
  - Residual dose rates around the existing target
  - Procedures and dose planning
- **New Target design**
  - Impact on radionuclide vector
  - Residual dose rates & handling
- **Ventilation requirements**
  - Radioisotope production
  - Different operational scenarios
  - Dose to the critical group
- **Cooling System & Implications**
  - Contamination: facts/hypotheses
    - Inspection
    - Possible Repair
  - Corrosion: facts/hypotheses
    - Inspection
    - Possible Repair
  - Intervention scenario
    - Planning & Optimization