Towards a modified n_TOF Facility and Increased Radiation Safety

ATC/ABOC Days, 21st January 2008

*M. Brugger, on behalf of the **n_TOF Team***

Overview

- **Inspection of the old target** and implications for the new target design
  - visual inspection and Laser measurements
  - dose rate measurements, FLUKA calculations and comparison with measurements
  - summary of observations and important conclusions for the new target design
- Chosen **conceptual design**
  - layout
  - installation and operation
- **FLUKA calculations** for RP and Neutronics
- Main points requested by **last year's review** and how they are addressed by the new layout
- **Additional safety requirements**
- **Status and conclusions**

Target Interventions

- **Target removal** was performed at the **27.09.2007**
- Target **visual inspection** & photography
- Pit & pool inspection (web camera)
- First **dose rate measurements** of the target and pit
- Measurement of hole at the **beam impact** location
- **Samples taken** from the target to be analyzed by CERN & CIEMAT
- **Updated FLUKA simulations** of the target activation, as well as detailed maps for pit and pool
- **Target surface inspection** using a dedicated custom-built (and developed) laser system
- **Detailed dose rate measurement** of the target and pit (November 2007)
- Extensive study of the **target corrosion mechanism**

Target Inspection

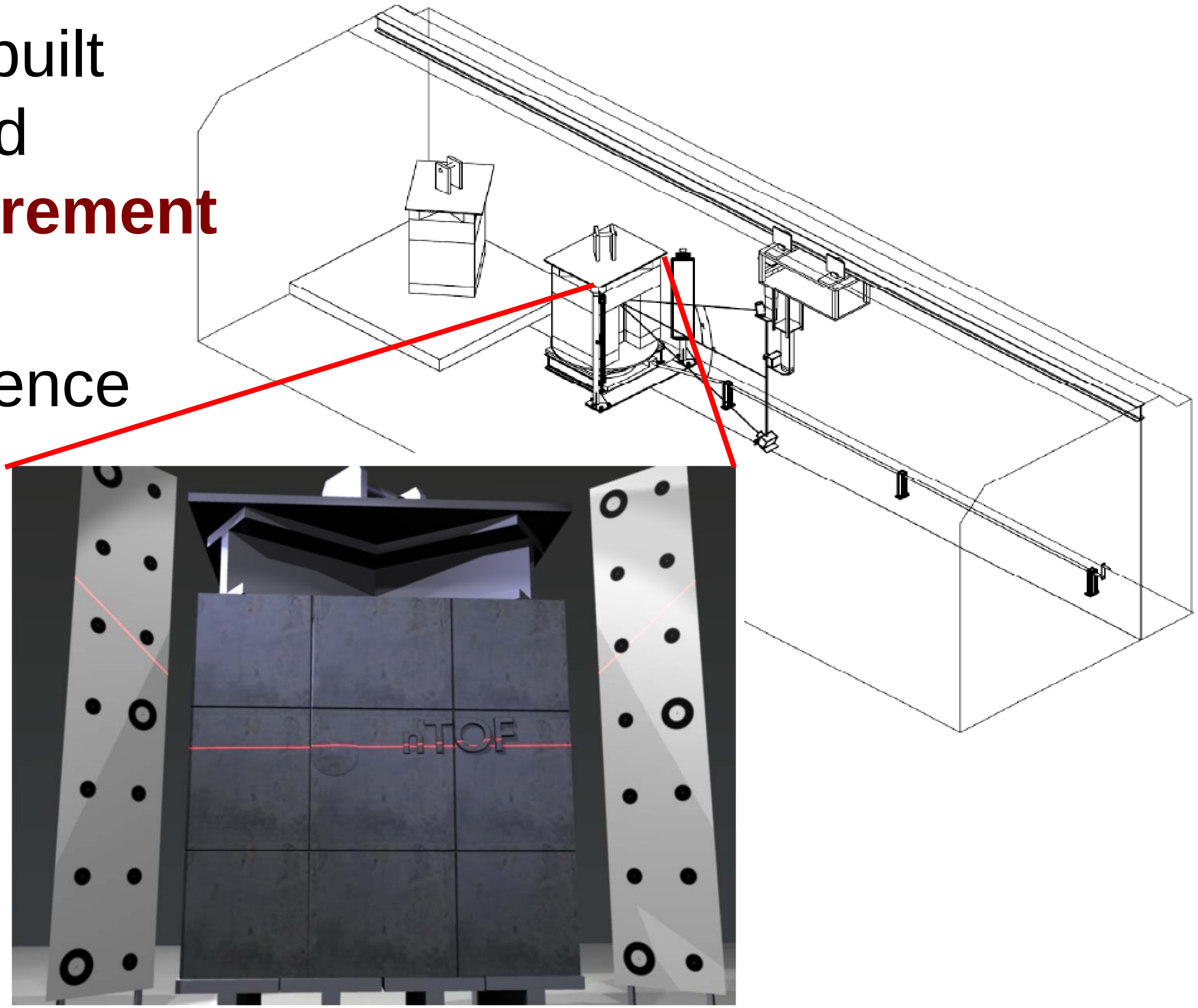
- **Pitting corrosion** caused a hole at the proton impact location
- Important **surface oxidation** due to rupture of protection layer when the drying (heating) was performed (flush)
- Target shape didn't allow for a correct water flow at the **entrance face**
- Modular assembly lead to a **mechanical instability** and deformation

Pit & Pool Inspection

- **Oxide deposits** on the floor and the top of the container
- **Possible signs of corrosion** on the proton entrance window.
- Neutron **exit window is in a good shape** but the possible corrosion under the scotch tape is not evaluated

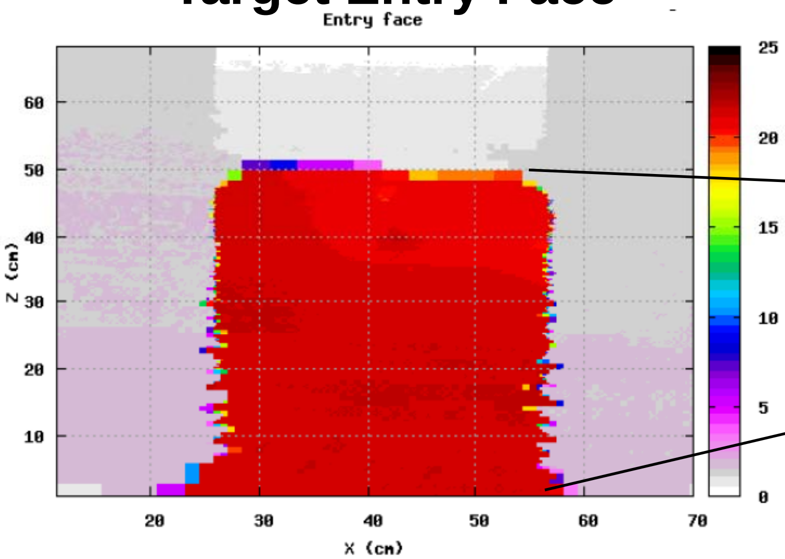
Laser Surface Measurements

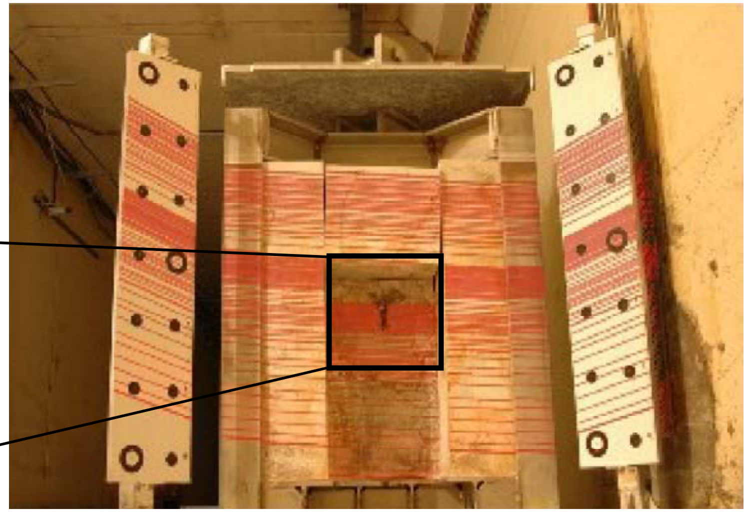
- Fully custom built and developed **Laser measurement system**
- Modular reference frame
- Special Analysis Software
- **Complete survey**



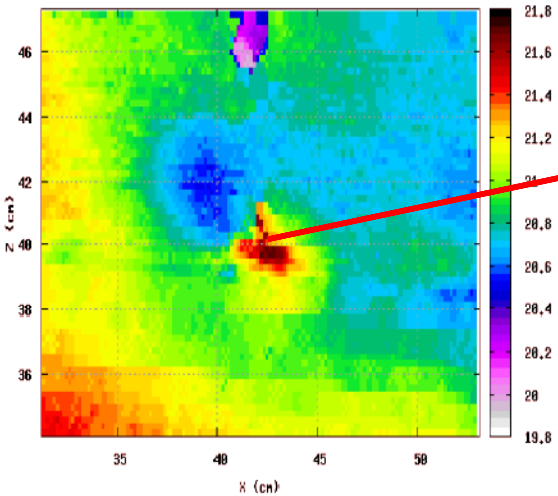
Laser Surface Measurements

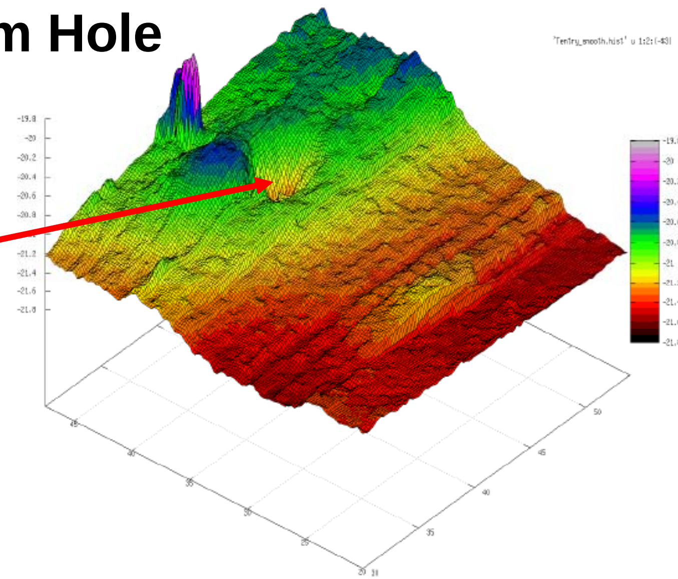
Target Entry Face





Proton Beam Hole

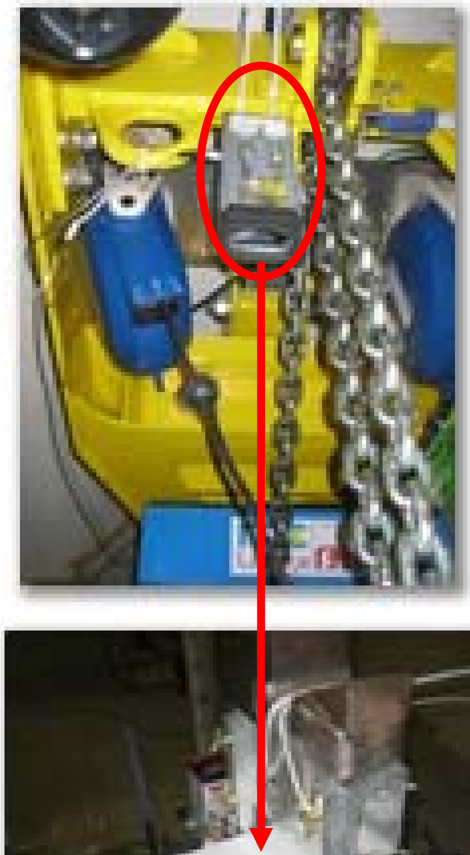




- Proton entry face is displaced by roughly 1.5cm
- Good visibility of the proton beam hole

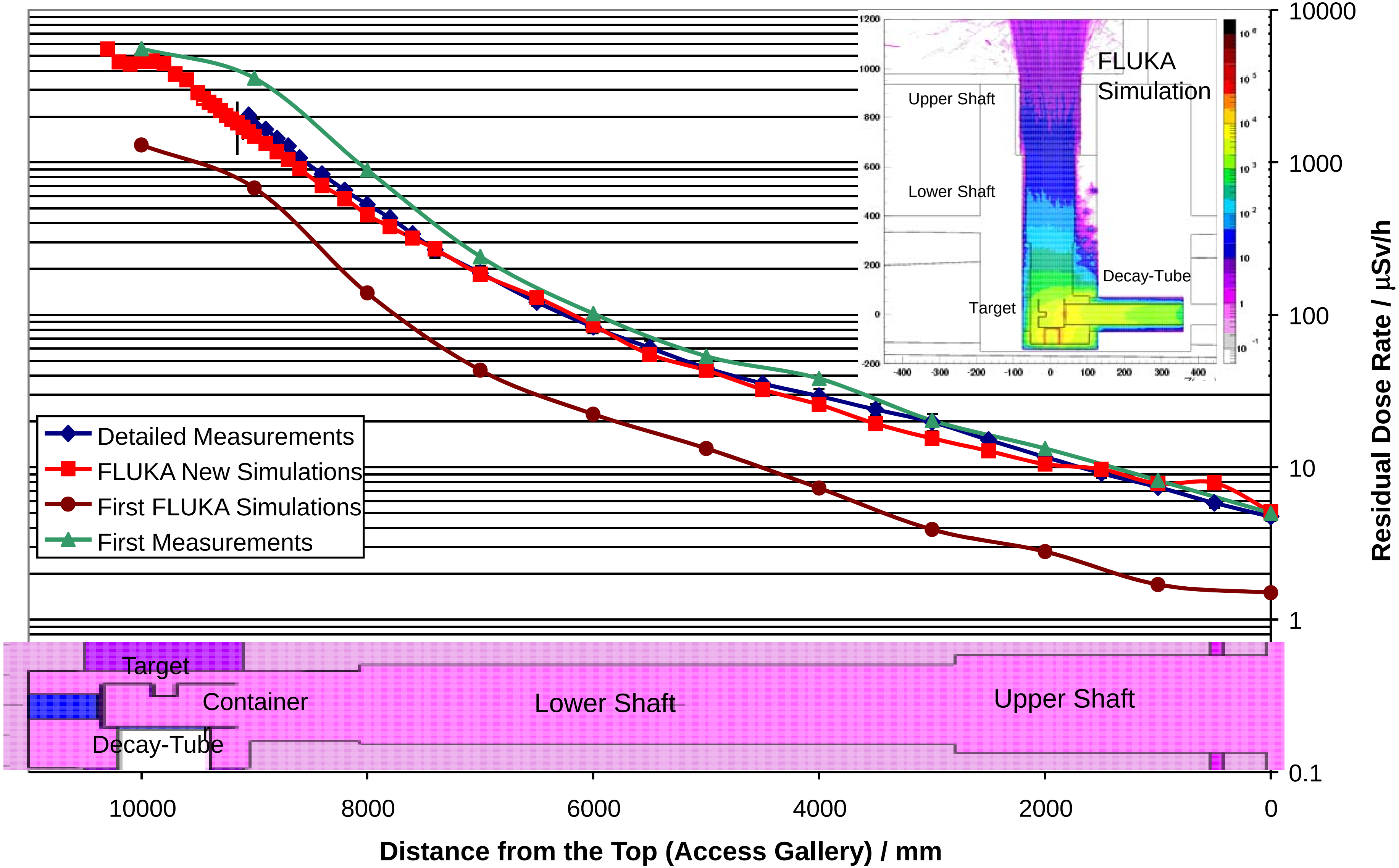
Detailed Dose Rate Survey

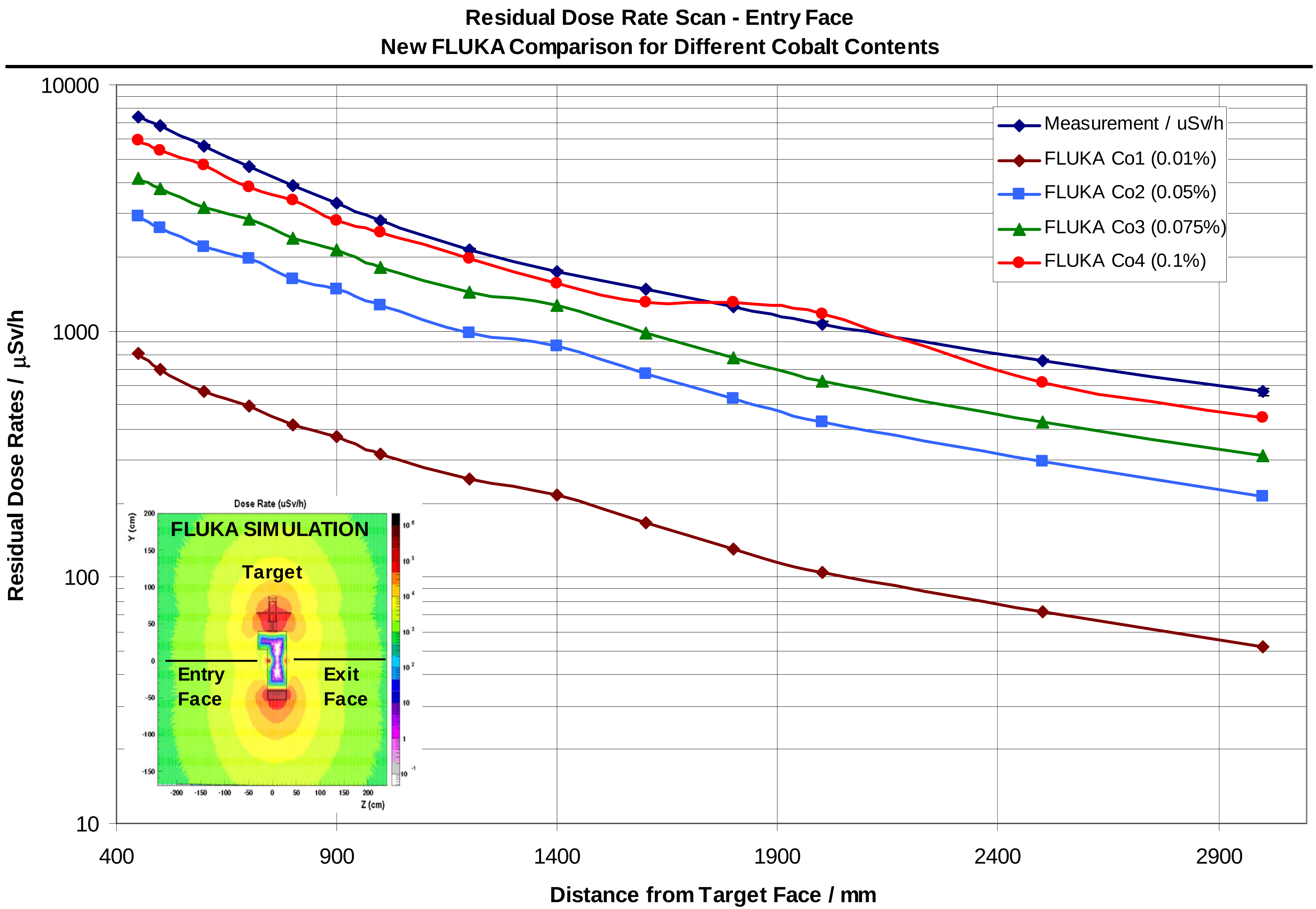
Inside the pit: using a laser attached to the crane to control the position of the remote detector (attached to the hook)



Around the target: same method, starting at 3 meters distance & going towards the target surface.
(fully remote, thus possibility to wait & get enough statistics while performing continuous measurements)

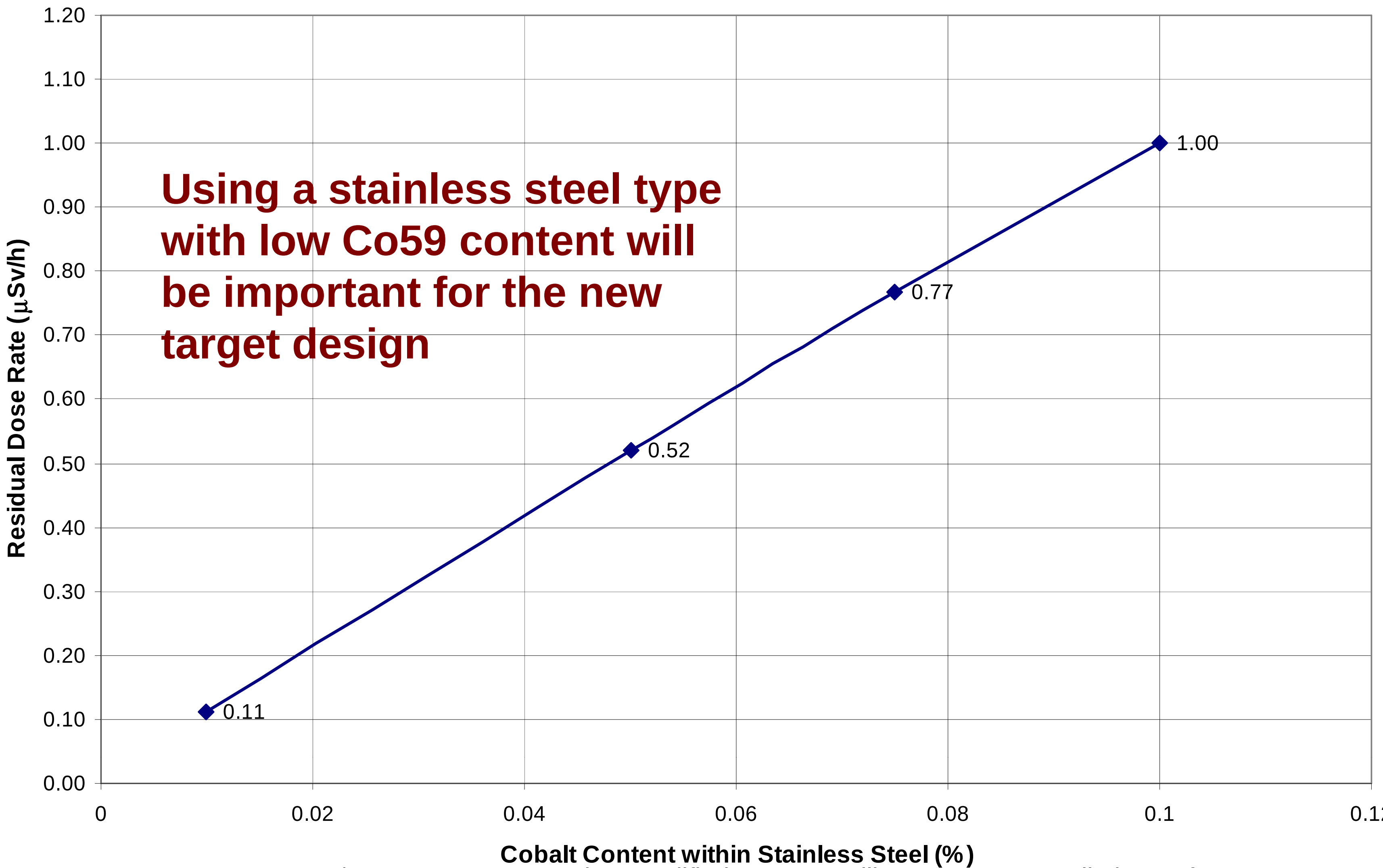
New FLUKA Comparison
after Detailed Pit Survey Measurements 01.11.2007




Residual Dose Rate Scan - Entry Face
New FLUKA Comparison for Different Cobalt Contents
Residual Dose Rates / µSv/h
10000
1000
100
10
400
900
1400
1900
2400
2900
Distance from Target Face / mm
Measurement / uSv/h
FLUKA Co1 (0.01%)
FLUKA Co2 (0.05%)
FLUKA Co3 (0.075%)
FLUKA Co4 (0.1%)
Dose Rate (uSv/h)
FLUKA SIMULATION
Target
Entry Face
Exit Face
Y (cm)
Z (cm)

Dependency on Cobalt Content

Residual Dose Rate (μSv/h) as a function of the stainless steel Cobalt content
(representative for location in front of the target support)



What we've learned…

- **Insufficient cooling**, in particular at the **hot spot** (proton entrance lead surface)
- **Additional oxidation** due to flushing with hot air (target drying)
- **Mechanical instability** due to block structure
- Lack of chemical stabilization of the cooling water, enhancing the probability of **pitting corrosion**
- **Stainless steel type** leading to **important Co^{60} activation** (neutron capture on Co^{59}), thus becoming the dominant radiation source for most of the measured locations
- **Existing cooling circuit** contains important **shortcomings** when dealing with contaminated water

New Design Constraints I

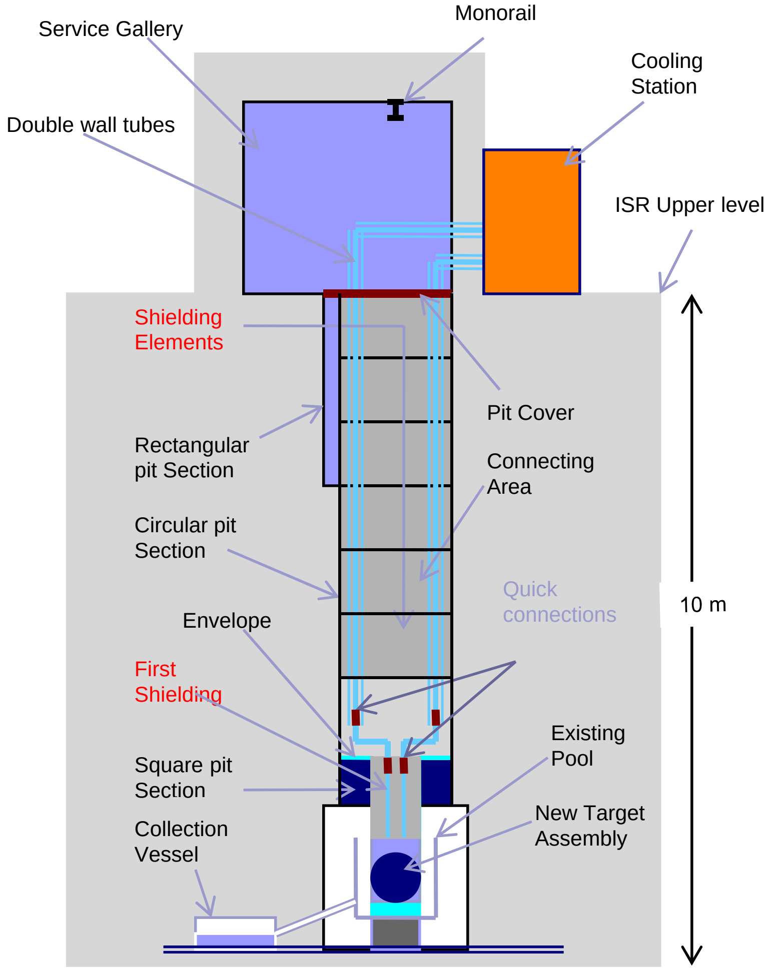
- Why a **modification of the old target cooling circuit** is not favourable
  - long and complicated intervention
  - contamination issues as well as partly important residual dose rates
  - high individual and collective doses
  - no access during operation
- Why the **uncladded lead target** is considered as being the best solution
  - good properties of Pb
  - problems with cladding (known and unknown)
  - high residual dose rates in case of using tungsten or tantalum and stringent implications for handling
  - known solution
- Why the **air-cooled solution** is not favourable
  - tantalum core needed, thus high residual radiation levels
  - difficult cooling as tantalum risks to oxidize
  - no sufficient CERN expertise for a target in such size

New Design Constraints II

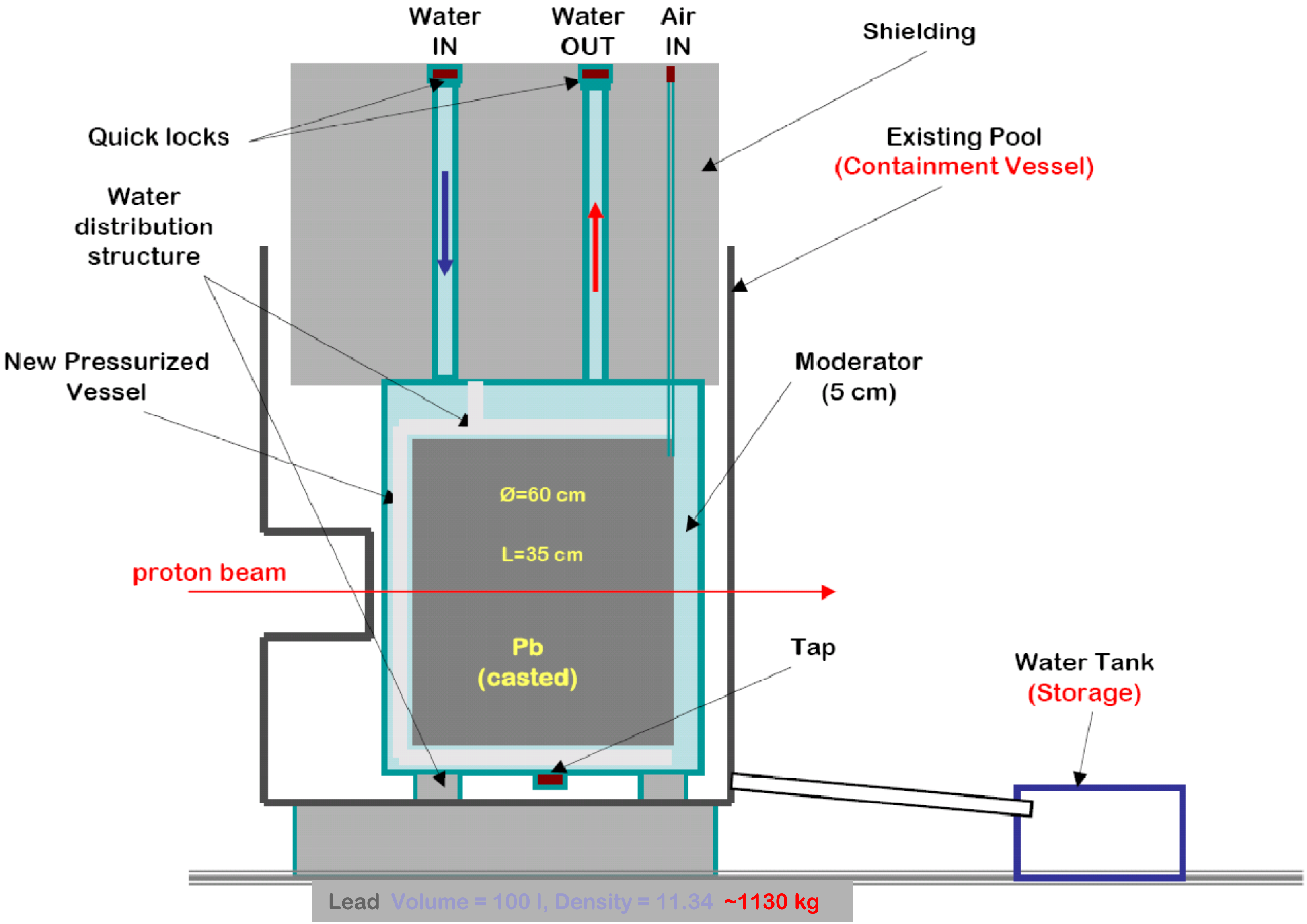
- Why a **stainless steel support structure** would be favourable
  - better mechanical properties when compared to aluminium
  - no possible need for separation before target can be disposed (radioactive waste storage)
  - expected high residual dose rates can be reduced by choosing a stainless steel type with low cobalt content
- **Alternatives (for lower residual dose rates)**
  - Aluminum structure (mechanical stability and waste issues)
  - Boron enriched water
- Mechanical status of the **exit window**
  - calculations for the neutron exit window show accumulated stress levels being low and acceptable for future use
- Evaluation of the possibility to install a **sweeping magnet** to allow for a distributed beam impact location
  - similar studies towards intensity reduction applying an increased bunch length, running at lower energy/intensity but higher ‘frequency’ (dilution)

New Target Design

- **Cooling station** equipped with a closed retention vessel
- **Double contained** piping between the cooling station and the target vessel
- **Water leak collection** in the old pool using the existing envelope
- The water collected in the pool is **extracted by an externally** accessible closed collection vessel

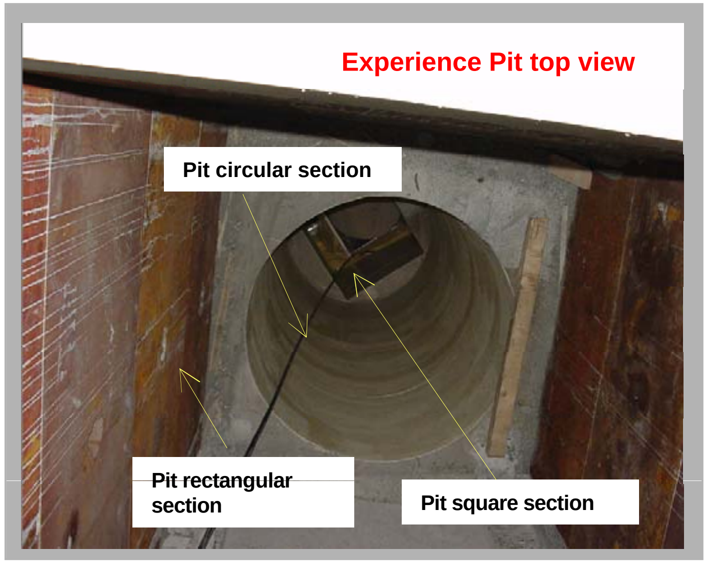


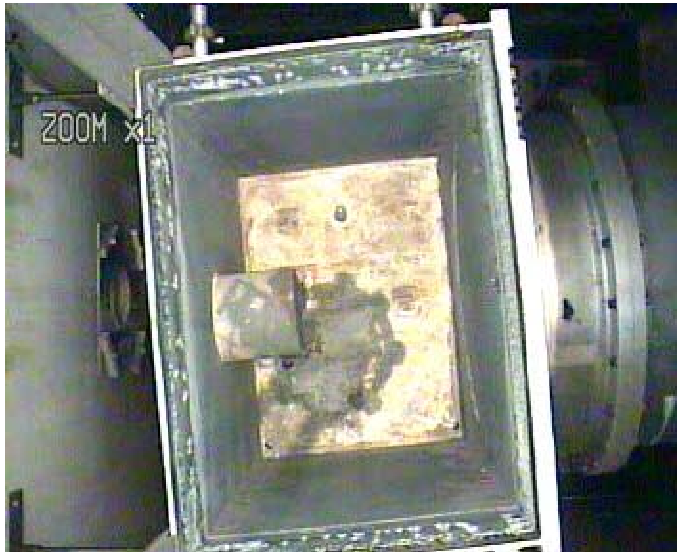
New Target Design



Installation Approach

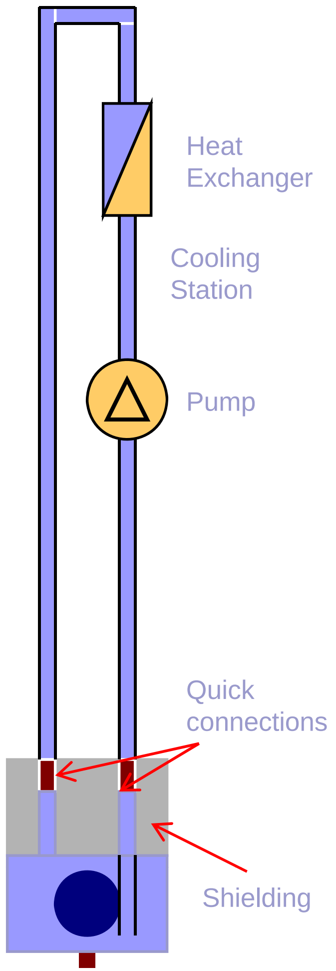
- New target and cooling assembly in the existin pool structure **without direct access to the target area** (can be performed during PS operation)
- **Old cooling station will be dismantled**, connection tubes stay in place but will not be used





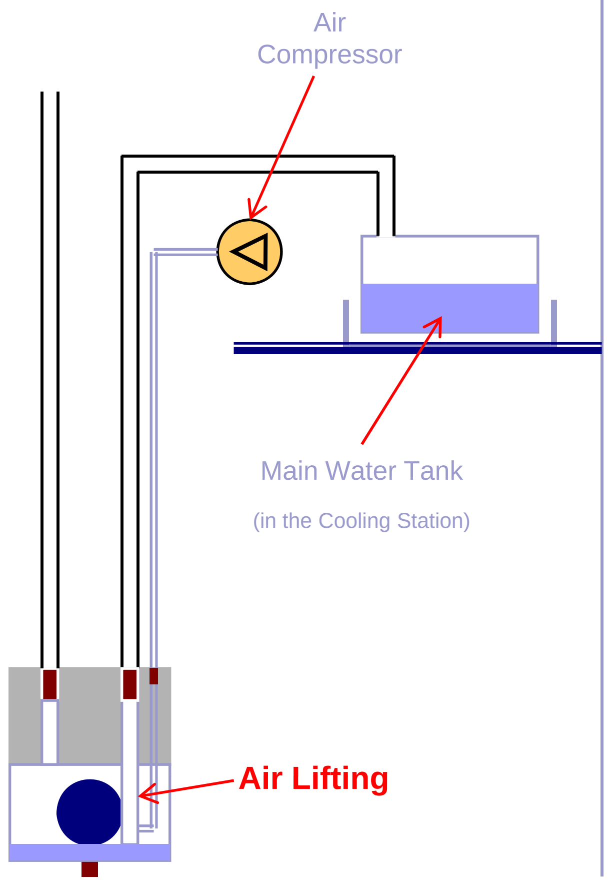
Operation Scenario 1

Normal Working Condition



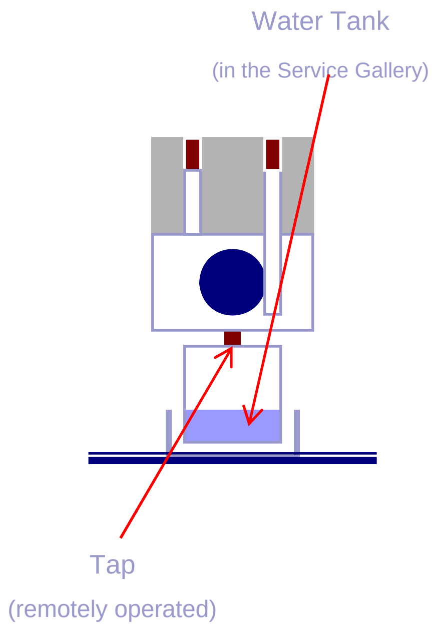
Replacement 90% of the water

(without Target removal)



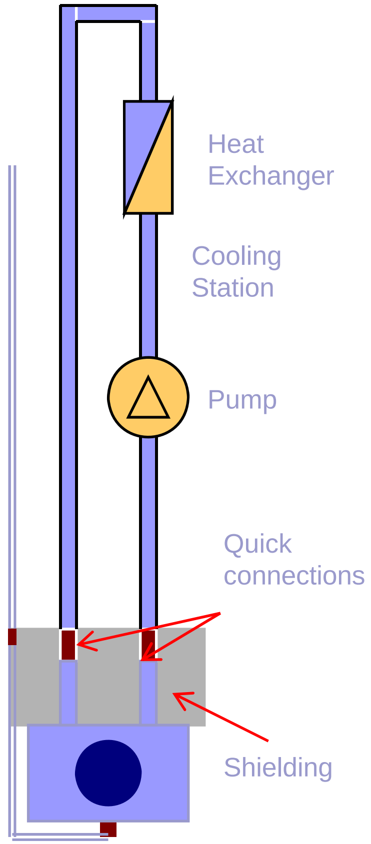
Emptying of the Target Container

(Decommissioning)

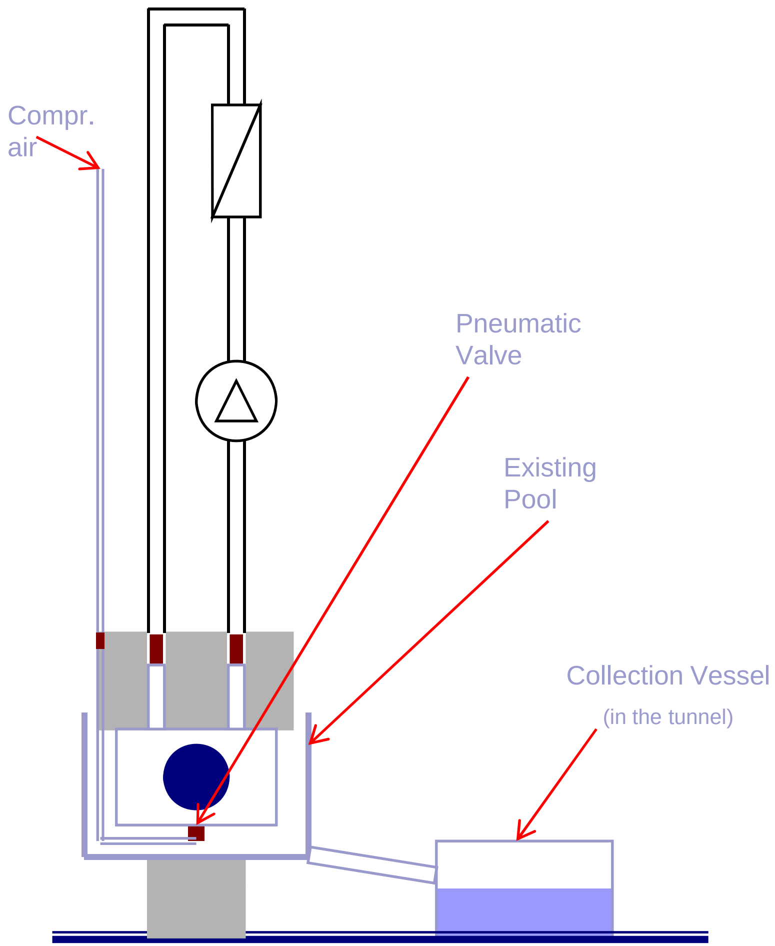


Operation Scenario 2

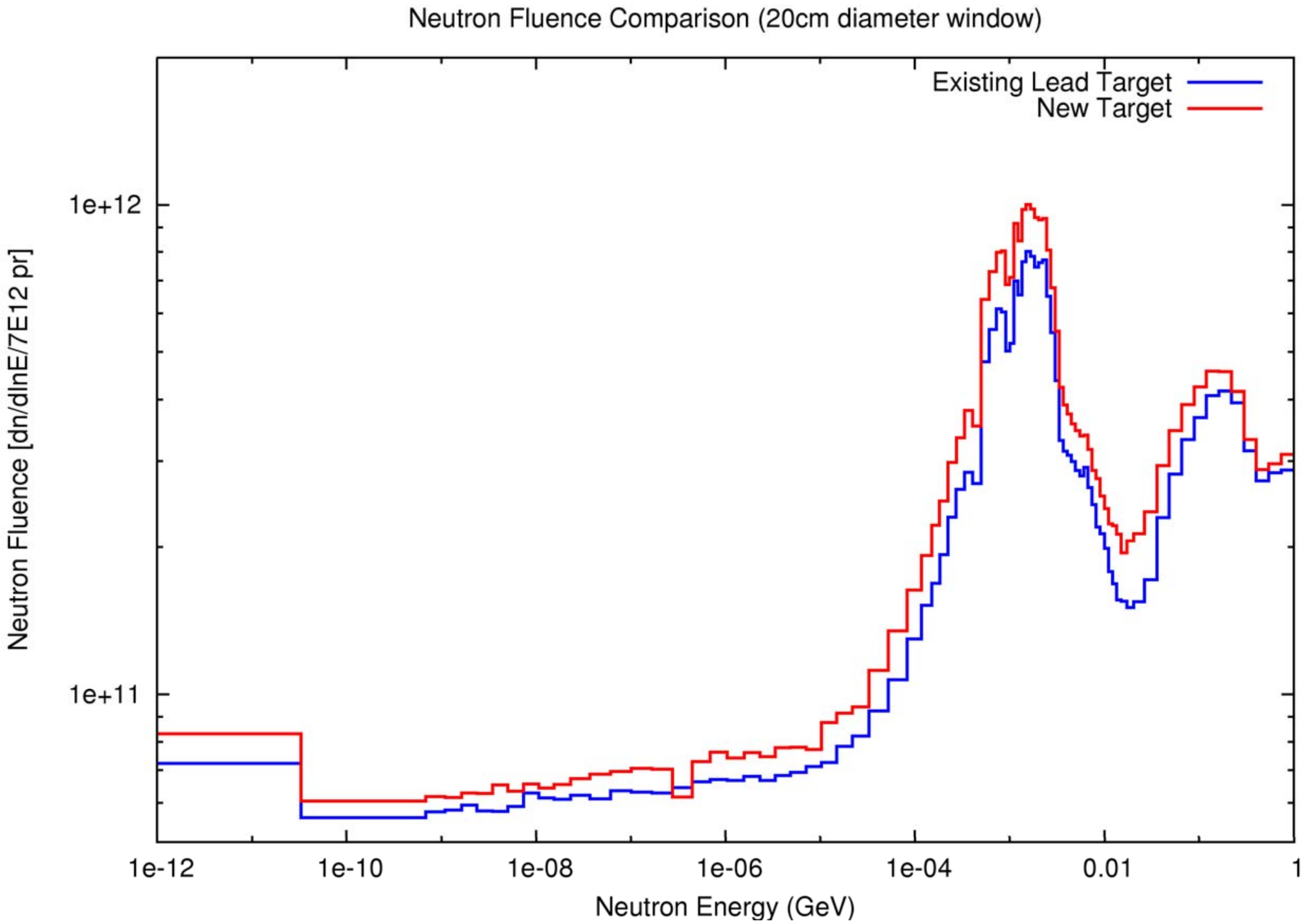
Normal Working Condition



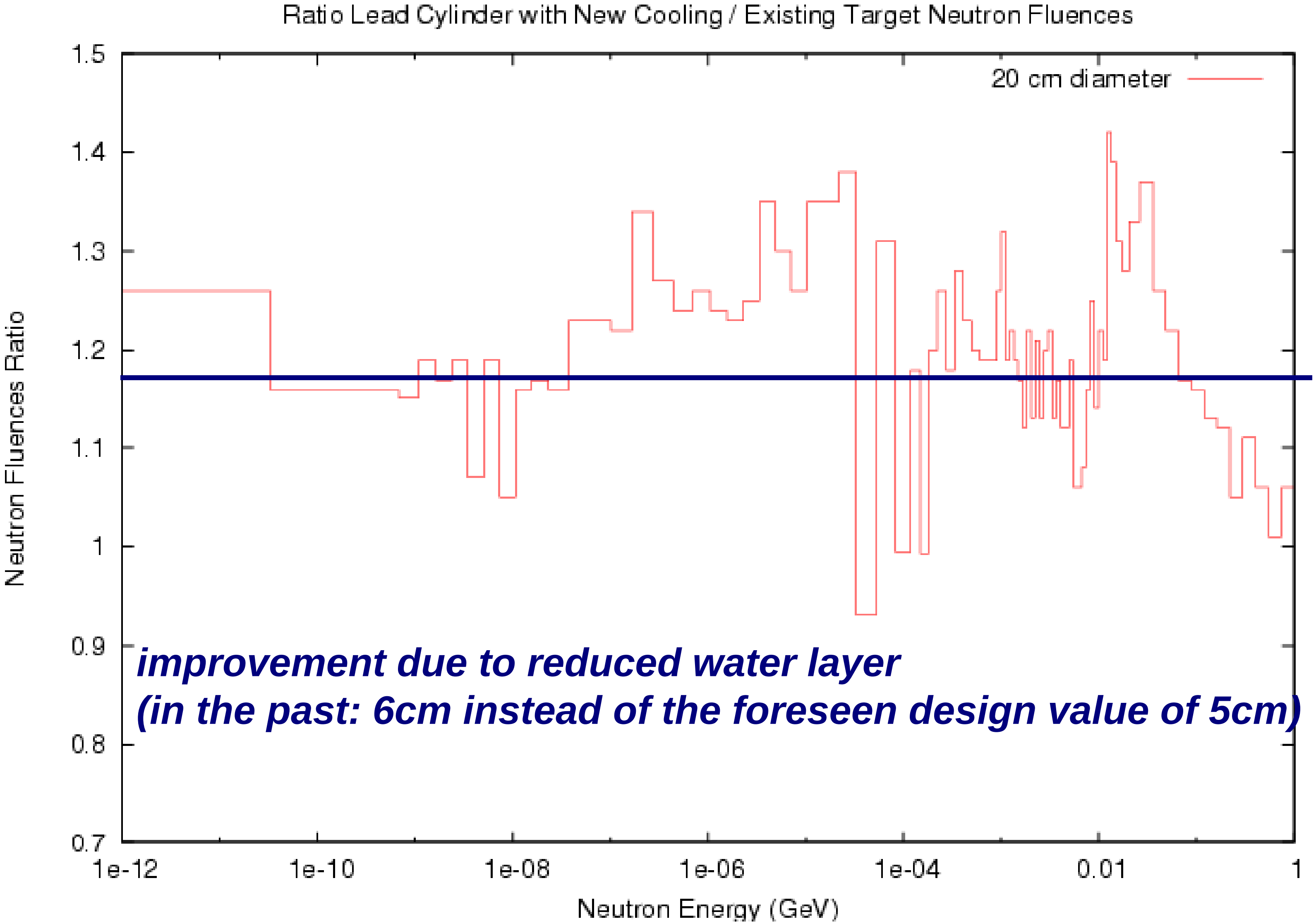
Emptying of the Cooling Circuit



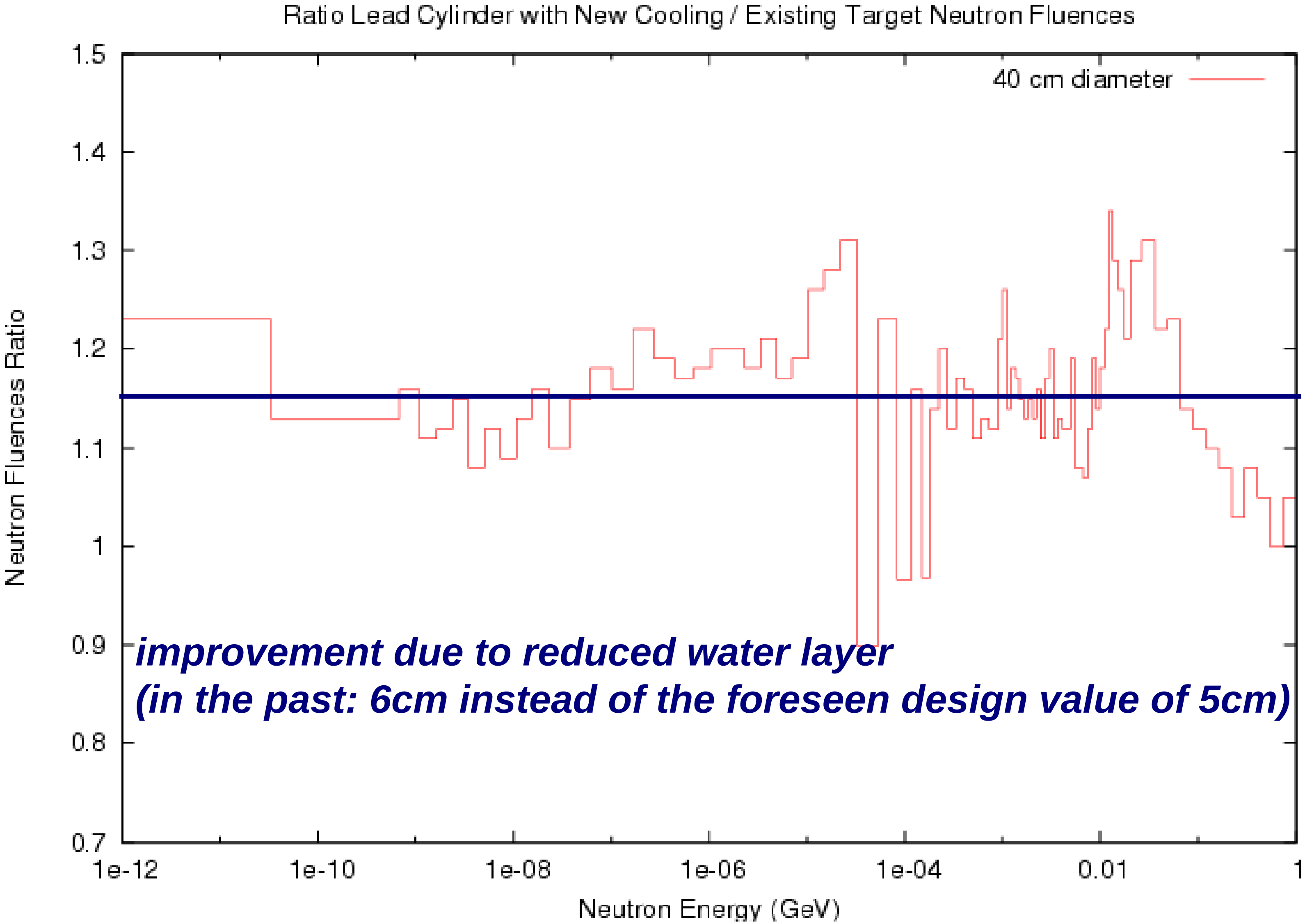
New Layout Neutron Fluences



New Layout Neutron Fluences



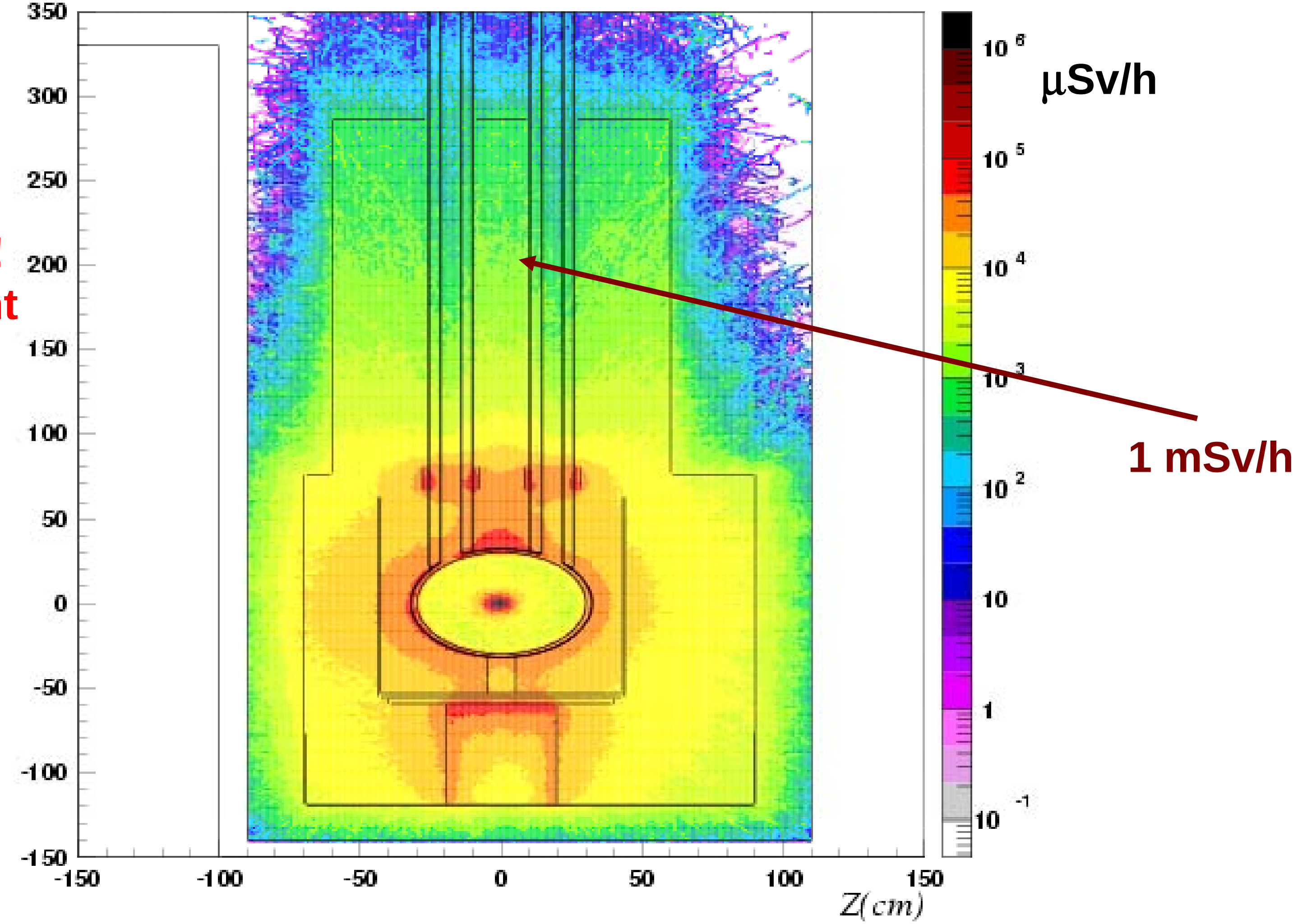
New Layout Neutron Fluences



Residual Dose Rates – New Target

6 months of Operation and 6 months of Cooling at Nominal Intensity

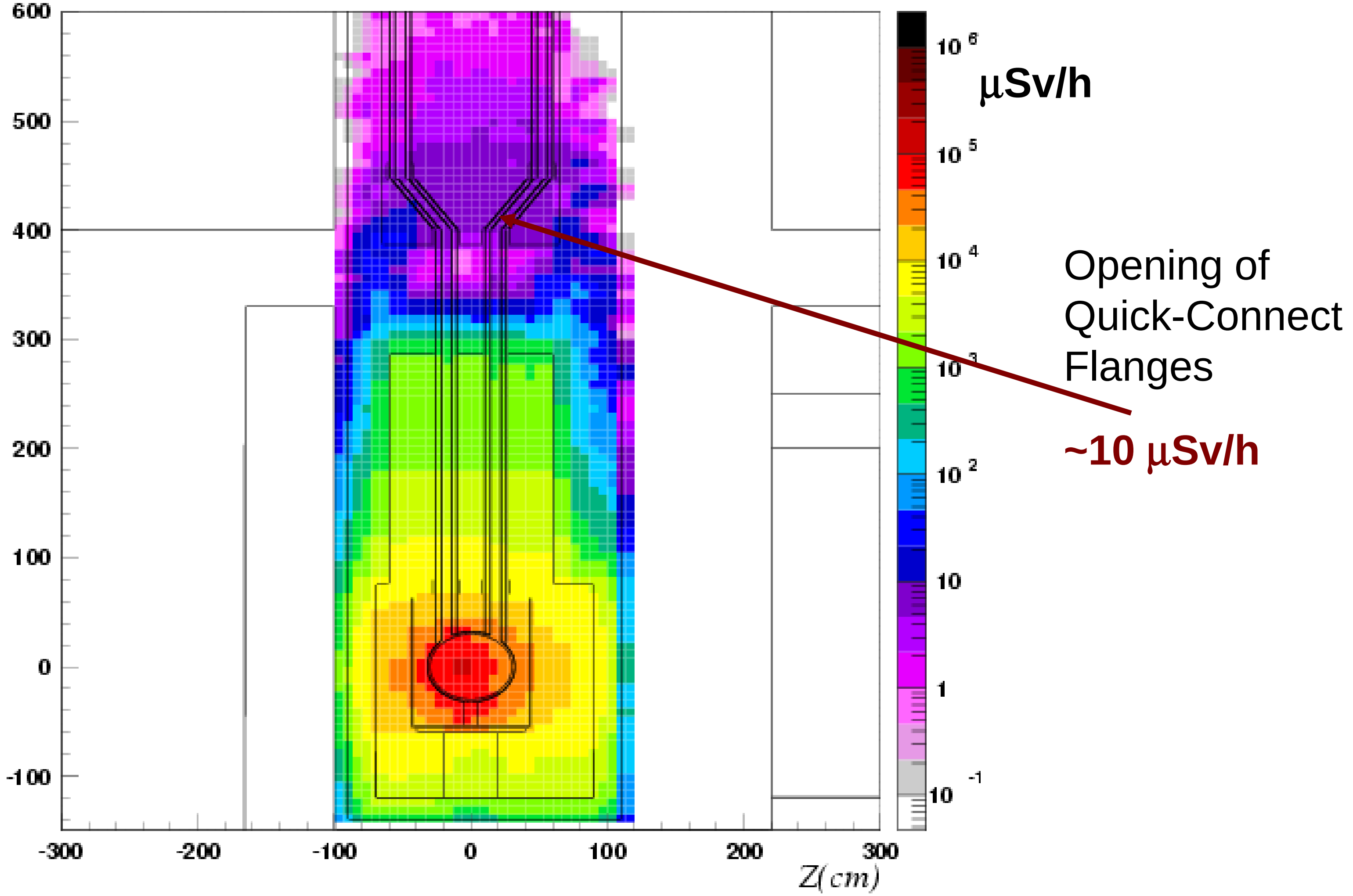
!!! 0.1% !!!
Co-Content
(as-is)



Residual Dose Rates – New Target

6 months of Operation and 6 months of Cooling at Nominal Intensity`

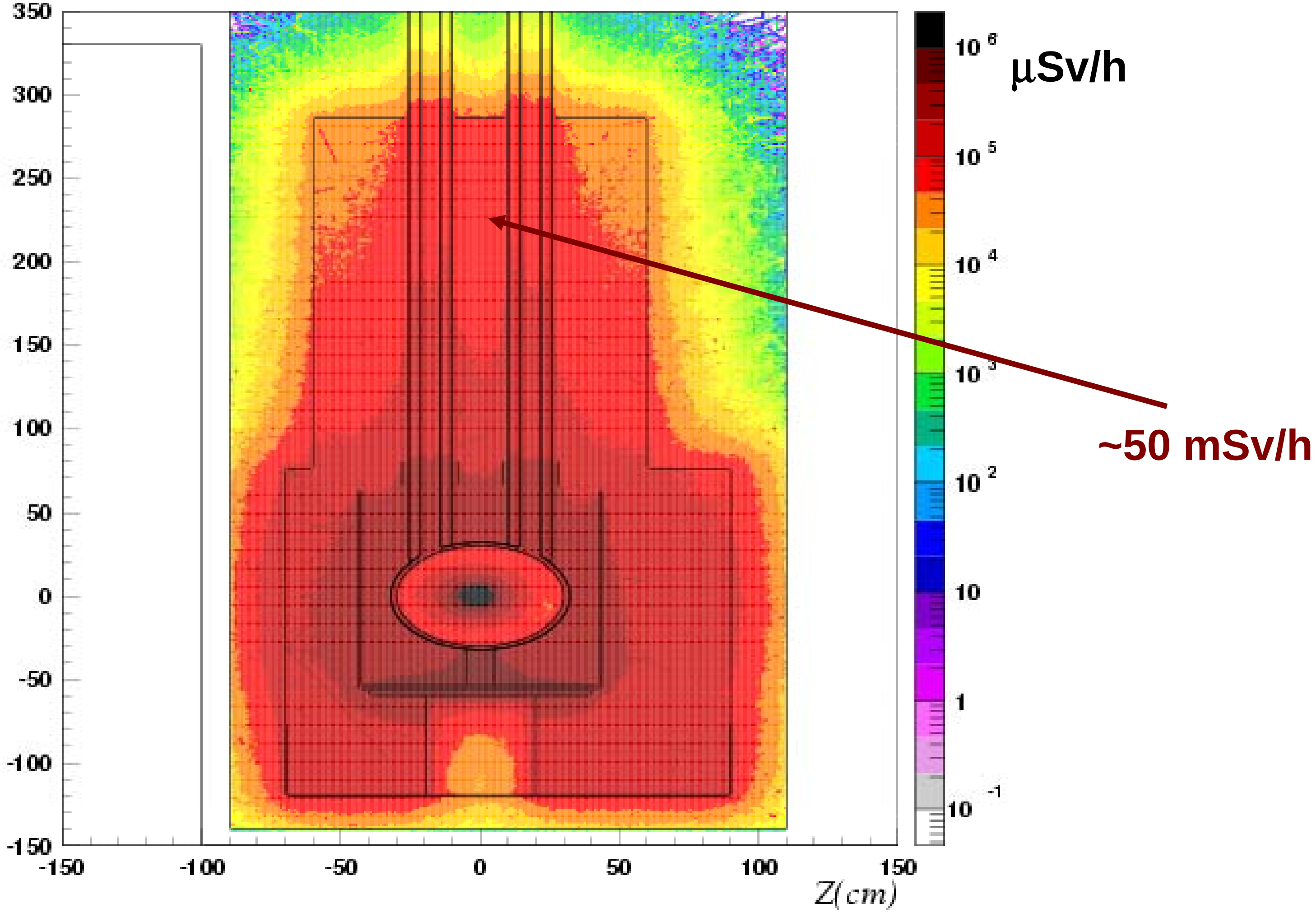
!!! 0.1% !!!
Co-Content
(as-is)



Residual Dose Rates – New Target

10 years of Operation and 1 year of Cooling at Nominal Intensity

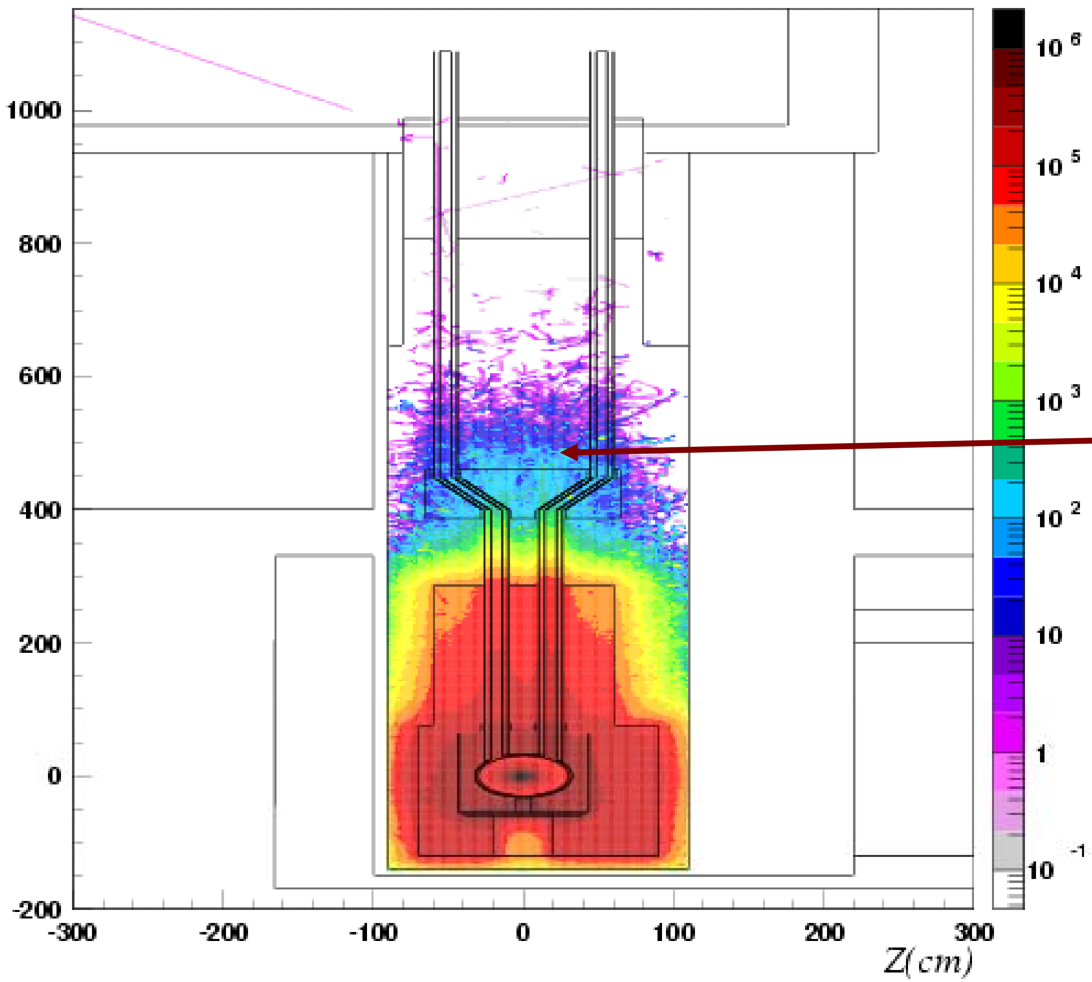
!!! 0.1% !!!
Co-Content
(as-is)



Residual Dose Rates – New Target

10 years of Operation and 1 year of Cooling at Nominal Intensity

!!! 0.1% !!!
Co-Content
(as-is)



Opening of
Quick-Connect
Flanges

~100 µSv/h

Review's Main Requirements

- **The risk of a water leak should be minimized**
  - *"it is clear that such a system will involve the activation of the cooling system, the latter has to be designed and built to cope with these contamination sources"*
  - **the planned pool assembly foresees a double contained cooling circuit with two possible purging options being installed in the existing pool structure**
    (thus taking advantage of a final triple containment)
- **Two-filter system in order to allow for continuous operation without exchange**
  - **filters will be installed on the top (dedicated area) and shielded locally, thus allowing easier access for exchange and sample taking**
- **Release of activated air has to be controlled**
  - **dedicated ventilation system with two operation functions (operation/access), optimized for lowest possible exemption**
- **Water chemistry should be controlled**
  - studied and suggested solutions to control the water chemistry are:
    - Ultra pure water solution
    - Bicarbonate solution

Additional Safety Requirements

- **Crane**
  - successfully upgraded before inspection
  - accepted solution
- **Access & interventions**
  - all standard interventions are performed in a fully remote way
  - target inspection showed how well exceptional interventions were planned for and individual and collective doses minimized
  - for the installation of the new target and cooling system an approach has been chosen to absolutely minimize personnel exposure and leading to expected low individual and collective doses
- **Water treatment**
  - a set of two resins will continuously clean the water and keep levels of contamination as low as possible
  - double contained circuit minimizes the risk of a leak
  - in case of a leak the old cooling basin will be used to collect the water in an external (closed) tank -> third layer protection
- **Radioactive waste**
  - smaller and more compact target design will lead to a reduced total mass needed for disposal
    - less total mass for lead target and support structure
    - a much lower amount of required cooling water

Status and Conclusions

- An **important combined effort** has been made during the past months for evaluating the status of the old target
- Its **status is well understood** and a consensus on the mechanism responsible for the target's present status has been reached between CERN and the Collaboration
- CERN and the Collaboration are preparing an action plan which allows to have a **new target ready for running by October 2008**
- A complete and detailed **engineering study is in progress**
- The preparation of a '**Safety File' is in progress** providing the operation procedures for the installation, running and decommissioning phases.
- A **HAZOP will be organized** to show that the facility can cope with a range of accident conditions.

Thanks To Many Helpers

Institutions, Departments,

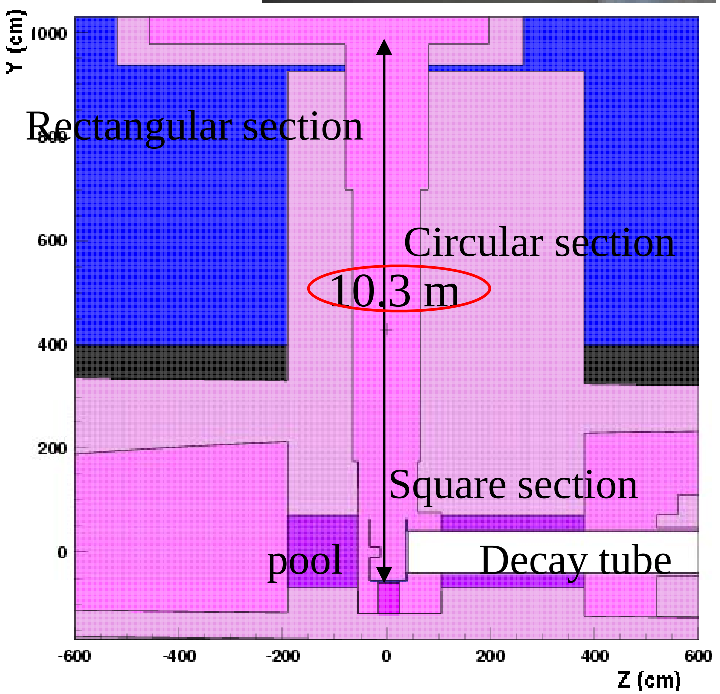
Groups, Sections

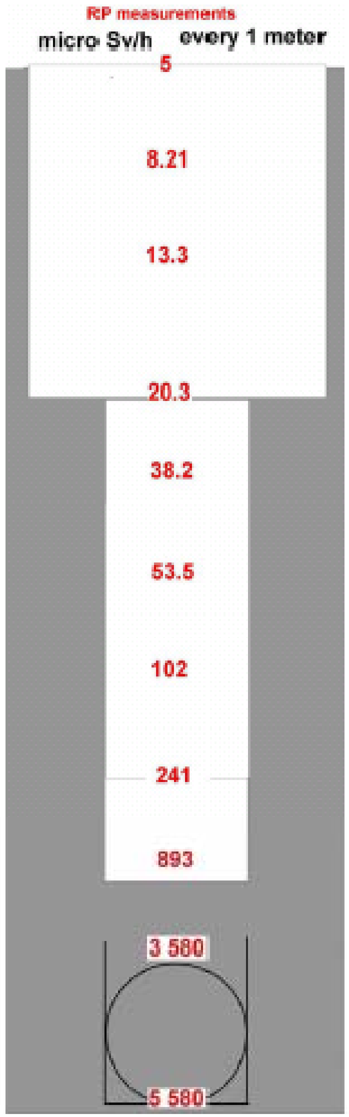
& People

BACKUP SLIDES

First Dose Rate Survey

- Pit survey with dose rate meter attached to a cord and reading the maximum recorded value (risk that variation in the readings due to range adjustments lead to too high values)
- Target survey with manual reading and measurements for a predefined set of locations





Important Findings & Changes

- **Pit & Target**
  - update of geometry (container, support, 30cm, steel faces)
- **Pit**
  - new survey with special dose rate meter and laser controlled distance
  - negligible contribution to residual dose rates coming from contamination
- **Target**
  - detailed survey with special dose rate meter
  - chemical composition stainless steel – cobalt content
    - important influence on residual dose rate distribution (up to a factor of 25 in the possible concentration range)
    - a cobalt content of 0.1% results a very good agreement (this concentration value is confirmed by existing steels at CERN)

Steels used at CERN

- Cast No E33408, Nippon Steel, Inspection Certificate (F.Bertinelli, used for LHC)
- Density 7.252 g/cm^3

Isotope	CERN-Spec	EA	EMPA
Fe	63.31	63.96	62.823
C	0.09	0.1	0.094
Cr	17.82	17.54	18
Mn	11.4	11.28	11.6
N	0.3	0.32	nb
Ni	6.58	6.23	6.7
P	0.02	0.016	0.022
Si	0.38	0.37	0.39
Mo	0.1	0.09	0.08
S	-	0.001	< 0.001
Cu	-	0.09	0.08
O	-	0.002	nb
Ti	-	-	< 0.01
V	-	-	0.07
Co	-	-	0.11
Nb	-	-	0.01
W	-	-	0.01

- CERN store 44.57.10.420.4 SCEM: 44.57.10.420.4, INOX RNDS.304L
- Density 7.908 g/cm^3

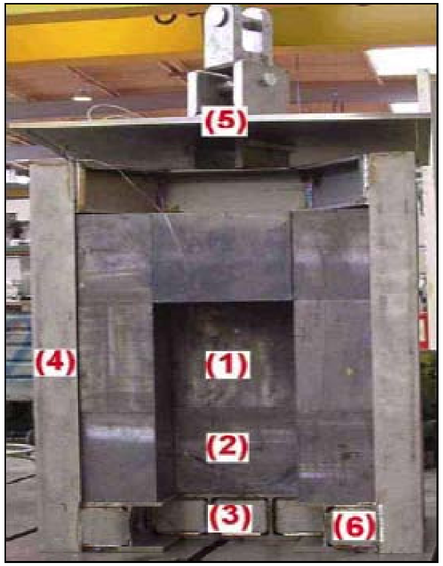
Isotope	CERN-Spec	EIG
Fe		69.1924
Cr	17-20	18.62
Ni	10-12.5	8.32
C	< 0.03	-
Si	< 1	0.648
Mn	< 2	1.52
P	< 0.045	0.0302
S	< 0.03	0.037
Mo		0.567
Cu		0.393
Al		0.277
Co		0.172
V		0.0704
W		0.0407
Ca		0.0368
Na		0.033
Mg		0.0166
Sn		0.0147
Nb		0.0083
As		0.0029

EA: *ICP-AES (AES=Atomic Emission Spectrometry)*
EMPA: *WD-XRF (wavelength-dispersive X-ray fluoresence spectrometry)*
EIG: *XRF*

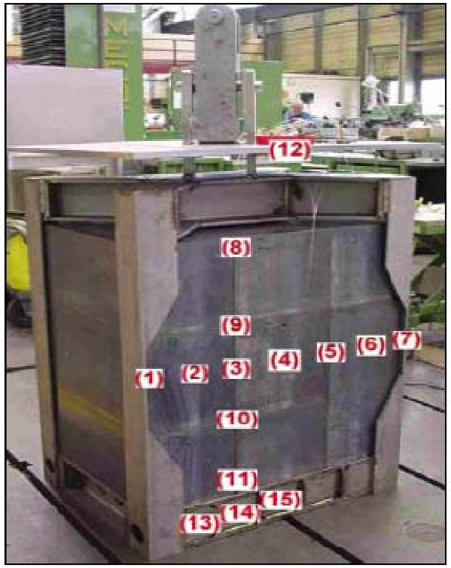
Residual Dose Rates Comparison

Location		Old FLUKA mSv/h	New FLUKA mSv/h				Measurements mSv/h	Ration Measurement/FLUKA					
@ 10 cm	Point	Co1 0.01%	Co1 0.01%	Co2 0.05%	Co3 0.075%	Co4 0.1%	Oct. 2007	Old	Co1	Co2	Co3	Co4	Main Material
Entrance	(1)	6.7	5.9	6.9	6.9	7.3	11	1.6	1.9	1.6	1.6	1.5	Pb
	(3)	3.6	5.8	26.9	39.7	51.8	52	14.4	9.0	1.9	1.3	1.0	SS
	(4)	2.1	1.7	7.2	10.5	14.8	21	10.0	12.4	2.9	2.0	1.4	SS/Pb
Exit	(3)	4.4	3.5	6.2	7.5	8.6	16	3.6	4.6	2.6	2.1	1.9	Pb/SS
	(14)	4.7	4.0	20.1	29.9	39.5	40	8.5	10.0	2.0	1.3	1.0	SS/Pb
Right	(1)	1.7	1.3	5.8	8.6	11.3	20	11.8	15.4	3.4	2.3	1.8	Pb -> SS!
	(5)	3.3	4.2	22.5	33.5	44.8	33	10.0	7.9	1.5	1.0	0.7	SS
Left	(1)	1.1	0.8	4.2	6.1	7.8	10	9.1	12.5	2.4	1.6	1.3	Pb -> SS!
	(3)	2.5	3.1	17.1	25.1	33.5	42	16.8	13.5	2.5	1.7	1.3	SS

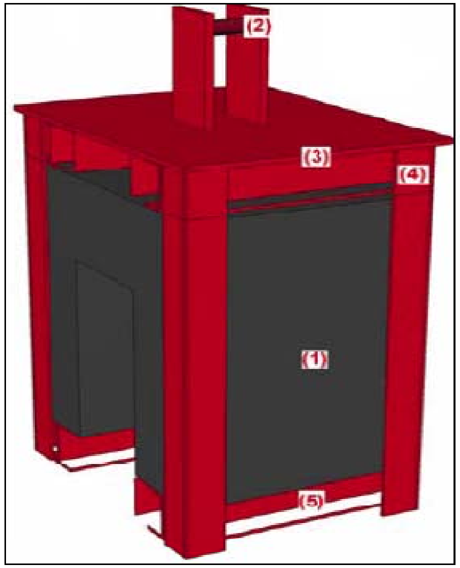
Entrance



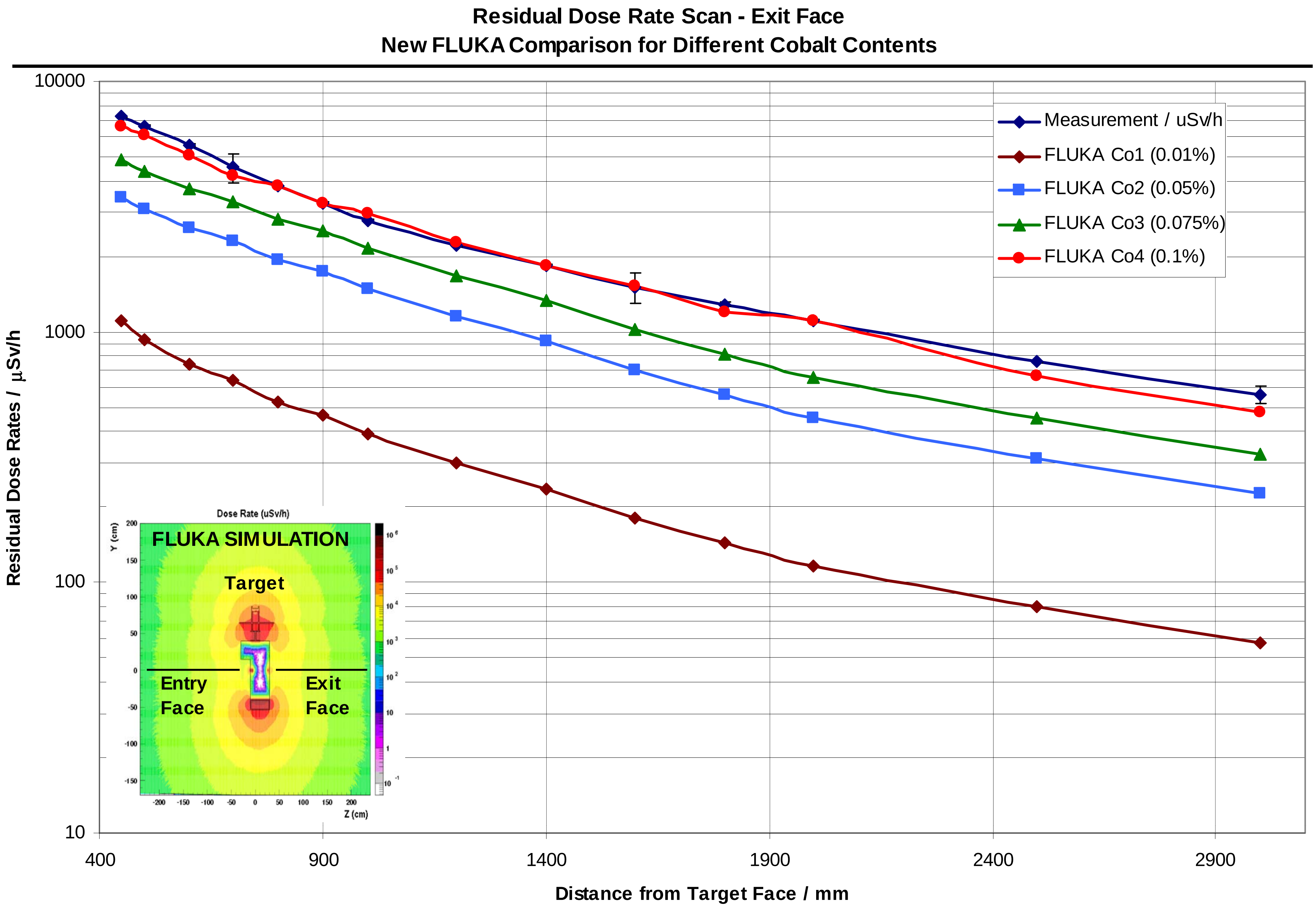
Exit



Right



Left


Residual Dose Rate Scan - Exit Face
New FLUKA Comparison for Different Cobalt Contents
Residual Dose Rates / µSv/h
Distance from Target Face / mm
Measurement / uSv/h
FLUKA Co1 (0.01%)
FLUKA Co2 (0.05%)
FLUKA Co3 (0.075%)
FLUKA Co4 (0.1%)
FLUKA SIMULATION
Target
Entry Face
Exit Face
Dose Rate (uSv/h)
Y (cm)
Z (cm)

Air Cooled Ta/Pb Solution

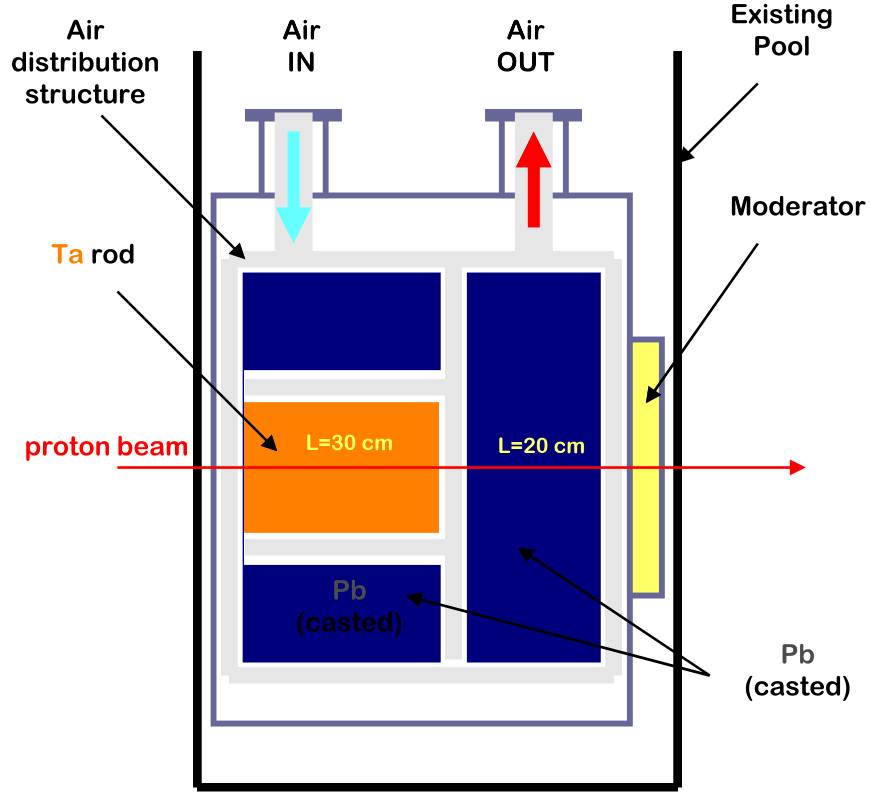
- **Advantage:**
  - all water related problems are avoided (containment, activation, decontamination,...)
- **Disadvantages:**
  - neutron flux reduction
  - increased activation
  - high air flux (>700 m3/h)
  - complex structure needed to distribute the air flux
  - in case of reaching the Ta heating limit (briddle) need to investigate in cooling with other gases (*e.g.*, Nitrogen)
  - Entirely new design (no acquired experience)
  - Unsolved moderation (solid?, liquid?)

Tantalum
Rod
Ø= 20 cm
L= 30 cm
Density = 16.69

~157 kg

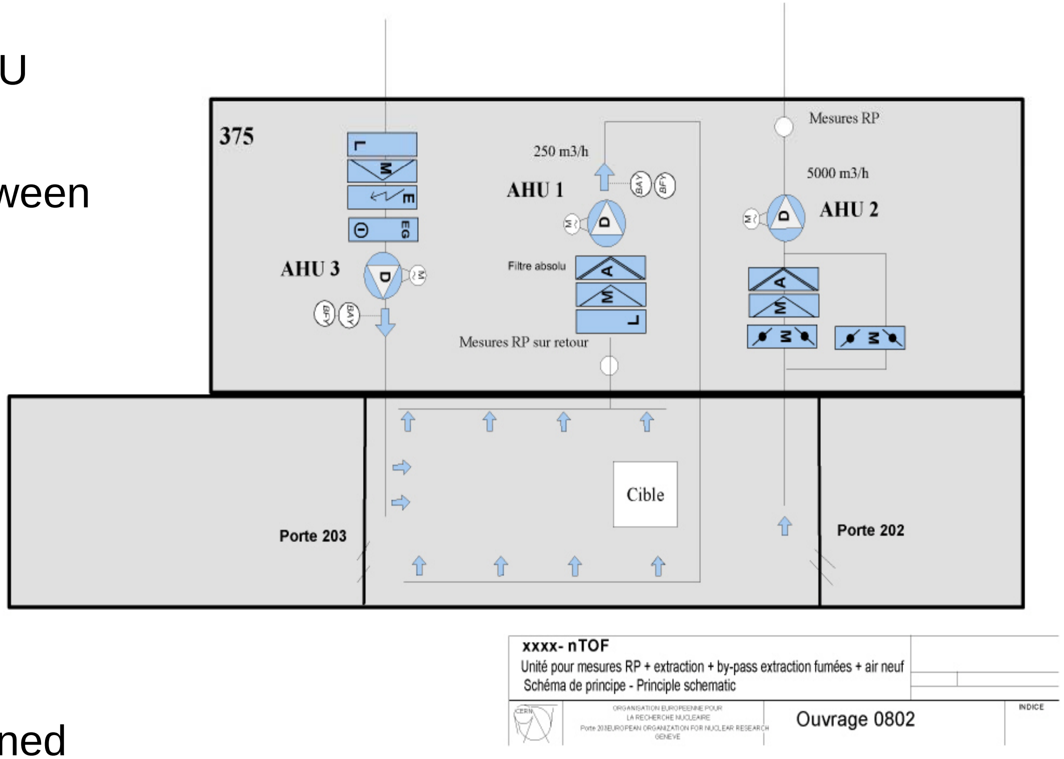
Lead
$Ø_{ext}$= 55 cm
$Ø_{min}$= 32 cm
L= 50 cm
Density = 11.34
~1074 kg

~1230 kg tot

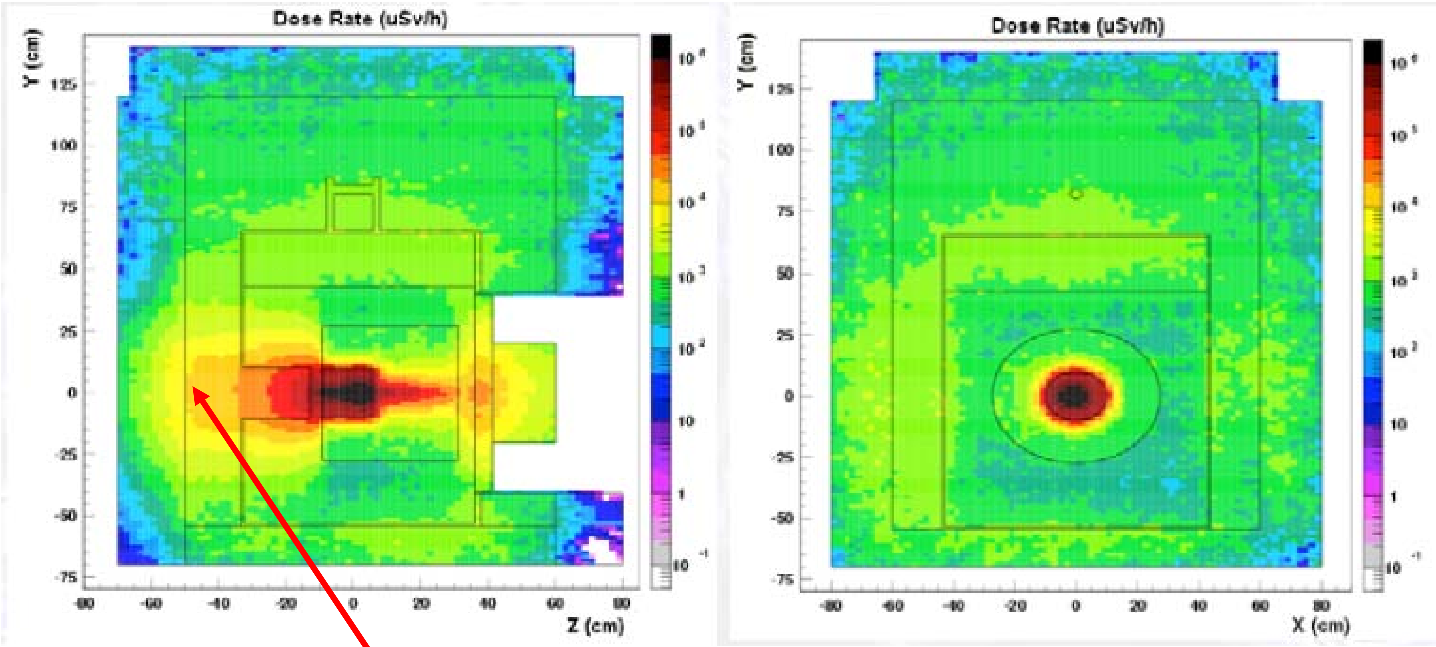


Ventilation Details

- **Principle (maximum solution)**
  - One 100% recycling AHU + one extraction AHU + one fresh air AHU
  - Differential pressure control
  - Area treated being comprised between doors 202 and 203
  - AHUs located in bldg. 375
- **Air Handling Units**
  - Recycling AHU, extraction AHU
  - Fresh air AHU fitted with heating and cooling coils
- **Operating modes**
  - To be determined
  - Smoke extraction policy to be defined



Residual Dose Rates – Tantalum



Low Cobalt Content: 0.01%

	Cooling Time = 1 year 8 months	Cooling Time = 3 years	Cooling Time = 10 years
At the beam entrance	1102.7	97.0	4.6
At the beam exit	15.9	10.7	2.0
At the top of the target (above the hook)	1.3	0.7	0.1
At 20 cm distance from the entrance face	148.0	12.6	0.5

Water Chemistry Details

- **General**
  - Conductivity sensor with integrated temperature sensor
  - Sampling outlet.
  - Sacrifice electrode
- **Ultra pure water solution**
  - Molecular oxygen sensor
  - Mixed bed resins
  - Degassing equipment
- **Bicarbonate solution**
  - pH meter
  - Chelating cation exchange resin
- **Additional Boron solution** to keep activation low
- In the current discussions the use of additives to control the water chemistry **might have negative drawbacks**
  - it might thus be favourable to use a continuous (simple) system of filter exchange allowing to keep contamination levels low
  - this is supported by the fact of having a double contained circuit and that CERN can now properly treat the additional wastewater coming from the resin exchange