

# Status of the CERN n\_TOF facility

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EFNUDAT Workshop

FZD, 13-15/2/2008

**FOR MORE INFO...**

<http://cern.ch/ntof>

# History

- **1997** - Concept by **C.Rubbia** validated by TARC exp. [CERN/EET/Int. Note 97-19]
- **May '98** - Further development of the initial idea towards a working facility [CERN/LHC/98-02+Add]
- **Aug '98** - CERN-GELINA joint Letter of Intent [CERN/SPSC/98-15, I220]
- **1999** - Construction started
- **Oct 2000** - First proton on the spallation target
- **2001-2004** - Phase I, Capture and Fission measurements of 36 isotopes
- **2005** - Accelerators Off at CERN
- **2006-2007** - Design and construction of a new spallation target

# n\_TOF Collaboration

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40 Research Institutions  
120 researchers

# n\_TOF Collaboration structure & operation

## n\_TOF Phase-1 (2001-2004)

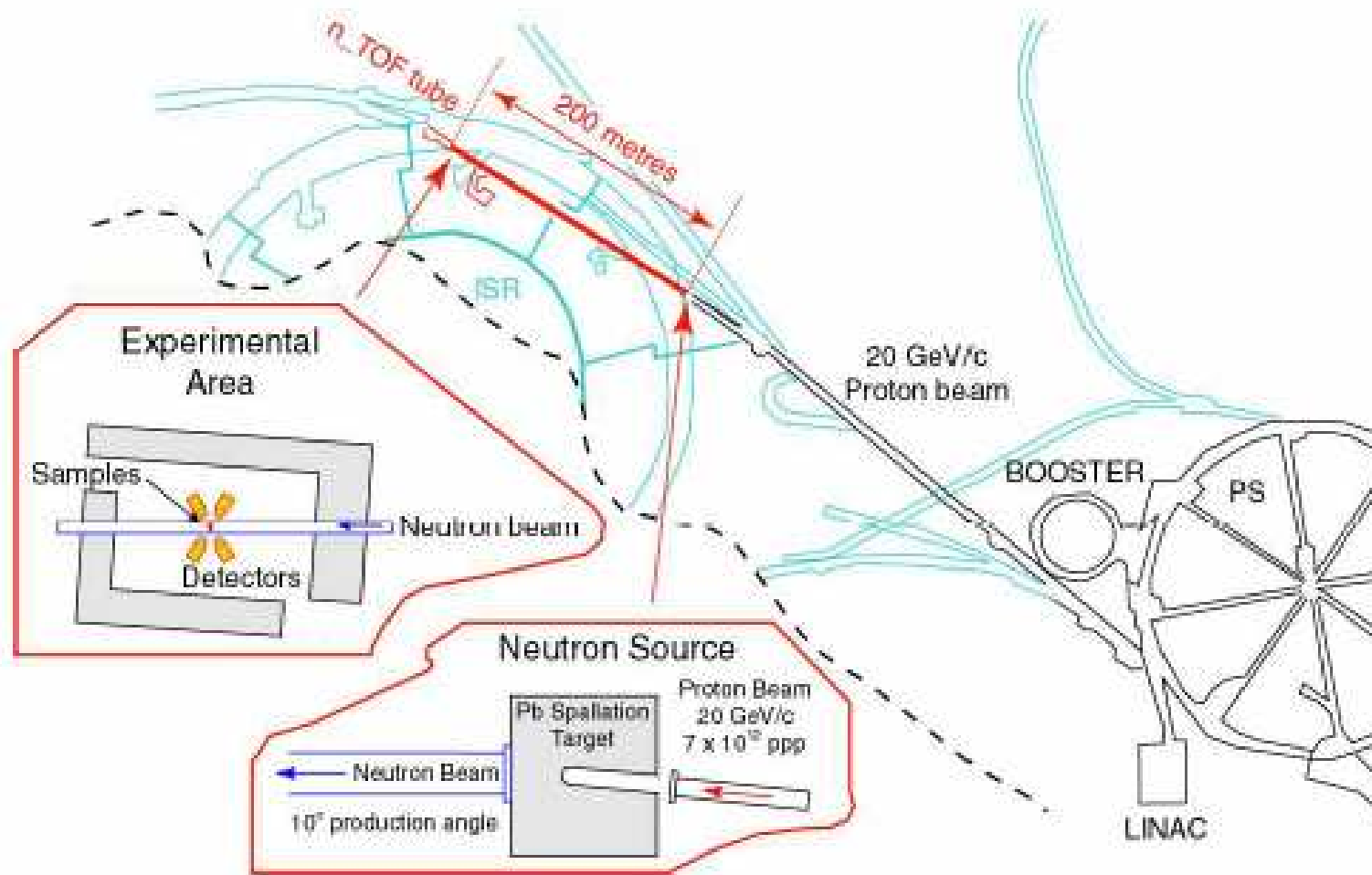
n\_TOF Collaboration Board  
Chairman, Spokesperson

- 23 n\_TOF teams
- all teams participates in the development, commissioning, and operation of detectors, daq, etc.
- all teams participated in all the experiments/measurements
- 16 partners in the n\_TOF-ND-ADS EC Project (FP5)  
2.4 MEUR investment in equipments (6.3 MEUR total budget)  
run over the period 2001-2004 (completed)

## n\_TOF Phase-2 (> 2008)

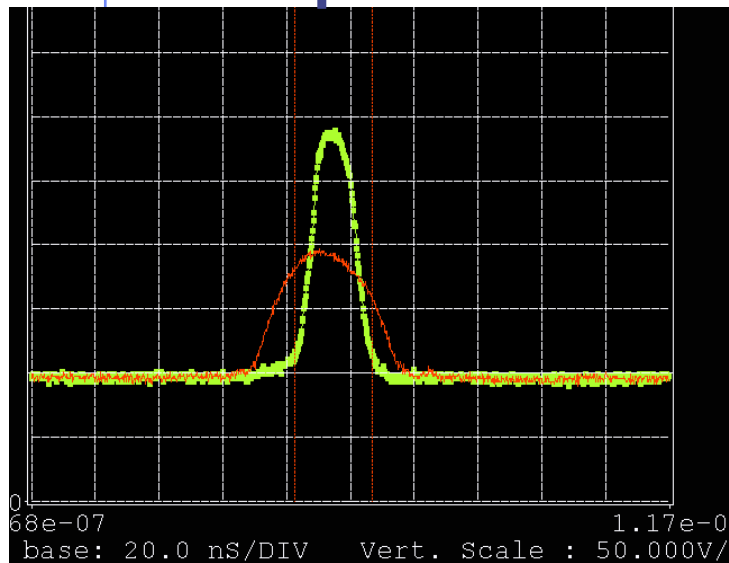
- n\_TOF Collaboration Board  
Chairman & Spokesperson
- Teams involved in individual proposals/experiment (with individual spokesperson)
  - Fe, Ni, Zn & Se proposal
  - Fission measurements proposal
  - n-scattering proposal
  - ...
- Common M&O budget
- Some team involved in EC/FP6 projects (EFNUDAT, EUROTRANS)

# The n\_TOF facility at CERN



# Proton Bunch

## Before and After Compression



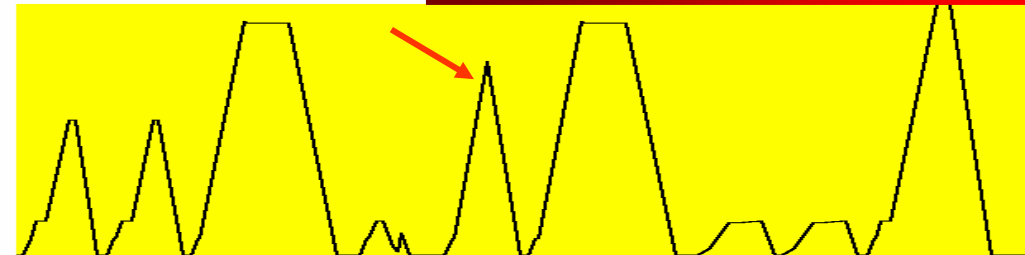
$7 \times 10^{12}$  pr/c @ 20 GeV/c  
RMS  $\leq 7$  ns

**FOR MORE INFO...**

<http://accelconf.web.cern.ch/AccelConf/e00/PAPERS/THP1B10.pdf>

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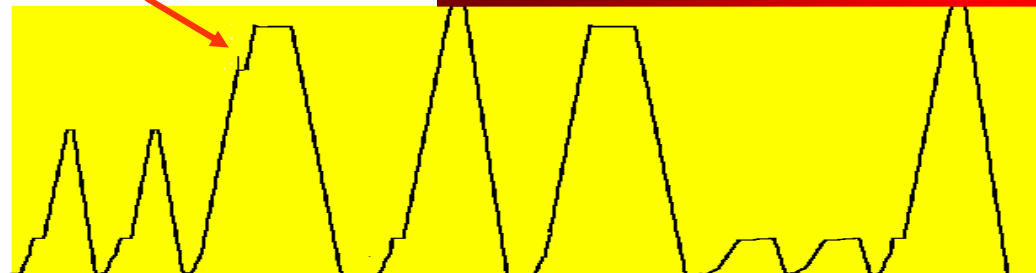
## Dedicated Mode



SFT SFT EASTC AD TOF EASTB SPP SPN MD

$I_p = 7 \times 10^{12}$  p,  $\Delta T_{\min} = 1.2$  s

## Parasitic Mode

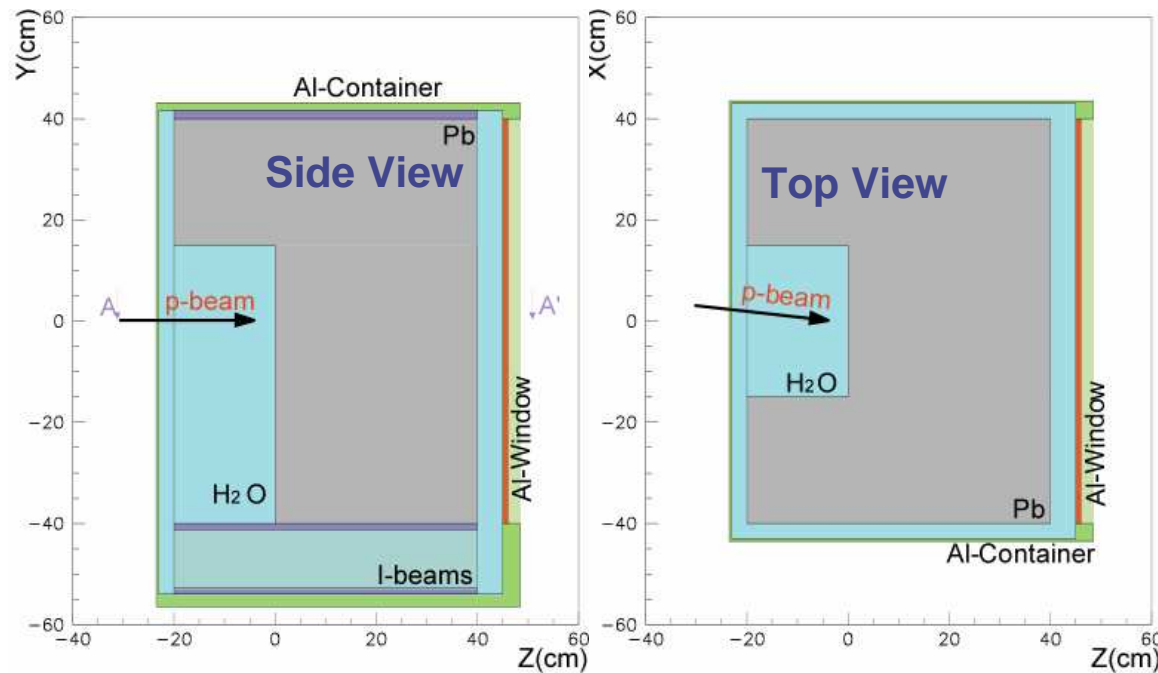


SFT SFT TOF/EASTC AD EASTB SPP SPN MD

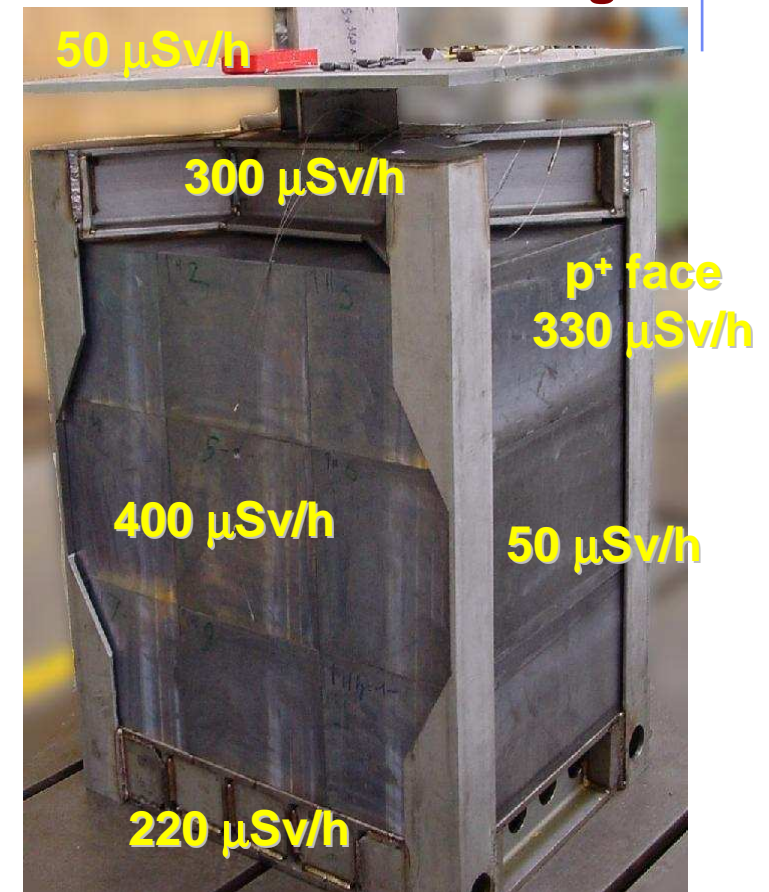
$I_p = 4 \times 10^{12}$  p,  $\Delta T_{\min} = 2.4$  s

# Phase I Spallation Lead Target

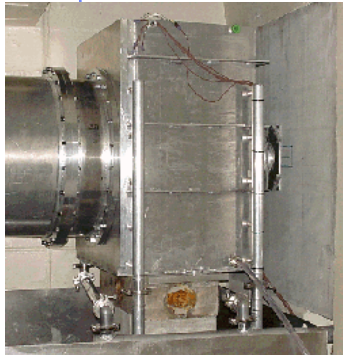
- Dimensions:  $80 \times 80 \times 60 \text{ cm}^3$
- Pure Lead: 4 t
- $\text{H}_2\text{O}$  moderator: 5 cm
- Al-window: 1.6 mm
- Al-container: 140  $\ell$



**1 month irradiation  
2 months of Cooling**



# n\_TOF Virtual Tour



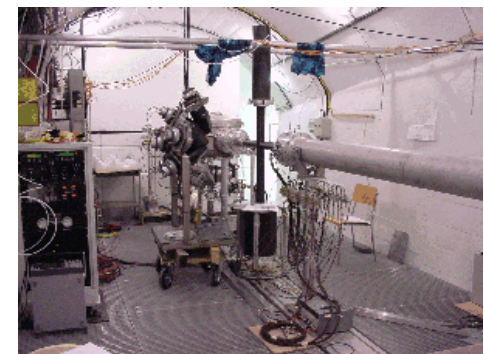
**Lead Container**



**Sweeping Magnet**



**2<sup>nd</sup> Collimator**



**Exp. Area**

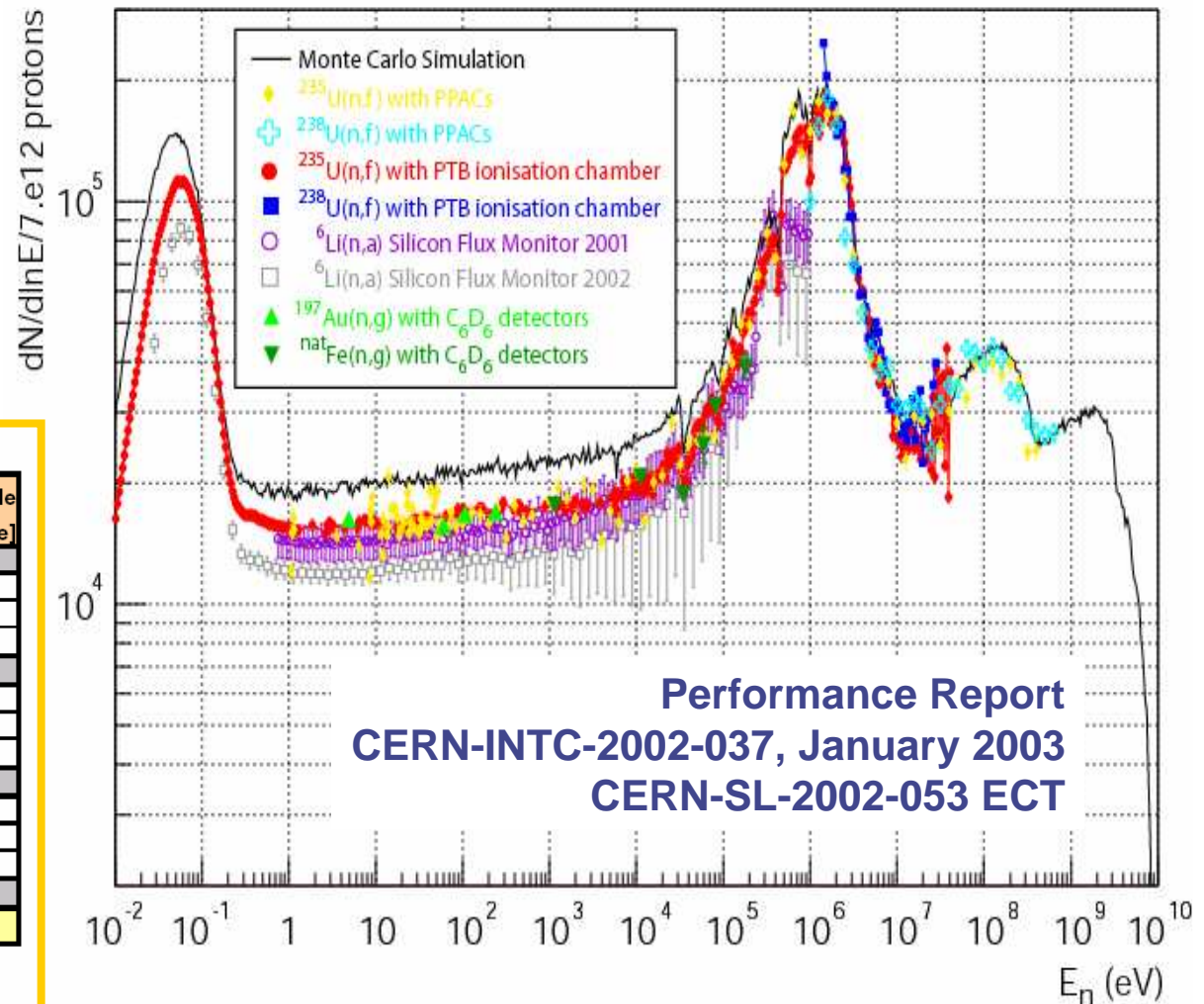
## n\_TOF basic parameters

proton beam momentum	20 GeV/c
intensity (dedicated mode)	$7 \times 10^{12}$ protons/pulse
repetition frequency	1 pulse/1.2s
pulse width	6 ns (rms)
n/p	300
lead target dimensions	80x80x60 cm <sup>3</sup>
cooling & moderation material	H <sub>2</sub> O
moderator thickness in the exit face	5 cm
neutron beam dimension in EAR-1 (capture mode)	2 cm (FWHM)

# n\_TOF beam characteristics

the neutron flux

2<sup>nd</sup> collimator  $\phi=1.8$  cm  
(capture mode)

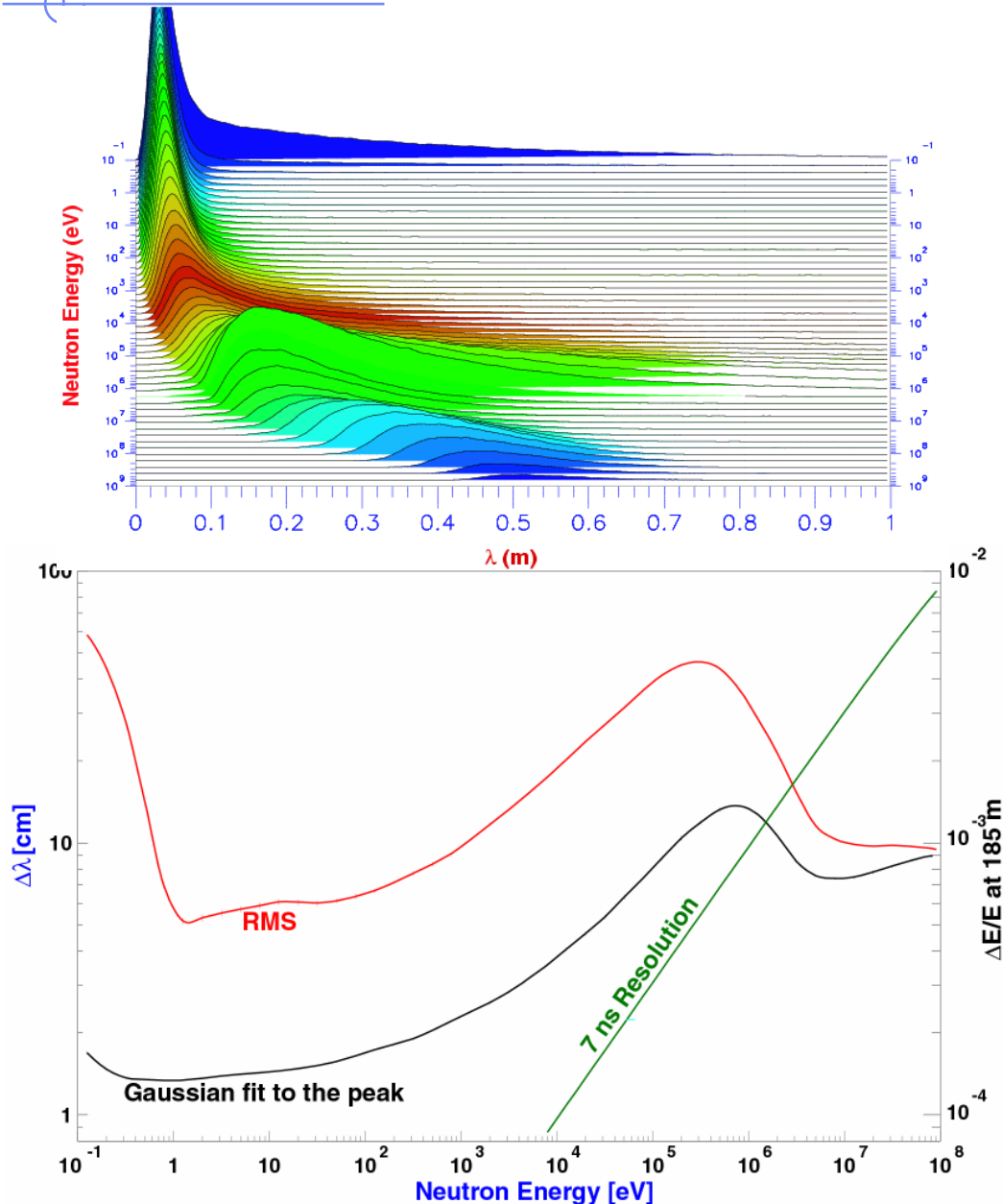


The neutron fluence in EAR-1

Energy range	Uncollimated	Capture mode	Fission mode
	[n/pulse/cm <sup>2</sup> ]	[n/pulse]	[n/pulse]
< 1 eV	2.0E+05	3.1E+05	2.0E+06
1 eV - 10 eV	2.7E+04	4.5E+04	2.9E+05
10 eV - 100 eV	2.9E+04	4.7E+04	3.1E+05
100 eV - 1000 eV	3.0E+04	5.1E+04	3.3E+05
<b>1 eV - 1 keV</b>	<b>8.6E+04</b>	<b>1.4E+05</b>	<b>9.3E+05</b>
1 keV - 10 keV	3.2E+04	5.4E+04	3.6E+05
10 keV - 100 keV	3.9E+04	7.1E+04	4.7E+05
100 keV - 1000 keV	1.1E+05	2.3E+05	1.5E+06
<b>1 keV - 1 MeV</b>	<b>1.8E+05</b>	<b>3.5E+05</b>	<b>2.3E+06</b>
1 MeV - 10 MeV	8.3E+04	2.4E+05	1.7E+06
10 MeV - 100 MeV	2.8E+04	7.2E+04	5.1E+05
> 100 MeV	4.4E+04	1.2E+05	5.6E+05
<b>1 MeV - &gt; 100 MeV</b>	<b>1.6E+05</b>	<b>4.4E+05</b>	<b>2.7E+06</b>
<b>Total</b>	<b>6.2E+05</b>	<b>1.2E+06</b>	<b>8.0E+06</b>

**Note:** 1 pulse is 7E+12 protons. Collimated fluence (fission and capture modes) is integrated over the beam surface.

# Resolution

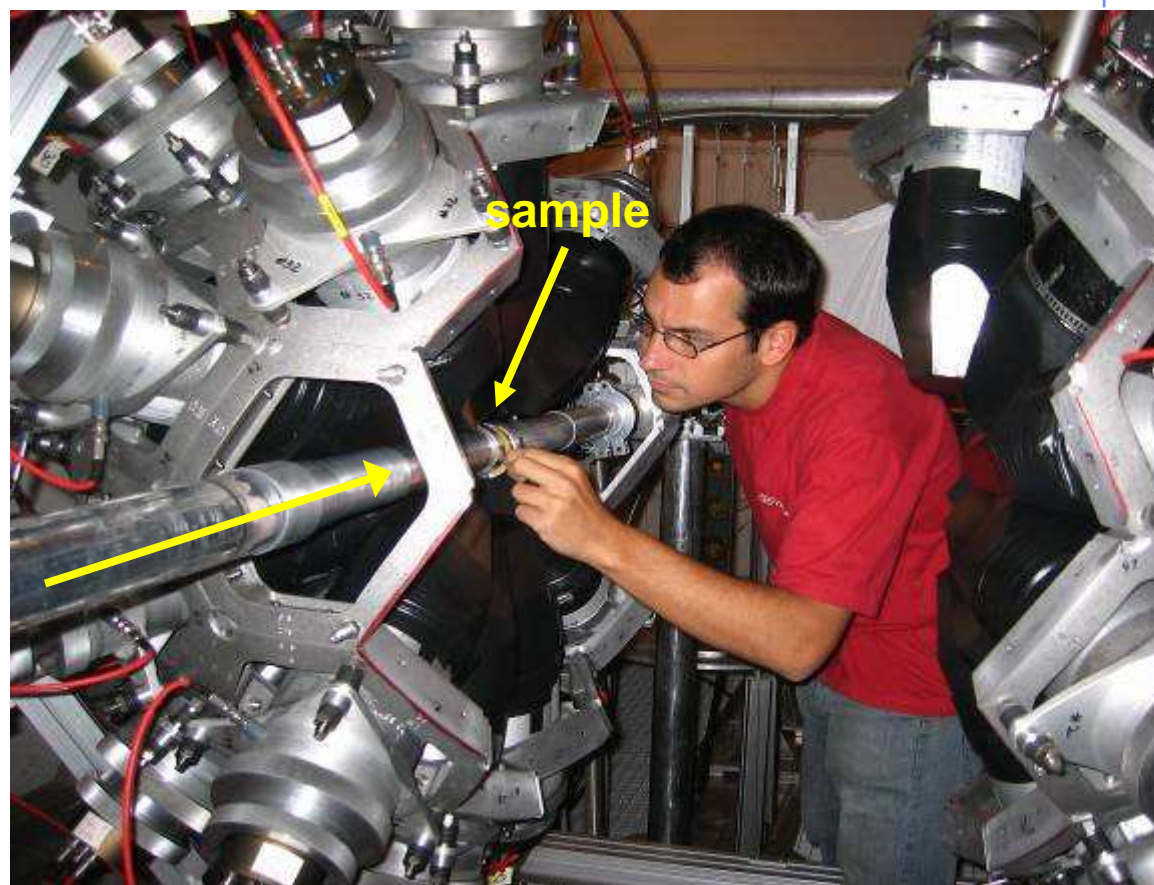


- The resolution experiences a **peak + a tail** due to the peculiarity of the moderation process of the lead + water moderator target
- $\Delta\lambda$  was represented with 2 ways: (i) as the sigma obtained by a **fit on the peak** of a small energy interval (20 bpd), (ii) as the **RMS** of the  $\lambda$  distribution over the same energy interval

# n\_TOF TAC for (n, $\gamma$ ) measurements

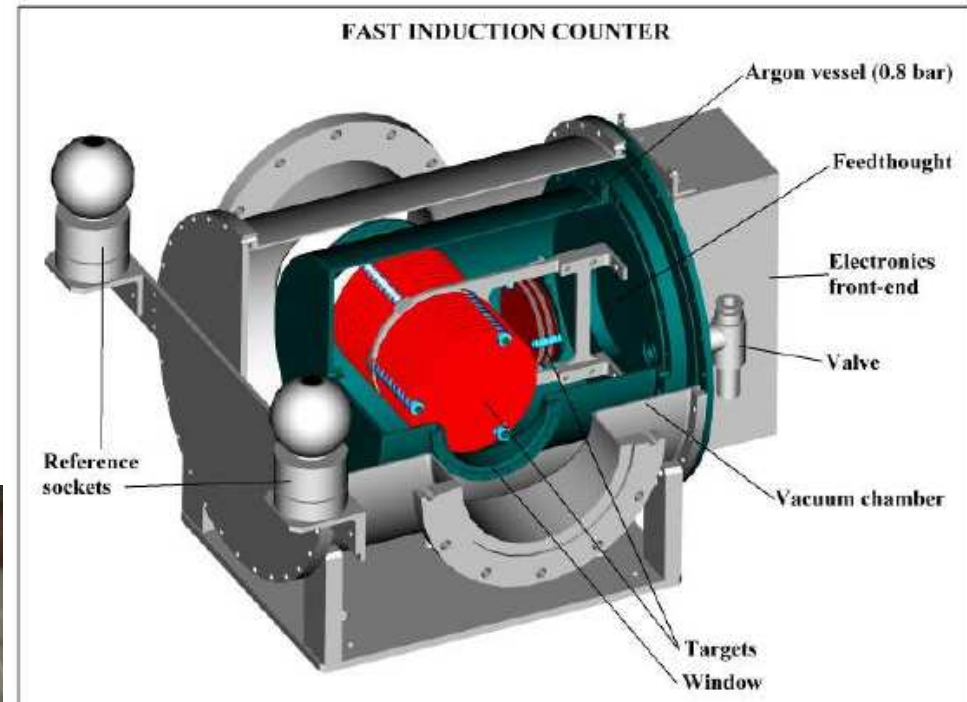
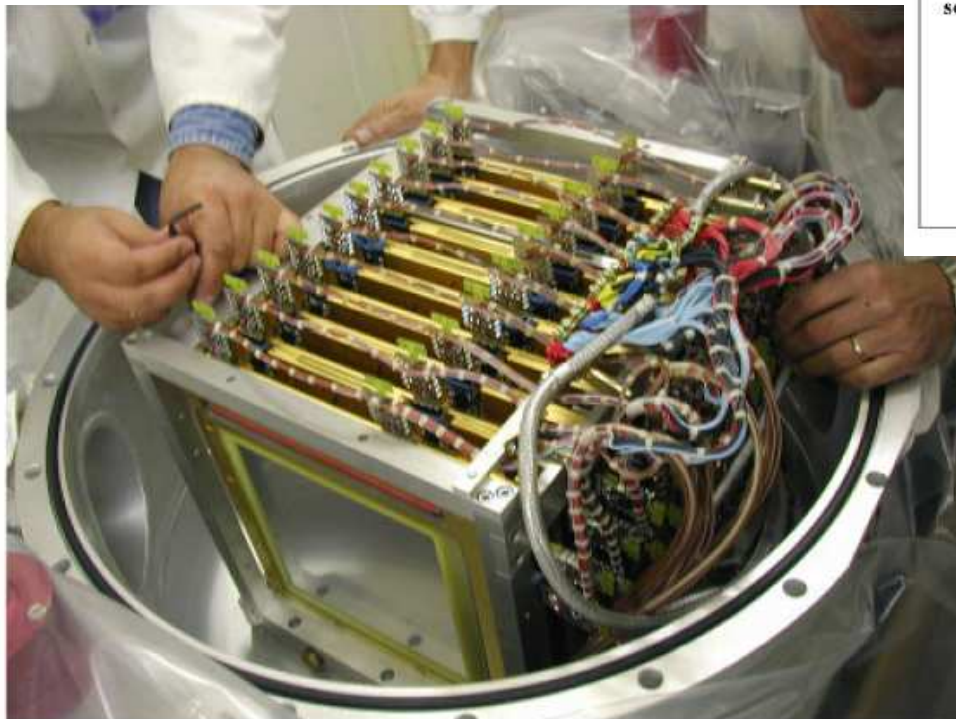
- Structure mounted in April-04
- 4 $\pi$  geometry: end of May-04
- 1.5 month commissioning
- Au(n, $\gamma$ ) & other standards

First measurement with a radioactive sample started in August 2004  
 $^{237}\text{Np}(n,\gamma)$



# n\_TOF fission detectors

- 20x20 cm<sup>2</sup>
- Isobutane gas 7 mbar
- HV 500-600 V
- 3 mm between electrodes
- 1 anode (a few ns signal width)
- Electrode thickness: 1.5 μm (Mylar+Al)
- Deposit thickness : 100-300 μg/cm<sup>2</sup>
- Backing thickness : 0.1 μm (Al)
- : 1.5 μm (Mylar)
- Fission event identification: T2 in coincidence with T1



- Gas: Ar (90%) CF<sub>4</sub> (10%)
- Gas pressure : 720 mbar
- Electric field : 600 V/cm
- Gap pitch : 5 mm
- Electrode diameter : 12 cm
- Electrode thickness : 15 μm (Al)
- Deposit thickness : 125 μg/cm<sup>2</sup>
- Backing thickness : 100 μm (Al)
- Window thickness : 125 μm

## Capture

$^{151}\text{Sm}$

$^{204,206,207,208}\text{Pb}$ ,  $^{209}\text{Bi}$

$^{232}\text{Th}$

$^{24,25,26}\text{Mg}$

$^{90,91,92,94,96}\text{Zr}$ ,  $^{93}\text{Zr}$

$^{139}\text{La}$

$^{186,187,188}\text{Os}$

$^{233,234}\text{U}$

$^{237}\text{Np}$ ,  $^{240}\text{Pu}$ ,  $^{243}\text{Am}$

## Fission

$^{233,234,235,236,238}\text{U}$

$^{232}\text{Th}$

$^{209}\text{Bi}$

$^{237}\text{Np}$

$^{241,243}\text{Am}$ ,  $^{245}\text{Cm}$

# n\_TOF experiments 2002-4

- **M**easurements of neutron cross sections relevant for Nuclear Waste Transmutation and related Nuclear Technologies
  - ◆ Th/U fuel cycle (capture & fission)
  - ◆ Transmutation of MA (capture & fission)
  - ◆ Transmutation of FP (capture)
- **C**ross sections relevant for Nuclear Astrophysics
  - ◆ s-process: branchings
  - ◆ s-process: presolar grains
- **N**eutrons as probes for fundamental Nuclear Physics
  - ◆ Nuclear level density & n-nucleus interaction

# Two sides to every story



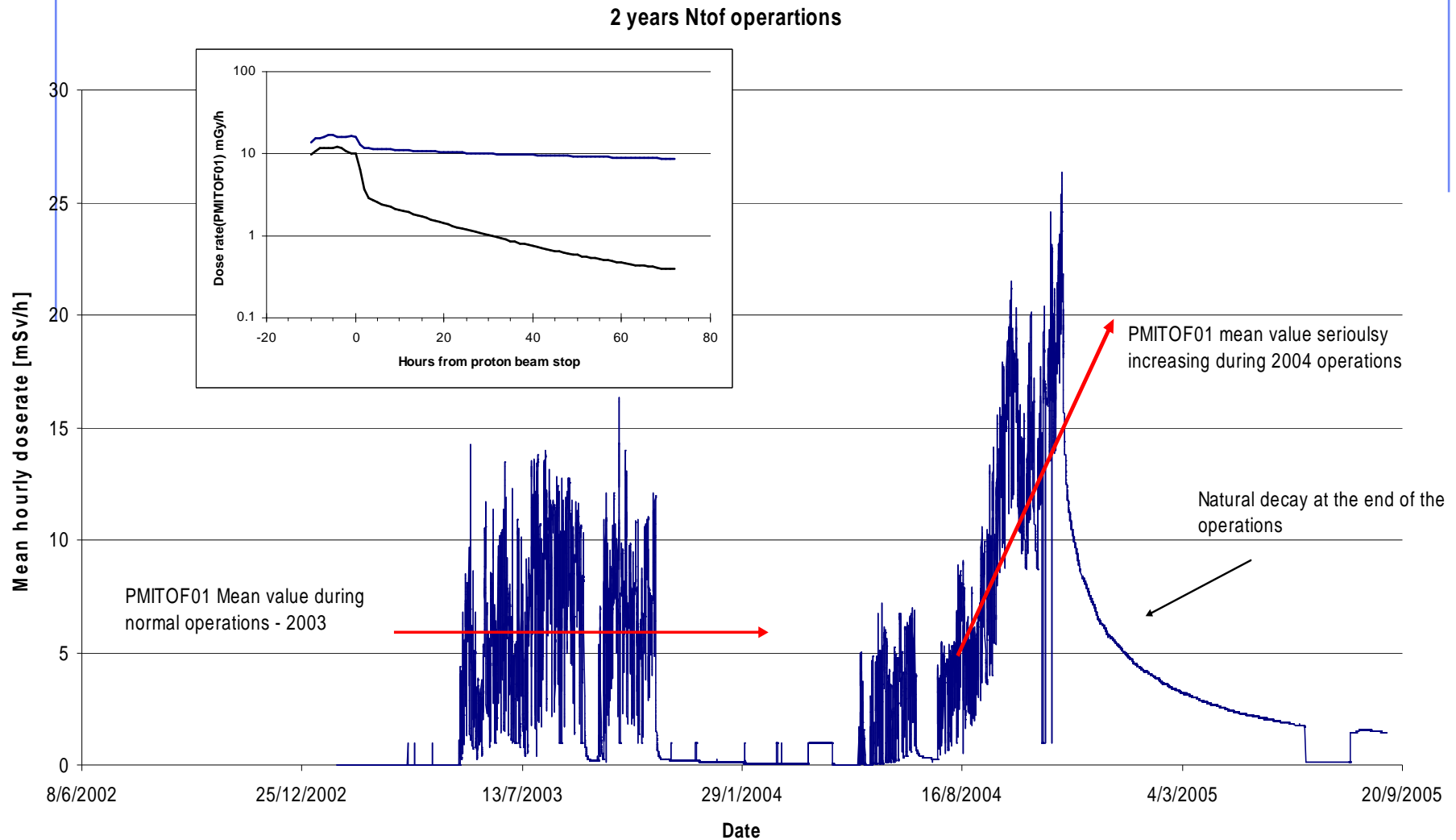
Front



Back

<http://www.kahunaburger.com>

# RP: Cooling circuit activation in 2004



# RP: Cooling circuit activation in 2004

Isotope	Activity concentration 11.11.2003 (Bq g <sup>-1</sup> )	Activity concentration 12.10.2004 (Bq g <sup>-1</sup> )	Activity concentration 16.11.2004 (Bq g <sup>-1</sup> )	Ratio Nov. 2004/ Nov. 2003
<sup>7</sup> Be	99.6	84.4	74	0.74
<sup>65</sup> Zn	4.49 10 <sup>-2</sup>	1.63	6.6	
<sup>88</sup> Y	2.88 10 <sup>-2</sup>	4.51	18	
<sup>172</sup> Hf/Lu	3.6 10 <sup>-2</sup>	6.44	23	
<sup>183</sup> Re	7.27 10 <sup>-2</sup>	8.83	73	
<sup>185</sup> Os	3.46 10 <sup>-2</sup>	25.9	120	
<sup>195</sup> Au	9.02 10 <sup>-2</sup>	59.0	360	

Isotope	Exemption Limit $L_E$ (Bq g <sup>-1</sup> ) or (Bq)	Activity concentration $a$ 16.11.2004 (Bq g <sup>-1</sup> )	Multiple of $L_E$	Total activity $A$ in 700 l	Multiple of 100 $L_E$
<sup>7</sup> Be	400	74	0.19	51800	1.3
<sup>65</sup> Zn	3	6.6	2.2	4620	
<sup>88</sup> Y	8	18	2.25	12600	
<sup>172</sup> Hf/Lu	8	23	2.88	16100	
<sup>183</sup> Re	10	73	7.3	51100	
<sup>185</sup> Os	20	120	6	84000	
<sup>195</sup> Au	40	360	9	252000	

Total Exemption Limit 100  $L_E$

# Target Interventions

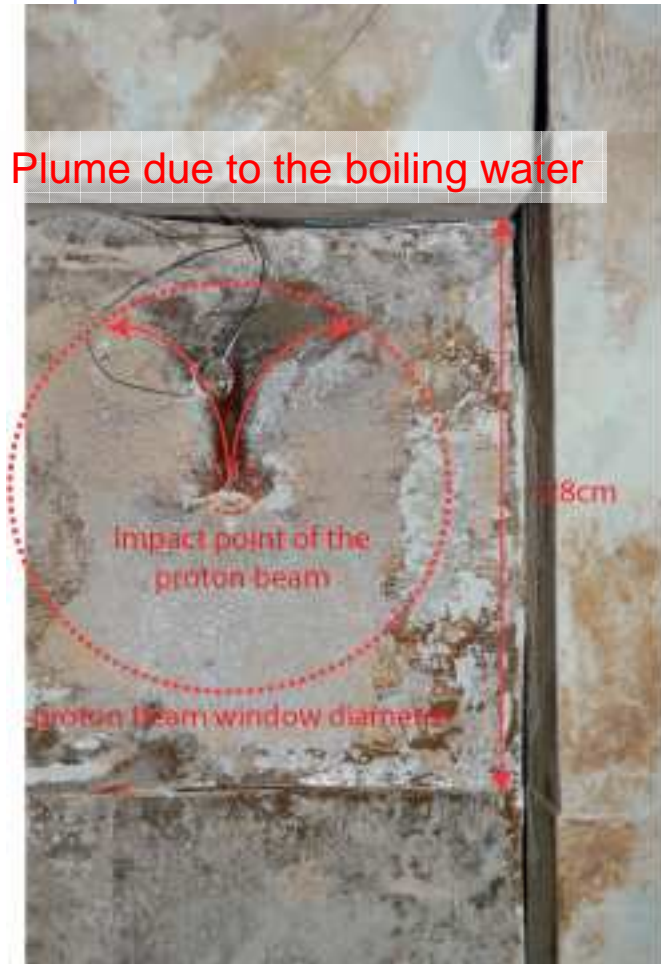
- Target removal was performed at the 27.09.2007
- Target visual inspection & photography
- Pit & pool inspection (web camera)
- First dose rate measurements of the target and pit
- Measurement of hole at the beam impact location
- Samples taken from the target to be analyzed by CERN & CIEMAT
- Updated 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



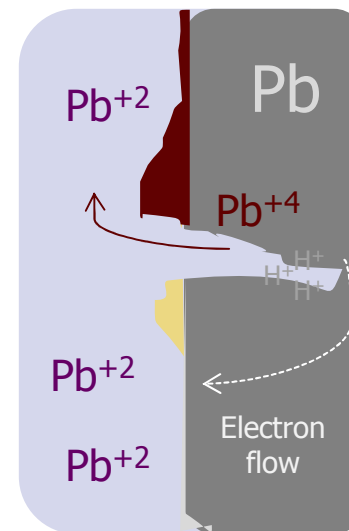
# Pitting Corrosion



The very hot (boiling) water carries more oxygen, thus allowing the Pb to change its oxidation state to higher values:

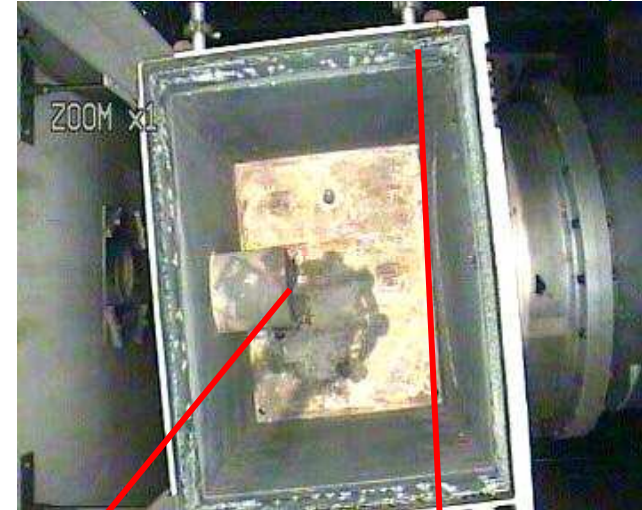


Hydroxides are formed and a very acid local medium which attacks the metal is produced:



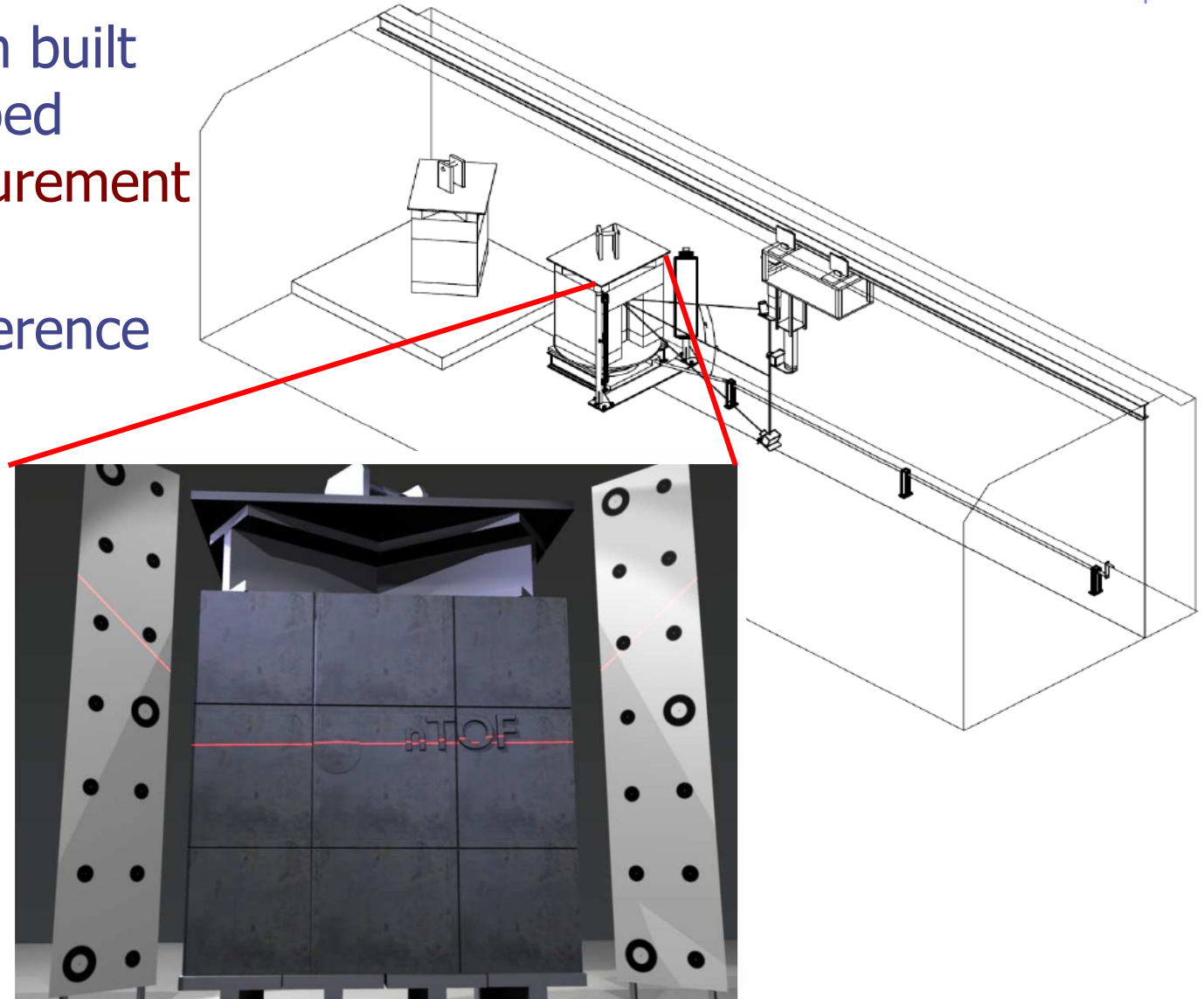
# Pit and Pool Inspection

- 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

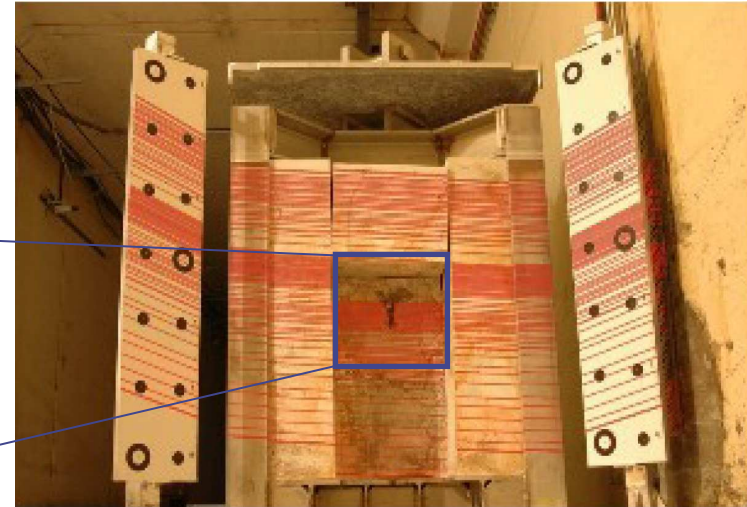
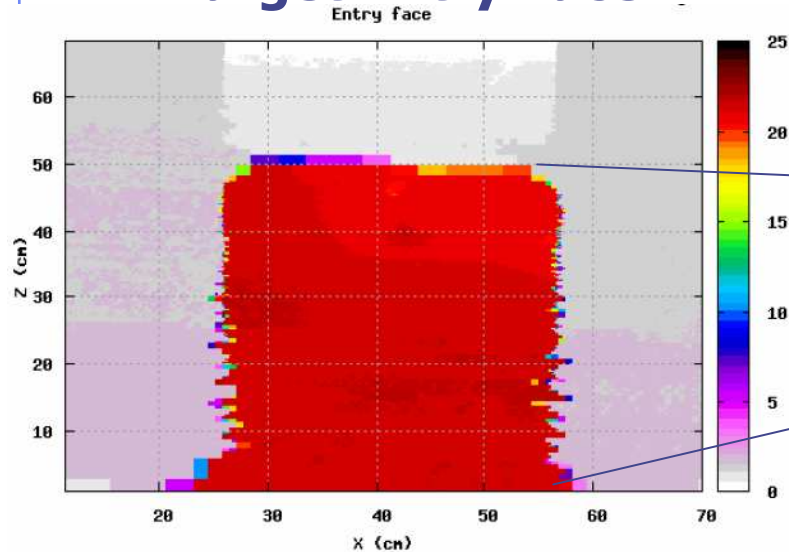
- Fully custom built and developed Laser measurement system
- Modular reference frame
- Special Analysis Software
- Complete survey
- Resolution  $300\mu\text{m}$



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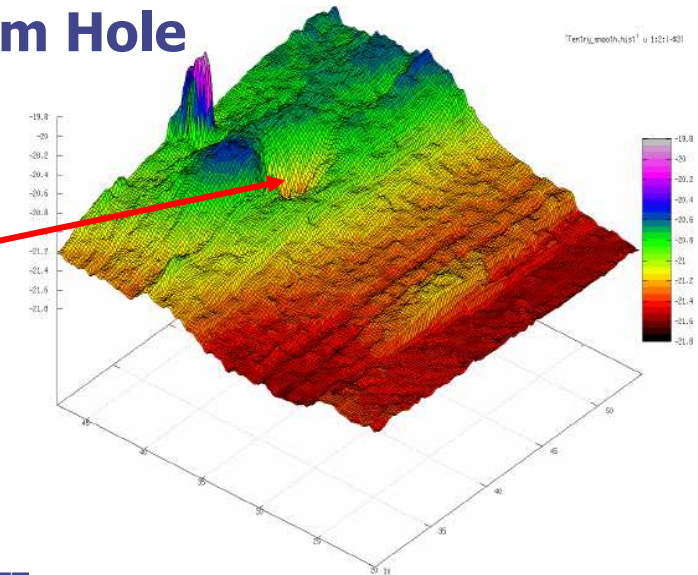
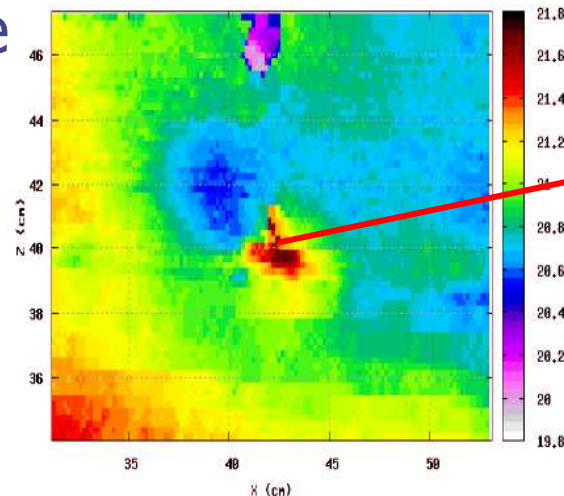
# Laser Surface Measurements

## Target Entry Face

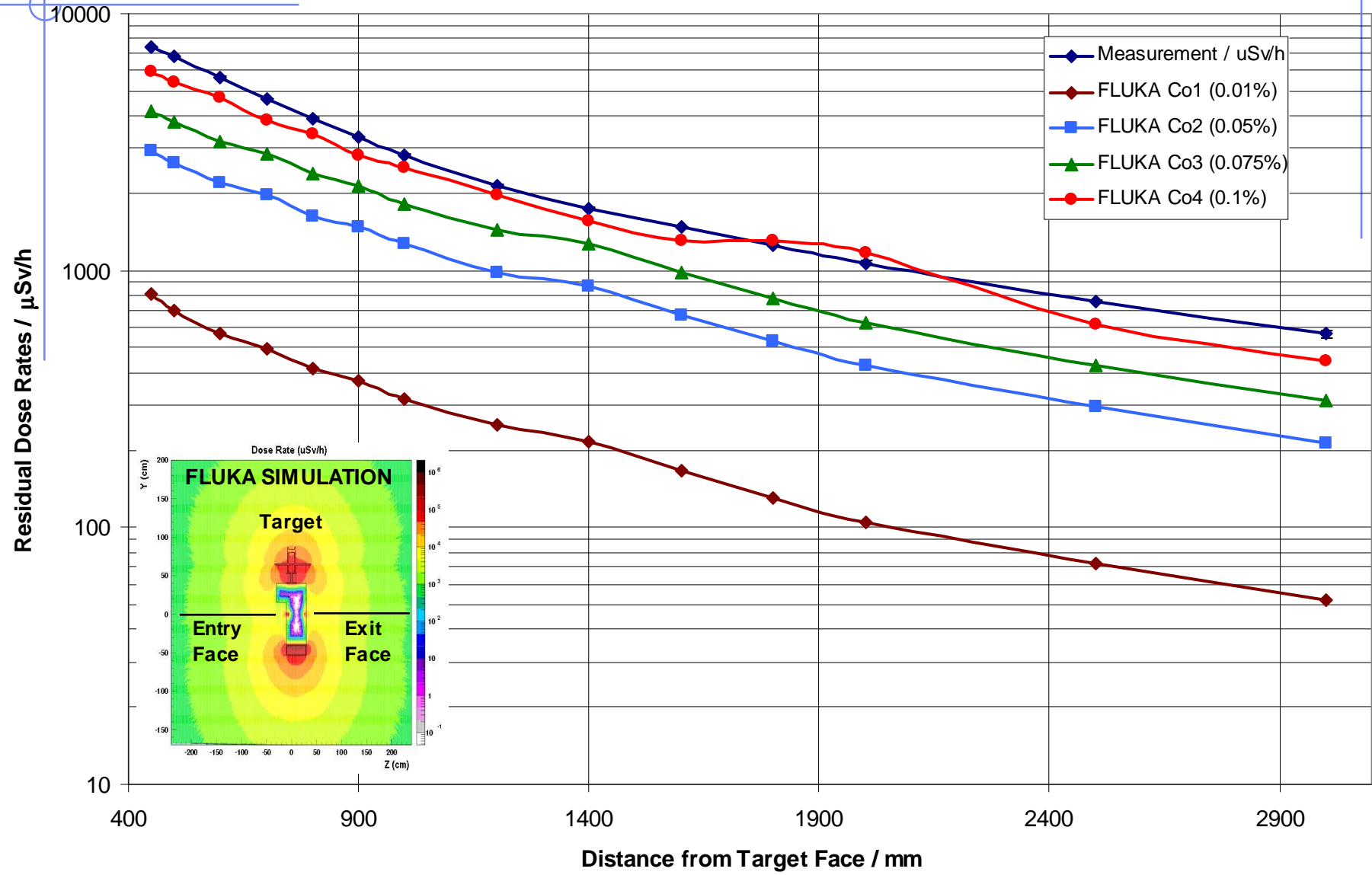


## Proton Beam Hole

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



### Residual Dose Rate Scan - Entry Face New FLUKA Comparison for Different Cobalt Contents



# What we've learned

- **Insufficient cooling**, in particular at the **hot spot** (proton entrance lead surface)
- **Additional oxidation** due to the target drying with air
- **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<sup>60</sup> activation** (neutron capture on Co<sup>59</sup>), 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

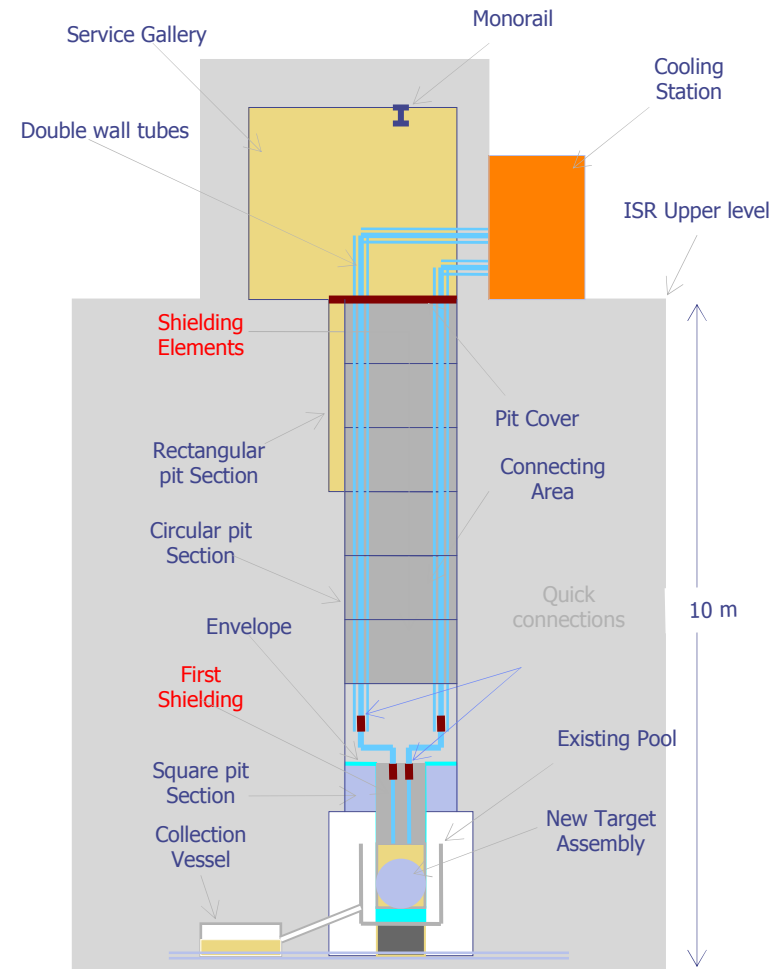
- Why a **modification of the old target cooling circuit** is not favourable
  - long and complicated intervention
  - contamination issues as well as partly important residual dose rates
  - high individual and collective doses
  - no access during operation
- Why the **un-cladded lead target** is considered 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

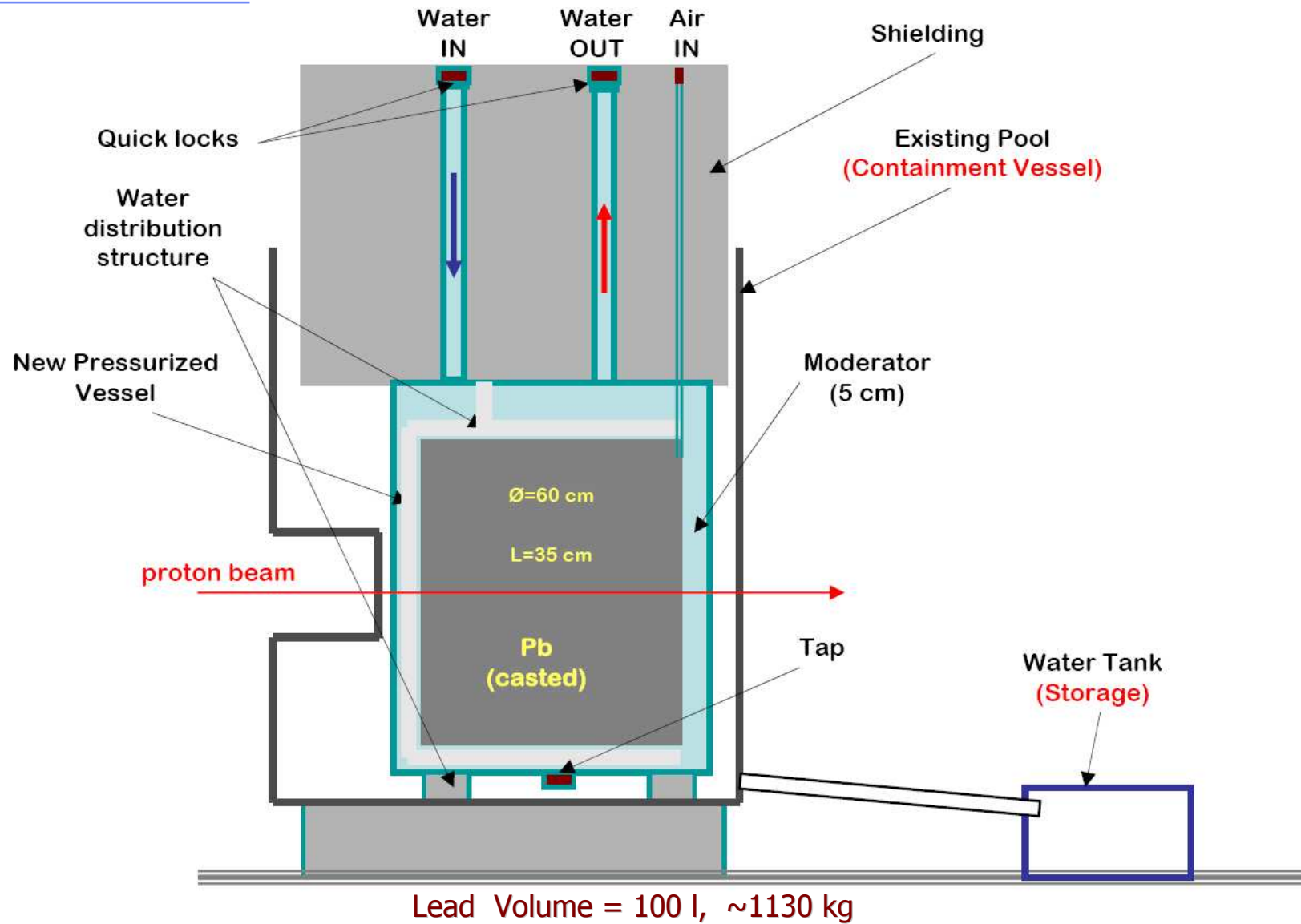
- Why a **stainless steel support structure** would be favourable
  - better mechanical properties when compared to aluminium
  - no possible need for separation before target can be disposed (radioactive waste storage)
  - expected high residual dose rates can be reduced by choosing a stainless steel type with low cobalt content
- **Alternatives (for lower residual dose rates)**
  - Aluminum structure (mechanical stability and waste issues)
  - Boron enriched water
  - Borated paraffin blocks outside the target
- 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 beam size or bunch length, running at lower energy/intensity but higher 'frequency'

# 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**

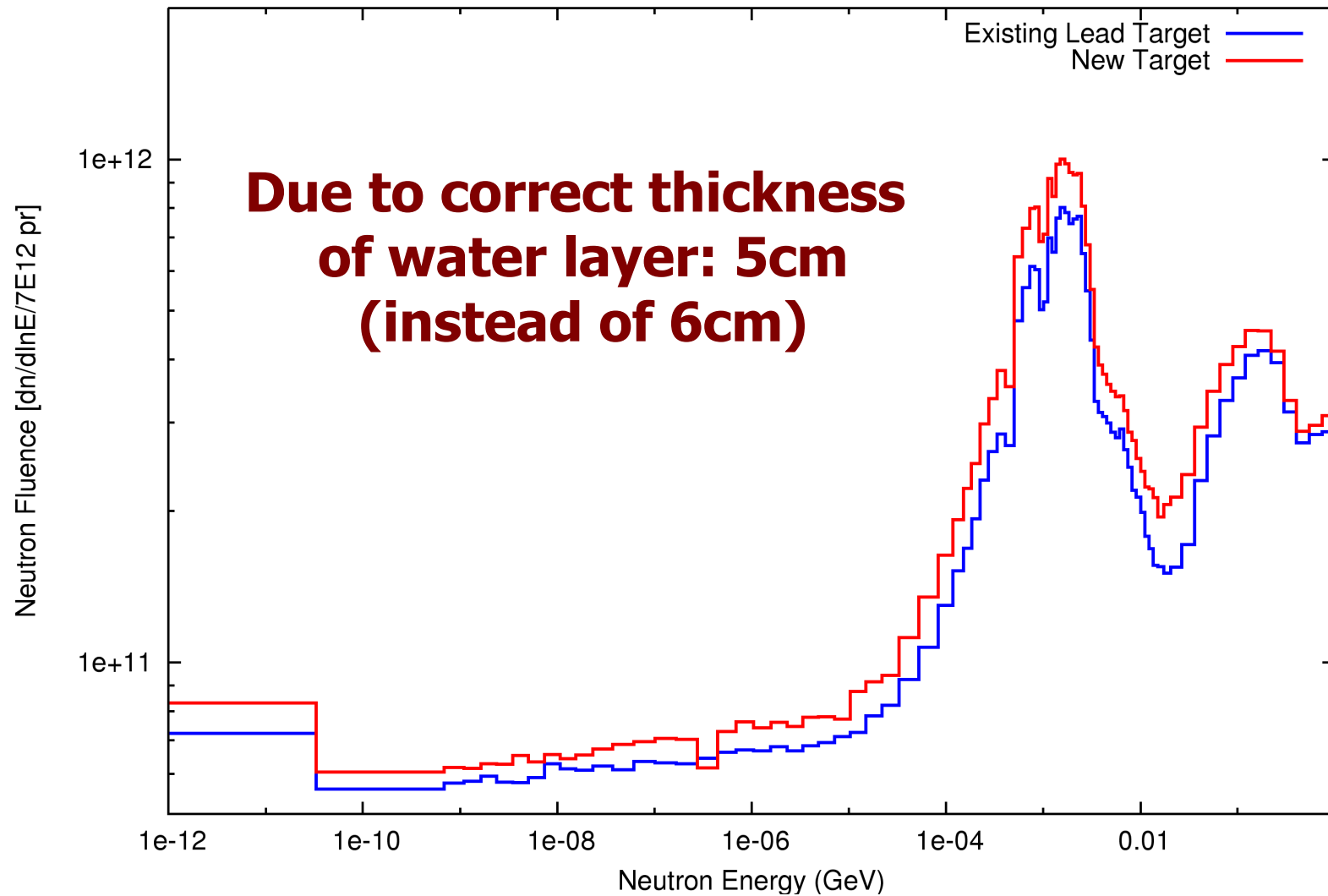


# New Target Design



# New Layout Neutron Fluences

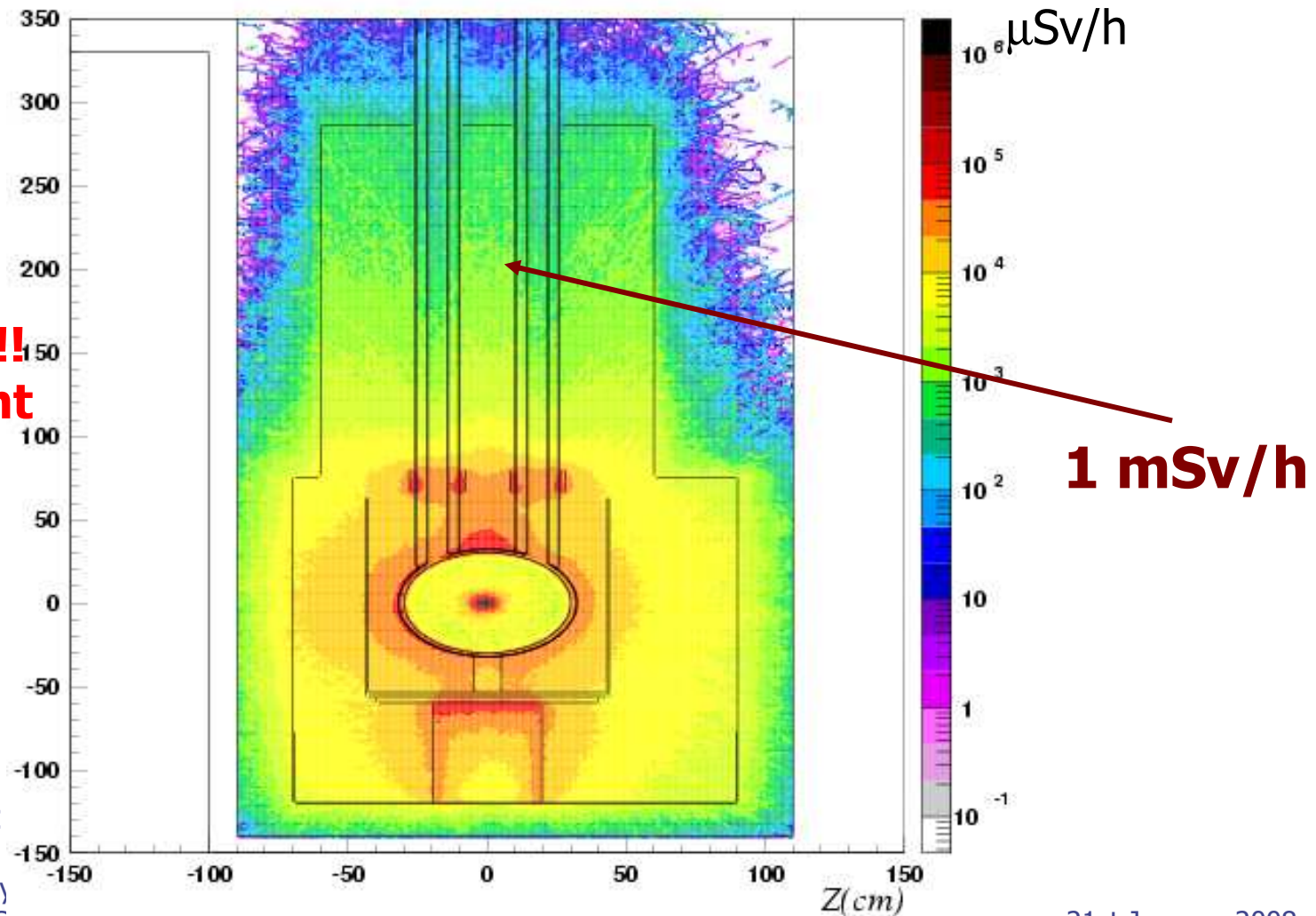
Neutron Fluence Comparison (20cm diameter window)



# Residual Dose Rates

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

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



ATC/ABOC  
Towards a  
TOF Facility  
Radiation Safety

# Summary

- n\_TOF has produced a numerous and unique results on both capture and fission cross section, during the 4 years of operation 2001-04
- Stopped for 2 years due to radioprotection issues
- The target investigation helps us to understand the problems
- A new design has been envisaged to address these problems
- Pending approval from an external review (14/2/2008)
- Scheduled to be operational in Sep 2008