

**Radiation Protection lessons**  
Experiences with operating beams for  
Neutrino experiments

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# Outline

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- ▶ Experiences at CERN:  
a bit of history - from WANF to CNGS
  - ▶ Principle problems at WANF & improvements of the CNGS facility
- ▶ Lessons learned from CNGS, MiniBooNE, NuMI and K2K

# Neutrino studies at CERN at the SPS

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Two major neutrino facilities at CERN at the SPS (Super Proton Synchrotron)

- ▶ **The old one:** The **West Area Neutrino Facility (WANF)** of the CERN SPS was commissioned along with the SPS accelerator itself in 1976
  - ▶ This facility was used until the area was shut down in 2000. The beam line was operated at proton intensities of up to  $3 \times 10^{13}$  ppp (450 GeV)
- ▶ **The new one:** **CNGS** was approved in 1999 and started beam operation in 2006 (up to  $4.8 \times 10^{13}$  ppp, 400 GeV).

# WANF vs. CNGS - I

- ▶ No shielding around the beam line
  - ▶ High residual dose rates during maintenance or repair work
  - ▶ Air activation



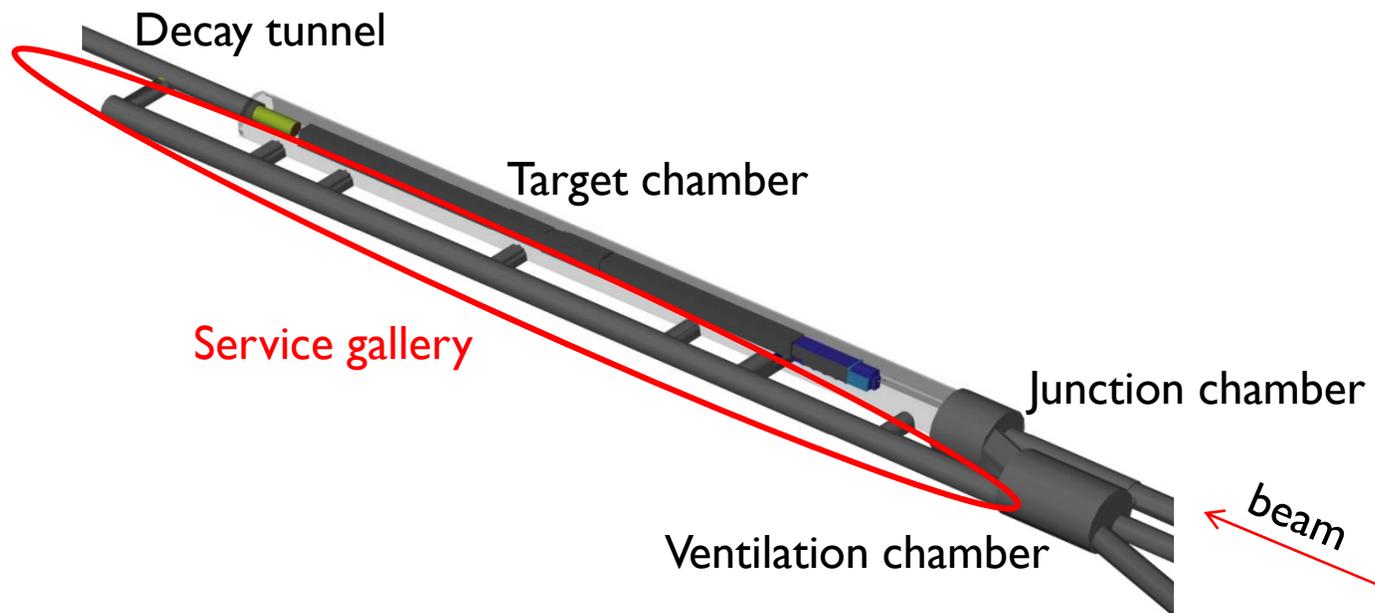
WANF



CNGS

## WANF vs. CNGS - II

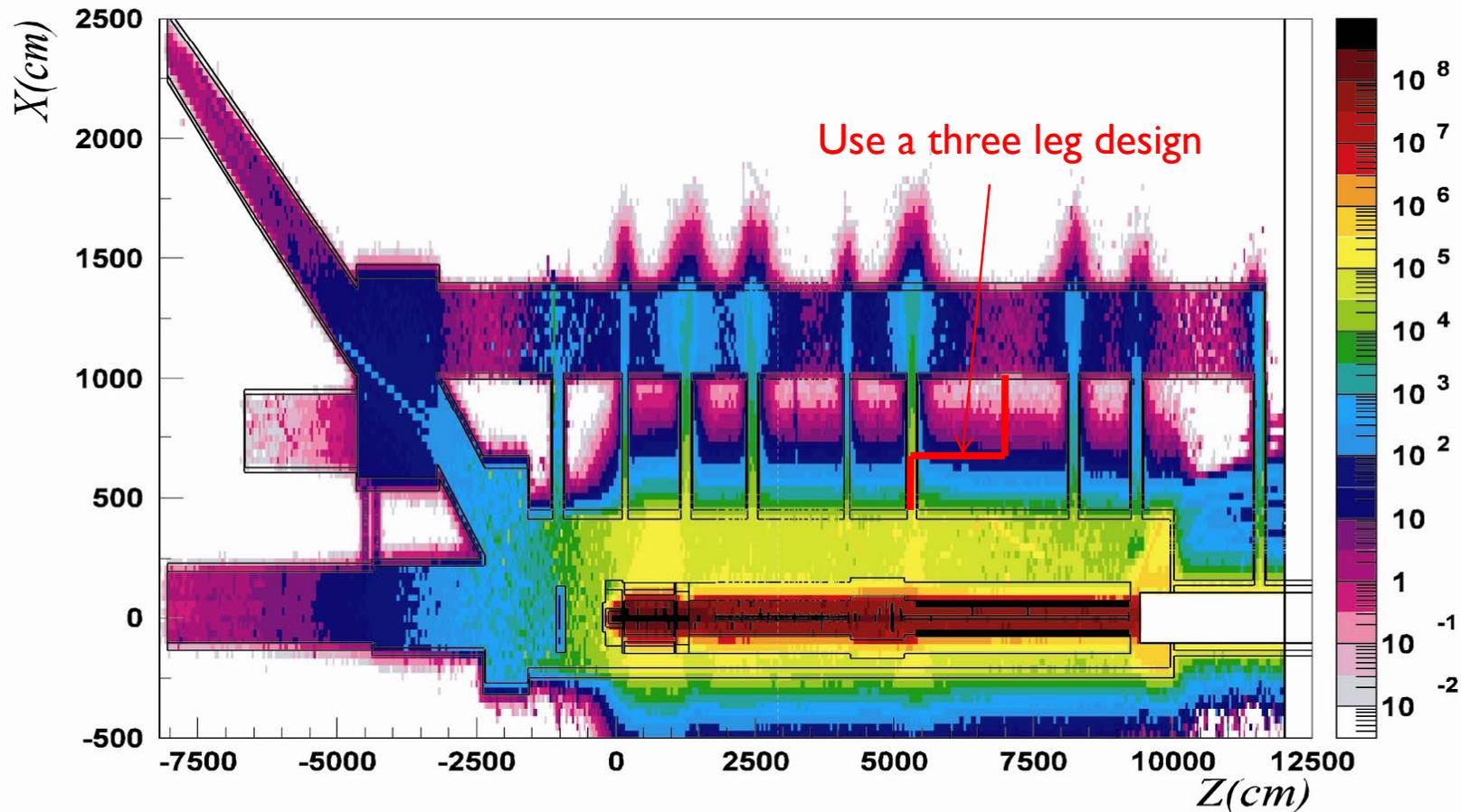
- ▶ WANF - Absence of a service gallery



- ▶ CNGS - a separate service gallery minimizes occupancy of the target chamber. Most of the equipment (pumps, cooling units, power supplies, cable trays, etc.) did not have to be located in the target chamber. Less activation of components, lower collective dose during interventions.

# Prompt dose rate in CNGS ( $8E12$ pot/s)

Prompt Dose Equivalent Rate (mSv/h)



Reference: M. Lorenzo Sentis, A. Ferrari, S. Roesler, L. Sarchiapone, CERN-OPEN-2006-009

## WANF vs. CNGS - III

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- ▶ **WANF**

- ▶ Part of the gear mechanism for the crane was made out of teflon.

- ▶ **CNGS**

- ▶ no teflon. Further, crane cables are located outside the target chamber when the crane is in its parking position. Thus, they are exposed to much lower radiation than compared to a storage location in the target chamber.

- ▶ **WANF**

- ▶ O'rings in pumps and motors were not specified to be radiation resistant.

- ▶ **CNGS**

- ▶ only radiation hard components were installed in the CNGS target chamber

- ▶ **WANF**

- ▶ Blocking of the vacuum shutter mechanism because of the degradation of the travel-limiter switches or thickening of grease due to radiation.

- ▶ **CNGS**

- ▶ shutter mechanism is located in the service gallery

# WANF vs. CNGS - IV

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- ▶ **WANF**

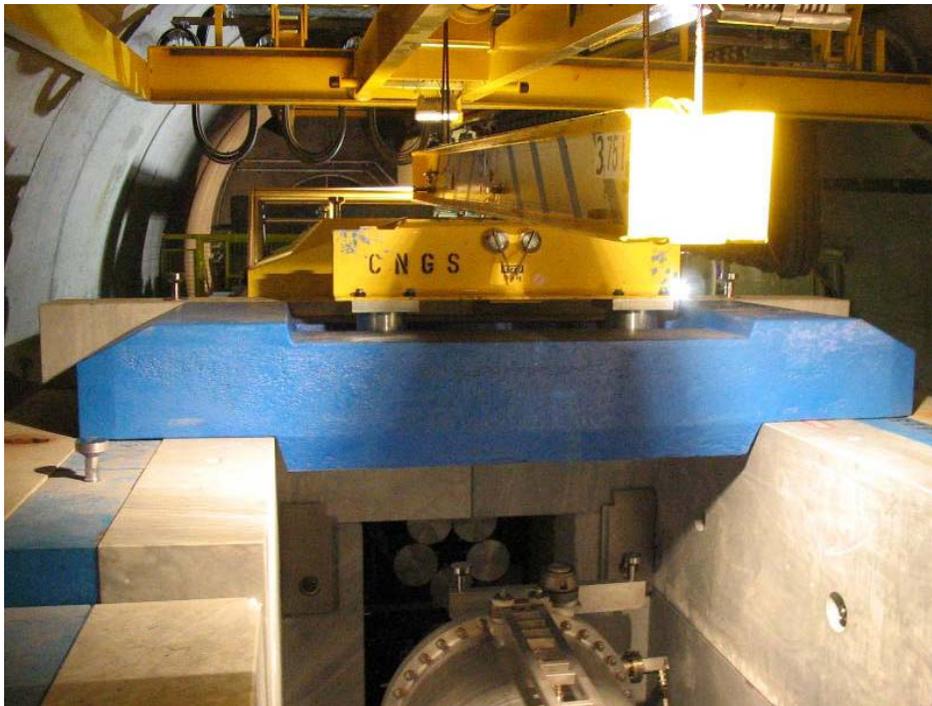
- ▶ There was a continued inability to provide a correct closed-circuit ventilation system
- ▶ Because of this, the decision was taken to stop the air circulation during operation. This caused strong rusting due to the build-up of humidity.

- ▶ **CNGS**

- ▶ The ventilation system is housed inside a 'ventilation chamber' which is separated from the target chamber. Maintenance of ventilation units can be done in a 'low' radiation area.
- ▶ Separate ventilation system is for the target chamber/service gallery, the proton beam-line tunnel and the access gallery. Therefore, no mixture of radioactive air with non radioactive air.
- ▶ Effective air dehumidifier was installed - reduces the problem of corrosion considerably.

# Further CNGS improvements

- shielding blocks at target, horn and reflector can be removed remotely

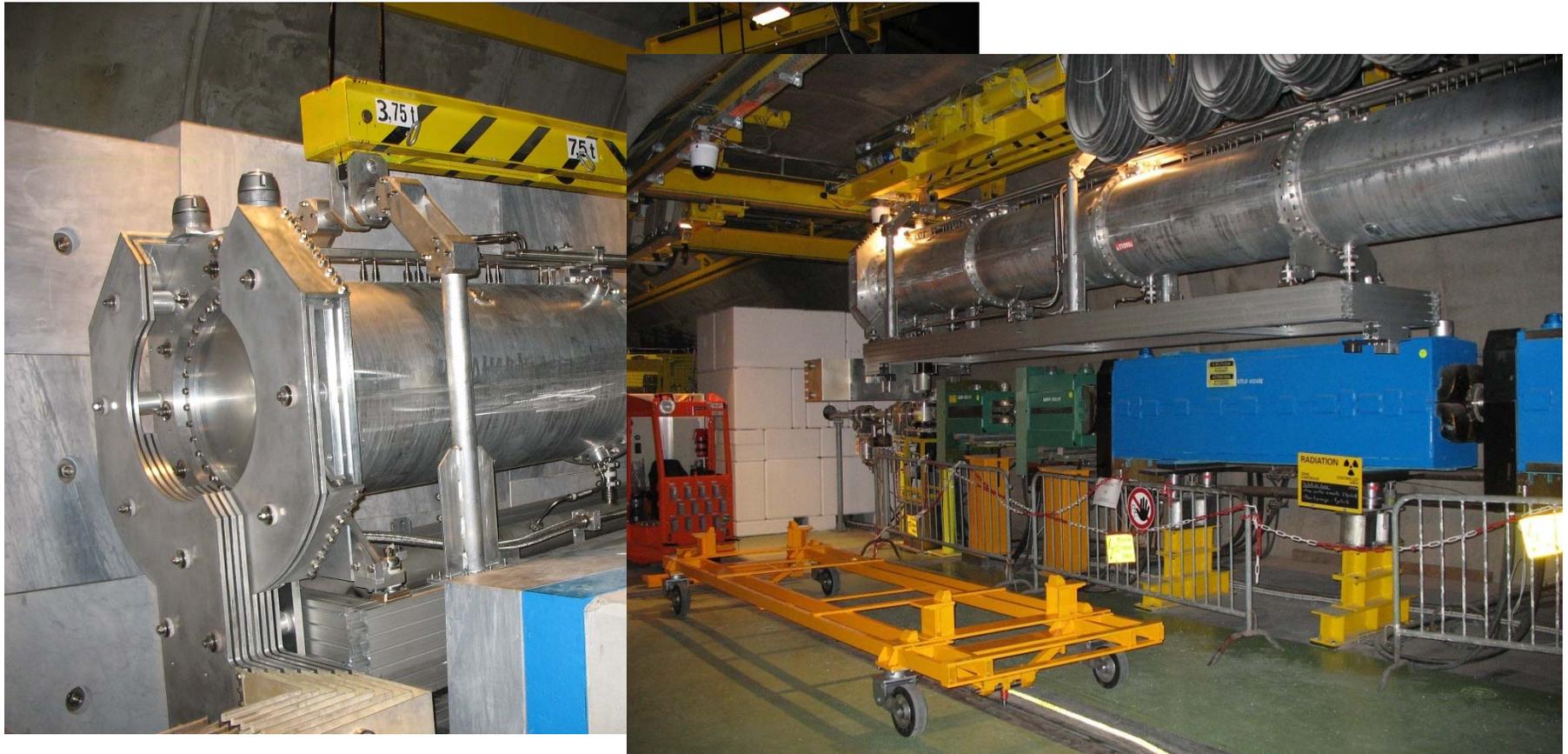


- marble shielding at target station



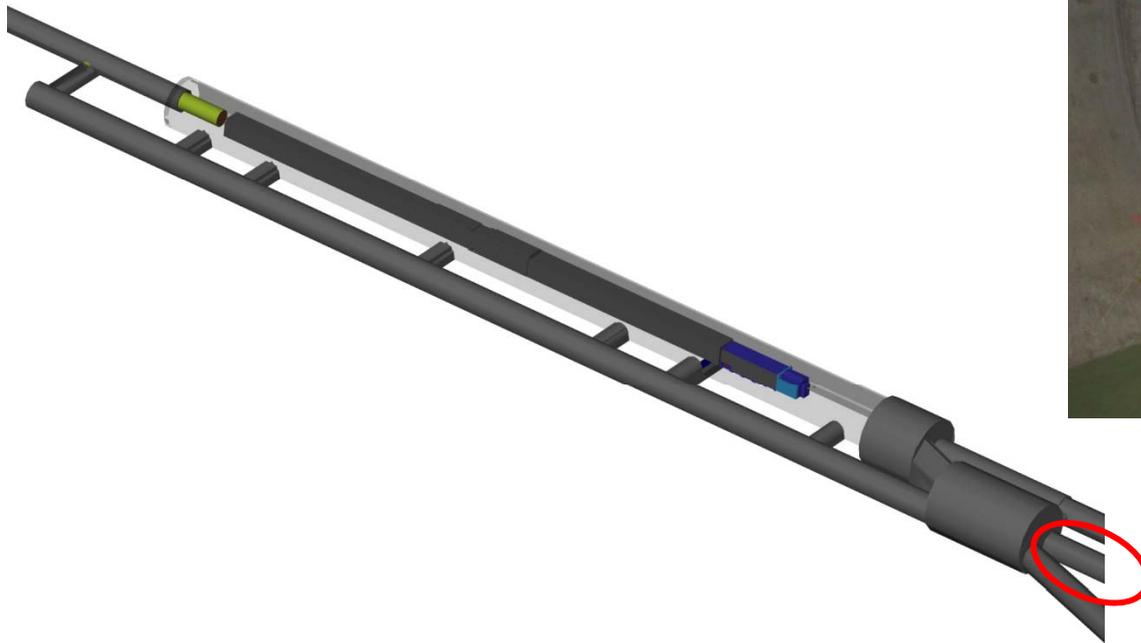
# Further CNGS improvements

- Remote exchange of radioactive items like target, horn, reflector and collimators in case of a failure. The crane console is located in the ventilation chamber... camera is mounted on crane.



# Further CNGS improvements

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- A special stub tunnel has been constructed to serve as a radioactive storage area. Transport into the storage area can be made with a remote controlled transport vehicle. No need for long (time and distance) transports of radioactive components to a storage location somewhere on the surface.

# Further CNGS improvements

- ▶ Used quick connectors for flanges, horn-stripline connection, horn water pipes.
- ▶ Choice of material - for example we used only stainless steel with no or very low content of cobalt.
- ▶ Redundancy function for 'delicate' items; for example target or two independent water cooling circuits for horn and reflector

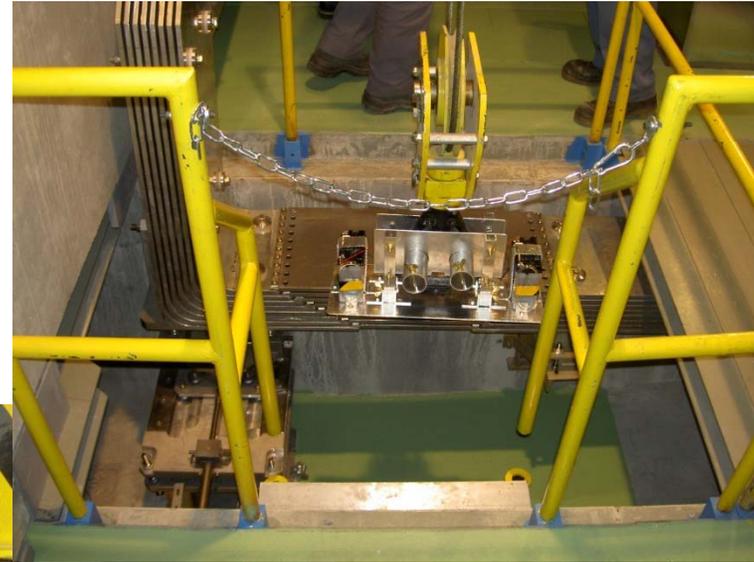
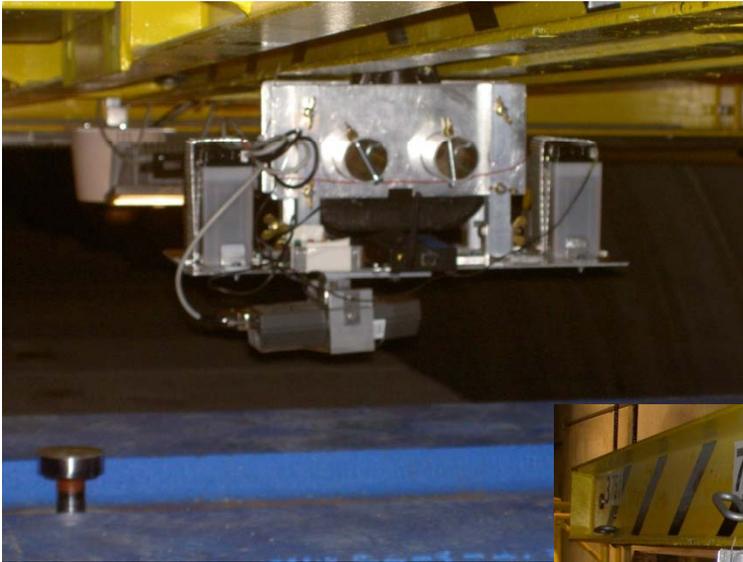


Switch for water circuits



CNGS target magazine

# Remotely controlled radiation survey - I



A survey platform has been developed to measure the residual dose rate in the CNGS cavern remotely



Reaches nearly any location in the target chamber. **Prevents exposure** of personnel to high radiation levels **during manual measurements.**

The platform can be mounted on the crane.

# Lessons learned from CNGS, NuMI, MiniBooNE and K2K

# Radiation accelerated corrosion and radiation damage is a big problem

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- ▶ Beam induced ionization of air creates a nitric acid environment. Examples of failures due to this fact
  - ▶ Mini-BooNE 25 m movable absorber. Two failures of steel chains



- ▶ Concerns over similar corrosion of NuMI Decay Pipe window (Al, 1/16" thick) have motivated NuMI to use He gas in decay pipe rather than evacuated.
  - ▶ Target and horn failures are mostly related to corrosion and radiation damage issues.
- ▶ T2K will house its target and horn in a Helium environment

# Material studies are needed

- ▶ Corrosion and air radicals are still a big problem in a 'humid' environment like water cooled target, horn etc.



Placed at WANF

Photos - courtesy of  
S.Rangod



Ongoing study – metal  
samples placed under  
the horn at CNGS

# Repair work

Failure of target, horn occurs more often than expected. However, what fails are items like water lines, ceramic isolators and not the main, expensive device.

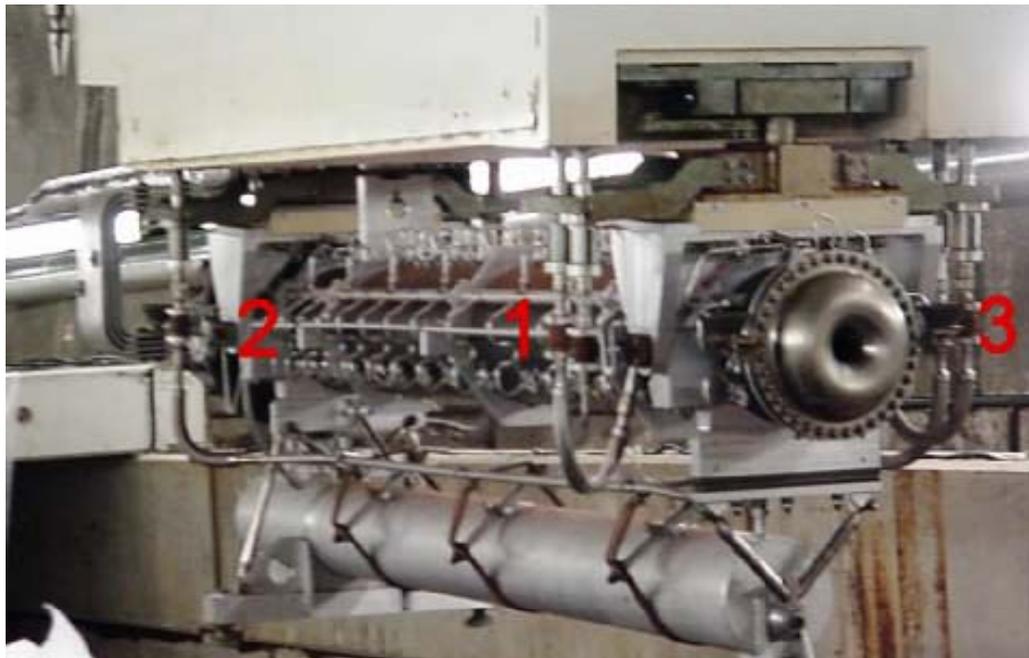
Therefore:

- have **spare part**
  - perform **dry runs** on spare part or mock-up
  - **Optimizing the work procedure**
  - use **remote exchange** and **transport** of activated items to the place where the work will be performed
  - perform work in a **work-cell** (presently only at NuMI).
- All these reduces the dose to the repair crew considerable



# Residual dose rate at NuMI horn in August 2006

Horn 1 ceramic replacement challenging



Point	Doserate @ 1 foot (mr/hour)	Doserate On Contact (mr/hour)
1	35000	75000
2	40000	75000
3	35000	80000

100 mr/h = 1 mSv/h

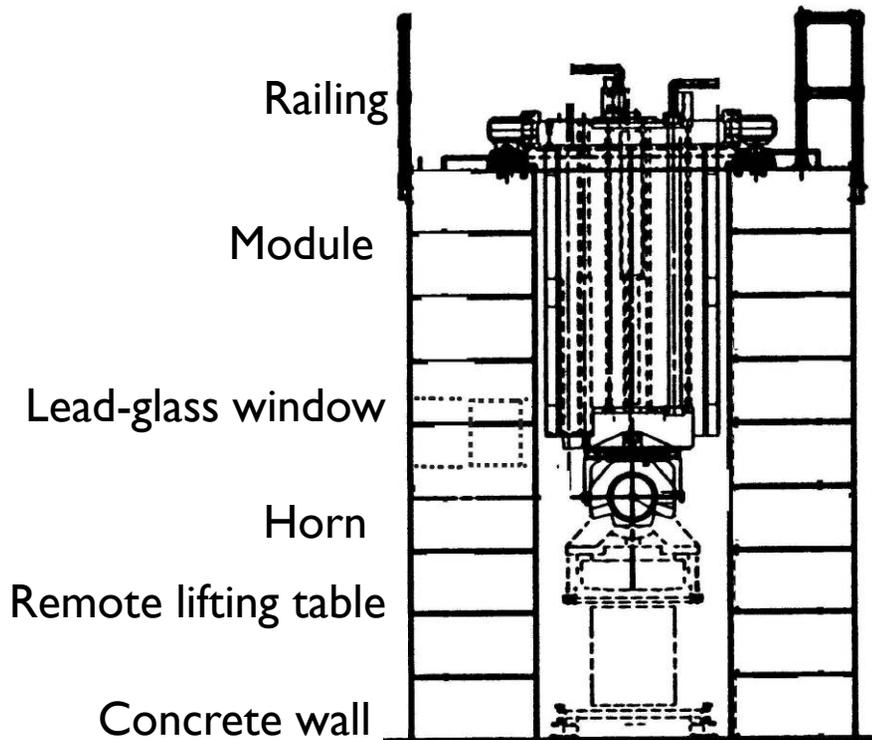
Repair people got weekly dose limit in seconds although the work was well planned and optimized with several dry runs.

→ Repair would have been impossible without a work-cell

# NuMI Work-Cell

Connections done through module by person on top of work cell

Shown during test-assembly above ground



# Tritium

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First seen at NuMI - Tritium levels were greater than expected in water pumped from NuMI tunnel. Measured up to ~30 pCi/ml in Nov. 2005

FYI - surface water limit in the US is 2000 pCi/ml and drinking water limit is 20 pCi/ml.

Task Force established and mitigation implemented

- ▶ condensate from an air conditioning unit in the target area was collected and disposed separately.
- ▶ Installation of two dehumidification systems. One for target hall and one for target chase air. They prevent tritiated humidity from passing through the decay hall and mixing with the tunnel water
- ▶ These measure reduce the amount of tritium that otherwise could reach the Fermilab surface waters by about a factor of seven.

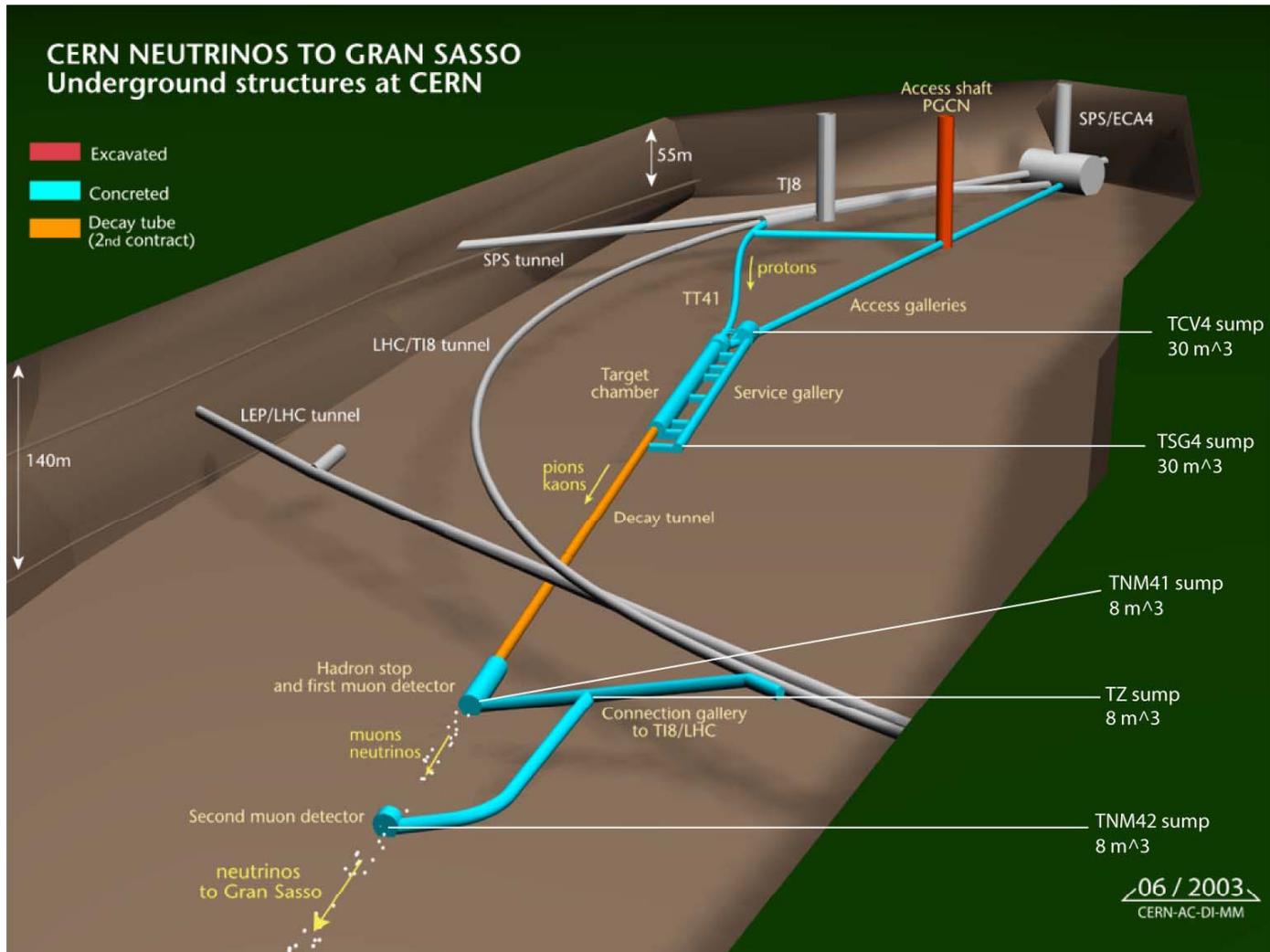
In addition, Fermilab started an investigation together with help from the Lawrence Berkeley National Laboratory (LBNL) to understand the tritium origin and transport

**Progress Report: Mobility of Tritium in Engineered and Earth Materials at the NuMI Facility, Fermilab - LBNL-61798**

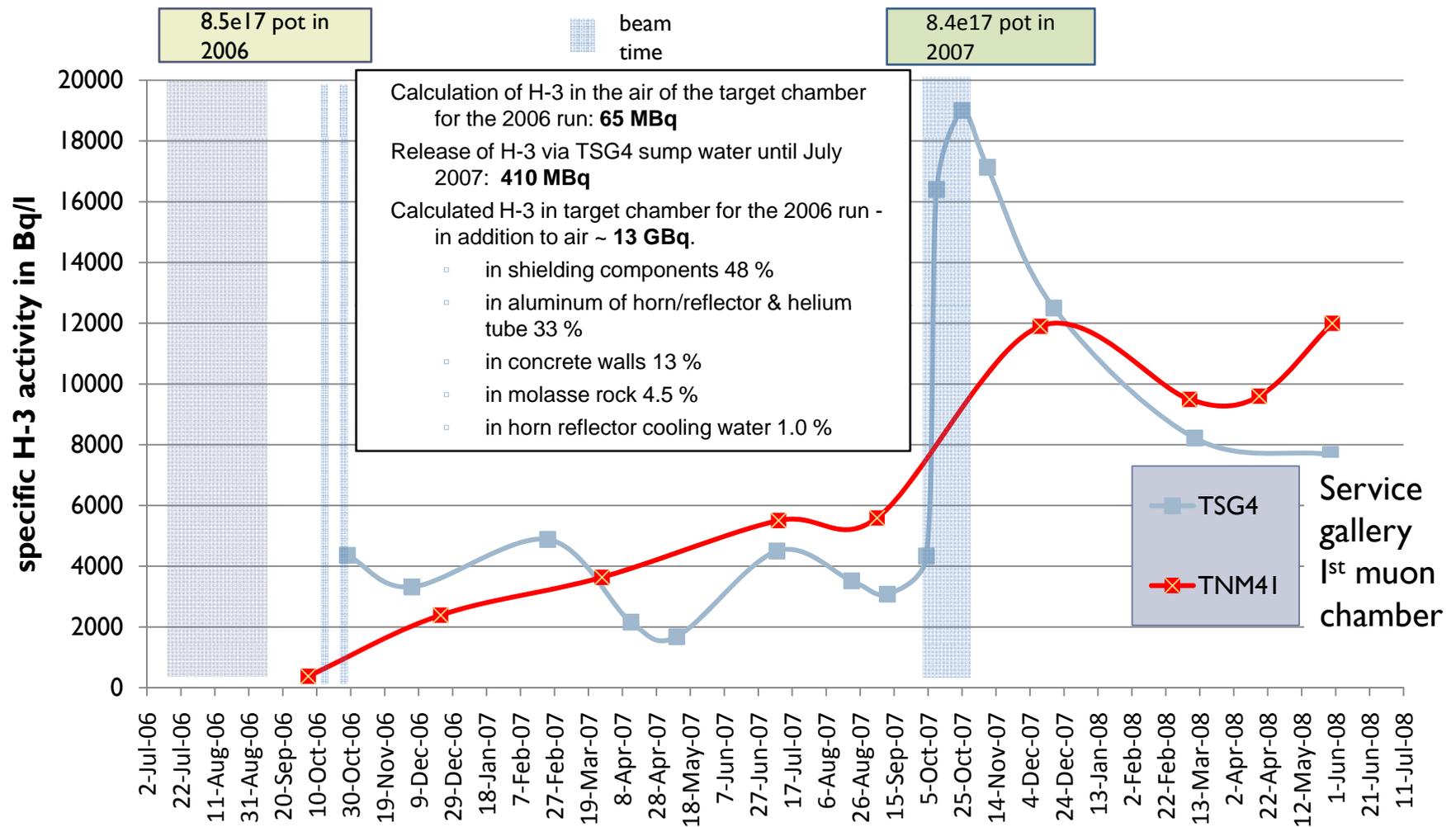
# Major findings from the report

- “..... movement of tritium through the facility is **dominated by vapor transport**”.
- “**In addition to the tritium directly produced** in the humid air during beamline operation, tritium is expected to enter the airstream by **diffusion of tritium produced in the shielding materials** close to the Target Pile and absorber.”
- “**Production of tritium in the concrete** and fractured rock along the Decay Pipe may provide **another source** of tritium that **is slowly released** by diffusive processes.”
- “**Once in the air phase**, tritiated vapor is transported by the ventilation system to other parts of the facility, where it **may condense, diffuse into the concrete and rock**, and—if conditions change—**diffuse back** from these materials. These transport, exchange, and phase partitioning processes explain why high tritium concentrations persist even when the beam is shut off.”
- “**Increased concentrations** of other radionuclides produced at the NuMI facility, such as **Na-22**, could also have a significant environmental impact; therefore, in addition to tritium, **transport of these radionuclides should be investigated.**”

# At CNGS similar findings



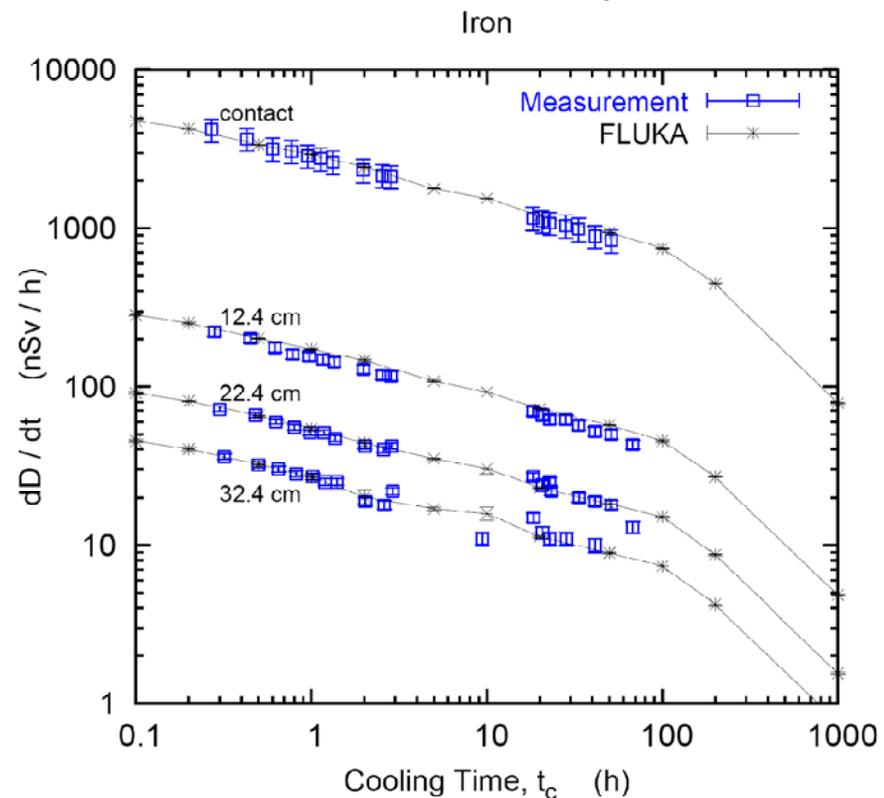
# Tritium in CNGS sumps



# Predictive 'power' of Monte Carlo particle transport codes

- ▶ Whereas the predication of prompt dose rates was rather good in the past also the estimates of induced dose rate is now a days remarkable
- ▶ Monte-Carlo Programs can predict residual dose rates and specific radioactivity (for most of the isotopes) within 20-30 % of errors. This allows much better design studies, optimizing of maintenance and repair work and better studies of waste management.
- ▶ However, chemical composition of components must be known - sometimes to trace element level.
- ▶ Do not design to regulatory RP limits, always keep a safety factor

Dose rate as function of cooling time for different distances between sample and detector



Reference: M. Brugger *et al.*, Radiat. Prot. Dosim. 116 (2005) 12-15

# Thank you

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