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Radiation Protection Lessons - Experiences with operating beams for neutrino experiments

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The high demand for more intense neutrino beams is closely related to an increase of the production of radioactive isotopes in target caverns, decay tunnels and hadron stop areas. This paper gives a (short) summary of radiation protection lessons learned from the past CERN neutrino facility WANF and also from presently operating facilities like NuMI or CNGS.

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1. Introduction

Accelerator driven neutrino beam operation has always been a big challenge not only for the reliability of components but also for radiation protection issues. The demands for higher beam power and intensity but also a tightening of annual dose limits are difficult to combine. However, careful design of high power neutrino facilities together with thoroughly optimizing of maintenance or repair work have shown significant improvements of existing neutrino facilities compared to past ones. This paper gives a (short) overview of problems which existed at a previous neutrino facility at CERN, describes the changes which have been adapted for the new facility and finally reports on lessons learned from existing installations at CERN and Fermilab.

2. Neutrino studies at CERN

Operation of high intensive proton beams in order to produce neutrinos has a long history at CERN. Neutrino physics started at CERN in 1963 using particles from the Proton Synchrotron (PS). This PS neutrino program continued until 1977 and the highlight was the discovery of the weak neutral current in 1973. A new neutrino program was proposed in 1971 during the planning of the Super-Proton-Synchrotron (SPS) project. It was decided to build a new facility in the west area of CERN, the West Area Neutrino Facility WANF. This facility was used until the area was shut down in 2000. The beam line was operated at proton intensities of up to 3×10^{13} protons per pulse (450 GeV). In order to continue neutrino physics at CERN, the CNGS facility (CERN Neutrinos to Gran Sasso) was proposed. CNGS was approved in 1999 and started beam operation in 2006 (up to 4.8×10^{13} protons per pulse, 400 GeV).

3. WANF vs. CNGS – improvements from a radiological point of view.

Although the beam intensities and energies used at both facilities were similar, three major differences between the WANF and CNGS facilities exist from the civil engineering point of view. All three changes significantly improved the radiological conditions for personnel but also for the environment. Whereas only little or no shielding (except around the target itself) was present at WANF, the whole CNGS secondary beam line from the target station down to the beginning of the decay tunnel is embedded in massive shielding (Figure 1 a-b). Particular emphasis was put into the choice of shielding material. Marble shielding blocks have been placed outside the iron target shielding and also around the horn. Induced activity in marble is known to be considerable lower than that in concrete. The CNGS shielding around the beam line components fulfils mainly three purposes. First it considerable reduces dose rates during maintenance or repair work inside the cavern, it reduces also the activation of air as the pathways of secondary particles are significantly shortened and also lowers the activation of the concrete tunnel walls. The last one is of special importance for de-commissioning of the facility in the future.

PoS(NuFact08)097

Figures 1 a-b: WANF (left) CNGS (right).

The second major improvement was the provision of a service side-gallery which gives access to the target chamber without exposing people to the most radioactive items in the chamber. This allows necessary equipment like pumps, cooling units, power supplies or cable trays to be installed in areas with much lower dose rates and activation and therefore significantly reduced radiation exposure during maintenance of these equipments. In addition, people making repairs on beam line components themselves can prepare the work in the service gallery and therefore minimizing the amount of time spent in the highest radiation environment. However, a future facility should not have straight connecting tunnels between the target cavern and the side-gallery but rather use a ‘three-leg’ design in order to reduce radiation streaming into the side-gallery.

The third improvement from the civil engineering viewpoint was the provision of a simple stub-tunnel as a storage area for radioactive items close to the target chamber. Consequently there is no need for long (time and distance) transport of highly radioactive components to a storage location somewhere on the surface.

Past experience from the WANF has early shown that significant dose will be received by personnel during exchange and transport of highly activated components like targets or horns. Therefore, remote handling of shielding blocks and remote exchange of faulty components is possible at CNGS. This even includes remote transport of an item into the storage area mentioned above. Cameras are installed onto the crane during such an intervention. The crane can be operated from a low radiation area upstream of the target cavern.

In addition, induced activity is monitored at CNGS by ten (fix installed) induced activity monitors (IAM). In order to allow a remotely controlled radiation measurement, a survey platform has been developed at CERN. This platform can be mounted onto the crane (equipped with cameras) and allows one to measure residual dose rates at nearly any location in the target chamber. Data from the detector are transmitted via a wireless connection to a laptop temporarily installed in a low radiation area upstream of the target cavern. Consequently, manual radiation surveys are rarely required and exposure of personnel during the survey to high radiation levels is therefore prevented.

More principal problems at WANF and the improvements for CNGS can be found in [1].

4. Lessons learned from CNGS, NuMI, MiniBooNE and K2K

Beam-induced ionization of air and therefore the production of aggressive radicals is still a major issue in existing target stations of neutrino beam facilities. These radicals create a nitric acid environment where corrosion poses a severe problem. Several examples underline this problem. MiniBooNE observed a reduction in neutrino flux which was traced back to failure of a steel chain supposed to hold a moveable absorber (heavy steel plates) out of the beamline. This problem was solved by using softer steel chains which are not subject to hydrogen embrittlement. NuMI has decided to fill Helium inside their decay pipe because they observed weakening of the decay pipe window (Aluminium 1/16 inch thick) due to corrosion. Especially for 'humid' environments like water cooled targets or horns failures are mostly related to corrosion and radiation damage. Effective air dehumidifiers are therefore essential. The T2K collaboration in Japan has even decided to house its target and horn completely inside a Helium environment.

The use of redundancy for delicate components like targets or water circuits for the cooling of horn/reflector or targets can increase the lifetime of components considerable. CNGS has installed a target magazine which contains 5 targets. In case of a failure of one target the magazine can be rotated remotely and bringing a new target into the beam line (Figure 2a). In case of a leak in the cooling circuit of the CNGS horn/reflector the circuit can easily be switched to the second circuit by moving a handle bar into the 'second' position (Figure 2b).

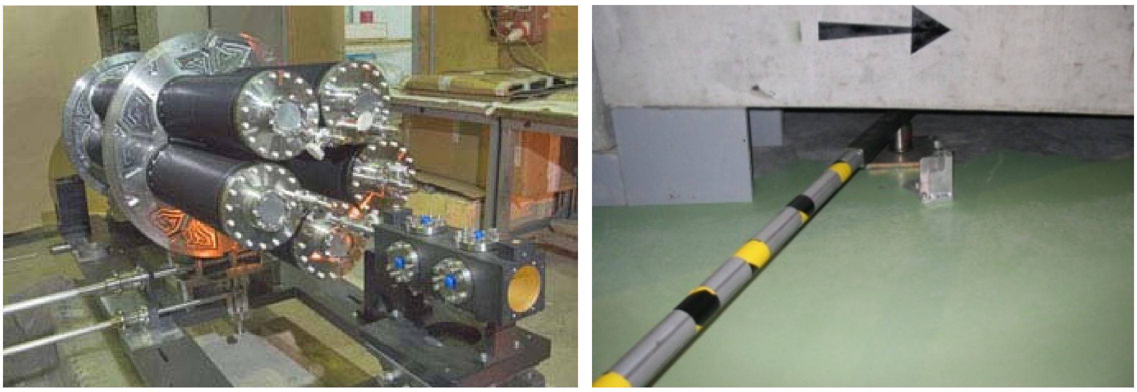

Figure 2 a-b: CNGS target magazine (left), switch of horn water cooling circuits (right).

Further, the correct choice of materials used inside high radiation areas is very important. For example, stainless steel should have no or very low content of cobalt. Experiences have shown that the dose rates (after longer cooling times) of irradiated stainless steel objects strongly depend on the amount of cobalt in the material. Similar conclusions can be made for concrete which should have a low content of sodium. Preferable would be to use marble shielding blocks instead of concrete. Although it is more expensive, the dose rate is significantly lower than that of activated concrete blocks.

Some general remarks can be given in case of necessary repair or exchange of faulty items. The exchange of highly activated objects should only be done remotely. Thus, the installation of a remote handling facility (simplest would be a crane) should be already planned during the design phase. Further, spare parts of sensitive equipment should be available. Repair of broken items can cause high doses to the repair team. Performing dry runs on (not activated) spare parts or mock-up models significantly improves a work procedure and therefore reduces the received doses. Work on highly activated objects should be performed in a shielded work cell. Future facilities in the MW power range will heavily rely on remote handling and the possibility to perform repair work in a well-shielded work cell which should be even equipped with a remotely controlled robotic arm.

Another lesson learned from existing high power target stations for neutrino production is the amount of tritium which was found in infiltration water close to the target cavern. At NuMI tritium content in water pumped out from the underground tunnels showed higher levels than expected. Two major modifications have been implemented: a) the condensate from an air conditioning unit in the target area was collected and disposed separately and b) two dehumidification systems were installed, one for target hall and one for target chase air. These prevent tritiated humidity from passing through the decay hall and mixing with the tunnel water. Finally, these measures reduced the amount of tritium by about a factor of seven that otherwise could reach the Fermilab surface waters. In addition, Fermilab started an investigation together with help from the Lawrence Berkeley National Laboratory (LBNL) to understand the tritium origin and transport [2]. Similar tritium issues were later also observed at CNGS.

5. Conclusions

Operation of high power target station of neutrino facilities poses a big challenge to keep dose rates minimal to which maintenance personnel could be exposed. Also induced activities in the structure of these facilities and its surroundings but also the magnitude of any release to the environment via air or water release have always to be as low as reasonably achievable. Existing facilities have shown that this is feasible providing careful design and optimized repair and maintenance procedures.

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