Fermilab-TM-2378

A summary of present Calculations on Tritium Production and Mobility in the NuMI Decay Pipe

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This document is a summary of our present (February 2007) understanding of the production and mobility of tritium in the NuMI decay pipe. The work summarized includes the calculation of tritium production performed by Byron Lundberg and the numerical simulation of tritium motion produced by consultants at LBNL. The calculations are available in the Projects Database[1]. The LBNL report[2] is available as TM-2379.

Introduction:

The issues of tritium production and motion in the NuMI facility can be considered in four parts. (For details of the geometry, refer to TM-2377)
In (approximate) order along the direction of the beam these are:

1. The tritium that enters the air-stream in the Target Chase. We assume that tritium in the air is in the form of HTO vapor. The tritium vapor created in the Target Chase follows at least three paths: (i) some of it is collected in the condensate of the chiller that is used to dry and cool the chase air; (ii) some of it leaks into the target hall where it is captured in the target hall desiccant and evaporated up a pipe known as SR3 : (iii) some of it - mechanism uncertain - passes into the drains below the decay-pipe. The tritium rates in the condensate and in the drains below the decay pipe are measured quite well and are the subject of a continuing study as efforts are made to mitigate tritium rates outside the target hall.
2. The tritium that is generated and contained in the iron and concrete shielding of the Target Chase. It is assumed that the target hall and chase will be dismantled and removed as part of the eventual decommissioning of the NuMI facility. The tritium stored in this concrete and iron is under study as it contributes to tritium in the air-stream in the Target Chase.
3. The tritium generated in the beam absorber at the end of the decay-pipe. It is assumed that the absorber will also be removed as part of the decommissioning. Some tritiated vapor is produced in the absorber enclosure and we mention here that mitigation measures are being considered to reduce the amount that enters the decay-pipe drains.
4. The tritium generated inside the concrete decay pipe and surrounding rock which accumulates and is partly released during beam operation. The study of this tritium is addressed here.

Tritium in the Decay-Pipe Concrete:

There are three questions of interest for the tritium in the decay pipe, corresponding to different stages of the NuMI facility life-cycle. One question is the amount and rate of release of tritium during the operation of the NuMI beam. When the facility is operating, the water flow is towards the NuMI tunnel, and the tritium which diffuses through the concrete will go into the drains beneath the decay pipe and be collected. The second question of interest is the rate of release and how the release rate evolves while the facility is maintained after the beam stops operating. Because the water flow continues to be inward, this release will continue to go to the drains and be collected. The third question is whether there will be any significant tritium release to be considered when the facility is decommissioned and the pumps are turned off allowing the facility to flood thus changing the flow of the surrounding water.

Inputs

There are four main ingredients required in calculating the amount and rate of release of tritium during the various stages of the life-cycle.

- a description of the motion of tritium through concrete and rock.
- the distribution of tritium formed in the decay-pipe per proton-on-target
- the external hydrostatic pressures
- a computer program capable of predicting the evolution of the tritium distributions based on the inputs for the tritium production, tritium mobility, the material geometry, and the hydrology.

We treat each of these in turn.

Mobility of Tritium in Concrete and Rock.

The mobility of tritium in concrete and rock is largely due to the presence and motion of water in the respective materials. Only the tritium in the water is considered mobile - the tritium formed in the solid aggregate is treated as immobile. Given the distance a spallation product travels (~mm), the concentration of tritium per unit volume in the water is the same as in the solid mass. The amount of water and its mobility depend significantly on the particular concrete and rock type. The porosity of the decay-pipe concrete is taken as 12% (this determines the amount of mobile tritium), the diffusion coefficient is taken 3.4×10^{-10} m^2/s and the permeability as 10^{-16} m^2, standard values for this concrete.

Production in the Decay Pipe Concrete

Lundberg has provided the distribution of tritium formed in the decay-pipe per proton-on-target[3] using the MARS[4] program. A detailed model of the NuMI target system, the target hall shielding and the decay pipe is used, and predictions are made for the generation of tritium as a function of distance (z) and radius (r) throughout the decay pipe. The model predicts a total of about 21 Ci formed in the decay pipe per 10^{20} protons on target.

The tritium density generated decreases along the beam pipe with a characteristic length of 200 meters; radially there are two components, one with a characteristic length of 12 cm into the concrete (from the decay pipe) and a second component with a characteristic length of 30 cm. The measured radioactivity of samples of the decay pipe taken 60 cm into the concrete (from its outer surface) is consistent with the prediction within a factor of 2, though it is recognized that this only tests the second component.

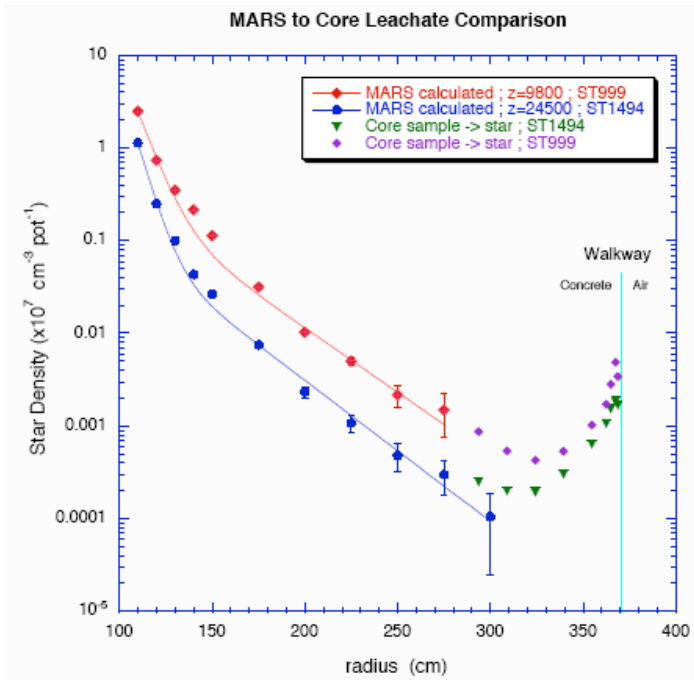

Figure 1 - the predicted distribution of tritium production in the decay-pipe concrete, and some measurements at two positions along the pipe (from Reference 3).

Hydrostatics and flows

The target-hall, the decay-pipe passage-ways, the drains and the MINOS detector hall are essentially at atmospheric pressure while the water in the surrounding rock is at a pressure determined by the depth below the water table taken as 690 ft. The resultant hydraulic pressure head and water flows are determined by the rock and concrete properties, and the geometry of the decay-pipe, the passage-way and the dimple-mat around the decay-pipe.

Computer Modeling

A two-dimensional model of a 60 m section of the NuMI decay-pipe and surrounding rock, averaging over `z', has been made as a first step to gaining some insight into the motion of the tritium formed. The model divides the cylindrical region from 0 (center of the decay-pipe) < r < 15 meters into ~2000 pieces of different sizes to accommodate the range of flow rates and tritium intensities. In particular, the passage way modelling requires a rather fine subdivison. The model is capable of incorporating the production distribution of tritium, the hydrology, and the properties of the rock and

decay-pipe concrete to predict the resultant water flows and evolution of the tritium distribution. To indicate the power of the technique, Figure 2 shows the grid used to describe the decay-pipe and surrounding rock. Figure 3 shows the resulting hydraulic pressure and water flows and Figure 4 shows the evolution of the tritium distribution in the concrete 1 year and 5 years after exposure.

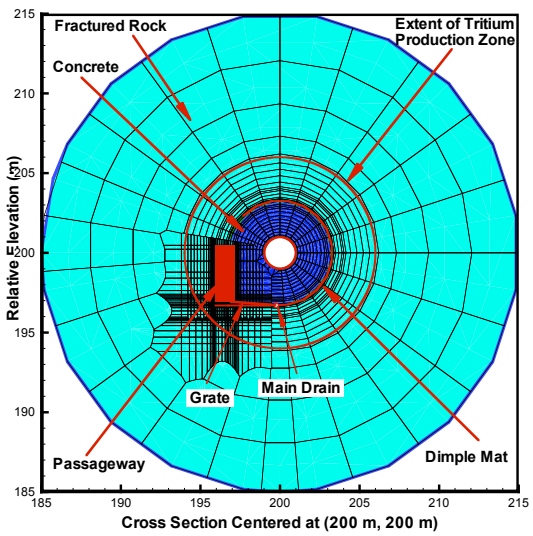

Figure 2: The grid used in the model. The grid is dense by the walkway to be able to model tritiated vapor in this region.

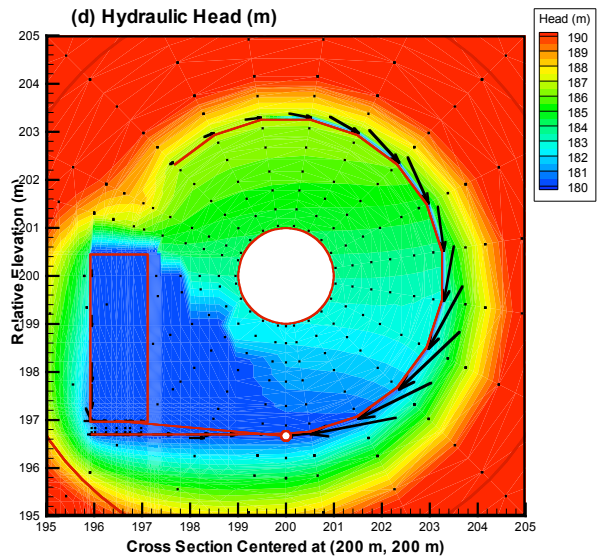

Figure 3: The hydraulic pressure head and resultant flow velocities

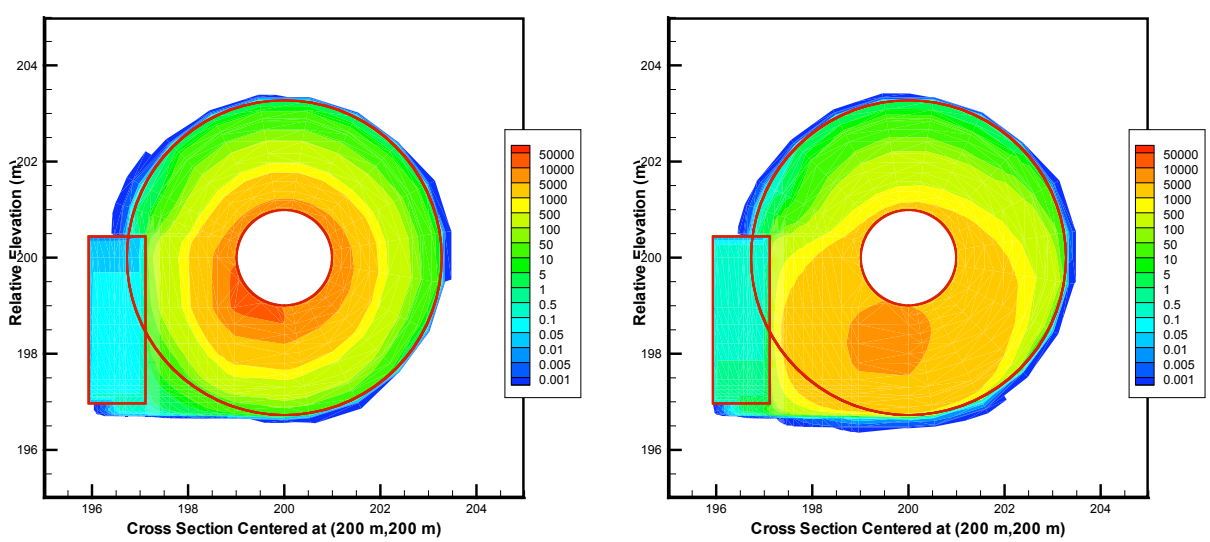

Figure 4 The distributions of tritium in the decay pipe, 1 year (left) and 5 years (right) after an exposure of 1.4×10^{20} protons on target - from reference 2.

A quantity of particular interest is the tritium concentration from the release of tritium from the decay-pipe and the surrounding rock in the drain that runs the full length below the decay-pipe. This has been calculated for the

first 60 meter section of pipe and is shown in figure 5 for the rock and the decay-pipe separately.

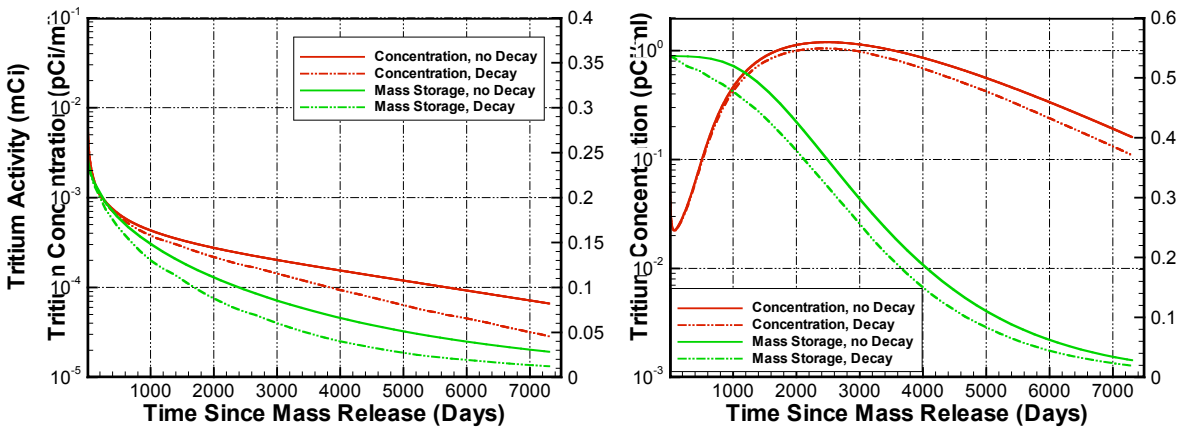

Figure 5 Tritium release to the drains and remaining in the rock (left) & decay-pipe (right) as a function of time after exposure of 1.4 $\times 10^{20}$ protons. The dashed lines incorporate the effect of the tritium decay. The values here have an uncertainty of +/- 50%.

As evident from the plots, the decay-pipe is a much more significant source than the rock, and its release peaks about 2500 days (6.8 years) after exposure. The maximum concentration in the drain from this section of pipe is about 1 pCi/ml; since the water flow that dilutes the tritium is roughly constant along the entire pipe and the dose decreases with distance along the pipe, we expect the concentration calculated for the whole pipe to give a similar or lower number[1].

Summary

Calculations for the production of tritium in the NuMI decay pipe predict a production of ~20 Ci/10^{20} protons on target. Comparison of core samples from the outer parts of the concrete shielding match the predictions within a factor of 2; this does not, however, test the prediction in the region of highest tritium density near the beam-pipe, and it may be useful to obtain samples from nearer the decay-pipe. It is not presently known what would happen to the release rates nor where the tritium would appear if the NuMI pumps are turned off.

The 2 dimensional computer model incorporating the local hydrology and concrete-properties, and the tritium production distribution, predicts a peak tritium release to the drains of ~ 1 pCi/ml 6.8 years after an exposure of 1.4 $\times 10^{20}$ protons on target. Extrapolating this to a NOvA run of 60 $\times 10^{20}$ implies a peak level of 50 pCi/ml in the drains about 4 years after the exposure.

References:

[1] http://projects-docdb.fnal.gov:/cgi-bin/Document Database/
[2] `Mobility of Tritium in Engineered and Earth Materials at the NuMI Facility, Fermilab', report by S. Finsterle et al., Earth Sciences Division, LBNL, Fermilab TM-2379
[3] Lundberg, B. `Tritiated Water in the Decay Region: Model Comparisons to Data', Docdb 136-v3, 12/10/2006
[4] N.V. Mokhov, "The Mars Code System User's Guide", Fermilab-FN-628 (1995);
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