Radiation Protection and Licensing

K. Vaziri,
FNAL Radiation Physics Team

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High Power Targets and Machine/Detector Interface Working Group

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Contents:

Regulatory Requirements

In addition to the conventional safety regulations and permits here are some specific radiological regulation from Fermilab's contract:

- 10 CFR 1021 (DOE NEPA rules)
- 10 CFR 835 (Occupational radiation protection - applicable and enforceable portions

- 35 IAC (State of IL environmental regs - applicable and enforceable portions)
- 40 CFR (Federal environmental regs - applicable and federally-enforceable portions)
- 49 CFR Transportation (Hazardous material Onsite & Offsite applicable portions)

- Atomic Energy Act of 1954 [amended], 42 USC 2011 et seq.
- Clean Air Act Amendments 1990, 42 USC 7401 et seq., and Illinois State Implementation Plan, 40 CFR 52 Subpart O
- Clean Water Act, 33 USC 1251 et seq.
- DOE Order 420.2B Safety of Accelerator Facilities
- DOE Order 458.1 Radiation Protection for the Public and Environment (100 mrem)
- DOE-STD-1196-2011 (April 2011)Derived Concentration standards Table and dose limits to the public

Need permit for radioactive air emissions, discharge to surface waters, ground water and sanitary sewers.

Regulatory standards can only get tighter: In design, practice As Low As <u>Reasonably</u> Achievable (ALARA).

Shielding for Prompt Radiation

Protect against dose to public and workers (and equipment)

- Direct and sky-shine
- Indirect,
  - surface and groundwater
  - Air emissions
  - Radio-activated material
  - Biota

Shielding against:

- Charged hadrons
- Neutral hadrons
- Secondary Muons
- Secondary Neutrinos!

Shielding material:

- Concretes, soil and marble
- Steel
- Polyethylene and borated polyethylene
- ~~Tungsten, lead and DP~~
- exotic mixtures; poly-concrete and poly-tungsten…

Trace Impurities: carbon, sodium, copper, nickel, chemically toxic

Shielding for Residual Radiation

- Very high radioactivation levels (modularize as much as possible)
- Mostly gamma emitters (after a few minutes)
- Marble effective for shielding residuals in place.
- High density material for shielding saves space, but not weight; shield boxes used for transport weigh many tons.
- Weight considerations may lead to nested coffins or plans for local storage.
- Need shielded repair cells
- Need remote handling capability
- Problems during lifting and moving are difficult to handle.
- Both short term and long term storage should be considered carefully and designed sufficiently.
- Disposal of highly activated objects is very costly! (waste volume reduction)

D&D have to be thought up at design stage, don't want to leave an expensive environmental problem behind.

Handling activated air

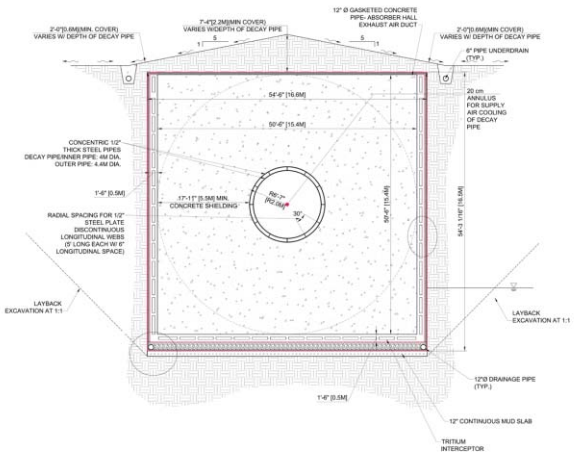
- Characterization and monitoring needed for prompt dose to workers and offsite release.
- Required to account for all air releases.
- NESHAP requirements
- For workers implement:
  - Real time monitoring
  - Implement cooling period (delay&ventilation)
- Release of activated air:
  1. Immediate release/almost no decay
  2. Decay in transit to release point
  3. Trap and contain to decay out

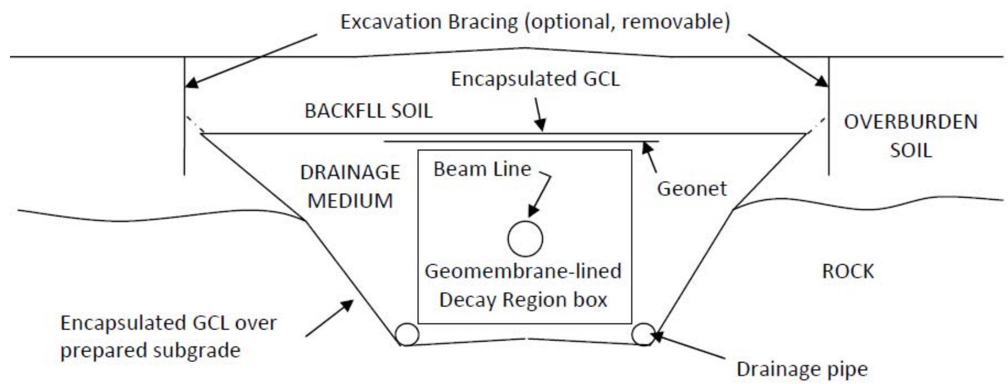
Tritium (and other radioactive contaminants)

- H-3 is produced in air, shielding, outside shielding and in the cooling systems.
- Readily exchanges with hydrogen in H_2O to form tritiated water, HTO.
- Ground and surface water protection.
  - Shielding
  - Isolation (diffusion and advection)
  - Containment (lifetime buildup in shielding and cooling loops)
  - Disposal (at above surface levels concentrations.)
- For groundwater need to know the hydrogeology of the location.

R&D of Ground-water Protection Methods

1) e.g. Geo-membranes for LBNE





- Material properties
- Life time
- Radiation damage studies
- Alternative material
- Collective knowledge

(e.g. liners used in nuclear power industry?)

Radioactive component storage

Need sufficiently shielded and contained:

- Short term (cool down for repair, transportation or later use)
- Long term (cool down for repair, disposal or future use)
- Containment (toxic, highly radioactive, Contaminated)
- Protection in storage considerations:
  - environmental
    - primary contamination
      - hot particles
    - Secondary due to natural erosion

Repair and Replace Philosophy

- Install&forget: expensive and nature is never that kind.

- Replace:
    - have to have spares to save down time
    - or if economically possible or repair is not possible.

- Repair considerations:
    - Assess hazards, develop shielding and specialized tools.
    - Repair time, cost and dose to workers needs to be optimized.

Repair Cell and Remote Handling capabilities

Requirements:

- Need area with crane coverage and work cell with sufficient space and shielding
- Shielded cell with through-the-wall manipulators
- lead glass shield window(s)/TV cameras
- shield plugs in ceiling for long-reach-tool access
- Area to separate components from modules to connect new components to "hot" modules, survey, and adjust alignment
- Remote Handling systems shall be integrated into the infrastructure of the complex
- Contamination controls

Component replacement:

- Module with component removed and placed into hot storage remotely for cool down period or next scheduled outage.
- Module with component attached taken from hot storage and placed remotely into a shield cask.

- Waste volume reduction

Layout area to provide most efficient component handling

Alignment and Stability

For high intensity beam-lines are designed

- To minimize beam loss
- To protect devices
- Shielding design may depend on maximum credible beam loss
- At high intensities, where the beam has a long lever arm (neutrinos 1200 km away), misalignment will cost beam time.

- Need relatively easy realignment capability.
- Need real-time alignment verification (BLM etc.)
- For devices that get highly radioactive, best to built self-alignment into the system as much as possible (alignment pins etc.)

Radioactive off-gas (especially for liquid metal targets)

- All targets, solid, liquid or gas, down to He, interacting with HE proton beam produce H, D, T. More Isotopes if higher mass.
- Hydrogen isotopes in target containers can cause explosion.
- Cooling systems, exposed to beam, also release hydrogen.
- Chemically toxic targets, specially liquid, at high power beam facilities require elaborate (expensive) containment, circulation, cooling, handling, repair and disposal facilities, plans and procedures.
- Extensive knowledge of physical and chemical properties of the target material needs to be learned, some through R&D.

Example of SNS mercury target next.

SNS Liquid Hg Target

1. Mercury Containment requirements

   No leaks outside the hot cell. Inside the cell, leaks are assumed.

2. Hot Cell / Remote Handling

   All mercury target and components must be contained, maintained, and packaged for off-site disposal inside hot cell.

3. Ventilation / Filtration

   Mercury vapor must be removed from the cell exhaust prior to subsequent conventional particulate filtration (HEPA).

4. Waste Handling

   All hot cell and ventilation system waste will be mercury contaminated. Activated mercury contaminated waste must be fully contained. Disposal options of SNS mercury "mixed waste" are VERY limited.

5. Water Cooling System

   The SNS process mercury is cooled with a secondary water cooling system.

6. Mercury Target Safety Considerations

   Accelerator safety order requires hazard and accident analyses to ensure workers, the public, and the environment are protected against hazards such as mercury toxicity and radioactivity.

Further Practices and R&D

- Sampling of shielding materials around existing facilities to develop/validate tritium transport models (e.g. coring of decay pipe concrete in NuMI)
- Analyze residuals activity for the radioisotope composition.
- Study to measure composition of target hall air (radio-chemical analysis) and relate to various parameters (humidity, beam intensity...)
- Validation/benchmarking of simulation specific to the facility.
- Build sampling elements into your experiment.

Use of Monte Carlo Simulation Codes

For prompt dose and residual activity Monte Carlo codes Need:

- Exact composition of material
- Exact geometry

- Excitation function for all elements, for all secondary and primary particles and for all reaction channels! (slows down the simulations)
- Decay chains for all radioactive species! (slows down the simulations)

(Target depletion, swelling, beam induced thermo-mechanical and dynamic effects such as diffusion of radionuclides in material are not in the existing Monte Carlo codes. These effects have to be taken into account separately)

Conclusion

1. Need to measure G-number for the formation of various caustic chemicals (e.g. nitrides & ozone) in air as a function of temp., humidity & pressure.
2. Not all nuclear reactions measurements data needed for Monte Carlo simulations exist. Some are calculated theoretically.
3. Need radiation damage data to fine tune simulation codes. Extant data rather old and not complete.
4. Need diffusion coefficients for H,d,T, He-3, He-4 in metals and other common shielding materials.
5. Need data on the mobility of Na-22 and Be-7 in air and on surfaces
6. Study of radio-chemical implications (including off-gasses) of possible liquid metal targets/cooling (Hg, LBE, Lithium)
7. Need quantifiable radiation induced corrosion data.