Irradiation Facilities in the US

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Types of Radiation Damage

1. Total Ionizing Dose
   - CMOS Electronics (to ~1 Grad)
   - Materials
2. Single Event Effects
   - Primarily Digital Electronics
3. Total Hadronic Dose
   - Crystals, including silicon (to ~1E16/cm^2)
   - Bipolar transistors

Total Ionizing Dose (TID)

- Caused by charged particles or photons.
- Testing with photons or [low energy] electrons is preferred because material is not activated (can also use protons with KE < ~3 MeV).
- Best US option = Sandia Gamma Irradiation Facility (^{60}Co = 1 MeV γs).
- Alternatives = Other sources (universities, BNL,…) or X-rays (can be integrated w/probe station; this is how CERN tests electronics).

Sandia Gamma Irradiation Facility

- Building holds 3 shielded "cells" in high bay area.
- 18 foot deep pool of deionized water located under most of high bay area.
  - Acts as shielding for arrays of ^{60}Co.
  - Facility houses ~0.5MCi of ^{60}Co.
    - Purchased from Nordion (Chalk River, Ontario).
    - $^{59}Co + n \rightarrow {}^{60}Co$
    - $^{60}Co \rightarrow {}^{60}Ni + e^- +$ antineutrino + 2 γs (1.17 & 1.33 MeV), 5.27 year halflife.
  - Not high enough energy to activate materials.
  - Dose rate at GIF up to ~5 Mrad/hr (1 Grad in ~10 days)
  - 7-10 minute wait after irradiation to allow ozone to be exhausted.
- Inside "Technical Area V"
  - No personal cameras allowed.
  - Escort required at all times.
  - Must be US Citizen?
- Fermilab has an open PO.
  - Cost for 1 Grad < $10k.
  - Can either do tests in person or send material for exposure.

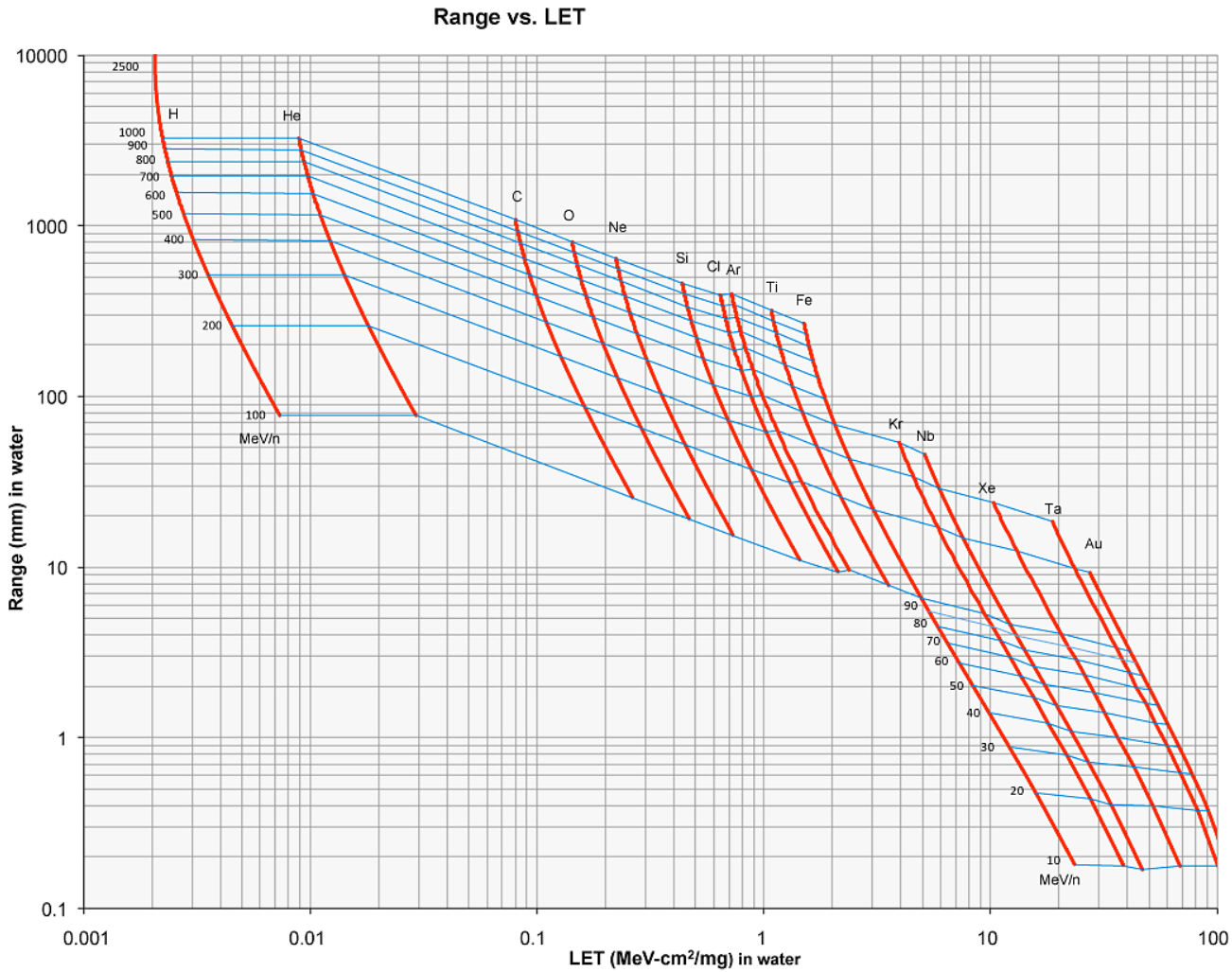
Single Event Effects

- Caused by locally heavy ionization.
  - Hadrons w/KE>Coulomb barrier & neutrons interact w/silicon (germanium) & create recoil nuclei or nuclear fragments; can produce large dE/dx in a "sensitive volume."
  - Can produce single event upset (bit flip), single event failure (gate rupture), or circuit disruption (latch-up).
- Best testing uses ion beams to determine cross section as a function of Linear Energy Transfer (LET).
- Best US Option = BNL NASA Space Radiation Laboratory.
- Alternatives: spallation neutrons, reactor neutrons, or protons can provide gross estimate of cross section.
  - We used 200 MeV protons from the Indiana University Cyclotron Facility (now shut down) in the past.

NASA Space Radiation Laboratory

- Uses beam from the BNL 2.5GeV Booster. Ions p – Au can be provided.
- Typically ~.3 sec slow spill every 4 sec. (7.5% duty factor).
- Up to 5E14 protons/hr, lower flux of ions.
- Beam spot ~1cm FWHM (1 GeV) up to ~20cm x 20cm.
- Dosimetry (2-3%) & beam monitoring provided.
- Facility funded by NASA.
- Cost ~$5000/hr for non-NASA users. Don't yet have a contract or user experience. I guess a well-designed SEE test would use 5-15 hrs. of beam time.
- Web site says, "NSRL operates 1,000–1,200 hours per year in three running cycles — typically early spring, early summer and autumn periods." Might be able to get beam outside these times as a non-NASA paying customer.

Facility covers >4 orders of magnitude in LET



Total Hadronic Dose

- Hadronic interactions create crystal defects (primarily vacancies and interstitials).
  - In silicon, these are sources of leakage current.
  - They can also trap mobile charges.
    - Reduces effective signal.
    - Modifies electric field (double junction effect in silicon).
  - Relevant dose for HL-LHC = up to ~1E16/cm^2.
- Currently no great US option (IUCF is closed).
  - Some have used medical accelerators (Mass General).
  - UNM has facilitated use of the LANL 800 MeV LINAC 2x/yr.
  - It would be possible to create a facility at Fermilab.

LANSCE = Los Alamos Neutron Science Center

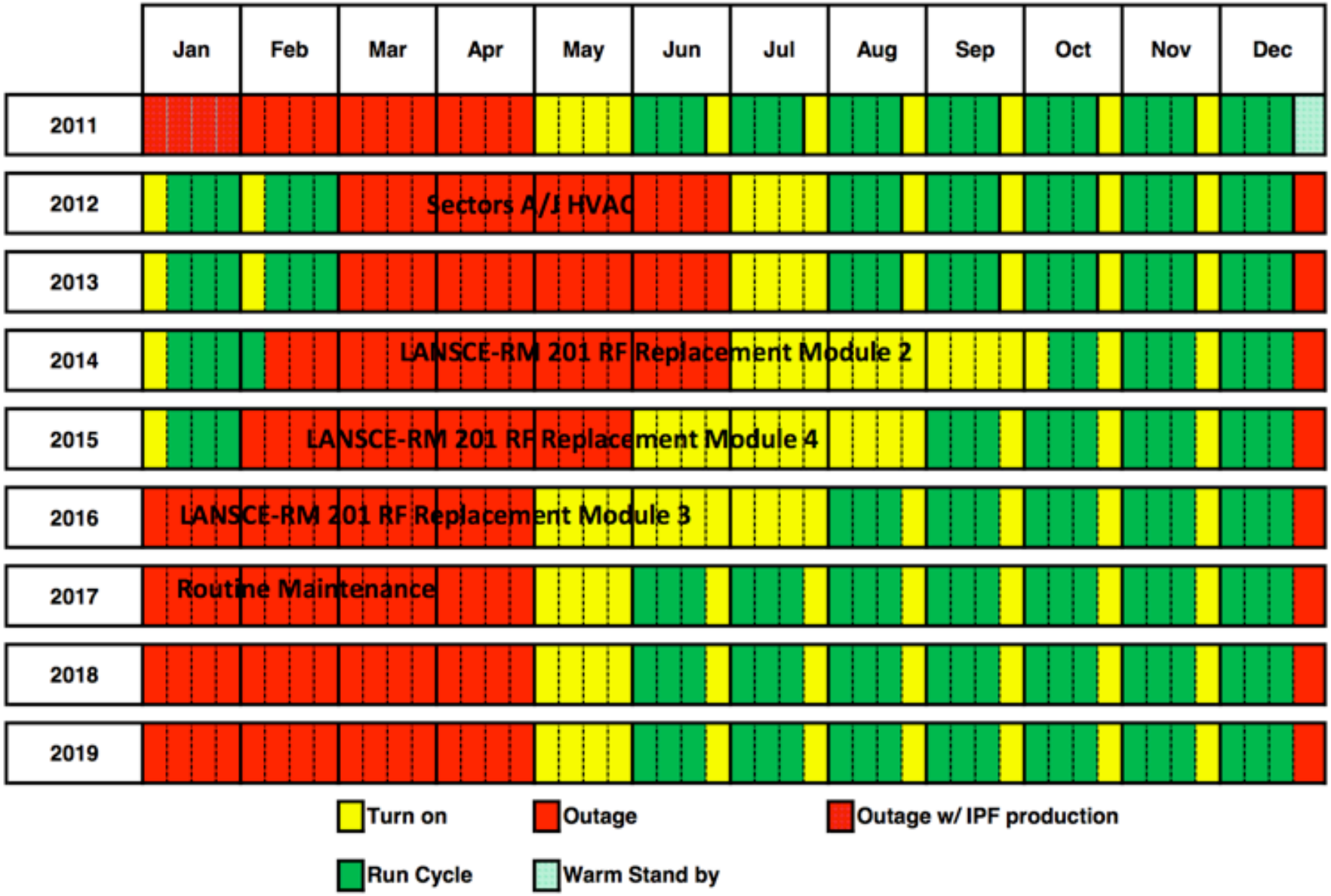
- 800 MeV LINAC accelerates H^- and H^+ (can be interleaved).
- Primary users:
  - Proton radiography
  - Lujan Neutron Scattering Center
  - Weapons Neutron Research
  - Ultra-cold Neutron Facility
- Accepts proposals annually
- LANL provides no beam instrumentation for radiation damage users.

UNM Facilitates use of LANSCE

- UNM HEP group has facilitated the use of LANSCE since 2007 (and also has an agreement with Sandia for use of the GIF & neutron sources).
- See presentation by Sally Seidel in January 2013 (ANL CPAD meeting): https://indico.fnal.gov/sessionDisplay.py?sessionId=4&confId=6050#20130110.
- Sally collects requests for beam exposure, writes, and submits a proposal to LANL annually. UNM typically requests 2 exposures of 2E16/cm^2 (~72 hours each).
- UNM prepares a stack of samples together with foils to measure dose and a diode array to measure the beam profile (good to ~1E15/cm^2). Foil activation is measured by UNM HEP group.
- UNM HEP group staffs shifts at LANL and encourages collaborators to take shifts also.
- No charge for beam time at LANL or use of facilities at Sandia.
- 2015 exposures are scheduled for September & December.

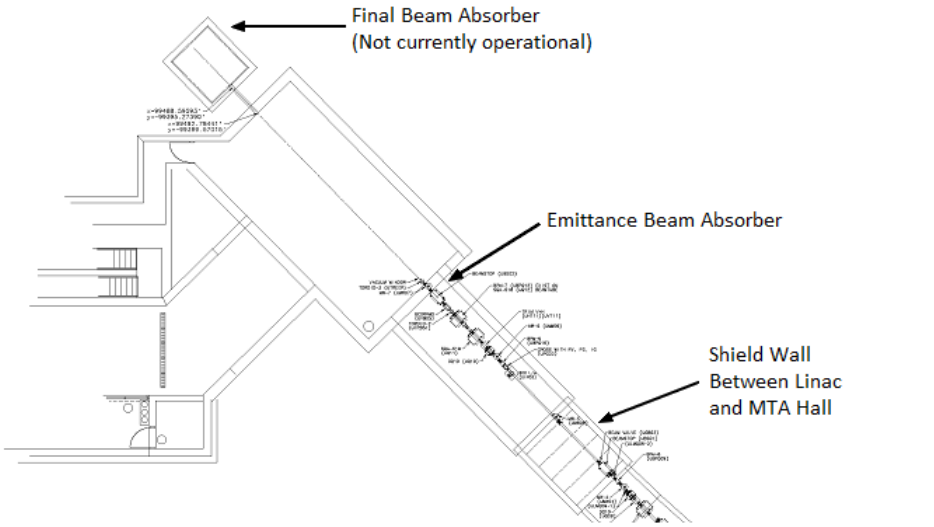
LANSCE Run Schedule During Risk Mitigation Project

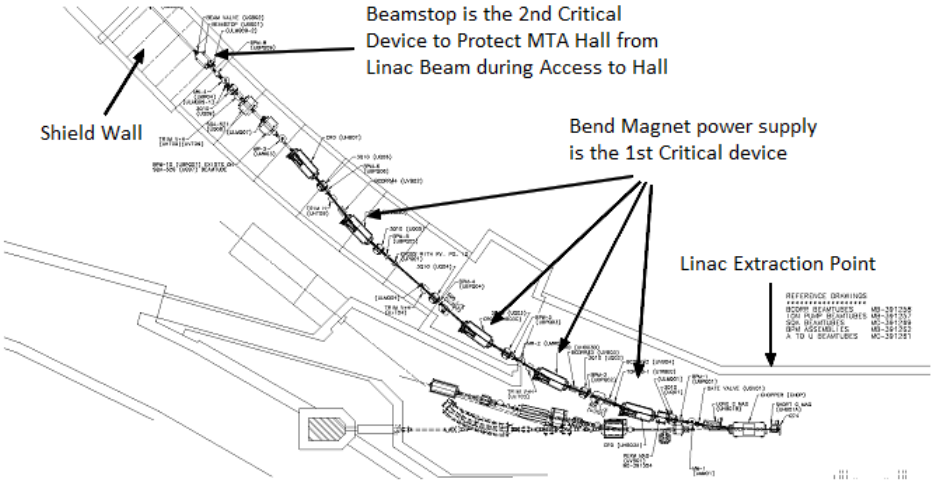
30-Jul-14



Possible Fermilab Facility

- MuCool Test Area (MTA) built to support R&D on muon cooling technologies (large cryogenic RF cavities, 5T superconducting magnet, LH2).
- Uses 400 MeV beam from the LINAC.
- Will operate as MTA through April 2016.
- LINAC group uses upstream area to measure LINAC parameters.
- Continued operation for accelerator R&D after 4/16 is anticipated.


Final Beam Absorber
(Not currently operational)
Emittance Beam Absorber
Shield Wall
Between Linac
and MTA Hall


Beamstop is the 2nd Critical
Device to Protect MTA Hall from
Linac Beam during Access to Hall
Shield Wall
Bend Magnet power supply
is the 1st Critical device
Linac Extraction Point

Compatibility

- MTA areas are sufficiently shielded to allow very high dose exposures.
  - 9.6E15/hr (600 pulses) upstream.
  - 9.6E14/hr (60 pulses) downstream.
- However, no area currently exists where devices can be irradiated without activating devices throughout the area.
- I believe we, working together with AD/APC, could establish a radiation test area that could be used with minimal impact on accelerator R&D.
  - Should we further explore this possibility?