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High Power Operations at the Low Energy Demonstration Accelerator (LEDA)

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Introduction-

Recently, the Low-Energy Demonstration Accelerator (LEDA) portion of the Accelerator Production of Tritium (APT) project reached its 100-mA, 8-hr continuous wave (CW) beam operation milestone. The LEDA accelerator (Fig. 1) is a prototype of the low-energy front-end of the linear accelerator (linac) that would have been used in an APT plant. LEDA consists of a 75-keV proton injector, 6.7-MeV, 350-MHz CW radio-frequency quadrupole (RFQ) with associated high-power and low-level RF systems, a short high-energy beam transport (HEBT) and high-power (670-kW CW) beam dump[a]. Details of the LEDA design features will be discussed along with the operational health physics experiences that occurred during the LEDA commissioning phase.

Design Features-

The LEDA injector was developed and refined over a number of years, capitalizing most significantly on the development of the microwave powered ion source from Chalk River Laboratories. During tuneup and commissioning, it was convenient to operate with variable current levels and differing values of duty factor. A high-voltage current modulator allowed completely arbitrary pulse lengths and duty factors, with concise transitions. The injector has achieved a sustained high-current, stable operation with well over 140 mA extracted from the ion source, coupled with high power and gas efficiency, and a most-impressive proton fraction (90%). Simple restart algorithms allow the computer control system to perform fully automatic and rapid recoveries from the majority of the infrequent beam faults.

LEDA's 350 MHz RFQ (Fig. 2) is one of the first implementations of a fully brazed, all-copper structure. The RFQ serves three functions:

- It provides the critical containment and transverse focusing of the low-energy proton, beam,
- It converts the continuous direct current beam from the injector into well-defined ion bunches with a frequency of 350 MHz,
- It accelerates the 75 keV input beam to a focused output beam of 6.7 MeV. Using specially contoured quadrupole vanes to focus, bunch, and accelerate the beam.

Precise control of cooling water temperature is required to maintain RF resonance during operation and allows changing the balance among the four resonant segments to effect an optimum longitudinal field profile. The very soft copper structure dictates a rigid heavy-duty steel support structure to carry the weight of the RFQ. A special mechanically elaborate suspension system is used to isolate the weight (nearly 2300 kg) of the RF window and waveguide feed assembly from the RFQ body.

The HEBT is used to transport the beam to the beam stop. The primary components of the HEBT are electromagnet quadrupoles, a variety of beam diagnostics and magnets that spread the beam out on the beam stop.

The beam stop (Fig. 3) is a radical departure from conventional design, incorporating a small-diameter, integral water shield and very low trapped-air volume to enhance portability and shielding, and to ensure low air activation. The near-total absence of air in the internal high-neutron environment almost completely eliminates air activation. The beam stop uses a water-cooled nickel beam stop with a 'cone shaped' ogive geometry. MCNP based computer programs were used to aid in beam stop design by estimating neutron production and consequential activation and dose rates. A number of different instruments on the ogive beam stop were used to give ample warning prior to failure (by melting) of the beam stop vacuum wall. In addition, water level sensors were used to ensure the beam stop assembly is always fully filled with water for effective neutron shielding. The water-cooled beam stop was designed to be capable of accepting full beam power and to withstand the maximum beam power densities.

The systems have been integrated, verified and used extensively, to show overall feasibility of the LEDA concept and detailed design. The unique challenge with the LEDA beam has been the high beam power (0.67 MW) and extreme peak power densities (exceeding 10 MW/cm2), that demand precise steering and focus control, that has left little margin for beam losses[b].

In addition to the beam characterization and high-current demonstrations done last year, detailed measurements of the beam halo are currently being setup. One of the primary causes of a halo are due to beam mis-focus. Because of the potentially adverse effects of the generation of halo particles in intense proton beams, a clear understanding of the mechanisms that lead to halo formation for current and proposed high-intensity linacs has produced a need to study this effect. A beam halo experiment will displace the HEBT. A linear transport channel has been assembled with the appropriate diagnostics for measuring the expected small beam component in the halo as a function of beam parameters (Fig. 4). A 52 quad transport line is being constructed following the RFQ. The experiment is based on the use of an array of high-dynamic-range wire and beam scrapers to determine the halo and core profiles along the transport channel. A pulsed beam with a 20 μsec pulse length and a 10^{-4} duty factor will have to be achieved in order to facilitate the use of direct wire and scraper measurements of the beam profiles. The purpose of this experiment is to make a detailed comparison, for the first time, between the theoretical model of halo formation and beam profiles in a controlled manner [c].

Health Physics Experiences-

ESH-1 Operational Health Physics at LANSCE has completed a series of measurements to characterize and validate predicted dose rates and contamination levels included in the LEDA Safety Assessment Document (SAD) (d).

The following is an excerpt from the LEDA SAD: "The only radionuclide inventory of any significance will be the activation products in the beam stop. No radioactive material will be brought into the facility, and the activation of air, water, and other parts of the beam line will be negligible relative to the beam stop activation." LEDA uses a Ni-201 conical shaped ogive beam stop that is enclosed by a 30" water shield.

The calculated radionuclide inventory discussed in the LEDA SAD is minimal from a risk analysis point of view, but it is not negligible from an operational viewpoint. Large area swipes were taken inside the linac beam pipe. Gamma spectral analysis found V-48, Mn-54, Co-56, Co-57, and Zn-65 contamination inside the RFQ beam pipe. Appropriate radiological contamination controls have been implemented for linac maintenance activities.

There were also unanticipated elevated dose rates near the downstream end of the RFQ, at the intersection with the high-energy beam transport. The dose rates ranged from 1,000 mrem/h 12 hours after beam off, decaying down to about 150 mrem/h after 6 weeks. A portable HPGe detector was used to characterize the external RFQ nuclide makeup. The activation nuclides measured outside the RFQ appear to be similar to that found in the swipe sample, with exception of Fe-59 and Co-60. In both measurements, Co-56 was most dominant, relative to the other identified nuclides in both the swipe and external gamma spec analysis.

LEDA SAD Table 4-11 indicates that a significant level of tritium (2.6E6 pCi/l) will accumulate in the beam stop cooling water, during a 6-month continuous production period. Detectable levels of tritium were not measured in the beam stop cooling water or in the shielding water. It was noted that the LEDA production period was very different than the 6-month continuous period used in the SAD calculations. LEDA operated regularly during that last quarter of the 1999 and delivered a total of 21,335 mA-h of proton beam. LEDA SAD Table 4-3 lists the activation gamma dose rate from the beam stop after a 6-month continuous production period. The table indicates 6 mrem/h outside the side wall shield after a 1 day period of decay and 1 mrem/h after 7 days. Measurements taken by ESH-1 yielded a maximum dose rate of 3 mrem/h at contact on the outside of the water shield wall after a 5 day period of decay. These results are in generally good agreement between the calculated and measures dose rates only after the short-lived activation products decayed.

Six TLD dosimetry plants were placed around the LEDA accelerator boundary to monitor radiation levels in occupied areas (Fig. 5). The plants were exposed to 10,584 mA*h for a total of 136 hours, resulting in a 78 mA average beam current. The plants were placed around the LEDA tunnel perimeter for a period of approximately 1400 hours, and were retrieved after the beam was turned off, on April 17, 2000 (Table 1). The TLD plants were placed on polyethylene phantoms to simulate whole-body dose response.

An attempt was made to place the TLDs at locations in proximity to the SAD based points. Monte Carlo (MCNP) radiation transport calculations were performed as part of the SAD (Table 2). The MCNP model was based on LEDA phase one (6.7 MeV, 100 mA) operating parameters and anticipated tunnel geometry.

Table 1. The LEDA TLD plant data.

TLD Plant Location	Gamma (uSv h^{-1})	Neutron (uSv h^{-1})	Total Dose (uSv h^{-1})
East Waveguide Shaft	0	0	0
West Waveguide Shaft	0	1	1
LEDA Roof Access	2	9	11
East Rollup Door	3	56	59
West Rollup Door	0	10	10
MPF-365 Lobby	0	0	0

Table 2. The LEDA SAD calculated prompt dose rates.

Location	Calculated Prompt Dose Rate (uSv h^{-1})	Ratio Calculated / TLD
East Waveguide Shaft	20	undefined
West Waveguide Shaft	30	30
LEDA Roof Access	10	0.9
East Rollup Door	700	12
West Rollup Door	10	1

A comparison of the data indicated differences between the MCNP theoretical and TLD measured values. For the most part, the calculated and measured data were comparable at the low dose rates involved. However, the East Rollup Door comparison raises some level of questioning. The calculations are being reviewed for conformance to as-built drawings, as part of the feedback process.

In 1999, the number of individuals working at LEDA issued dosimetry badges ranged from 64 to 77. Approximately 10% of these individuals received measurable doses. The average dose recorded was 8.4 mrem, exclusively from neutron exposure. The maximum dose recorded was 19 mrem.

The beam halo experiment will modify the radiation beam spill pattern locations. A new series of measurements will be required to re-characterize beam spills and activation levels as a result of inserting beam scrapers and profile monitoring equipment in the beam line. The addition of halo magnets has resulted in placing the LEDA beam stop almost directly under the vertical opening in the linac tunnel which has been used for placing very large objects into the tunnel. Real-time neutron and gamma monitoring equipment will be positioned on the concrete roof -top to monitor radiation levels.

Conclusion-

The measured radiation levels at LEDA involved only a few surprises. The contamination levels found inside the beam pipe and the upgrade and maintenance activities at the end of the RFQ were the major operational health physics concerns. The LEDA dosimetry results indicated that adequate hp controls were in place and radiation doses were being maintained ALARA.

References

a Rybarcyk, L.J., Schneider, J.D.; Smith, H.V.; Young, L.M.; Schulze, M.E. 'LEDA Beam Operations Milestone and Observed Beam Transmission Characteristics', proceedings of the XX International Linac Conference 2000. Monterey, August 2000: TUD15.

b Schneider, J.D., & Sheffield, R.L. 'LEDA—A High-Power Test Bed of Innovation and Opportunity', proceedings of the XX International Linac Conference 2000. Monterey, August 2000: TUD13.

c Colestock, P.L.; Wangler, C.K.; Allen, R.L.; Sheffield, D.; Gilpatrick and the Diagnostics Group; Thuot, M. and the Controls Group; The LEDA Operations Team 'The Beam Halo Experiment at LEDA', proceedings of the XX International Linac Conference 2000. Monterey, August 2000: THB07.

d Tomei, T.; Heindel, G.; Seidel, D. '12 MeV Low-Energy Demonstration Accelerator (LEDA)' Safety Assessment Document (SAD), Los Alamos National Laboratory: APT-DOC-011, 1997.

Figure 1.
Low-Energy Demonstration Accelerator.

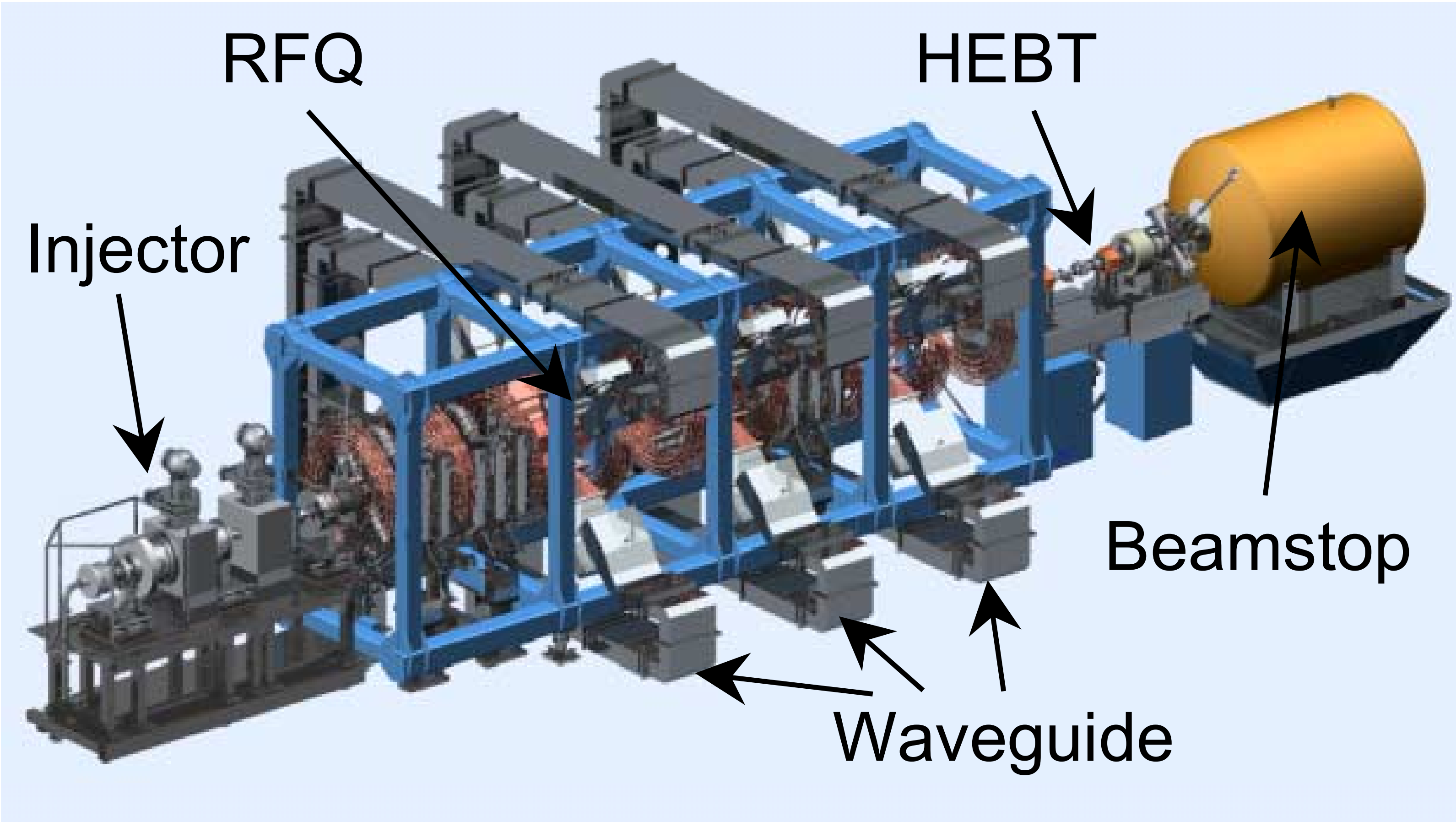

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Figure 2.

Leda's 350 MHz Radio-Frequency Quadrupole (RFQ).

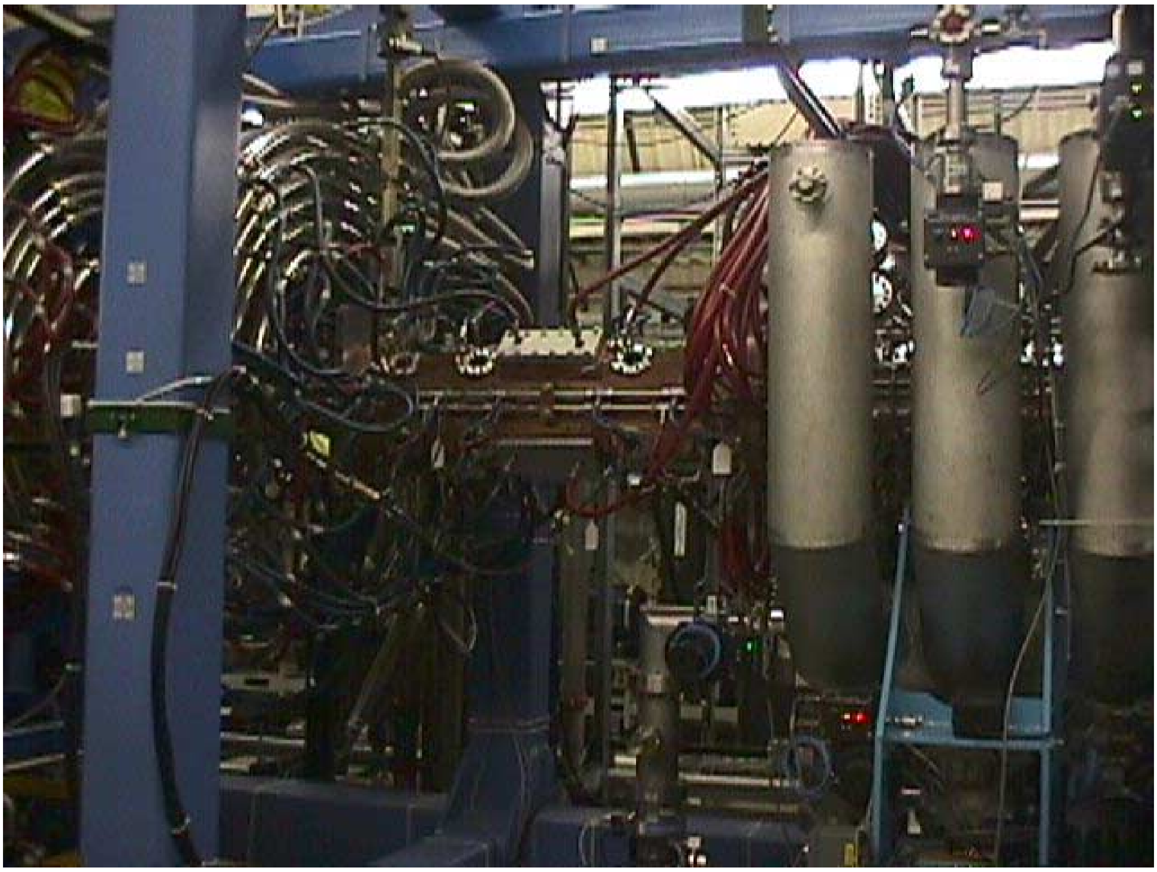

Figure 3.

LEDA water-cooled nickel beam stop.

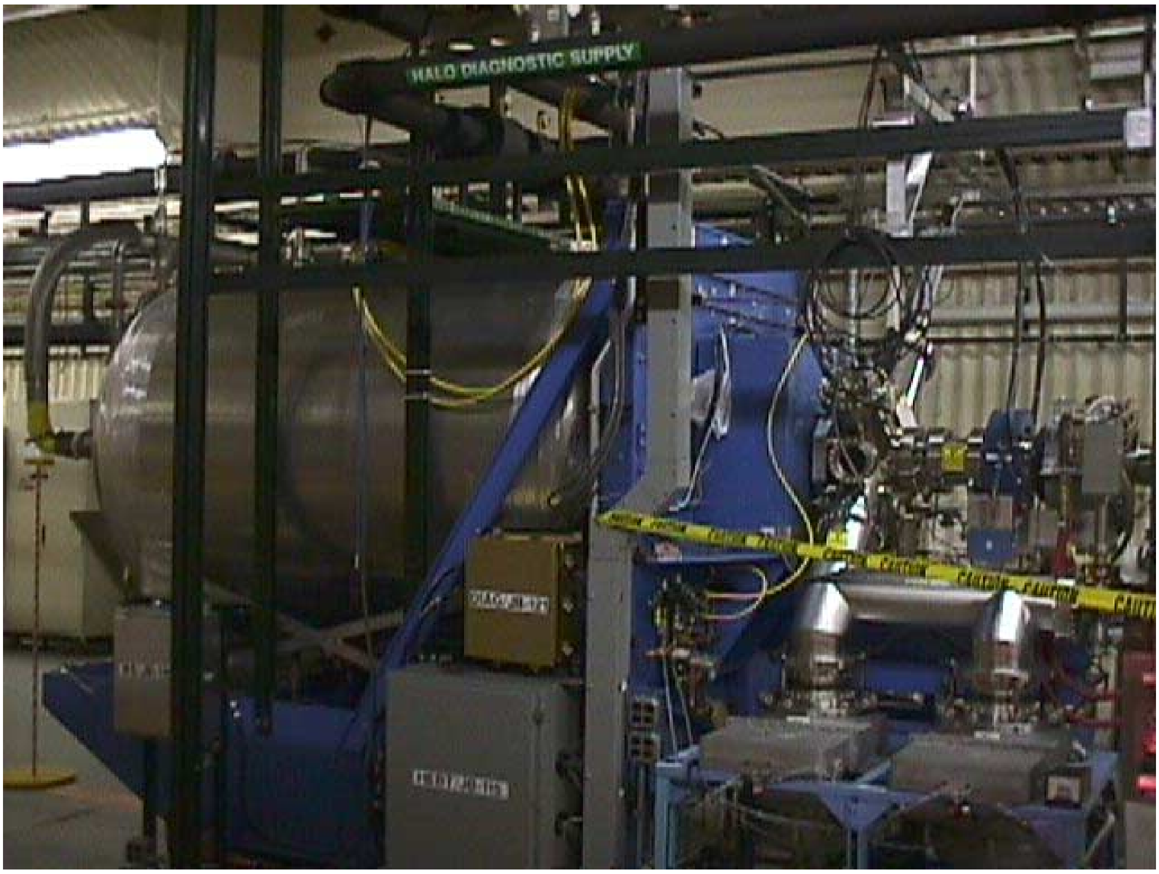

Figure 4.

LEDA Halo Magnets Installed onto End of RFQ.

Figure 5.

LEDA TLD plant locations.