RSAD for Nominal Operation of the Low Energy Recirculator Facility (LERF)

This Radiological Safety Analysis Document (RSAD) identifies the general conditions associated with running the Low Energy Recirculator Facility (LERF) in a baseline mode which can be used for many experiments. The document also describes controls with regard to production, movement, or import of radioactive materials to/from the LERF vault under the described nominal conditions.

CONTENTS:

1. Description

The nominal operation of the LERF is here stated to be:

- Recirculated Beam to 1G03 dump
- Less than 10 mA of beam current
- Beam energy in the dump of less than 15 MeV
- Beam power in the dump not to exceed 120 kW (Final Safety Assesment Document, August 27, 2012, pp. 28-29)
- Maximum beam energy in beam transport not to exceed 210 MeV
- Injector operated at less than 15 MeV
- Less than 1 microAmp of detected beam loss at any single location in beam transport to beam dump

This nominal configuration covers operation of the LERF as a Free Electron Laser and TeraHertz source and most recirculated electron beam experiments. Experiments, such as fixed target, internal target, and Isotope production, which deviate from this configuration will require a specific Radiation Safety Analysis Document addressing the experiment.

The worst case beam loss at a single point which occurs under normal conditions is less than 1 microamp of 200 MeV beam lost at a random point along the beam transport system. There is also the less severe case where a fraction of a microamp is lost continuously in the beam transport. Previous analysis (Stapleton, 1996), suggests a distributed 15 W/m (0.15 microamps@100 MeV) through the 60 m length of the accelerator is reasonable. The beamline is assumed to be about 2 meters from the west and north wall and 3 meters from the east and south walls and the ceiling.

2. Summary and Conclusions

In the baseline configuration described above, the LERF is not expected to produce measurable levels of radiation at the site boundary. However, radiological conditions around the LERF are monitored by the Radiation Control Department (RCD) to ensure that prompt radiation levels remain within expected values. The main consideration is working around and/or handling of activated beam line hardware. As specified in the Sections below, the modification/reconfiguration of

beam line hardware, removal of material from the vault, the transfer of radioactive material into or out of the facility, or modifications to radiation shielding must be reviewed and approved by the RCD. Adherence to this RSAD is vital.

3. Calculations of Radiation Dose at Site Boundary

The Radiological Control Supplement to the ES&H Manual contains design goals for annual effective dose applicable to workers and the public. These goals conform to the ALARA standard and establish prudent limits for designing shielding and engineered controls to limit exposure to direct radiation from the LERF accelerator. For radiological workers, the design goal is 250 mrem/y. This value equates to an average equivalent dose rate of 0.125 mrem/h by assuming that an individual would not be exposed in excess of 2000 hours in a year.

An average equivalent dose rate of 0.1 mrem/h outside the shielded and access-controlled areas of the accelerator will provide adequate radiation protection for personnel.

The closest site boundary to the LERF is 260 meters away to the south. Since the source term outside the shielded areas of the accelerator is less than 0.1 mrem/h and is about 6 meters (Stapleton, 1996) from the source point in the machine, at the site boundary the dose rate would be (0.1 mrem h^{-1})/(260 m/6 m)^2, or about 0.05 microrem/h. Assuming an annual operating time of 2000 hours the annual dose at the boundary should be less than 0.1 mrem.

4. Radiation Hazards

4.1 From Beam in Vault

4.1.1 Introduction. In any operation involving acceleration of charged particles there are various ways in which beam loss may occur. First, there are losses which are continuous long term, due to particles which do not lie within, or stay within the normal acceptance of the various parts of the machine. These are the most difficult to estimate but they can be the cause of a significant part of the prompt radiation experienced because they occur during the entire machine operations period. Secondly, there are losses which occur due to mis-setting or mis-

steering of the beam or due to non-optimal performance of some of the machine equipment. In some cases, these give rise to degradation of specific beam parameters such as energy spread or beam size and can give rise to definable loss points such as maximum dispersive regions or points of large Betatron functions in the transport system. Thirdly, there are losses at the beam termination points, or so called beam dumps. LERF vault radiation measurements were made during the Darklight test runs (Cowan, 2013) using a combination of two NaI/PMT detectors and a neutron monitor. These measurements have been correlated with reasonable agreement to measurements using the installed Rapid Access monitors in the vault. The measurements all confirm that the radiation source term calculations for the LERF (see the references) are conservative.

4.1.2 Summary. Beam losses in the LERF vault are understood and well mitigated by installed shielding. Hazards from prompt radiation outside the shield are low, and are well mitigated by the shielding described in section 5. However, the radiation hazard in the vault during beam operations is high and potentially lethal. Therefore, prior to going to Beam Permit, several actions will occur. Announcements will be made over the intercom system notifying personnel of a change in status from Restricted Access (free access to the vault is allowed, with appropriate dosimetry and training) to Sweep Mode. All magnetic locks on exit doors will be activated. Persons trained to sweep the area will enter by keyed access (Controlled Access) and search in all areas of the vault to check for personnel.

After the sweep, another announcement will be made, indicating a change to Power Permit, followed by Beam Permit. The Run-Safe boxes will indicate "OPERATIONAL" and "UNSAFE". IF YOU ARE IN THE VAULT AT ANY TIME THAT THE RUN-SAFE BOXES INDICATE "UNSAFE", IMMEDIATELY PRESS THE “PUSH TO SAFE” BUTTON ON THE BOX.

Controlled Area Radiation Monitors (CARMs) are located in strategic areas around the LERF to ensure that unsafe conditions do not occur in occupiable areas. The Radiation Control Department (RCD) will monitor the CARMs and make surveys as necessary to assess the impact of the experiment on radiation levels around the LERF.

4.2 Hazard from Activation of Beamline Components

Low level activation of beamline components is possible in most regions of the machine. However, when operated in energy-recovery mode, without a fixed target, the LERF historically produces very modest levels of activation, occurring at tight apertures and high dispersion areas. Reviews of surveys shows that radiation areas are rare, as are contact dose rates above 20 mR/h. A survey taken after the Darklight test run found contact radiation levels as high as 35 mR/hr and whole body dose rates about 2 mR/h in the first arc. The activation levels during this run represent a reasonable upper bound on expected activation during operations covered by this RSAD. Radiation or High Radiation Areas are possible but not likely. Low-level activation of hardware, shielding and structural materials is possible throughout the machine.

Consequently, the vault is permanently posted as an RCA and Radioactive Materials Area, and all materials present in the vault during beam operations must be surveyed and cleared by a Radiation Control Technician prior to removal (Radiation Control Supplement , 2010).

No work is to be performed on beam line components which could result in dispersal of radioactive material (e.g. drilling, cutting, welding, etc.). Such activities must be conducted only with specific permission and review by the RCD.

4.3 Other Sources

All radioactive materials brought to Jefferson Lab shall be identified to the Radiation Control Department. These materials include, but are not limited to radioactive check sources (of any activity, exempt or nonexempt), previously used targets or radioactive beamline components, previously used shielding or collimators, or He-3 containers. The RCD inventories and tracks all radioactive materials onsite. The RCD may survey the experimental setup before experiments begin as a baseline for future measurements if significant residual activity levels are present.

5. Shielding

5.1 Bulk Shielding. Both empirical and detailed Monte Carlo methods were employed to determine the amount of concrete, sand, and earth used to shield the LERF. The empirical methods represented standard approaches which have

been used for many years to define the bulk shielding. The methods are from such works, authors, and installations as NCRP-51, Swanson, Sullivan and SLAC and represent experience from both calculated and experimental results. The detailed Monte Carlo calculations used standard radiation transport and source defining code such as MARS12/PICA and GEANT/DINREG. Operational experience at the LERF has validated the shielding design. The shielding design is primarily driven by neutron radiation, but in some locations and directions, photons dominate the shielding requirements (Stapleton, 1996; Thomas, 1996). Overall, the bulk shielding requirements are well addressed and additional calculations unnecessary unless the beam configuration (eg. insertion of a target) is changed (Stapleton, 1995). For purposes of this RSAD, the concrete block shield at the south wall equipment door is considered part of the bulk facility shielding, as well as the steel and polyethylene shielding at the 1G and 2G dumps and the optical chicane in the IR beam transport line. Although moveable, heavy equipment is required to reconfigure these shields. They are inspected periodically, and assumed to be in place for all beam operations in the LERF.

5.2. Moveable Shielding. A number of generally small, moveable shielding packages are installed at the LERF. These shields are configuration-controlled and inspected as part of start-up of operations (JLAB, 2015c). The following moveable shield packages are required to be in place for all beam operations covered by this RSAD.

- 04-FEL-11 – Inline tuneup dump
- 04-FEL-14 – Injector recirculation “crotch” (barrier)
- 05-FEL-01 – Penetration outside drive laser room
- 05-FEL-02 – Penetration in User Lab 3 SW corner
- 05-FEL-03 – Penetration in User Lab 6 SW corner

These shielding configurations help ensure the typical prevailing conditions assumed for this RSAD are maintained (eg. User Labs do not become RCAs). In the event any of these configurations are modified, the Radiation Control Manager must approve the deviation in writing, or the reconfiguration must be part of an approved, experiment-specific RSAD.

5.3 Shielding Configuration Control

Per Appendix 3D “Shielding Policy for Ionizing Radiation” in the Radiation Control

Supplement to the JLAB ES&H Manual, all shielding affecting personnel shall be validated by initial radiation surveys and subsequently checked for proper configuration at regular intervals.

All shielding affecting personnel radiation safety shall be subject to configuration controls. All shielding identified in the Accelerator Safety Envelope shall meet configuration management requirements specified for a Level 1 CM system in the Conduct of Engineering Manual. The Accelerator Safety Envelope has specific requirements regarding periodic evaluation of shielding integrity.

All shielding affecting personnel radiation safety will be checked as part of the RadCon checklist prior to RF or beam operation in the LERF vault if the vault has been in Restricted Access for more than 24 hours, as specified in the LERF Operations Directives.

The design and installation of moveable shielding shall be approved by RCD. For moveable shielding, preparation of the design package, configuration control and periodic inspections shall be documented as required by RCD procedures.

6. Operations Procedures.

All personnel must comply with LERF administrative controls. These controls are outlined in the LERF Operations Directives (LERF Operations Directives, 2015). There may be additional controls in the form of Operational Safety Procedures (OSP), Temporary Operational Safety Procedures (TOSP) or any verbal instructions from the RCD. A general access Radiation Work Permit (General Access RWP, 2015) is in place which governs access to building 18 and the LERF vault. The original is kept on-line as part of JLAB's web based training. It must be read and signed prior to entry into the vault or designated areas of the gallery.

Radiation surveys verify the absence of prompt radiation and identify areas where activation of beamline hardware may require radiological work controls or access controls. A detailed radiation survey (see the Radiological Control Manual) must be performed any time entry into the LERF accelerator enclosure is required after electron beam has been accelerated through a superconducting cavity (when conditions allow, Controlled Access entry to the vault is permitted via the "rapid

access" monitoring system, in accordance with the protocols for its use (LERF Operations Directives, 2015)).

The survey sheet must be posted in the Radiation Survey Log. These sheets must be filled out in pen, signed, and dated by the survey team. Once complete, the Crew Chief will review and sign it if all entries are verified to be complete. The RCD is responsible for collecting previous survey records, leaving only the results of the latest survey of each area in the log. A copy of the survey sheet is posted outside the vault. Personnel should check this copy prior to starting work on the vault.

An inspection of the LERF to check for inadvertent modification of RCD related equipment and shielding is required when the vault has been open to restricted access for longer than 24 hours continuously. A Radiation Checklist is completed by the RCD and given to the Crew Chief for review and filing (LERF Operations Directives, 2015).

Radiation Work Permits (RWPs) are the standard work authorization documents used to control radiological work. RCD will require RWPs based on established trigger levels.

Standard RSAD controls apply: RCD shall be contacted for any of the following activities:

1. Entry to Radiation Areas or High Radiation Areas
2. Movement of shielding or collimators
3. Maintenance of known or potentially contaminated systems
4. Any destructive modifications to activated components (drilling cutting, welding, etc.)

All posted guidance and instructions for contamination controls, shielding configuration, and access to radiological areas must be adhered to.

NOTE: Work planning for all radiological work shall be coordinated through the LERF work coordinator (J. Coleman) using the ATList work planning tool.

7. Decommissioning and Decontamination of Radioactive Components

Experimenters shall retain all experimental equipment brought to Jefferson Lab for temporary use during the experiment. After sufficient decay of any radioactive materials, they shall be delivered to the experimenter's home institution for final

disposition. All transportation shall be done in accordance with United States Department of Transportation Regulations (Title 49, Code of Federal Regulations) or International Air Transport Association regulations. In the event that the experimenter's home institution cannot accept the radioactive material due to licensing requirements, the experimenter shall arrange for appropriate funds transfers for disposal of the material. Jefferson Lab cannot store indefinitely any radioactive or experimental equipment.

Approvals:

_____ _____

Radiation Control Department Head Date

References

Cowan, R. e. (2013). Measured Radiation and Background Levels During Transmission of Megawatt Electron Beams Through Millimeter Apertures. *NIMA-S-13-00699-3*, 21.

(August 27, 2012). *Final Safety Assesment Document.*

JLAB. (2010, July 1). Radiation Control Supplement . *JLAB ES&H Manual*.

JLAB. (2015). *General Access RWP*. Retrieved from On line training: https://misportal.jlab.org/railsForms/rad_work_permits/45081/briefing

JLAB. (2015a). LERF Operations Directives.

JLAB. (2015b). Accelerator Operations Directives.

Stapleton, G. (1995). *Shielding and Other Radiation Safety Requirements for the 200 MeV Recirculating Linac with Energy Recovery for the UV FEL.* JLAB.

Stapleton, G. (1996). *Bulk Shielding Design Calculations.*

Swanson, W. (1979). *Radiological Safety Aspects of the Operation of Electron Linear Accelerators.* International Atomic Energy Agency.

Thomas, R. H. (27-28 February 1996). *Report of the FEL Radiation Review Committee.* JLAB.

JLAB. (2015c). Radiation Safety Checklist for Resumption of LERF Operations after Restricted Access.