Radiological Safety Analysis Document for the Hall-B CLAS12 Run Group D/E Runs

This Radiological Safety Analysis Document (RSAD) will identify the general conditions associated with the CLAS12 Run Group D & E (RG-D/E) runs in Hall B, and the controls associated with regard to production, movement, or import of radioactive materials.[1]

1 Description

The physics run of the CLAS12 RG-D/E will take place in winter-spring of 2021 in experimental Hall B. The CLAS12 is a multipurpose detector system based on a toroidal (forward detector) and a solenoid (central detector) superconducting magnets. The detector system includes Cherenkov Counters, Drift Chambers, Scintillator Counters, Silicon-strip detectors, Micro-mega gas detectors, and Calorimeters. In this run period CLAS12 will be used in its standard detector and shielding configuration.

RG-D/E run will use up to 11 GeV (5 passes) electron beam, with currents up to 150 nA. This run will use several different targets ranging from cryogenic, liquid deuterium (LD_2), to heavy solid targets. Targets will be located inside the vacuum scattering chamber that is installed inside the central detector in the center of the 5 T solenoid magnet. There are two configurations for running with multiple targets. The first target system will consist of two of the same-kind solid target foils, ^{12}C, ^{27}Al, ^{63}Cu, ^{118}Sn, and ^{208}Pb, mounted inside a 20 mm diameter Kapton cell (similar to the liquid target cell that is installed on cryo target lines), spaced in ~ 5 cm from each other. The cell will be purged with cold He to dissipate heat generated in

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Run Info w/. Hall-B Nuclear Target Assembly

Targets	Thickness (F-1 / F-2) (cm)	Density ($g.cm^{-3}$)	Areal Density ($mg.cm^{-2}$)	Radiation Lengths (T/X_0)	Beam Current (nA)	Per-Nucleon Luminosity ($cm^{-2}\ s^{-1}$)
D_2	5	0.164	820	0.0065	70	$2\ 10^{35}$
^{12}C	0.344 / 0.172	1.747	600 / 300	0.014 / 0.007	60	$2\ 10^{35}$
^{63}Cu	0.08 / 0.04	8.96	717 / 358	0.056 / 0.028	50	$2\ 10^{35}$
^{118}Sn	0.06 / 0.03	7.31	439 / 219	0.05 / 0.025	70	$1.73\ 10^{35}$
^{27}Al	0.116 / 0.058	2.7	313 / 157	0.013 / 0.0065	70	$1.24\ 10^{35}$
^{208}Pb	0.028 / 0.014	11.35	318 / 159	0.05 / 0.025	70	$1.26\ 10^{35}$

Figure 1: Targets for RG-D/E Run Configuration I, their characteristics, proposed beam currents to run on each target, and the per-nucleon instantaneous luminosity.

the foils from the beam interaction. Separately, CLAS12 cryotarget with 5 cm LD_2 and without (empty target) will be used in this configuration. The list of targets for the first configuration, their characteristics, proposed beam currents, and the per-nucleon luminosities are presented in Fig. 1.

The second target configuration uses so-called dual-target concept, where 2 cm long LD_2 target is always on the beam while solid targets will be inserted one at the time using University of Santa Maria (USM) target system. The USM target system will be fitted over the downstream end of the standard CLAS12 cryotarget. This target holder uses a movable tape system to contain solid targets, which may be selected individually. The list of target arrangements, their characteristics, proposed beam currents and the per-nucleon luminosities for this configuration are presented in Fig. 2.

As mentioned above, the target systems will be installed inside the beam vacuum, in a foam scattering chamber. The vacuum will be disconnected between the upstream and downstream beamlines. There is a $\sim$ 40 cm of air between the exit window of the target scattering chamber and the

Run Info w/. USM Dual Targets

Targets	Thickness (cm)	Density ($g.cm^{-3}$)	Areal Density ($mg.cm^{-2}$)	Radiation Lengths (T/X_0)	Beam Current (nA)	Per-Nucleon Luminosity ($cm^{-2}\ s^{-1}$)
^{12}C (+ LD_2)	0.172 (2)	1.747 (0.164)	300 (328)	0.007 (0.0026)	85	$2\ 10^{35}$
^{63}Cu (+ LD_2)	0.04 (2)	8.96 (0.164)	358 (328)	0.028 (0.0026)	70	$1.78\ 10^{35}$
^{118}Sn (+ LD_2)	0.03 (2)	7.31 (0.164)	219 (328)	0.025 (0.0026)	70	$1.42\ 10^{35}$
^{27}Al (+ LD_2)	0.058 (2)	2.7 (0.164)	157 (328)	0.0065 (0.0026)	85	$1.52\ 10^{35}$
^{208}Pb (+ LD_2)	0.014 (2)	11.35 (0.164)	159 (328)	0.025 (0.0026)	70	$1.26\ 10^{35}$

Figure 2: Solid targets for RG-D/E Run Configuration II. Each solid target will be on the beam simultaneously with 2 cm long LD_2 target. Listed are the target's characteristics, expected beam currents to run on each target, and the per-nucleon instantaneous luminosity.

entrance window of the downstream beamline. Both windows are 50 μm thick aluminum. The per-nucleon luminosity during the run will be $\leq 2 \times 10^{35}$ $cm^{-2}s^{-1}$. During running with beam currents above 15 nA at 11 GeV ($\sim$160 W), the Hall B beam stopper (a 30 cm long, water cooled-copper absorber) will be positioned before the Faraday Cup to prevent overheating. Production data taking will use $\leq$ 85 nA beam current, the highest current, 150 nA, will be used for the empty target runs.

For the beam tune and Möller runs, the beam will be directed into the beam dump in the Hall B Tagger dipole yoke. On top of the Tagger yoke, additional lead and borated-poly shielding is added to limit radiation leakage to the CLAS12 detectors and electronics. The additional shielding and a nickel collimator have been thoroughly simulated using a GEANT model of the beamline and the Tagger dipole magnet. Downstream of the collimator box, additional shielding is installed from boratedpoly blocks to minimize neutron background.

2 Summary and Conclusions

The experiment is not expected to produce significant levels of radiation at the site boundary. However, it will be periodically monitored by the Radiation Control Department to ensure that the site boundary goal is not exceeded. The main consideration is the manipulation and/or handling of target(s) or beamline hardware. As specified in Sections 4.2 and 7, the manipulation and/or handling of target(s) or beamline hardware (potential radioactive material), the transfer of radioactive material, or modifications to the beamline after the target assembly must be reviewed and approved by the Radiation Control Department. Adherence to this RSAD is vital.

3 Calculations of Radiation Deposited in the Experimental Hall (the Experiment Operations Envelope)

The radiation budget for a given experiment is the amount of radiation that is expected at the site boundary as a result of a given set of experiments. This budget may be specified in terms of mrem at the site boundary or as a percentage of the Jefferson Lab design goal for dose to the public, which is 10 mrem per year. The Jefferson Lab design goal is 10% of the DOE annual dose limit to the public, and cannot be exceeded without prior written consent from the Radiation Control Department Head, the Director of Jefferson Lab, and the Department of Energy.

Calculations of the contribution to Jefferson Lab's annual radiation budget that would result from running under a broad variety of conditions typical of Hall B operations indicate that the contribution from this experiment will be negligible. With this expectation, we have not carried out calculations for the specific running conditions of this experimental group.

This expectation will be verified during the experiment by using the active monitors at the Jefferson Lab site boundary to keep up with the dose for the individual setups from Hall B and the other Halls. If it appears that the radiation budget will be exceeded, the Radiation Control Department will require a meeting with the experimenters and the Head of the Physics Division to determine if the experimental conditions are accurate, and to assess what actions may reduce the dose rates at the site boundary. If the site boundary dose approaches or exceeds 10 mrem during any calendar year, the experimental program will stop until a resolution can be reached.

4 Radiation Hazards

The following controls shall be used to prevent the unnecessary exposure of personnel and to comply with federal, state, and local regulations, as well as with Jefferson Lab and the experimenter's home institution policies.

4.1 From Beam in the Hall

When the Hall status is Beam Permit, there are potentially lethal conditions present. 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 Hall 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 to the Hall. One of persons doing the sweep will stay at the door, while other(s) will search in all areas of the Hall 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 HALL AT ANY TIME THAT THE RUN-SAFE BOXES INDICATE UNSAFE, IMMEDIATELY HIT THE BUTTON ON THE BOX.

Controlled Area Radiation Monitors (CARMs) are located in strategic areas around the Hall and the Counting House to ensure that unsafe conditions do not occur in occupiable areas.

4.2 From Activation of Target and Beamline Components

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 non-exempt), previously used targets or radioactive beamline components, or previously used shielding or collimators. The Radiation Control Department inventories and tracks all radioactive materials onsite. The Radiation Control Department will survey all experimental setups before experiments begin as a baseline for future measurements.

The Radiation Control Department will coordinate all movement of used targets, collimators, and shields. The Radiation Control Department will assess the radiation exposure conditions and will implement controls as necessary based on the radiological hazards.

There shall be no local movement of activated target configurations without direct supervision by the Radiation Control Department. Remote movement of target configurations shall be permitted, providing the method of movement has been reviewed and approved by the Radiation Control Department.

No work is to be performed on beamline 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 control of the Radiation Control Department.

5 Incremental Shielding or Other Measures to be Taken to Reduce Radiation Hazards

None.

6 Operations Procedures

All experimenters must comply with experiment-specific administrative controls. These controls begin with the measures outlined in the experiment's Conduct of Operations Document, and also include, but are not limited to, Radiation Work Permits, Temporary Operational Safety Procedures, and Operational Safety Procedures, or any verbal instructions from the Radiation Control Department. A general access RWP is in place that governs access to Hall B and the accelerator enclosure, which may be found in the Machine Control Center (MCC); it must be read and signed by all participants in the experiment. Any individual with a need to handle radioactive material at Jefferson Lab shall first complete Radiation Worker (RW I) training.

There shall be adequate communication between the experimenter(s) and the Accelerator Crew Chief and/or Program Deputy to ensure that all power restrictions on the target are well known. The beam current/power and other beam parameter restrictions shall be documented in the Operational Restrictions list at OPS restriction webpage[2]. Exceeding these power restrictions may lead to excessive and unnecessary contamination, activation, and personnel exposure.

No scattering chamber or downstream component may be altered outside the scope of this RSAD without formal Radiation Control Department review. Alteration of these components (including the exit beamline itself) may result in increased radiation production from the Hall and a resultant increase in the site boundary dose.

7 Decommissioning and Decontamination of Radioactive Components

Experimenters shall retain all targets and experimental equipment brought to Jefferson Lab for temporary use during the experiment. After sufficient decay of the radioactive target configurations, 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 fund transfers for disposal of the material. Jefferson Lab cannot store indefinitely any radioactive targets or experimental equipment.

The Radiation Control Department may be reached at any time through the Accelerator Crew Chief (269-7050).

[2] http://opweb.acc.jlab.org/internal/ops/ops_webpage/restrictions/ops_restrictions.html

Approvals:

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Radiation Control Department Head Date

8 Appendix: Radiation Damage to the CLAS12 Electronics from the Beam Dump in the Hall B Tagger Dipole Magnet Yoke

While most of the CLAS12 electronics are located away from the beamline, the front-end electronics boards (FE boards) of the SVT and the MVT are in close proximity to the beamline, about 2 m to 3 m upstream of the target location.

8.1 Radiation Damage to the Standard Electronics Components in the Hall

The experiment is not expected to produce significant levels of neutron radiation that may cause damage to the Hall B electronics located on the Forward Carriage or on the Space Frame. The beam energies and the integrated luminosity of the experiment are in the same range as for the CLAS nuclear target experiments. Furthermore, all sensitive electrons that are mounted close to the beamline are upstream of the target where not much radiation is expected. Most of the produced electromagnetic radiation (Möller electrons) will be guided by 5 T solenoid field into a tungsten shield pipe. Part of that radiation will be absorbed by the shield, part will be guided to the beam dump. Some of electronics modules mounted on the Forward Tagger will be beyond the tungsten shield and will not see much radiation.