Exposure Control for Operations and Maintenance at the Accelerator Production of Tritium

by
D. H. McGuire
Westinghouse Savannah River Company
Savannah River Site
Aiken, South Carolina 29808


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ABSTRACT

The APT will be designed and operated to support continuous tritium production. Tritium is an essential ingredient in U.S. nuclear weapons. The APT will be designed and staffed to support continuous production of tritium by trained, qualified, and certified personnel.

Challenges facing the workforce of the Accelerator for Production of Tritium (APT) include operation, repair and replacement of components that are either activated by the proton beam or contaminated in a support service function. In addition to compliance with standard industry and DOE radiological protection requirements, the APT will incorporate protective measures that are specific to accelerator applications or unique to the APT. It is these customized radiological protection features that is the focus of this paper.

In order to avoid or minimize radiation and contamination exposure to personnel, a three part approach will be implemented involving:
I. Incorporation of ALARA into O&M culture and work methodology
II. Use of remote operations and maintenance techniques
III. Design features

DISCUSSION

The APT will produce a 100mA, 1700MeV proton beam which is directed onto a tungsten target surrounded by a lead blanket. Tubes filled with 3He gas are located adjacent to the tungsten target and within the lead blanket. Spallation neutrons created in the tungsten and lead by the energetic protons are moderated by the lead and cooling water, and absorbed by 3He to create about 40 tritium atoms per incident proton via the 3He(n,p)T reaction. The tritium is then separated from the resulting 3He, tritium, protium gas mixture. The plant must meet its production requirements while minimizing both public and worker exposure to radiological and nonradiological hazards and materials. Remote operations will be used, as appropriate, to comply with sound ALARA (As Low As Reasonably Achievable) exposure principles.

Due to the inaccessibility of many components while the beam is on, significant maintenance is planned around outage periods. Planned biweekly outages of 8 hour duration are coupled with a 24 hour outage once a month. In addition, an extended annual outage is planned to allow retargeting. Large jobs such as window, target or blanket module replacement, major system overhauls or significant modifications to tunnel components will bound the annual outage requirements.

A variety of surveillances and inspections will be required for the APT. The conditions for performing inspection of various systems during both operation and shutdown will be varied. Requirements for design features, specific equipment, and access needed to accomplish these inspections will be dictated by ALARA and accessibility concerns. The design will allow for performance of these inspections with minimum access to radiologically controlled areas. Because access to the accelerator tunnel will be prohibited during operation, readouts for measurement devices of a system will be placed outside the tunnel. Closed circuit camera systems will also be used for periodic monitoring of the accelerator tunnel areas for
cooling water and cryogenic leaks therefore eliminating
the need for personnel entry.

I. ALARA

APT plant design will incorporate ALARA concepts in order to minimize radiological hazards associated with operations and maintenance. Operators and technicians will be able to conduct routine activities without undue exposure to radiation or contamination. Remote capabilities will be provided where appropriate to minimize exposure to personnel performing the function. The plant is to be operated with the philosophy of maintaining radiologically clean operating areas with timely recovery of those areas that become contaminated through loss of containment. For example, while the target vessel may become contaminated, spread of contamination outside of the vessel pit as a result of retargeting operation would not be acceptable. Thus, the design will stress confinement features such as airflow directional control from clean areas into potentially contaminated areas. The design will provide for containment of contamination at its sources, and provide for ease of decontamination by the use of appropriate surface coatings and/or covers. Physical controls and electronic surveillance to prevent and detect inadvertent or unauthorized access to High and Very High Radiation Areas shall be provided. The APT will be designed to operate in a way to minimize radioactive waste needing disposal.

The key to safe job performance with minimal radiological risk and minimal waste is good pre-planning. Rad Con personnel will be included in job pre-planning and approval where any contamination or other radiological hazard may be present. An ALARA checklist shall be a part of every work package planning. A Radiation Work Permit (RWP) will be issued for all radiological work specifying the hazards, conditions, protective clothing and monitoring requirements required to perform the job. Only those personnel with proper training and radiological qualifications will be allowed to perform radi worker assignments.

“Hands-on” repairs of activated or contaminated equipment will be avoided where possible. The favored strategy will be to find a work-around that allows the component to cool [radiologically] prior to repair or to be scrapped. This strategy requires a higher number of spare parts, and an efficient means for inventory control. Where inventory or schedule restraints dictate repair of an activated or contaminated component, some means of decontamination and/or use of temporary shielding shall be employed to limit the dose to the worker. Remote handling systems (RHS) are used at the APT where ALARA or temperature considerations restrict contact maintenance.

The design basis whole body dose (internal and external) to an individual worker shall be ALARA and less than 500 mrem per year. Design basis individual worker extremity and skin doses shall be ALARA, not to exceed 10 rem per year. Compliance with the ALARA principle and regulatory dose limits is accomplished in part by designing the radioactive portions of the plant to meet predetermined maximum area radiation levels. The radiation zoning criteria for the plant are given in Table 1.

<table>
<thead>
<tr>
<th>Radiation Zone</th>
<th>Design Basis Maximum Area Radiation Dose Rate (mrem/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>2</td>
<td>&lt;0.25</td>
</tr>
<tr>
<td>3</td>
<td>≤5.0</td>
</tr>
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</tr>
<tr>
<td>5</td>
<td>≤500, 000</td>
</tr>
<tr>
<td>6</td>
<td>&gt;500, 000</td>
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</tbody>
</table>

Accelerator

The primary hazard associated with the accelerator is localized ionizing and nonionizing radiation produced by normal beam operation or accidental beam impingement on accelerator surfaces (i.e., beam spill). Worker protection is provided by a redundant and diverse combination of shielding, radiation monitoring systems, a beam-shutdown system, personnel access-control systems, and effluent control. Passive shielding is provided throughout the accelerator tunnel to limit exposure of workers during all normal and credible accident conditions in accordance with DOE requirements.
Prior to personnel entry into the accelerator tunnel for maintenance, the tunnel air will be exchanged several times and sampled. Tunnel entry protocol will also include a radiological scan and identification of hot spots [to avoid] in the vicinity or along the route to the job site.

Target-Blanket (T/B)

The primary radiation concerns in the T/B systems are hard gamma emitted from the target modules, and spallation products in the primary coolant stream formed by transmutation of oxygen in the heavy water. The tungsten neutron source (target) is mounted inside a cylindrical steel vacuum vessel that is shielded both inside and outside to reduce the radiation dose rate to acceptable levels. Radiation monitoring systems and strict enforcement of access control are also used to prevent personnel exposure inside the T/B building. Air flow direction and pressure differentials are maintained in a manner that ensures gradient is from clean regions towards regions that are potentially contaminated.

A radiological concern in T/B heat removal systems is the accumulation of spallation products (namely beryllium-7) in piping and equipment (e.g.- pumps, heat exchangers). The heavy water coolant is isolated in a closed loop and therefore prevented from any direct or indirect contact with the target material. Shielding is provided for all components of the primary heat removal system sufficient to keep radiation dose rate to workers within the limits specified in Table 1.

Maintenance of T/B systems shall be performed with emphasis on Rad Con principles in order to minimize release or spread of contamination, and to ensure that the radiation field is well characterized prior to maintenance. Rad Con will specify appropriate area or localized shielding requirements to ensure personnel safety and keep exposure ALARA. As required, some maintenance activities will be performed remotely or delayed until activation products decay.

Tritium Separation Facility (TSF)

The primary hazard in the TSF is exposure of workers to tritium oxide. The total dose from tritium oxide is 10,000 to 30,000 times that of elemental tritium. Because the TSF contains only elemental tritium (0.1% tritium oxide assumed for conservatism), the hazard from a release of the TSF inventory without oxidation is minimal. The event of concern for the TSF is a tritium release with oxidation. Worker protection within TSF is based on tritium operational experience at existing facilities. Protection for workers is first provided by a secondary tritium confinement around tritium processing equipment with an inert atmosphere and tritium cleanup system. Should an event cause a breach of both the process confinement and the secondary confinement, the processing room and HVAC provide for directing the release away from the workers and through a monitored stack. Tritium monitors in TSF alert the operators to leave the processing area. Because the number of events that can cause a double breach of TSF confinements along with oxidation are limited, the risk for worker exposure within TSF is minimal.

II. REMOTE TECHNIQUES

Remote retargeting

The T/B vessel will house the target and blanket modules. The target modules measure up to 7m high, weigh between 60-80 tons, and must be replaced annually. The target modules will be emitting radiation levels that will preclude hands on work and therefore must be replaced remotely. The use of an overhead bridge crane and a separate rail mounted electromechanical manipulator was determined to be the most effective means for handling the modules, and the associated jumpers. Required remote activities will include the preparation for radioactive linebreaks, disconnection, connection, and post maintenance testing (including liquid and gas system leak testing) of these components.

Remote manipulation will be required for radioactively contaminated cooling water and gas transfer jumpers that connect T/B modules to the balance of the process systems. The manipulator (or tele-robot) will be used to make and break remote connections on helium-3 pipe jumpers to a tritium leak-tight requirement. The SRS has vast experience in remote connectors, as well as in making tritium connections hands-on inside a glovebox, but the AFT will be the first-of-its-kind application of achieving a tritium leak tight connection by use of a remote connector.
The target bay crane is remotely controlled when transporting highly radioactive modules from the T/B vessel to the storage pool or when transporting other highly radioactive material within the target bay. The target bay crane is mounted on rails along the walls of the target bay. The crane spans the entire width of the bay and can travel to both ends of the bay, including the area over the truck/train access port. The crane control station is located in a remote control room isolated from the radiation shine emanating from the module during transport. Radiation shield windows are located at strategic points to offer a direct view into the target bay where and when exposure limits allow. The control station for the bridge manipulator is also located in the same control room.

Resin bed cranes are used to transport radioactive resin bed filters from their installed locations in the resin bed cells to a point accessible to the target bay crane. Resin beds can be remotely sluiced and replenished.

Coupons used in materials studies will be installed/removed from the targets periodically. Means for remote coupon removal and shielded transport [to area of analysis] will be provided.

Remote decontamination

For those contaminated components that warrant repair, a confined cell/area will be provided to perform decontamination prior to the hands-on repair. Workers may be required to wear personnel protective equipment depending upon the extent of contamination.

The Accelerator and High Energy Beam Transport (HEBT) RHS consists of remotely controlled mobile vehicles and overhead hoists to allow remote replacement of components in the accelerator and HEBT tunnels and bridge cranes for remote replacement of components in the HEBT buildings.

There are two types of remote manipulator vehicles utilized. One battery-powered, dual-manipulator vehicle having two electric manipulators, is provided to connect and disconnect components and replace light components in the accelerator and HEBT tunnels. An automatic tool changer allows either of the manipulators to use different tools to accomplish these functions. One battery-powered, single-manipulator vehicle having one hydraulic manipulator is provided to support and manipulate heavier components in the accelerator and HEBT tunnels. The dual-manipulator and single-manipulator vehicles are remotely controlled from portable control stations that can communicate with the vehicles by an umbilical cord or by radio control from inside or outside the tunnel. For control from outside the tunnel, the control stations are connected to permanently installed cables to antennae in the tunnel sections. The dual-manipulator and single-manipulator vehicles have multiple video cameras that can display views on multiple monitors on the portable control stations. A microphone on each vehicle provides audio monitoring at the portable control stations. Battery charging stations for each manipulator vehicle are provided in each tunnel entrance ramp.

Tunnel monorail hoists are used to support and move heavy components. These hoists are mounted on monorails to provide access to routinely replaced components accessible from above. The hoists can be remotely operated by connecting a pendant with a long cable to a plug on any hoist.

Robotic surveillance

Three identical remotely dispatched mobile surveillance robots provide camera views in the accelerator and HEBT tunnels during all modes of accelerator operation. These surveillance robots may also provide audio, radiation, and air-activation monitoring in the tunnels. The robots have battery chargers in the tunnels with remote docking and undocking capabilities. The robots are controlled from a control station in the main control room. They can be sent on routine patrols through the tunnel sections or can be dispatched to specific locations in the tunnels. Monitors at the control station provide views from the video cameras on the robots as well as data from the radiation and air-monitoring systems. The data can be displayed on color-coded maps of the tunnels.

Two identical mobile surveillance robots are used to provide camera views, audio feedback, and radiation data of the T/B primary cooling systems when personnel access to the area is not allowed. The two mobile surveillance robots are usually stored on separate floors of the T/B building below the operating deck at autonomous charging docks. There are no normally closed doors between the charging dock and any of the rooms containing components of the primary cooling system or between the charging dock and a building elevator to allow access for the robot during operating mode of the accelerator. The control station for the surveillance robots is located in the MCR.
In-service inspections

In-service inspections will be used to support the predictive maintenance program. In order to achieve the required plant availability, planned and unplanned outages will be handled in a well coordinated and efficient manner. This effort requires emphasis on predictive maintenance measures to detect and trend component degradation, and to anticipate component failures which in turn enables preoutage planning and readiness. Also, predictive maintenance will be used to avoid unnecessary or premature maintenance tasks, thereby avoiding unnecessary exposure.

III. DESIGN FEATURES

Some of the general design considerations that reflect sound ALARA principles include:

- The design shall incorporate separation and shielding of components that may become activated or contaminated, such that repair of one component may be in progress without risk of exposure from another component.

- Equipment requiring frequent access for monitoring, surveillance, or maintenance shall be placed in a location which facilitates performing these tasks.

- For hands-on maintenance of equipment in radiologically controlled areas, means of permanent and/or temporary shielding shall be provided such that the maintenance activity may take place in a low [radiation] background area. Likewise, for maintenance work on potentially contaminated equipment, means of draining, flushing and/or decontaminating the equipment shall be incorporated into design.

The accelerator portion of the APT is located within a well-shielded, limited-access area that relies on passive and active safety features to protect workers. The Radiation Monitoring and Protection System (RMPS) is designed to protect the public and plant personnel from radiological hazards during all modes of operation. RMPS accomplishes this task by shutting down the accelerator beam, initiating safety systems as appropriate, providing monitoring and controls to maintain the APT in a safe shutdown condition, and by providing SSCs and administrative controls to prevent inadvertent access to hazardous beam induced radiation areas by plant personnel.

The RMPS consists of two main subsystems. These are the Target/Blanket Beam Shutdown Subsystem (TBBS) and the Radiation Exposure Protection Subsystem (REPS). TBBS provides a functionality to protect the facility from releases associated with the T/B design basis accidents (DBAs). TBBS is designed to trip or remove the beam from the target/blanket before damage to the target/blanket could occur that would result in a release above applicable safety evaluation guidance. TBBS also initiates Cavity Flood and provides post accident monitoring of the target, cavity and Residual Heat Removal (RHR) operation.

The TBBS subsystem consists of primary and backup redundant safety related target/blanket sensors, logic solvers and beamtrip mechanisms and Main Control Room (MCR) displays and controls.

The T/B Backup Beam Shutdown system is designed to shutdown the accelerator beam due to various accident scenarios in T/B process systems. It also serves as a backup to the Primary Beam Shutdown system. This is accomplished by the use of instrumentation to detect target overheating and logic to initiate a beam shutdown. In addition, controls provide the plant operator with the ability to monitor process conditions and to initiate beam shutdown manually. The Backup Beam Shutdown system can initiate the RHR systems and Cavity Flood system, and provide post accident monitoring of the target and cavity.

The Backup Beam Shutdown logic is designed to detect an over-temperature condition in the target assembly. Temperature sensors are installed on the tungsten neutron source ladder exit pipe to detect a DBA. These signals are wired to redundant logic panels.

The backup beam shutdown logic solvers monitor the tungsten neutron source ladder exit temperature. When the logic has determined that the high temperature limit for the target has been exceeded, redundant shutdown signals will be sent to shutdown the beam. The mechanism for the backup beam shutdown system uses a different technology than that used by the primary beam shutdown system. The backup beam shutdown logic will also actuate the Cavity Flood system, if the tungsten neutron source ladder exit temperatures exceed a high limit.
REPS is a radiation monitoring and entry interlock system designed to keep personnel out of radiation areas (i.e., accelerator tunnel) when there is a possibility of measurable radiation exposure. REPS will prevent beam transport if a beam spill is detected, or if an entryway door/gate is opened into a protected area that could lead to a radiation hazard. A key control system is provided to allow operations to control the access of personnel to protected areas.

The REPS is designed to shutdown beam transport in order to eliminate prompt radiation hazards to personnel in protected areas. The logic to terminate beam transport is designed to be fail-safe. This is accomplished by the use of instrumentation to detect high radiation levels, high beam current levels, and unauthorized entry into prompt radiation protected areas.

Audio/visual alarms are provided at the entryways and within the prompt radiation protected areas to warn personnel of actual or impending radiation hazards. Operator interface is provided at the protected area entryways to control access by means of key control, and on the Local Access Control panels to initiate and control sweeps of protected areas. The REPS Logic cabinets are located in the MCR, where the plant operator is provided REPS system status and alarms and controls to insert beamplugs, initiate warning alarms prior to beam transport, and perform diagnostics.

REPS provides safety-significant beam shutdown and administrative controls to protect the plant worker. Each area that is to be protected from prompt radiation hazards will have a locked door, local access control panels, audio/visual alarms, sweep and scram switches, and key control based on the potential radiation hazard. When the logic detects an accelerator tunnel high radiation concentration or inadvertent access to a prompt radiation area, redundant signals will be sent to beamplugs to shut down the transport of the beam. Status of the prompt radiation protection areas and indication of the radiation levels will be provided on safety-significant panels in the MCR. The sensors, interlocks and beamplugs that are required to terminate beam transport are redundant.

The REPS has both active and passive features to protect the plant worker. Areas directly affected by the beam are provided with personnel access control barriers. These areas are also protected by sensors that detect high radiation or inadvertent access to the areas which are interlocked with beamplugs.

Sweeps of the protected areas are conducted prior to permitting the beam to enter an area. Sweeps start and end with warning horns. The sweep procedure uses sweep switches located throughout the protected areas to enforce a thorough inspection of the area. Scram buttons are located in the protected areas to allow an individual to abort the beam delivery if the individual is somehow left inside the area after a sweep.

"Scram" switches shall be provided as part of the interlock circuit to terminate beam transport at a point that will mitigate a prompt radiation hazard to personnel. Scram switches shall be provided in areas where personnel have access and there is a potential dose equivalent (PDE) level greater than 5 rem in TBD minutes. The scram switches shall be readily accessible so that an individual who is caught in an area during pre-startup or actual operations can shut down the production of radiation in the area. Scram switches shall be manually reset only locally at or near the area protected by the switch.

Sweep switches should be provided in prompt radiation areas with potential dose equivalent (PDE) levels greater than 0.1 rem and shall be provided in areas with PDE levels greater than 25 rem as a means of verifying that a search has been performed.

Sensors and Detectors

Each door or gate that is used as an entryway into a prompt radiation protected area is provided with redundant position sensors, based on the potential dose equivalent. Once a sweep of an area has been performed, any unauthorized attempt to enter a high prompt radiation area will cause an actuation signal.

Redundant radiation detectors (gamma and/or neutron) monitor the prompt radiation protected areas. Redundant beam current sensors monitor the beam. These devices are used to assure that beam current limits are not exceeded.

Beamplugs and Other Blocking Devices

Redundant beamplugs are used at the low energy portion of the accelerator to terminate beam transport when the REPS logic initiates an actuation signal. Upon the loss of a signal from the REPS Logic panels, the beamplugs are inserted (fail-safe).
Other design features directed at personnel exposure reduction include:

- Components designed modularly, easy to replace.
- Use of permanent shield walls:
  - between primary coolant motor & pump
  - between primary HX and other components
  - T/B vessel cavity shield door
- Coolant loop polishing
  - remote sluicing of ion exchange resin beds
- Easily deconable surfaces
- Retargeting air flow directional control
- Cladding of tungsten
- Large aperture to beam diameter ratio
- Boronated water in low energy beam stop shield tank
- Klystron garages (x-ray shield)
- CAMS to monitor for tritium release
- Double containment of tritium systems
- Storage of modules in pool

REFERENCES
