LA-UR-02-1259

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Title:

DARHT: INTEGRATION OF SHIELDING DESIGN AND ANALYSIS WITH FACILITY DESIGN

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Submitted to:

**12th Biennial Radiation Protection and
Shielding Division Topical Meeting
Radiation Serving Society
La Fonda Hotel, Santa Fe, NM
April 14–17, 2002**

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Prepared by the Los Alamos National Laboratory
Dynamic Experimentation Division

For the
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Dynamic Experimentation

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TABLE OF CONTENTS

Section	Description	Page
TABLE OF CONTENTS		ii
SUMMARY		1
1.0	BACKGROUND	1
2.0	APPROACH	2
3.0	RADIATION SOURCES	3
3.1	Normal-Beam Radiation Sources	3
3.2	Abnormal-Beam Radiation Sources	4
4.0	RADIATION TRANSPORT TO DOSE LOCATIONS	4
5.0	DOSE DESIGN OBJECTIVES	5
6.0	MODELING OF RADIATION SOURCES AND TRANSPORT	6
7.0	DOSE REDUCTION DESIGN	8
8.0	CONCLUSION	9
9.0	ACKNOWLEDGEMENTS	9
10.0	REFERENCES	9

DARHT: Integration of Shielding Design and Analysis with Facility Design

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SUMMARY

The design of the interior portions of the Dual Axis Radiographic Hydrodynamic Test (DARHT) Facility incorporated shielding and controls from the beginning of the installation of the Accelerators. The purpose of the design and analysis was to demonstrate the adequacy of shielding or to determine the need for additional shielding or controls. Two classes of events were considered: 1) routine operation defined as the annual production of 10,000 2000-ns pulses of electrons at a nominal energy of 20 MeV, some of which are converted to the x-ray imaging beam consisting of four nominal 60-ns pulses over the 2000-ns time frame, and 2) accident case defined as up to 100 2000-ns pulses of electrons accidentally impinging on some metallic surface, thereby producing x rays. Several locations for both classes of events were considered inside and outside of the accelerator hall buildings.

The analysis method consisted of the definition of a source term for each case studied and the definition of a model of the shielding and equipment present between the source and the dose areas. A minimal model of the fixed existing or proposed shielding and equipment structures was used for a first approximation. If the resulting dose from the first approximation was below the design goal (1 rem/yr for routine operations, 5 rem for accident cases), then no further investigations were performed. If the result of the first approximation was above our design goals, the model was refined to include existing or proposed shielding and equipment. In some cases existing shielding and equipment were adequate to meet our goals and in some cases additional shielding was added or administrative controls were imposed to protect the workers. It is expected that the radiation shielding design, exclusion area designations, and access control features, will result in low doses to personnel at the DARHT Facility.

1.0 BACKGROUND

As part of the U. S. Science Based Stockpile Stewardship Program, the Department of Energy (DOE) is building the Dual Axis Radiographic Hydrodynamic Test (DARHT) Facility to provide the world's most advanced weapons test facility (Figure 1). DARHT can be used for a wide range of tests and experiments from small-scale material science studies through full-scale tests of mock nuclear weapons components. DARHT will generate high speed, high resolution, three-dimensional, and time-sequenced x-ray images. The first axis of DARHT has been completed and used to produce images of weapons components that have significantly higher spatial resolution and penetration than was previously possible.

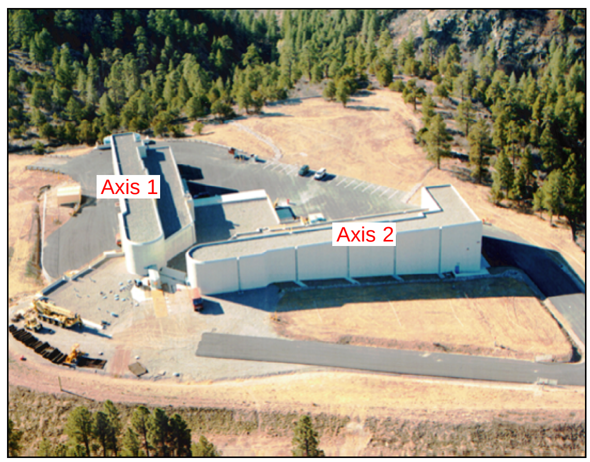

Figure 1 Areal View of the DARHT Facility

The DARHT Accelerator Building contains 39,650 sq. ft. It houses two accelerators, high-speed electronic and optical instrumentation, and equipment for the accelerator building and for operational support (Figure 2). The accelerators occupy two long wings or halls. A power-supply hall parallels each accelerator hall to house the electrical hardware that drives pulses in the accelerator. The detection chamber, control room, supporting facilities, assembly room, equipment room, and other workspaces are located between

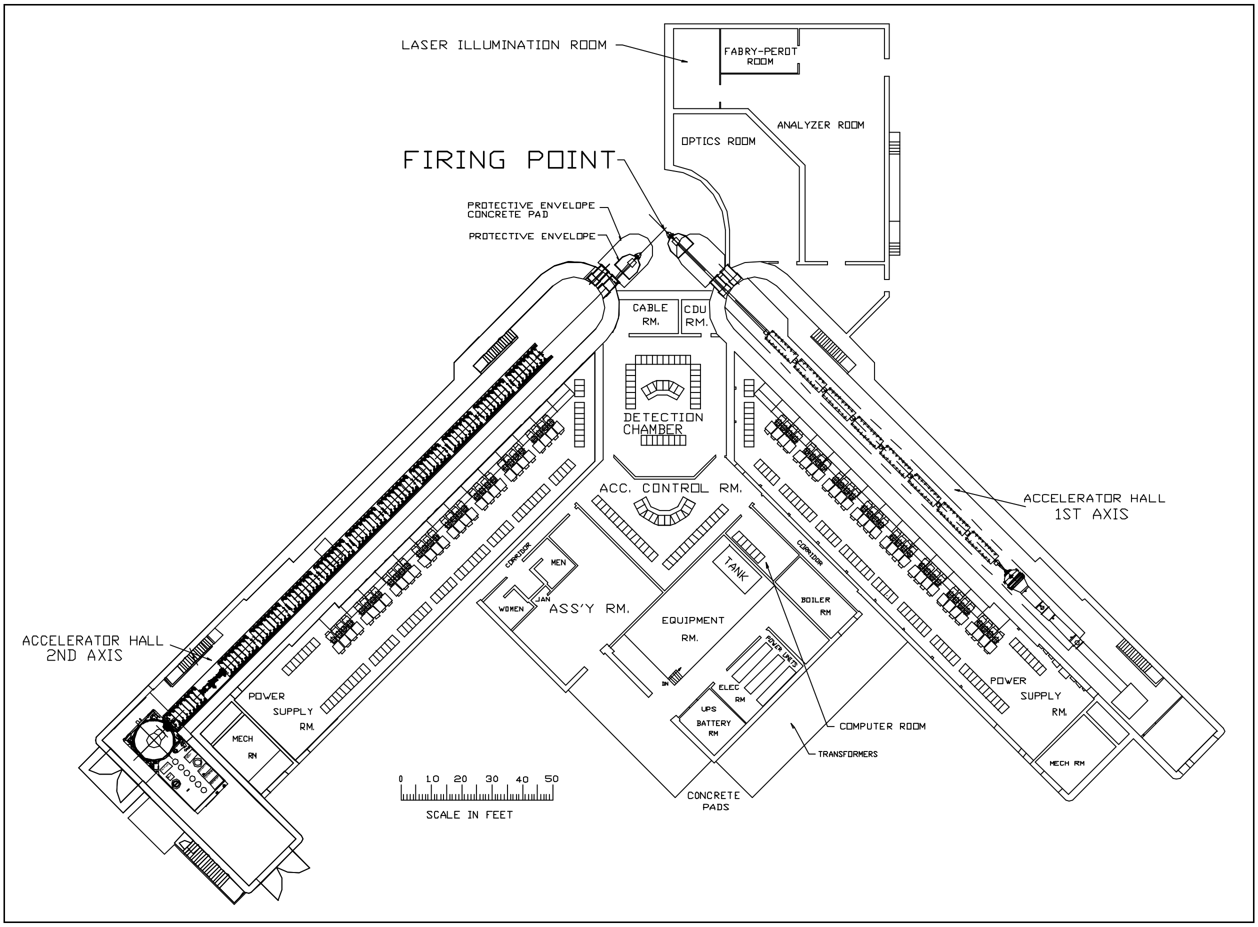

Figure 2 Plan View of DARHT Facility

the wings. The building is constructed of reinforced concrete, some of which is earth sheltered, which was designed primarily to resist blast forces from the detonation of explosives, but also to shield operating personnel from the radiation produced by the electron and x-ray beams. A reinforced-concrete floor provides radiation shielding for the equipment and personnel located beneath the accelerators.

During the construction of Axis-1, it was decided to provide an accelerator for Axis-2 that was both physically larger and produced an electron beam that developed approximately 30 times the integrated beam charge of the Axis-1 accelerator. This larger integrated beam intensity created a host of radiation shielding issues that were unique to the Axis-2 accelerator.

2.0 APPROACH

This paper presents the methodology used to analyze the radiation protection characteristics of the Axis-2 accelerator and building. Analysis methods for Axis 1 are discussed elsewhere.[1] Activation of accelerator structural components caused by photonuclear reactions is expected to be at a low level and has not been analyzed in this paper. Air activation is discussed in another paper to be presented at this conference.[2] An analysis of the doses from the normal and abnormal stopping of the Axis-2 beams is presented here. Doses were calculated for locations throughout the Axis-2 buildings, for the access-controlled Firing Site at the intersection of the two beams, and for uncontrolled areas external to the buildings such as parking areas and roadways.

Because the Axis-2 accelerator is to be commissioned in several phases, dose calculations were performed for each of the commissioning phases: Injector Commissioning, Accelerator Commissioning, and Downstream Transport and Target Commissioning. Injector Commissioning will test the injector, the first cell bank, and the Beam Cleanup Zone (BCUZ) at maximum beam energy of 4.7 MeV. Accelerator Commissioning will test the capability of the remaining accelerating cell banks downstream of the BCUZ to properly accelerate the beam to 20-MeV. The final phase of Downstream Transport and Target Commissioning will test the capability to send four sub-pulses from each 2-μsec, 20-MeV beam pulse to the x-ray producing tungsten or tantalum target to enable time-sequenced images. The four sub-pulses are magnetically "kicked" out of the primary beam. The remainder of the beam is magnetically bent to the Main Beam Dump. There are two operating modes for this final configuration. The first is beam transport to the Shuttle Dump, just downstream of the accelerating cells, that when engaged stops the beam to allow accelerator tuning while workers are performing experimental setup in the Firing Site. The second is for the Shuttle Dump unengaged thereby allowing beam transport to the target as previously described.

Those areas of the Axis-2 accelerator that were initially assigned as Exclusion or Non-Exclusion areas based on the original plan to duplicate the Axis-1 accelerator in the Axis-2 building received special attention. For example, the Axis-2 accelerator hall was expected to be and to remain an exclusion area during pulsing of the Axis-2 accelerator. The Firing Site and Blast House external to the accelerator halls were expected to be exclusion areas whenever beam was sent to the x-ray target and on to the Firing Site. However, it was expected that the extent of the Firing Site exclusion area might have to be enlarged because of the increased integrated beam charge of the Axis-2 accelerator. Primary consideration was given to ascertaining that doses in those areas initially planned to be Non-Exclusion areas remained at acceptable levels and, if not, to provide guidance for dose reduction. Of special concern were wall penetrations or structural characteristics that might result in significant doses to some occupied areas because of the greater integrated beam charge of the Axis-2 accelerator. The overall goal of the dose analysis effort was to discover all the areas of potential radiation hazard prior to the operation of the Axis-2 accelerator.

Dose reduction measures based on this calculated dose analysis might later be relaxed based on the results of the planned radiation monitoring program if it can be demonstrated that the actual operational doses were much less than the calculated doses.

3.0 RADIATION SOURCES

The current versus time profile of the electron beam pulse is generally depicted in Figure 3. The entire beam is intentionally or unintentionally stopped in accelerator components and in doing so results in photon and perhaps neutron production. Intentional and unintentional beam stoppages are hereafter referred to as normal and abnormal beams, respectively. The electron-photon cascading during stoppage of the electron beam in accelerator components causes photon production, primarily bremsstrahlung. With increasing atomic number (Z) of the slowing-down material, total photon production increases, photon energy spectrum hardens, and photon directional spectrum skews more in the direction of the electron beam. The photons produce neutrons when transporting through material with energies greater than the photoneutron reaction threshold. For a given photon energy spectrum, normally the threshold decreases and neutron production increases with increasing Z of the reacting material. It follows then that neutron production is greater when photons are produced in higher Z material and subsequently transported through higher Z material, which may or may not be the photon production material.

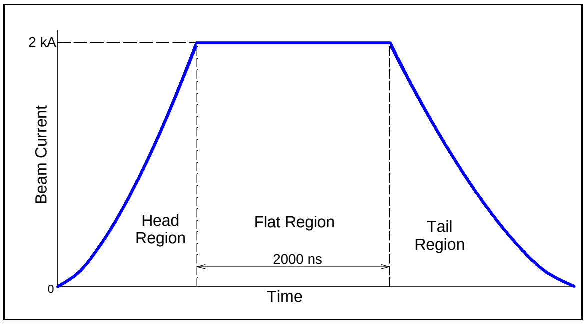

Figure 3 General Depiction of Electron Beam

3.1 Normal-Beam Radiation Sources

1. BCUZ. Under ideal conditions, the head and tail regions of the beam are removed in the BCUZ, leaving the 2-kA 2000-ns flat region undisturbed.

2. Injector Commissioning Beam Dump. This dump is a cylinder of graphite at least large enough to stop all 4.7-MeV beam electrons. It has a small hole along its center line to allow a very small portion of the electron beam to pass through to the spectrometer. Any photons produced by the pass-through beam, as well as the photons produced in the dump, will be attenuated by temporary shielding downstream of the spectrometer.

3. Accelerator Commissioning Beam Dump. This dump is composed of a graphite cylinder attached to a tungsten-alloy cylinder. The graphite dimensions were selected to stop all 20-MeV beam

electrons, and the tungsten alloy serves to attenuate photons produced in the graphite. Like the 4.7-MeV Dump, this dump has a small hole along its center line to allow a very small portion of the electron beam to pass through to the spectrometer, and again any photons produced by the pass-through beam will be attenuated by temporary shielding downstream of the spectrometer. Significant neutron production occurs near the upstream end of the tungsten alloy.

4. Shuttle Dump. This dump is composed of a two-cylinder arrangement of graphite and tungsten alloy with a steel/tungsten shroud around the graphite that extends upstream from the upstream face of the graphite. The purpose of the shroud extension is to stop any beam electrons that might bypass the graphite. A small amount of bypass is possible because the beam is deliberately spread over the face of the graphite to minimize heat-induced mechanical stresses. Like for the Accelerator Commissioning Dump, significant neutron production occurs near the upstream end of the tungsten alloy.

5. Target. It is either tantalum or tungsten whose thickness is selected to optimize photon imaging. Electrons passing through the target are bent by a permanent magnet to the inside of the thick-tungsten shield around the target. Significant neutron production occurs in the target.

6. Main Beam Dump. It is a graphite cylinder with dimensions selected to stop the magnetically bent portion of the 20-MeV beam not magnetically “kicked” to the target.

3.2 Abnormal-Beam Radiation Sources

1. Electron Beam Arcing from High-Potential Column to Wall of Injector Vacuum Tank. Arcing results from breakdown of column components. Photons production occurs during stopping of arc in wall of Vacuum Tank.

2. 3.2-MeV Electron Beam Impinging on Injector Anode.

3. Electron Beam Impingement in Beam Pipe. This abnormal beam is due to unintentional steering of the beam into the pipe wall or impingement into a foreign object accidentally left in the beam pipe. It is assumed to occur anywhere along the beam pipe at beam energies from 3.2 to 20 MeV. However, occurrences inside cell banks were ignored because of high attenuation offered by cell windings. Consequently, occurrences were evaluated in three primary axial regions: (1) at 4.7 MeV between injector- and accelerator-cell banks, (2) at 20 MeV downstream of the accelerator cell banks, (3) at 8.2-MeV in the last axial gap between accelerator cell banks before the 3-ft to 5-ft thickness transition of the Accelerator-Hall walls. No other gaps were considered for two reasons: (1) due to decreasing beam energy and Accelerator-Hall wall thickness in the upstream direction, exterior wall doses from the 8.2-MeV gap bound those from all upstream gaps; (2) due to increasing beam energy and constant 5-ft wall thickness in the downstream direction, doses from all downstream gaps are bounded by the 20-MeV wall doses downstream of the accelerator cell banks.

4. Full beam sent to target due to inoperative kicker magnet.

4.0 RADIATION TRANSPORT TO DOSE LOCATIONS

A large number of transport paths were chosen to calculate doses at locations of concern. Some of these dose locations are shown in Figure 4 and Figure 5. The paths are grouped into five broad categories: (1) transport through solid material assuming no penetrations, (2) direct transmission from source through a penetration, (3) direct transmission from source to vicinity of entrance of penetration entrance followed by scattering down the penetration, (4) transmission from source to Accelerator-Hall concrete shell followed by scattering to and through penetrations, and (5) air and ground scattering of target radiation. Not every transport path was calculated for every source; a judgment was often made whether the transport path from a particular source would result in significant dose. The transport paths considered are listed as follows:

- Transport through concrete shell of Accelerator Hall: roof, exterior wall, wall on Power-Supply-Room side, and floor above Equipment Room
- Direct transmission down beam pipe to Firing Site
- Direct transmission from site of anode accident to personnel side entry in Marx Injector Room
- Scattering from Accelerator Hall walls to rear double doors and personnel side entry in Marx Injector Room
- Direct transmission from source to entrances of cable ports and chill-water pipe in wall between Accelerator Hall and Power Supply Room followed by scattering down the ports and pipe

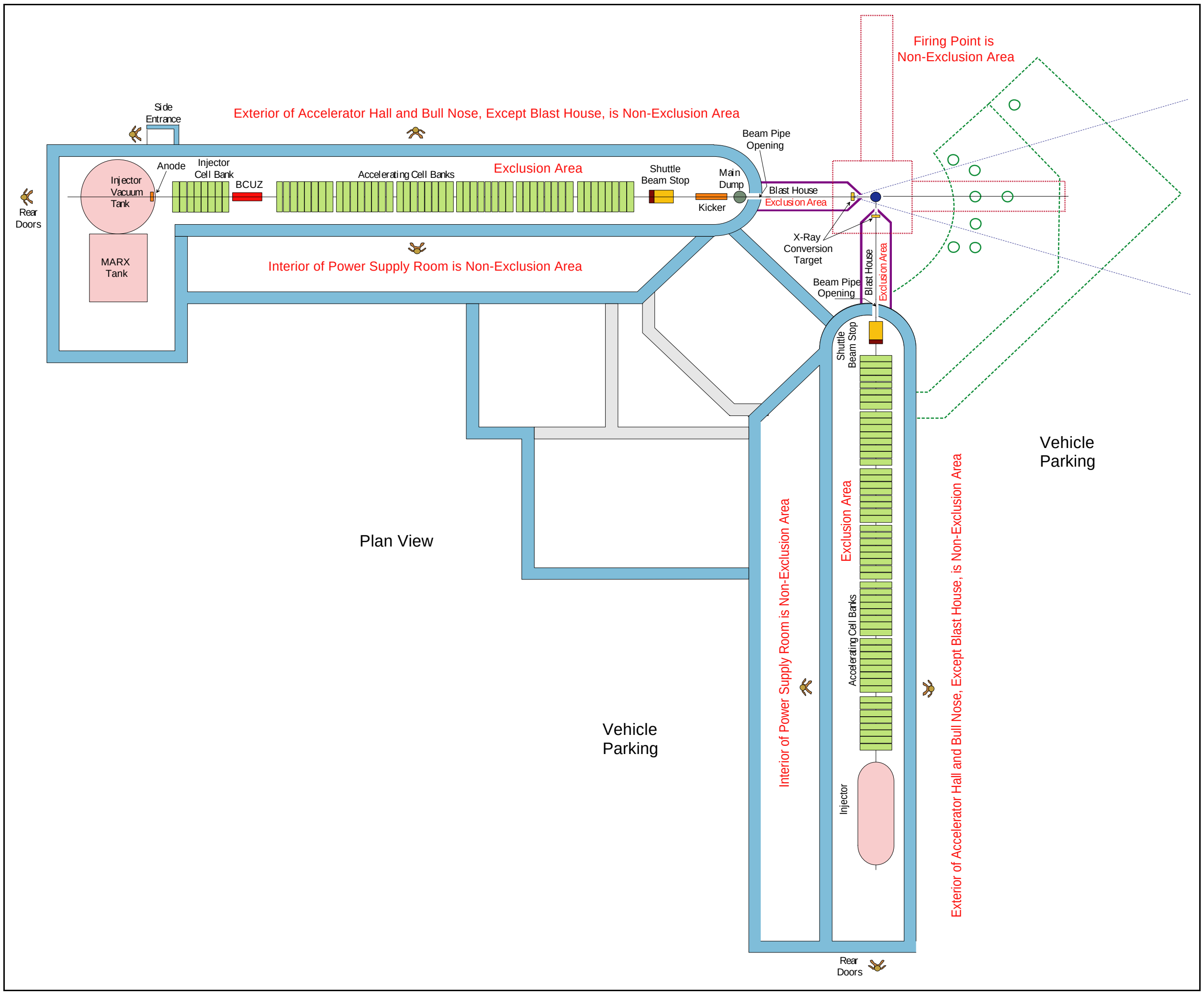

Figure 4 Plan-View Depiction of Calculated Dose Locations for DARHT

- Direct transmission from BCUZ to ventilation duct in floor of Accelerator Hall followed by scattering to door of stairwell entry from Power Supply Room
- Transport from BCUZ through ceiling of stairwell entry from Power Supply Room followed by scattering to stairwell entry door
- Target radiation scattered by air and earth berm to vehicle parking lot outside Analysis Room
- Direct target transmission to camera ports in ceiling of Optics and Analysis Rooms below Firing Site followed by scattering down the ports

5.0 DOSE DESIGN OBJECTIVES

For normal beam conditions, the DOE-specified design objective of less than 1 rem/yr was used.[3] To apply this objective requires specifying the annual number of accelerator pulses and personnel occupancy at dose locations. A conservative 10,000 annual pulses was assumed for each commissioning stage and operating mode. Worker dose was estimated only for individual locations; there was no attempt to estimate the sum of doses a worker would receive at multiple locations. If dose was calculated to be less than 1 rem/yr for 100% occupancy, then no further action was taken. Otherwise, reduced occupancy was invoked if it could be justified; at most dose locations occupancy is much less than 100%. If dose still exceeded 1 rem/yr, shielding or occupancy exclusion was imposed or radiation protection monitoring was invoked to reduce dose to less than 1 rem/yr. Radiation protection monitoring was invoked for general locations where actual dose received, even at 100% occupancy, as measured by personal dosimeters, is expected to be much less than calculated dose. Calculated dose should nearly always be greater due to

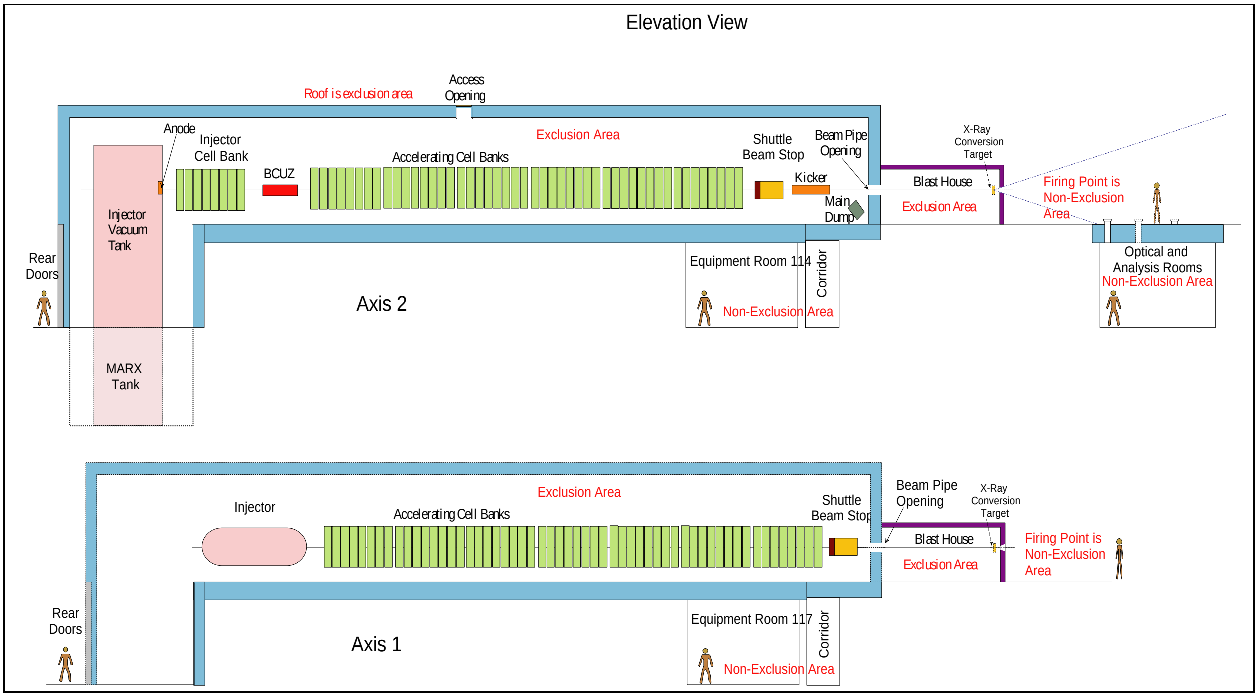

Figure 5 Elevation-View Depiction of Calculated Dose Locations for DARHT

conservative assumptions, e.g., it being calculated at a worst-case location within a larger location in which workers move about. To be specific, if calculated dose is 10 rem/yr, and personal dosimeters are read monthly, the radiation protection monitoring system will flag any monitored worker at that location before they receive 1 rem. However, because measured dose will likely be much less than the calculated 10 rem/yr, it is unlikely that any the worker would ever be flagged and be subjected to occupancy restrictions.

No DOE-specified design objective exists for abnormal-beam conditions, but the DARHT Project imposed a goal of less than 5 rem for each abnormal-beam condition. Two very conservative assumptions were imposed for satisfying this dose objective: 1) except for high potential arcing to the vacuum tank, all abnormal beams were assumed to persist for 100 pulses before being detected and 2) 100% occupancy was imposed at the worst dose location during the abnormal beam condition. Only one pulse was assumed for high potential arcing to the vacuum tank because a single arc would be easily detected. If calculated dose exceeded 5 rem per abnormal beam condition, shielding or controls were imposed.

Independent of calculated doses for normal and abnormal beams, the radiation-protection monitoring program will be used to ensure that personnel do not receive more than 1 rem/yr of normal-beam dose or verify that they do not receive more than 5 rem during an abnormal-beam condition. In addition to personal dosimeters worn by all workers, dosimeters will be placed at locations with potentially elevated doses. If a significant abnormal beam is detected, personal dosimeters will be read immediately for workers in the vicinity of the abnormal beam.

6.0 MODELING OF RADIATION SOURCES AND TRANSPORT

Radiation doses were calculated with the Monte-Carlo radiation transport code MCNP Versions 4C and 4C2,[4] data library MCNPXS[5], and energy-dependent fluence-to-dose conversion factors for effective dose equivalent.[6,7] Versions 4C and 4C2 of MCNP are hereafter referred to as MCNP4C and MCNP4C2, respectively. Starting with the electron beam impinging on material, either code can generate photons in coupled electron-photon transport and transport the photons to dose tallies where the recorded fluences are converted to photon dose with the fluence-to-dose conversion factors. MCNP4C2 has the additional capability of producing neutrons from photons and then transporting the neutrons to dose tallies where the recorded fluence is converted to neutron dose. Also, the transporting neutrons can produce photons that can be transported to photon dose tallies.

The modeling of normal and abnormal electron beam impingement on materials was highly idealized and conservative. This was necessary because of incomplete knowledge of beam parameters and practical necessity to simplify modeling.

Modeling similarity exists among normal-beam impingements on the BCUZ, Injector-Commissioning and Main-Beam Dumps, target, and abnormal-beam impingements along the beamline and at the injector anode. In every case, the beam was assumed to impinge perpendicularly at the center of the upstream face of a disk of the actual material being impinged and whose axis coincides with the beam direction. Except for the target, disk dimensions were selected to approximately maximize photon emission and are therefore similar to the electron slowing-down range corresponding to the beam energy. For normal beams on the dumps, the full 2000-ns flat region of the beam is impinged on a disk of graphite. For normal beam on the BCUZ, the head, "pre-crowbar" tail, and 100-ns of the flat region were assumed to impinge on a disk of stainless steel. The 100-ns region was included to account for delay in shutdown of a straying beam, and the "pre-crowbar" tail is the region of the tail that exists before the beam is shunted and goes to zero almost instantaneously. For abnormal beams, the whole beam (head, 2000-ns flat, and tail) is impinged on a stainless steel disk. Except for normal-beam on the Main Beam Dump and abnormal-beam on the anode, beam impingement direction was coincident with the beamline. Impingement on the main dump coincided with the dump axis, which is tilted downward from the beamline. For anode impingement, the beam was azimuthally deflected from the cathode toward the edge of the anode in the plane defined by the beamline and dose location.

The modeling of normal-beam impingement on the Accelerator Commissioning and Shuttle Dumps was more complicated due to incomplete knowledge of spatial variation of the impinging beam. The full 2000-ns flat region of the beam was assumed to impinge on both dumps. For all doses from the Commissioning Dump, the beam was uniformly and perpendicularly impinged on the upstream face of the graphite over an area equal to that of the inside of the beam pipe. For doses from the Shuttle Dump directed down the beam pipe, the beam was uniformly and perpendicularly impinged over the whole upstream face of the graphite. To account for the lateral dose from possible bypass beam impinging on the tungsten/steel shroud extension, 10% of the beam (much more than anticipated) was assumed to uniformly impinge at constant polar angle on the inside surface of the extension, and the polar angle was varied to 90°.

Simple approximations were made in modeling time variation of energy and current in the head and tail regions of the impinging electron beam.[8] Electron current and energy were assumed to be constant during the flat region of the beam. Energy in the head and tail regions was modeled as the sum of energy gains in the injector and accelerating cells. The energy gain in the injector was assumed to increase linearly over the whole time regime of the head and decrease linearly over the whole time regime of the tail. The energy gain in the accelerating cells was assumed to be zero over the first half of the head, increase linearly over the last half of the head, decrease linearly over the first half of the tail and be zero over the last half of the tail. For both the head and tail, the electron current was assumed to be proportional to the injector energy gain to the 3/2 power.

Due to long computer times necessary for electron transport to generate sufficient photons, it was rare to calculate photon dose in a single-step MCNP calculation starting from beam electrons impinging on material. For abnormal beams and normal beams on the BCUZ and Injector-Commissioning and Main-Beam Dumps, and target, doses were mostly determined in two steps consisting of (1) first calculation of the electron beam slowing down in steel or graphite and tallying polar-angle and energy distributions of photons emerging from the steel, and (2) second calculation of the tallied distributions from the first calculation used as a source for transporting photons to dose tallies.

For the Accelerator Commissioning and Shuttle Beam Dumps, doses were calculated in different multi-step calculational sequences, depending on type and direction of particle transport and available methods for neutron generation and transport. For forward photon and photoneutron transport directed down the beam pipe or lateral photoneutron transport through the Accelerator-Hall concrete shell, MCNP4C was employed using approximate multi-step methodology.[9,10] The first step for the three transport modes consisted of generating a photon source by tallying photons emerging from the graphite region. For forward transport, photon dose was calculated by transporting photons from this source through the tungsten-alloy region and then down the beam pipe. Calculating both forward and lateral photoneutron dose was done in two additional steps. In the first step, photoneutron spatial generation was improvised in the tungsten alloy by incorporating photoneutron-production cross sections as fluence tally modifiers in photon transport in the tungsten alloy. In the second step, using an ad hoc photoneutron energy spectrum and assuming isotropic photoneutron emission, neutrons were started from their generated spatial distribution and transported either axially through the tungsten alloy and then down the beam pipe or laterally through the tungsten alloy and the concrete shell. As a check on this approximate methodology for calculating the doses from photoneutrons, MCNP4C2, when it became available, was used to calculate the forwardly directed doses starting from the photon source. The resultant doses were similar to those from the approximate methodology.

Two steps were employed for lateral photon transport through the Accelerator-Hall concrete shell from the Accelerator Commissioning and Shuttle Beam Dumps. The first step utilized the surface-source-write capability of MCNP. With the impinging electrons on the graphite as the source, photons were individually recorded in a file listing their position, energy, and direction if they passed through a set of surfaces either partially or totally enclosing the dump. For the Shuttle Dump, the surfaces enclosed the whole dump, whereas for the Commissioning Dump they enclosed only the graphite region. In the second calculation, photons from the surface-source file were started on the same surfaces on which they were recorded and then transported through the remaining portion of the dump – tungsten alloy shield for the Commissioning Dump and nothing for the Shuttle Dump – and the concrete shell.

Neutron doses from the tantalum target were not calculated in areas occupied by workers during downstream transport. This decision was based on the small ratio of neutron-to-photon doses calculated for various polar angles and at 1 m from an isolated tantalum target. The neutron doses were calculated in one step with MCNP4C2 starting with the electron beam and were small relative to the photon doses over the whole (-180º, 0º) polar-angle range.

Forward photon emission from the target was limited to a polar-angle cone of 17º. This cone is an upper bound estimate of emission formed by the permanent tungsten shielding around the target. No shielding credit was taken for any removable shield and collimator that will often be present when beam is sent to the target.

The dose at the beam-pipe opening inside the Axis-1 bullnose due to photons emitted from the Axis-2 target striking an object at the firing point and then scattering down the Axis-1 beamline was calculated for worst-case assumptions. The worst combination of locations of the Axis-2 target and Axis-1 target shield assembly and parameters for the object at the firing point was assumed. The Axis-2 target was located as close as possible to the firing point, and the Axis-1 target shield assembly was located as far as possible away from the firing point. The object at the firing point was a slab subtending the 17º polar-angle emission cone and rotated counterclockwise 45º relative to the Axis-2 beamline, and whose material composition and thickness were varied to maximize photon scattering down the Axis-1 beamline.

7.0 DOSE REDUCTION DESIGN

The calculated dose analysis determined the shielding configurations and exclusion areas necessary to provide adequate dose reduction. The analyses confirmed the high radiation hazard near radiation sources inside the Accelerator Hall and in the Firing Site when beam is sent to the Target and therefore the need to exclude occupancy in these areas. All other exclusion areas present only moderate radiation hazard. Except for the roof and near penetrations, the Accelerator-Hall concrete shell provides sufficient dose attenuation for radiation sources located inside the Hall. Shielding and exclusion areas were necessary to reduce dose exposure through the penetrations and the roof was designated as an exclusion area. The dose analysis determined that all areas outside the Accelerator-Hall enclosure, except the Firing Site and the shielded exclusion area around the personnel entry door to Marx Injector Room, can be occupied when beam is sent to the target.

A complete list of added shielding and exclusion-area designations follow:

Added shielding

- Injector Commissioning Beam Dump

- Accelerator Commissioning Beam Dump
- Shuttle Beam Dump for Downstream Transport
- Plugs for camera ports in Optics and Analysis Rooms
- Shielded exclusion area around personnel entry door to Marx Injector Room
- Shield fill material around beam pipe in opening in Bullnose wall through which beam pipe passes.
- Temporary shield in beamline downstream of accelerator cells banks during Injector Commissioning
- Temporary shield in beamline downstream of spectrometer during Accelerator Commissioning
- Shield fill in laser port through Accelerator Hall floor above Equipment Room

Regions designated as exclusion areas

- Interior of Accelerator Hall during any pulsing of the accelerator
- Firing Site when sending beam to target
- Roof of Accelerator Hall during any pulsing of the accelerator
- Blast House during Accelerator Commissioning and downstream transport either to Shuttle Dump or target
- Cable trays near cable ports in wall separating Accelerator Hall and Power Supply Room during any pulsing of the accelerator
- Entrance from Power Supply Room to stairway leading to Accelerator Hall in the axial vicinity of the BCUZ during any pulsing of the accelerator
- Near chilled water lines in wall separating Accelerator Hall and Power Supply Room during any pulsing of the accelerator (will be included in exclusion area of cable trays near cable ports)

Doses were not calculated for some locations where large doses are possible, but are already inside exclusion areas designated so because of high doses calculated at other locations in the exclusion area. For example, doses through the chill-water penetrations were not calculated because the penetrations are located inside the cable-port area that was already designated as an exclusion area because of high doses from the cable ports.

These shielding additions and exclusion-area designations might be relaxed if doses measured during accelerator pulsing turn out to be much less than calculated normal-beam estimates. This must be done with caution. It must be established that the radiative state of the accelerator during future operations with the relaxed measures will be similar to that during the dose measurements. Any measures implemented to mitigate calculated abnormal-beam doses cannot be removed on the basis of dose measurements, which normally would include only normal-beam dose.

8.0 CONCLUSION

It is expected that the radiation shielding design, exclusion area designations, and access control features, will result in low doses to personnel at the DARHT Facility.

9.0 ACKNOWLEDGEMENTS

The authors acknowledge the support and involvement of numerous persons working on the DARHT Project.

This work was performed under the auspices of the U.S. Department of Energy, Los Alamos National Laboratory, which is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36.

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