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PHASE 2

Final Safety Analysis Report for the Ground Test Accelerator (GTA)

October 1994

Prepared by Los Alamos National Laboratory
Accelerator Technology (AT) Division
Los Alamos, NM 87545

Although it seems that we will never know exactly what caused this accident, a probable scenario can be pieced together from the facts as found by the jury, the photographs which were taken, and the analysis of the experts. It was quite evident that the tank was severely damaged in the fire which occurred on Saturday, September 7th. It also appears that the tank was venting normally up until Sunday morning when the decision was made by the man in charge for Air Products & Chemicals, Inc., the manufacturer and party responsible for the tank, to remove the vacuum which provided insulation to the liquid hydrogen contained in the inner tank. There is some speculation, and no absolutely conclusive evidence, that a partial blockage occurred in the pressure relief system for the tank as a result of either impurities in the tank contents, water sprayed on the tank after the fire, water condensed from the atmosphere following the removal of the vent stack by Air Products employees on Saturday evening, or from the nitrogen purge placed on the tank Saturday evening. The analysis of photographs, reveals that the partial blockage apparently in existence up until Sunday morning was not so severe as to prevent the escape of reasonable amounts of hydrogen which are normally vented. The release of the vacuum on the tank resulted in a dramatically increased rate of venting, and because of the partial blockage the increased amounts of gas could not escape. The result was the buildup in pressure during the course of one to two to three hours Sunday morning resulting in the rupture of the tank around noon.

If there is a moral to the story as far as fighting future fires in pressurized tanks, it must be that nothing should be done to drain the tank until it is absolutely certain that the valves and control mechanisms provide adequate control to the people in charge. Here, the main pressure gauge of the tank was apparently on a blocked line, and although the gauge itself was replaced, the Air Products people were never able to know what the pressure inside the tank was. They interpreted the reading of Zero pressure to mean that the tank was venting normally at atmospheric pressure, when in fact pressure was building at an ever-increasing rate. It is apparent that the Air Products people would not have cracked the vacuum had they known the actual conditions, and presumably the proper way to prevent a re-occurrence of this disaster is to insure that the gauges, valves, and controls are in working order before any actions are taken on a damaged tank.

Chief Haskell Keeton
Fire Marshal A. C. Black
17000-7478
November 16, 1973
Page Three

We thank your again very much for your assistance in this matter, and complement you on the operation of your professional department. If I can provide any further information to you, please do not hesitate to call on me.

Yours very truly,

ROBINS, DAVIS & LYONS

David F. Herr

David F. Herr

DFH/ld

cc: Robert Lee

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

memorandum

TO: Walt Stewart, A-4, MS F611

DATE: September 29, 1989

THRU: Ron Stafford, HSE-DO, MS K491

MAIL STOP/TELEPHONE: K490/5-0239

FROM: Jean Dewart, HSE-8

SYMBOL: HSE8-89-595

SUBJECT: **DISPERSION OF HYDROGEN FROM POSTULATED ACCIDENTS AT THE GROUND TEST ACCELERATOR (TA-53)**

Summary

Downwind air concentrations of hydrogen were calculated for four postulated accident scenarios at the Ground Test Accelerator (GTA) at Technical Area (TA) 53. Air concentrations were compared to the flammable and explosive limits of hydrogen and an estimate of the mass of hydrogen available for detonation was made. The blast damage by distance was also calculated.

The analysis uses several conservative assumptions; the results of these calculations can be considered a "worst-case" analysis for an unconfined cloud. However, the question of partial confinement by nearby structures has not been addressed. The results of the calculations may call for a more detailed analysis.

The calculations indicate the potential for a detonatable cloud to extend up to 140 m downwind from GTA and a flammable cloud to extend up to 280 m downwind. The detonation analysis shows that the distance to heavy damage (see Table 5 for description of damage) ranges from 15 to 25 m from the center of detonation. When the height of the cloud rise above the ground is considered, the distance to heavy damage will be above most of the nearby buildings. The distance to repairable damage ranges from 30 to 50 m from the center of detonation. Considering the cloud rise, nearby buildings could receive repairable damage. Major glass damage could be expected at other TA-53 buildings.

Other questions that these calculations do not address include:

1) probability of occurrence for each accident scenario, and

2) probability of detonation given an explosive mixture of hydrogen.

A description of the calculations are attached.

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CMR-4 (2), MS A150

WHAZAN Model

Several submodels of the WHAZAN (World Bank HAZard ANalysis) computer code (Technica 1988) were used in this analysis. WHAZAN was developed by the World Bank to evaluate hazards for proposed chemical plants. The submodels used included: liquid outflow, pool spreading and evaporation, dense gas dispersion, and unconfined vapor cloud explosion.

Source Term

The source terms for each accident scenario were calculated by Fred Edeskuty and Walt Stewart (1989):

LH2 Transfer Line Break near the Storage Dewar	2847 g/sec,
LH2 Transfer Line Break at Bend	730 g/sec,
LH2 Transfer Line Break at Run Dewar	530 g/sec, and
LH2 Fill Line Break	830 g/sec.

The source terms were also independently calculated using the WHAZAN model for liquid outflow with similar results. The hydrogen is released in liquid form at 20 ^{o}K.

NASA Spill Tests

NASA conducted a series of liquid hydrogen spill tests in 1980 at the White Sands Missile Range (Chirivella 1986). The release rates for these tests are within an order of magnitude of the release rates postulated for the GTA accident scenarios. The calculation methods used in this analysis were used with the NASA source terms to calculate the extent of the flammable cloud. The calculated values were then compared to the observed values (Table 1). The methods used produced a reasonable comparison of downwind flammable cloud extent for neutral (Test 7) and slightly unstable (Test 6) atmospheric conditions (no tests were performed at night under stable conditions). For the two tests conducted under unstable atmospheric conditions (Tests 3 and 4), the downwind extent of the flammable cloud was underpredicted by a factor of 2 to 3. During Test 5, the calculation overpredicts the downwind extent by 75%. However, it is noted that Tests 3, 4 and 5 provided the poorest data recovery because of adverse wind directions, so it is not certain what produced the poor comparison. For this analysis, because of the underprediction of downwind cloud extent, it is concluded that the calculation methods are not appropriate for unstable atmospheric conditions.

Theoretical Calculations

A numerical study of two very large liquid hydrogen spills, 3 million gallons and 1500 gallons, was performed by Mike Williams (Edeskuty 1980). Williams concluded that a flammable cloud could exist for large distances (4 km for the 1500 gallon spill and 40 km for the 3 million gallon spill) under stable nighttime conditions.

Dispersion Analysis

At 20 ^{o}K, liquid hydrogen is heavier than air. The WHAZAN dense cloud dispersion model (Cox and Carpenter, 1980) was used to calculate the spread of the liquid hydrogen as it released during the accident. The model includes the effects of gravitational spreading, heating of the cloud by the ground, entrainment of air into the cloud sides as a function of the area of the cloud size, and entrainment of air into the cloud through the cloud top as a function of the atmospheric stability. For all release scenarios, the hydrogen mixes with air in a few meters to form a neutrally buoyant cloud. Thus for this analysis, the phase of dense cloud dispersion was neglected and only the neutral and buoyant stage of the cloud was modeled.

The pool spreading and evaporation model was also used for a comparison calculation. For each scenario, hydrogen evaporates as it is released. Thus the release rate for each accident scenario is used as the source term in the dispersion calculation.

Plume rise was calculated using the Briggs equations for buoyant plume rise (Briggs 1975). It was assumed for this calculation that there was no initial vertical velocity. This is a conservative assumption. It is unlikely that the initiating event of the accident would cause the hydrogen to flow horizontally from the pipe break. It is more likely that the hydrogen would be released downward, allowing it to "bounce" up from the ground, or released upward with an initial vertical velocity. This is consistent with the field tests performed by NASA (Dr. Jose Chirivella, personal communication, 1989). The plume height for each release with distance is presented in Table 2.

Downwind dispersion was calculated using a Gaussian dispersion equation (Slade 1968) using dispersion coefficients developed by Briggs (1973). Calculations were made for two meteorological conditions: slightly unstable (C) daytime and slightly stable (E) nighttime. Wind speeds of 1 and 3 m/sec were assumed for both cases. The 1 m/sec speed is common during the morning and nighttime hours; the 3 m/sec speed is the annual average wind speed for Los Alamos.

The effect of nearby buildings potentially confining the released hydrogen has not been considered. Partial confinement by the buildings may increase the potential for detonation and produce locally higher concentrations of hydrogen than have been calculated in this analysis. Two factors which will tend to increase the dispersion of the cloud have not been considered in this analysis: the turbulence produced by the accident initiating the spill and the enhanced dispersion produced by the nearby buildings.

The distances to the downwind limit of flammability and detonatability are presented in Table 3 for the various atmospheric conditions. The distances range from 30 m to 280 m for a flammable cloud and 20 m to 140 m for a detonatable cloud.

Detonation Analysis

Hydrogen is considered flammable between 4% and 76% and detonatable between 18% and 59% concentration by volume (Hord 1976). The volume of the cloud within the detonatable limits is determined from the distance between the centerline concentrations of 18% and 59% and assuming a Gaussian distribution of hydrogen off centerline. For each case, this makes the detonatable cloud a long tube in shape. The estimated mass of hydrogen in the detonatable range, assuming the longest downwind distance to the detonatable cloud, for each accident scenario is presented in Table 4.

The unconfined vapor cloud explosion submodel of WHAZAN was used to calculate the blast overpressure and damage produced in each accident scenario. The model calculates the damage radius as follows:

$$r(s) = C(s) * (N * E)^{1/3},$$

where r is the radius to a level of damage, m,
C(s) is a coefficient defining the level of damage (Table 5),
N is the yield factor, assumed to be 0.11, and
E is the total energy of the explosion, the heat of combustion times the mass.

The calculation assumes that all of the mass is located at a point; it does not take into consideration the "tube" shape of the detonatable hydrogen. The distances to the different categories of blast damage for each accident scenario are presented in Table 6.

The distance to heavy damage ranges from 15 to 25 m. When the height that the cloud rises above the ground is considered, the distance to heavy damage will be above most of the nearby buildings. The distance to repairable damage ranges from 30 to 50 m. Considering the cloud rise, nearby buildings could receive repairable damage. Major glass damage could be expected at other TA-53 buildings.

References

Briggs 1973: G.A. Briggs, Diffusion estimation for small emissions. In "Atmospheric Turbulence and Diffusion Laboratory 1973 Annual Report" (NOAA/ATDL, Oak Ridge, TN, Publication no. ATDL-106), pp 83-145.

Briggs 1975: G.A. Briggs, "Plume Rise," in Lectures on Air Pollution and Environmental Impact Analyses, American Meteorological Society, Boston, Massachusetts, October 1975.

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Hord 1976: J. Hord, "Is Hydrogen Safe?" National Bureau of Standards, Department of Commerce, Report No. NBS-TN-690, October 1976.

Slade 1968: D. H. Slade, Ed., "Meteorology and Atomic Energy," U.S. Atomic Energy Commission report TID-24190 (July 1968).

Technica 1988: "Techniques for Assessing Industrial Hazards, A Manual," World Bank Technical Paper Number 55, Technica, Ltd., The World Bank, 1818 H St. N.W., Washington, D.C., 20433, June 1988.

Table 1. **Comparison of Downwind Extent of Flammable Cloud: NASA Test Data versus Calculated**

Maximum Downwind Distance to Flammable Cloud (m)

NASA Test Number	NASA Test Data	Calculated Value	Atmospheric Stability
7	60	70	D
2	75	80	A
5	110	175	D
3	125	40	B
6	160	180	C
4	210	115	B

Table 2. Plume Height with Distance, m

Source Term g/sec	wind speed m/sec	Downwind Distance, m 25	50	75	100	150	200
2347	1	50	85	110	135	180	215
	3	18	30	37	45	60	70
730	1	35	55	70	85	110	140
	3	10	20	23	30	38	45
530	1	30	50	65	80	100	125
	3	10	15	21	25	35	40
830	1	35	55	75	90	120	145
	3	12	20	25	30	40	50

Table 3. [illegible]

Distance to End of Flammable Cloud (4% H_2 conc), m

Source Term (g/sec)	daytime 1 m/sec	daytime 3 m/sec	nighttime 1 m/sec	nighttime 3 m/sec
2347	130	80	280	170
730	70	40	140	90
530	60	30	120	70
830	70	40	160	90

Distance to End of Detonatable Cloud (18% H_2 conc), m

Source Term (g/sec)	daytime 1 m/sec	daytime 3 m/sec	nighttime 1 m/sec	nighttime 3 m/sec
2347	60	40	140	80
730	30	20	70	40
530	30	20	60	30
830	30	20	70	40

[illegible]

Source Term (g/sec)	daytime 1 m/sec	daytime 3. m/sec	nighttime 1 m/sec	nighttime 3 m/sec
2847	30	20	50	30
730	10	10	30	20
530	10	10	30	10
830	10	10	30	20

Table 5. Values of Level of Damage Coefficient

(s)	Limit Value ($mJ^{-1/3}$)	CHARACTERISTIC DAMAGE To Equipment	to People
C(1)	0.03	Heavy damage to buildings and to process equipment	1% death from lung damage >50% eardrum rupture >50% serious wounds from flying objects
C(2)	0.06	Repairable damage to buildings and damage to the facades of dwellings	1% eardrum rupture 1% serious wounds from flying objects
C(3)	0.15	Glass damage	Slight injury from flying glass
C(4)	0.4	Glass damage to about 10% of panes	

Table 6. Distances to Damage Categories from Hydrogen Cloud Detonations, m

Mass of hydrogen, kg	Heavy Damage	Repairable Damage	Major Glass Damage	10% Glass Damage
10	15	30	75	200
20	20	40	95	250
30	20	45	110	290
50	25	50	130	350

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

memorandum

TO: Keith Boyer/Jan Novak, MP-7, MS H840

DATE: September 11, 1989

FROM: Paul R. Guthals, QAO *Paul*

MAIL STOP/TELEPHONE: A120/7-3535

SYMBOL: ADO/QA-89-764

SUBJECT: REVIEW OF CVI/GTA QUALITY ASSURANCE PROGRAM PLAN

The review of the CVI Quality Assurance Program Plan (by Paul Guthals, QAO and Lloyd Schemp, MEE-9) was at your request. The documents reviewed consisted of the following: 1. CVI Quality Assurance (QA) Manual, 2. CVI QA Plan (29 July 89), 3. LANL/CVI subcontract (effective date 12 June 1989) 9-L69-9086Y-1, 4. Statement of Work (21 Oct 1988) 9-L69-9086Y, 5. CVI Technical Proposal for the Cryogenic Cooling System GTA (# P18879 19 Dec 88), 6. CVI "Best and Final Offer" (15 Feb 1989).

All of these documents needed to be reviewed for us to develop an understanding of the GTA and CVI QA responsibilities and interactions. Generally the CVI approach (on paper) to quality is good. CVI's quality program implementation is being paid for under the subcontract. GTA, therefore, needs to take the utmost advantage of CVI's QA activities to insure that the Safety Analysis Report (SAR) and any pre-operation reviews and demonstrations are adequately supported. This includes an active QA role by local project people. This latter facet has been discussed with Ed Kemp and Walt Stewart.

Our interviews and documentation reviews pointed out an issue involving the lack of clarity on the contractual commitment by CVI for implementation of a QA program. The SOW makes little or no direct reference to a QA requirement. CVI does, however, address the issue and its solution in the Technical Proposal (# P18878 19 Dec 88, #5 above). The subcontract incorporates this proposal in a somewhat "back handed" fashion (section F #2-4 of Subcontract, #3 above). It states that the Technical Proposal will be used in resolving inconsistencies "if incorporated into this subcontract by reference or otherwise." No "reference or otherwise" can be identified as the subcontract presently stands. We would recommend that a contract modification statement be made incorporating the Technical Proposal as a subcontract requirement source to, among other things, preclude any misunderstanding about the requirements for an acceptable CVI QA activity in support of this contract.

The significance of QA in the satisfaction of DOE safety and project management requirements prompts a more general comment. Quality programs and their assurance (QA) for projects such as GTA should be an integral part of a project from its earliest inception. It becomes increasingly difficult to begin implementation of such an activity (QA) at later times and still make convincing cases that we have adequately satisfied all of the DOE pre-operational requirements. These, of course, need to be satisfied to insure modern day operation approvals. A "Good Faith" effort leading to an early project-wide QA program's development and implementation will surely pay dividends in obtaining the required approvals, as well as having our overall system work with a minimum number of "glitches."

We hope that our review comments and advice will prove to be useful in the successful conclusion and eventual operation of GTA. Please do not hesitate to contact me at 7-3535 if we can be of further assistance.

PRG:wh

Cys:
CRM-4, MS A150
File

APPENDIX T

GROUND TEST ACCELERATOR

SYSTEM DESIGN DESCRIPTION

RADIATION PERSONNEL SAFETY SYSTEM

Prepared by Los Alamos Technical Associates, Inc.
Revised March 15, 1993

TABLE OF CONTENTS

FIGURES AND TABLES

1.0 INTRODUCTION

The System Design Description (SDD) for the Radiation Personnel Safety System (RPSS) includes an in-depth description of the physical and electronic systems used to protect personnel before, during, and after operation of the Ground Test Accelerator (GTA). This includes descriptions of the primary and secondary safety-barrier systems, system-design requirements, system limitations, operational aspects of the system, and significant calibration and maintenance of the system instrumentation.

Figure 1-1 shows a top-view of the GTA layout and important components of the RPSS. The exclusion area houses the GTA accelerator, which is a source of dangerous neutron and air-activation product radiation. The hard-wired personnel safety interlock system is designed to directly prevent personnel from entering the beam tunnel exclusion area while the accelerator is in a potentially hazardous mode of operation. This primary safety-barrier system control is designed to prevent inadvertent access through shield doors into the beam tunnel. The RPSS provides a rapid means (scram switches) of shutting down the beam, or preventing accelerator start up if someone is left inside.

Regulatory guidance criteria outlining the contents of this document are promulgated in draft U.S. Department of Energy (DOE) Order 5480.ACC (DOE, 1991) and American National Standards Institute N43.1 (ANSI).

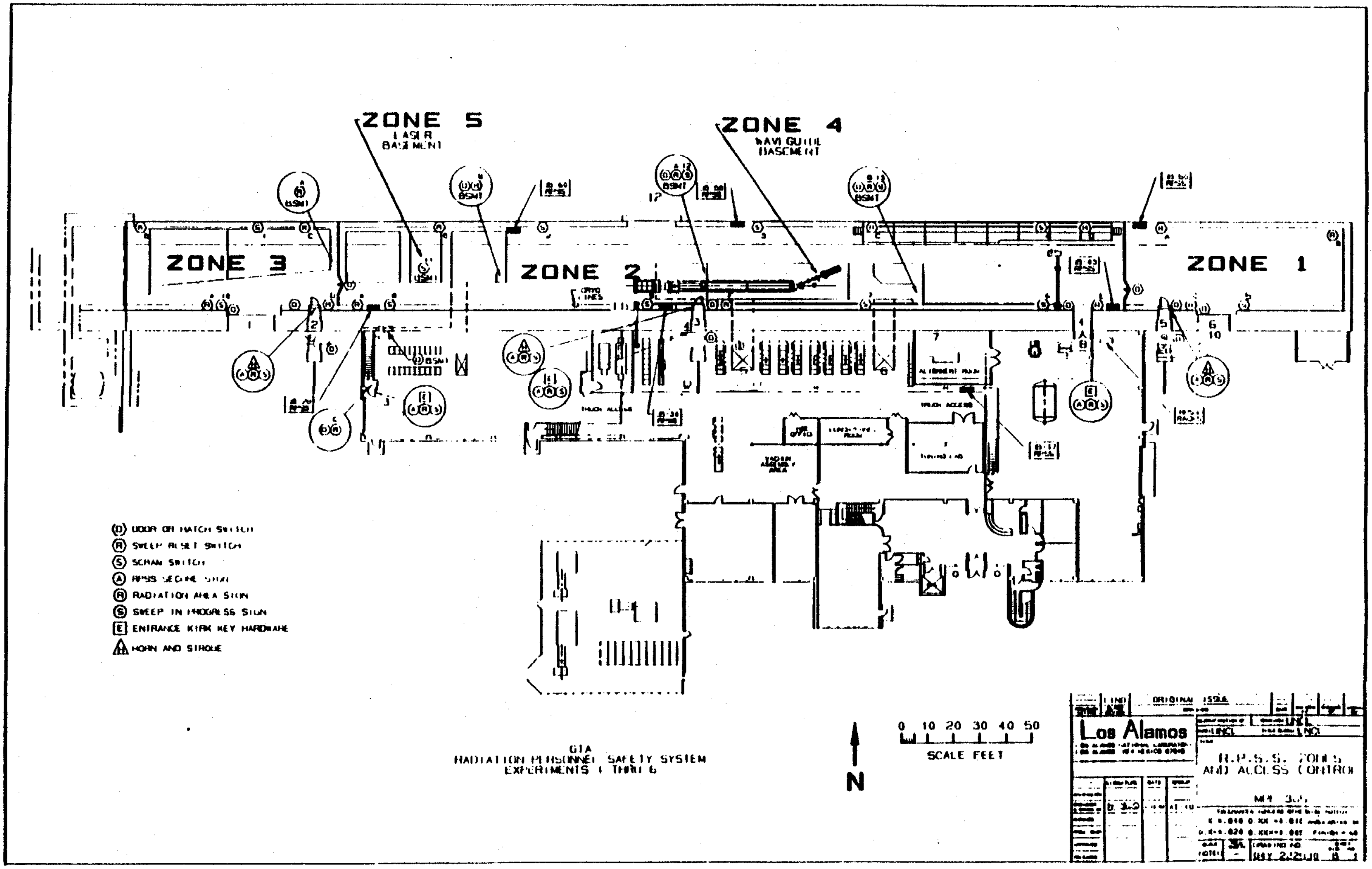


Fig. 1-1. Location of the beam tunnel, access doors, and RPSS components.

2.0 SYSTEM FUNCTIONS

The RPSS is specifically designed to protect GTA personnel from radiation exposure by:

- ensuring that personnel are not present in the beam tunnel or underlying basements, during 24-MeV beam operation with radio-frequency (RF) power;
- preventing entry to the beam tunnel and underlying basements, during 24-MeV beam operation with RF power; and

The RPSS is designed to take specific action if one, or more, of these conditions are jeopardized. These actions include terminating the beam power by using a beam plug at the low energy end of the beam and stopping the RF power supplied to the accelerator.

3.0 DESIGN DESCRIPTION

This section describes the system configuration and performance characteristics. Figure 3-1 shows the RPSS safety components overview discussed below. Figure 3-2 shows the feedback interactions between RPSS components in different locations of the GTA complex.

3.1 System Description

The RPSS is designed to ensure that no person is left inside the beam tunnel or underlying basements during 24-MeV beam operation with RF power. Before RF high-voltage can be turned on, or the low energy beam transport (LEBT) beam plug can be withdrawn, a start-up announcement is made over the public-address (PA) system, warning horns are sounded, SWEEP IN PROGRESS signs are turned on, a personnel clearance sweep by a two-person team is made, red warning lights are flashed, and a final warning horn is sounded. After a further delay, DANGER - VERY HIGH RADIATION - RPSS SECURE signs are illuminated, and accelerator turn on may begin.

Other safety design features include scram switches in the exclusion area, which are positioned so that no person can be more than 50 feet from one. Exit doors from the exclusion area can always be opened from the inside. Opening any door, gate, or hatch will shut down the accelerator. A person left inside the exclusion area could be exposed to harmful radiation levels. The RPSS is designed, however, to make the probability of a person being left inside extremely small.

Two barriers at each doorway controlled by the RPSS prevent inadvertant entry to the exclusion area during RF or beam operation. The two truck access doors are blocked by massive concrete shield blocks. At the other five doorways, neither of the two barriers can be opened except with captive keys, which can be released only from the control room. The key release is powered with a standby power supply to assure emergency access into the beam tunnel if there is a power outage. Any violation of the area such as the opening of a door or gate or pushing a SCRAM switch, trips the RPSS and prevents beam operation. The SCRAM switches, doors, and gates are separate inputs to the RPSS logic sytem and provide several layers of redundancy backup.

The RPSS also will shut down the accelerator if an attempt is made to gain access to the exclusion area once RF and beam energy are on. The accelerator cannot be operated unless the RPSS is secure. With the exception of two doors (1 and 6), which are truck access doors blocked by concrete shield blocks, opening any door or shield plug door requires a key release from the control-room operator. Operation of the key-release solenoid trips the RPSS and shuts down the accelerator. Opening any door or shield plug operates a

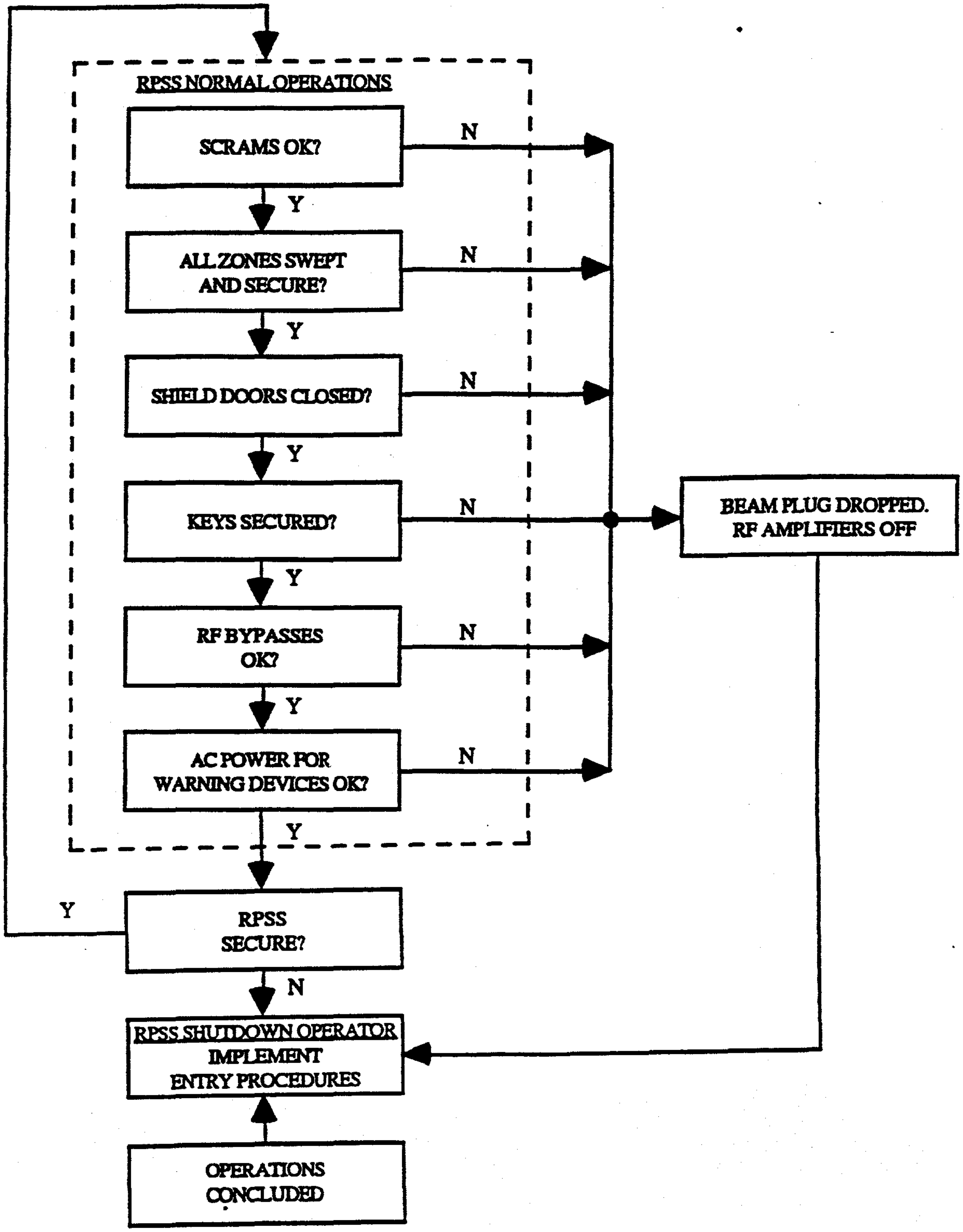


Fig. 3-1. Overview of the RPPS.

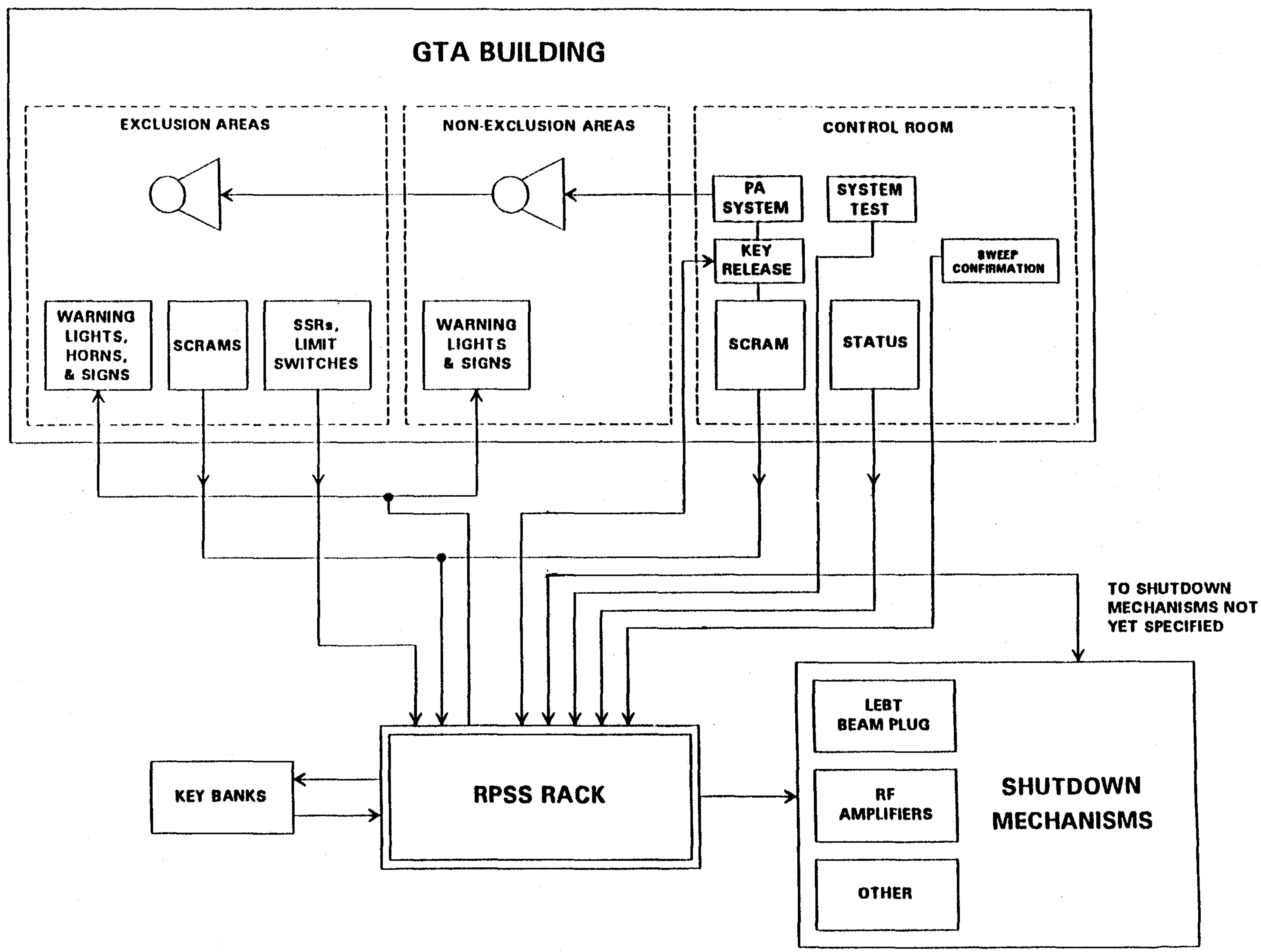


Fig. 3-2. RPSS system configuration.

limit switch that will also trip the RPSS. Each entry other than the truck doors is doubly secured, because it has both a shield door and another door, both of which are equipped with limit switches. Flashing red warning lights and illuminated signs at the entries warn personnel of the status of the exclusion area. The RPSS is designed to make the probability of entry during beam operation extremely small.

If the RPSS is tripped, a beam plug is inserted in the LEBT and all RF high-voltage is turned off. In addition, through interaction with the run-permit system, the extractor pulse is inhibited, turning the beam off at the source.

3.2 Configuration

The RPSS has consists of: an access-control system that is intended to prevent unauthorized, or accidental, entry into areas where the radiation-dose rate due to normal operation of the accelerator could exceed five rem/hour. Elements of this system include physical barriers, signs, warning lights, and audible warning devices, and a body of administrative procedures (to be defined) that define conditions for safe entry and lockup. (See Section 4.1.2 for a summary of the access-control system design features.)

3.3 Design Considerations

The objective of the RPSS is to prevent injury from excessive radiation exposure. The system is highly reliable. High -grade components are used to assure dependability and long life. The RPSS is designed to make the chances of a serious radiation-exposure accident small.

The interlock design is simple and consistent with the necessary radiation protection. It uses hard-wired electronic relays, which are easy to use and trouble-shoot. The number of false trips should be minimal. The RPSS is further designed to fail safe in the event of a general loss of alternating current (ac) power or loss of direct current (dc) power to the RPSS logic circuits. (See Section 5.3 for more detail on failure modes and effects.) Individual components, which fail, also fail safe because any failure results in a relay opening and trips the RPSS.

4.0 DESIGN REQUIREMENTS

The design of the RPSS conforms to the safety system requirements promulgated by draft DOE Order 5480.ACC (DOE, 1991) and applicable standards (ANSI) on the design and operation of particle accelerators.

4.1 System Performance Characteristics

RPSS performance features are summarized in this section.

4.1.1 RPSS Interlock Design

The features associated with the RPSS interlock design include:

- The interlock design is simple and consistent with the protection needed. It employs hard-wired relays, and it is easy to use, understand, and troubleshoot. The number of false trips should be minimal.
- Loss of ac power to the RPSS or dc power to the logic circuits or to components in the beam area trip the RPSS and cause beam shutdown.
- Beam shutdown on an RPSS trip is effected in two ways: a beam plug is inserted in the LEBT line, and RF power to the intertank matching system (IMS) and drift-tube linac (DTL) is turned off.
- To reduce the likelihood of accidental damage or tampering, all cables and connections are protected. Cable runs, outside of wire trays, are in conduits or ducts dedicated to the RPSS. Connections between system components are made in locked junction boxes from which all non-RPSS wiring is excluded. Logic equipment is mounted in a stand-alone locked rack. RPSS junction boxes and racks are labeled with appropriate warnings concerning unauthorized disturbance.
- Status panels at two principal entry doors to the exclusion areas and in the control room track the progress of a sweep and lockup and facilitate identification of faults.
- Contacts from the RPSS summation are used in other interlock systems such as run permit, beam plug permissive, and RF permissive, but other interlock systems have no input to the RPSS. This is consistent with the intent to keep the logic and operation of the RPSS as simple as possible.

4.1.2 Access-control System

The features associated with the design of the RPSS access-control system include:

- Illuminated signs indicating the status of the access-control system. These are positioned outside each of the three principle entries (see Fig. 1-1) to the exclusion area and at three locations inside the beam tunnel. Warning horns and strobe lights are mounted in the tunnel near each set of illuminated signs.

- Scram switches in the beam tunnel and the underlying basements have large, red mushroom-head buttons, which are clearly visible, labeled, and readily accessible. They are located so that no person can be more than 50 feet from the nearest scram switch.

- Inner doors cannot be locked from the inside. Shield plugs and doors are equipped with emergency-exit mechanisms. In the unlikely event that someone does not hear the warning horn and sweep announcements, and is missed by the sweep team, he can push a SCRAM switch and exit the tunnel by any of five doors. SCRAM switches are spaced no more than 100 ft apart.

- Before accelerator turn on, members of the operating group perform a personnel clearance sweep and lockup of the beam tunnel and underlying basements. The sweep is initiated by illuminating the SWEEP IN PROGRESS signs, sounding a three-second horn, and a voice announcement on the PA system. All doors are locked from the outside to prevent people from entering behind the sweep team. Safety sweep reset switches (SSRs) define the search route to assure that all areas come into view of the sweep team. After each of the five zones is swept, the sweep team requests a sweep verification from the control room operator. After verification, a ZONE SECURE light is turned on. When all zones are secure, all shield doors are closed (i.e., two truck access doors and the other five doorways), and all Kirk keys are returned to the key banks, a three-second horn is sounded and red strobe lights are turned on in the beam tunnel. After a 60-sec delay, RPSS SECURE signs are illuminated inside the beam tunnel and at the doors outside the tunnel, and the RPSS interlocks are satisfied.

- Any violation of the area, such as the opening of a door or gate or pushing a scram switch, trips the RPSS and prevents beam operation. In the unlikely event that someone does not hear the first warning horn and sweep announcement, and is missed by the sweep team, he can push a scram switch and exit the tunnel by any of five doors. The scram switches and doors, as well as gates, are separate inputs to the RPSS logic and provide additional layers of redundancy to back up the sweep.

- During a sweep, if any zone has not been entered since the last authorized sweep, it does not need to be reswept.

- When the RPSS is secure, access is blocked to the beam tunnel at each doorway. Two truck access doors are blocked by massive concrete shield blocks. The other five doorways can only be opened with captive keys, which can be released only from the control room. The key release is powered with a standby power supply to assure emergency access into the beam tunnel in the event of a power outage.

4.2 Instrumentation and Control

The physical RPSS is a rack-mounted, hard-wired relay control system featuring a key release from the control room. Only the control room can activate the sweep key release.

4.3 Interface

The RPSS system interfaces are illustrated in Fig. 1-1. For interfaces between systems, RPSS serves as an input to both run-permit and fast-protect systems. RPSS interfaces with the beam plug and RF interlocks. No other system acts as an input (for example, RPSS is a one-way control flow).

4.4 Reliability

RPSS components such as relays, lights, horns, and other warning devices or integral components, are procured off the shelf items designed to be highly reliable. In the case of relays, a component failure will trip the RPSS, so it will fail safe. Malfunction of warning devices, such as lights or signs are acknowledged by the RPSS and must be reconciled before RPSS checkout continues.

The RPSS system will then have four layers of protection: Kirk-key interlock system at tunnel entrances, SCRAM switches and auditory alarm warning systems inside the tunnel, beam status lights inside and outside the tunnel, and zoned manual sweep procedures.

4.5 Initial Installation

No special conditions are required for installation of the RPSS. As installation proceeds, subsystems are checked for operational malfunctions according to manufacturers' specifications. (A preoperation checklist has already been written. The list's completion requires that the RPSS system be accepted.) When RPSS installation is complete, the entire system will receive a final checkout which specifically checks that beam-plug insertion and RF shut-down occur when the RPSS is tripped. The RPSS system is designed, reviewed, and tested under GTA QA requirements.

5.0 SYSTEM LIMITATIONS

There are no specific operating limits for the RPSS primary safety barriers.

5.1 Precautions

Only personnel authorized by the project manager are permitted to maintain or modify the RPSS or perform RPSS interlock checks.

Spare Kirk keys for the RPSS are locked up by the project manager. They are used only when both segments of a broken key are presented. If a key is lost, the key bank, key release box, and door-lock cores must be replaced.

Bypass of an input to the RPSS may be done only with written approval of specific persons designated by the project manager. Bypassed interlocks are logged with time, date, reason, method, time limit for which the bypass is approved, and the signature of the person approving the action. A new approval is required if the condition requiring the bypass persists past the stated time period. Bypasses are recorded in two logbooks: one is in the control room and the second is on the RPSS control rack.

System trips are investigated before the fault is cleared and the accelerator turned back on. Circumstances of the occurrence are thoroughly documented, and the incident is studied to determine if modifications are warranted.

5.3 Failure Studies

Failure of an interlock is very serious. Facility management is notified immediately if any part of the RPSS fails in its intended purpose. Accelerator operation is halted until the reason for the failure is understood and corrected. Notification of higher authority is made based on DOE reporting criteria (DOE, 1990). Reporting requirements do not apply to malfunctions found on initial installation or on initial checkout after system maintenance or modification.

The RPSS interlock-check procedure is performed at intervals no greater than one month before experimental-run periods and immediately after any modification or maintenance on the system and before beam operation. This procedure checks proper functioning of every input, all system logic, and all shutdown mechanisms. In addition to this rigorous testing, overall operation of the system is tested biweekly during experimental-run periods. A system test switch is available in the control room for this purpose. A key release at any one of three doors serves the same purpose.

Tables V-1 and V-2 define the terms used in the failure modes and effects analysis (FMEA) presented in Table V-3. In that analysis, system failures are postulated and potential consequences are assessed. The most consequential failure mode of the analysis occurs when an Albatross neutron monitor fails at a time when neutron radioactivity is present outside the beam tunnel exclusion area where personnel are located. Potential consequences are assessed to be a "IIIc" status implying that personnel may be exposed to hazardous radiation resulting in minor injury. All other most significant failure modes postulated to occur before, or during, beam operation result in a "IVf" consequence status, in which beam operation is interrupted but no personnel injury results.

Table V-1 Numeral Descriptor for the Effects Category of the FMEA

Category	Hazard Category	Consequences
I	Catastrophic	May cause death, loss of the facility operation, or severe impact on the environment
II	Critical	May cause severe injury[a], severe occupational illness, major damage to a facility and/or operation, or major impact on the environment
III	Marginal	May cause minor injury, minor occupation illness, or minor impact on the environment[b]
IV	Negligible	Will not result in significant injury, occupation illness, or significant impact on the environment

a - or death to a worker
b - or moderate damage/impact to a facility/operation

Table V-2 Letter Descriptor for the Effects Category of the FMEAs

Description	Level	Effect
Frequent	a	Hazardous material release to the environment
Reasonably	b	Hazardous material release within the building
Occasional	c	Personnel exposure to hazardous material
Remote	d	Personnel exposure to other than hazardous material
Extremely	e	Loss of operational capability
Impossible	f	Loss of system capability

Table V-3 FMEAs for Radiation Personnel Safety System

Item #	Identification from Drawing No. 94Y-222930	Description	Failure Modes	Failure Mechanism	Failure Detection	Failure Compensation	Effects	Criticality Ranking
1	Door limit switch	Prevent inadvertent entry into exclusion area during beam or RF operation	RPSS fails to trip when the exclusion area door opens	Mechanical	Detected during periodic testing	Kirk key and lock system prevents door opening without active participation of control-room operator	No effect if this is the only failure of the system	IVf
2	Hatch limit switch	Prevent inadvertent entry into exclusion area during beam or RF operation	• Hatch limit switch fails to open when hatch opens	Mechanical	Detected during periodic testing	Kirk key and lock system prevents opening without active participation of control-room operator	No effect if this is the only failure of the system	IVf
3	Scram button	Shuts down operations to ensure that no person is in the exclusion area (beam tunnel and underlying basements)	• Fails to shut down the accelerator	• Mechanical/ Electrical	• Detected during periodic testing	• Other scram switches are located nearby; doors can always be opened from inside exclusion area; opening any door, gate, or hatch will also shut down the accelerator	• No effect if this is the only failure of the system	IVf
4	Sweep reset switch	Acknowledge that area has been swept	• Sweep reset switch fails	• Mechanical/ Electrical	• Detected during periodic testing	• None	• Sweep procedure cannot be completed	IVf

Table V-3 FMEAs for Radiation Personnel Safety System (concluded)

Item #	Identification from Drawing No. 94Y-222930	Description	Failure Modes	Failure Mechanism	Failure Detection	Failure Compensation	Effects	Criticality Ranking
5	Horn	Warn that sweep is in progress	• Failure of a warning horn	• Electrical	• Detected during periodic testing	• Two other horns in tunnel provide backup	• No effect if this is the only failure	IVf
6	Strobe	Warn that sweep is in progress	• Failure of a flashing red strobe light	• Electrical	• Detected during periodic testing	• Two other strobe lights and illuminated signs in tunnel provide backup; illuminated signs provide backup outside entry doors	• No effect	IVf

6.0 OPERATIONS

The main operating procedures of the RPSS are summarized in this section. These include operating procedures describing the beam, tunnel sweep, and lockup conducted before beam turn on and entry procedures conducted after beam shutdown.

6.1 Start-up Operations

The RPSS has a very large role before beam turn on. During start-up operations, the RPSS is intended to ensure that the beam tunnel and underlying basements are clear of personnel before beam or RF operations that produce a radiation hazard.

General rules to follow in the sweep procedure are detailed in appendices C and E, which include the sequence of procedures for conducting the sweep and interlock check.

6.2 Normal Operations

Once the beam has been turned on, the RPSS switches roles from ensuring that personnel are not inadvertently in the beam tunnel before the beam is tuned on to ensuring that personnel do not gain entry to the tunnel during operations or that radiation does not leak from the tunnel to other areas of the facility.

When the RPSS is secure, two barriers block access to the beam tunnel at each doorway. Two truck access doors are blocked by massive concrete shield blocks. At the other five doorways, neither of the two barriers can be opened except with captive keys, which can be released only from the control room. The key release is provided with a standby-power supply to assure emergency access to the beam tunnel if a power outage occurs.

6.3 Shut-down Operations

Once beam operation is concluded, shutdown operations include reentry into the beam tunnel. General rules require that if the beam has been accelerated downstream of the radio-frequency quadrupole (RFQ) after the tunnel was last secured, a HS Health Protection technician must be present to conduct a radiation survey of any zones to be entered. The specific procedures required for reentry into the exclusion area are detailed in Appendix E.

6.4 Infrequent Operations

A feature has been specifically designed into the RPSS to override its normal operation. Overriding the RPSS has beneficial advantages under special experimental circumstances and will occur infrequently and, then, only under rigorous administrative control using special work permits. During such events, an exclusion area will be established and defined by a rope barrier around the accelerator to limit radioactive dose rates as determined by laboratory health and safety personnel. The area will be marked as "controlled area" in accordance with Laboratory administrative requirements and DOE radiation protection requirements (DOE, 1988).

7.0 MAINTENANCE

7.1 Maintenance Approach

The RPSS interlock check is performed at least once each month and before beam operation (i.e., experie-mental cycle) and immediately after any modification or maintenance on the system. This procedure checks for proper functioning of every input, all system logic, and all shut-down mechanisms. In addition to this rigorous testing, the overall operation of the system is tested biweekly. A system test switch is available in the control room for this purpose. A key release at any one of three doors serves the same purpose.

Failure of either type of test is reported to facility management. Notification of higher authority is made based on DOE reporting criteria. Reporting requirements do not apply for malfunctions on initial installation or on initial checkout after system maintenance or modification. Only personnel authorized by project managers are permitted to maintain, modify, or perform RPSS interlock checks.

7.2 Corrective Maintenance

Corrective or constructive maintenance such as improved logic, circuits, or components will be implemented into the RPSS from time to time. As with other maintenance practices, only personnel authorized by the AT-10 group leader are permitted to maintain, modify, or perform RPSS interlock servicing.

7.3 Preventative Maintenance

The RPSS interlock check procedure is annually reviewed by individuals designated by facility management. The review concentrates on the procedure's effectiveness in discovering design or installation errors and failed components.

7.4 In-service Inspection

Activities that may be regarded as in-service inspections are discussed under preventative maintenance. (See Section 7.3.)

7.5 Surveillance

Surveillance of the RPSS system is performed at routinely scheduled maintenance intervals as determined by administrative procedures.

REFERENCES

ANSI, American National Standards Institute, "American National Standard N431.1 Radiological Safety in the Design and Operation of Particle Accelerators," ANSI N43.1-1978, May 1979.

U.S. Environmental Protection Agency, "National Emission Standards for Hazardous Air Pollutants (NESHAPs)," Code of Federal Regulations, Protection of the Environment, Title 40, Part 61, December, 1991.

DOE 1988, U.S. Department of Energy, "Radiation Protection for Occupational Workers," DOE Order 5480.11, December 21, 1988.

DOE 1991, U.S. Department of Energy, "Safety of Accelerator Facilities," DOE 5480.ACC, November 15, 1991.

DOE 1990, U.S. Department of Energy, "Occurrence Reporting and Processing of Operations Information," DOE 5000.3A, May 30, 1990.

GLOSSARY

ac	alternating current
Ag	silver
DAC	derived air concentration
dc	direct current
DTL	drift-tube line
EPA	U.S. Environmental Protection Agency
FMEA	failure modes effects analysis
GM	Geiger-M¸ller
GTA	Ground Test Accelerator
HEPA	high-efficiency particulate air
HS	health and safety
IMS	intertank matching section
LAMPF	Clinton P. Anderson Meson Physics Facility
LEBT	low energy beam transport
LINDA	laser induced neutralization diagnostic apparatus
NESHAP	National Emission Standard for Hazardous Air Pollutants
NPB	neutral particle beam
PA	public address
RF	radio frequency
RFQ	radio frequency quadrupole
ROP	routine operating procedure
RPSS	radiation personnel safety system
SDD	system design description
SOP	standard operating procedure
SSR	Safety Sweep Reset switches

APPENDIX A TYPICAL DRAWINGS

For typical drawings of the radiation personnel safety system refer to sheets 1 through 22 of Drawing No. 94Y-222930.

APPENDIX B COMPONENT LIST

1. Potter Brumfield KHU-17D11-24 4PDT relay as required

2. Midtex Relays Inc. 657-12COA2 24VDC Time Delay relay as required

3. C&K Unimax KSJP-T Limit Switches for doors/gates as required

4. MicroSwitch BZE6-2RQ2 Limit switches for doors/gates as required

5. Square "D" KRIU pushbutton assembly as required

6. Square "D" KP-1 pilot light assembly as required

7. Square "D" Type KA operator switch block assembly as required

8. Square "D" Type KY-1 Enclosure boxes as required

9. Square "D" KR9R Switch operators as required

10. Wieland #57.503.0053.0 Terminal block assembly as required

11. Brown Boveri Electric Type "T" Kirk-Key Transfer assembly as required

Components listed above, or their equivalent, are used throughout RPSS. Items such as conduits, wire trays, wire type, junction boxes, etc. are of standard variety used through out the facility.

APPENDIX C GENERAL OPERATING PROCEDURES FOR THE BEAM-TUNNEL SWEEP

This section provides general information on the GTA's standard operating procedure (SOP), which includes the beam-tunnel sweep procedures conducted before beam and/or RF turn on. The sequence for conducting the sweep procedure is delineated in the SOP for the RPSS.

General rules to follow in the sweep procedure include:

- The sweep is composed of two RPSS qualified people, at least one of whom must be a member of the GTA operations group. A third person is required in the control room.
- The GTA operations group is responsible for conduct of this procedure.
- All areas of each zone being swept must be checked visually and with special attention to alcoves, spaces between shield plugs and inner doors, and spaces above, below, and behind equipment. One member of the sweep team shall keep the main sweep path under observation to ensure that no one passes unobserved from an unswept area to a swept area.
- Zones that have not been entered since being secured need not be reswept after an entry to another zone.
- This procedure describes the most likely of the permissible sequences for securing the tunnel and basements. Zones are swept in the order 1,3,4,2,5. (See Fig. 1-1.) Other permissible sequences are

    a. 3,4,1,2,5, or

    b. 5,3,4,1,2.

APPENDIX D OPERATING PROCEDURES FOR REENTRY TO THE BEAM TUNNEL

This section describes the procedures that govern reentry to the beam tunnel after it has been secured.

General rules require that if the beam has been accelerated downstream of the RFQ after the tunnel was last secured, an HS Health Protection technician must be present to conduct a radiation survey of any zones to be entered. Entry may be made through door 3, 4, or 7.

Specific procedures include:

- obtain a key release for the door to be entered and take all six keys;
- verify that RPSS indicates not secure on signs and status panel;
- leave the shield door open, but lock the entry door until the radiation survey is complete; and
- block the entry door and secure the keys in the key-bank.

APPENDIX E GENERAL OPERATING PROCEDURES FOR THE INTERLOCK CHECK SYSTEM

This section provides general information on Routine Operating Procedure (ROP) No. 1 as it relates to the Interlock Check Procedure. This procedure checks proper operation of each component of the RPSS and the system logic. The interlock check procedure is delineated in the ROP.

General rules for this procedure include:

- The procedure must be performed at intervals not greater than six months, immediately after any maintenance or modification of the RPSS, and before an experimental cycle.
- Only personnel authorized by the project manager may perform checks.
- Three people are required: one in the beam tunnel; one in the equipment aisle outside the tunnel; and one in the control room.
- Positive steps must be taken to prevent withdrawal of the LEBT beam plug or turn on of the RF amplifier systems while this procedure is being performed.
- Any malfunction discovered must be immediately reported to the project manager. Exceptions are the initial checkout following installation and following maintenance or modification of the system when the problem is a direct result of the modification. In any event, the malfunction must be noted on the checklist, corrected, and rechecked before the item is initialed.
- Make the following announcement before starting this procedure: RADIATION PERSONNEL SAFETY SYSTEM INTERLOCK CHECKS ARE BEGINNING. TEMPORARILY DISREGARD ALL WARNING HORNS, SIGNS, AND STROBES.
- Make the following announcement after the interlock checks are completed: RADIATION PERSONNEL SAFETY SYSTEM INTERLOCK CHECKS ARE COMPLETED. HEED ALL WARNING DEVICES.

Appendix U

Phase 2 Shielding Calculations

Rough Notes for GTA Radiation Summary

Assumptions

The GTA accelerator cannot run at more than a 2% DF. Approximately a 2% DF is a fundamental limit for the ion source (2 ms @ 10 pps). 2% DF is also a limit for the rf power tubes, set by the high-voltage power supply and by thermal effects in the output tube.

Normal beam operation will occur at much less than the 2% DF, but all shielding calculations will be done for the full 2% DF on a short-term (≤ 1 hr) basis.

During all beam runs at 24 MeV, all personnel will be excluded from the beam tunnel. A specially designed safety system, the Radiation Personnel Safety System (RPSS) will be used to ensure that the beam tunnel is evacuated before and during all beam runs. The GTA beam tunnel was built with 8-foot thick, high-density concrete walls or thick cover of earth to prevent dangerous radiation levels at occupied locations.

During startup and immediately after all configuration changes, health physics personnel will monitor the actual radiation levels to confirm performance relative to design.

Thick Target Neutron and Gamma Yields for 24 MeV Protons

(# protons/s in 50 mA beam = 3.12E+17)

Target Material	n/p	gamma/p	n/50 mA beam	gamma/50 mA
Copper	0.0068	0.0229	2.12E+15	7.14E+15
Aluminum	0.0017	0.0177	5.30E+14	5.52E+15
Carbon	0.0002	0.0056	6.24E+13	1.75E+15
Beryllium	0.0167	0.0003	5.21E+15	9.36E+13
Iron	0.0048	0.0168	1.50E+15	5.24E+15

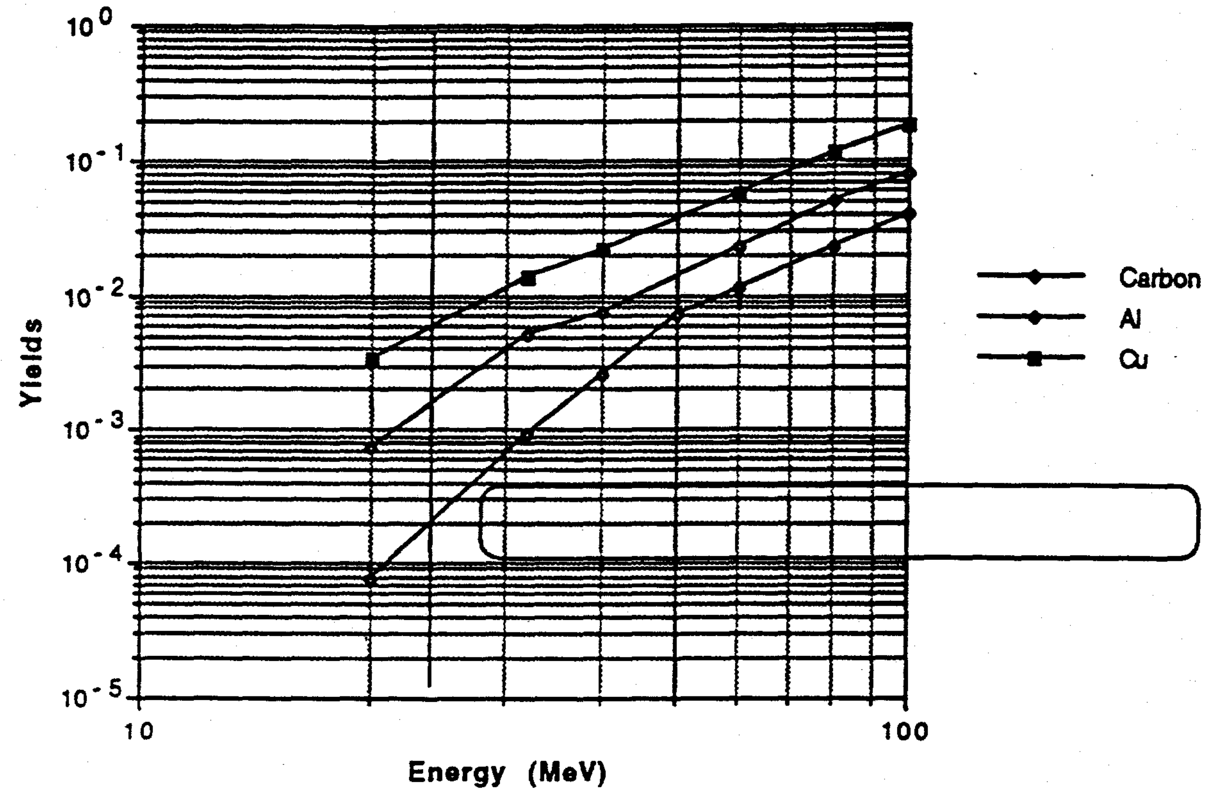
Assume beamstop material is carbon (Graphite) for 2.00% DF

	neutrons	gammas	
Total # produced per s	1.248E+12	3.4944E+13	
Flux (at 2 m)	2.48E+06	6.95E+07	per cm^2 - s
Equivalent dose	3.10E+02	1.76E+04	REM/hr
Flux (at 10 m)	9.93E+04	2.78E+06	per cm^2 - s
equivalent dose (10 m)	12.41	7.65E+02	REM/hr
Required Attenuation Factor	4.97E+03	3.06E+05	
Shield Thickness (Concrete/Lead)			
Concrete (regular)	55.4	105.5	inches

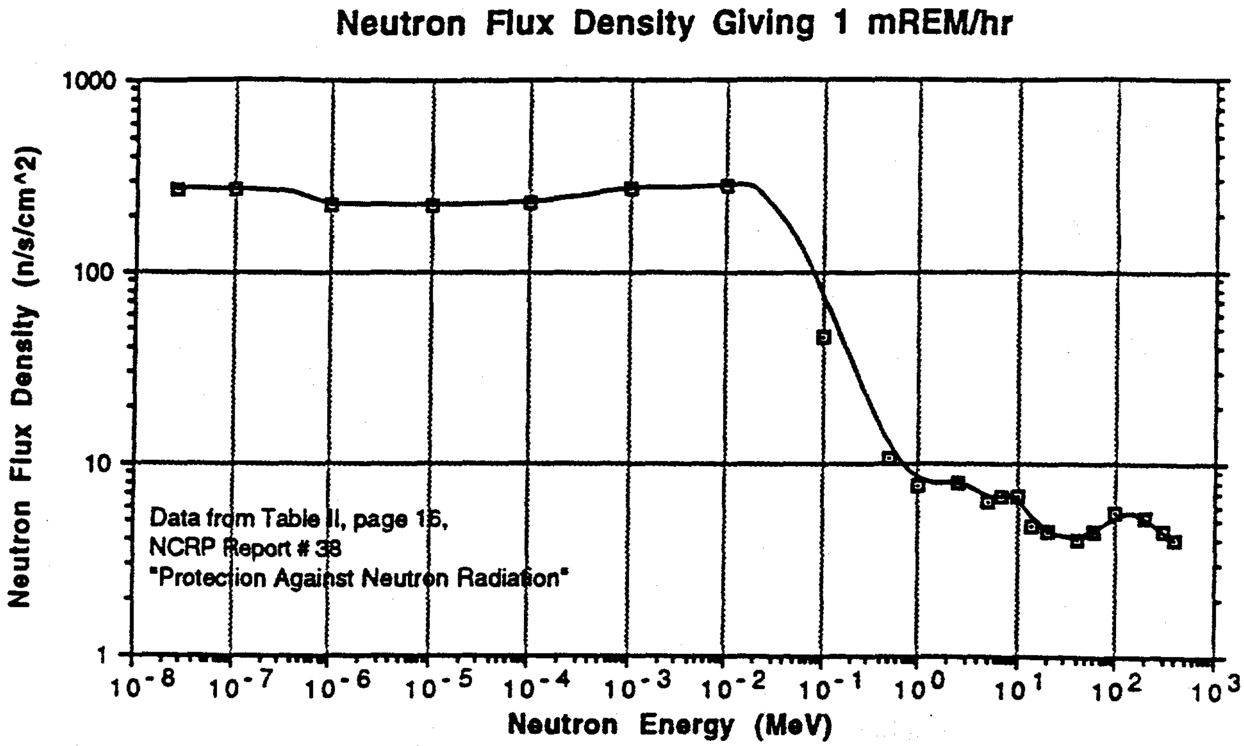
Concrete (high-density)	44.4	inches
Lead	13.0	inches

The estimated number of neutrons produced per incident proton is shown below:

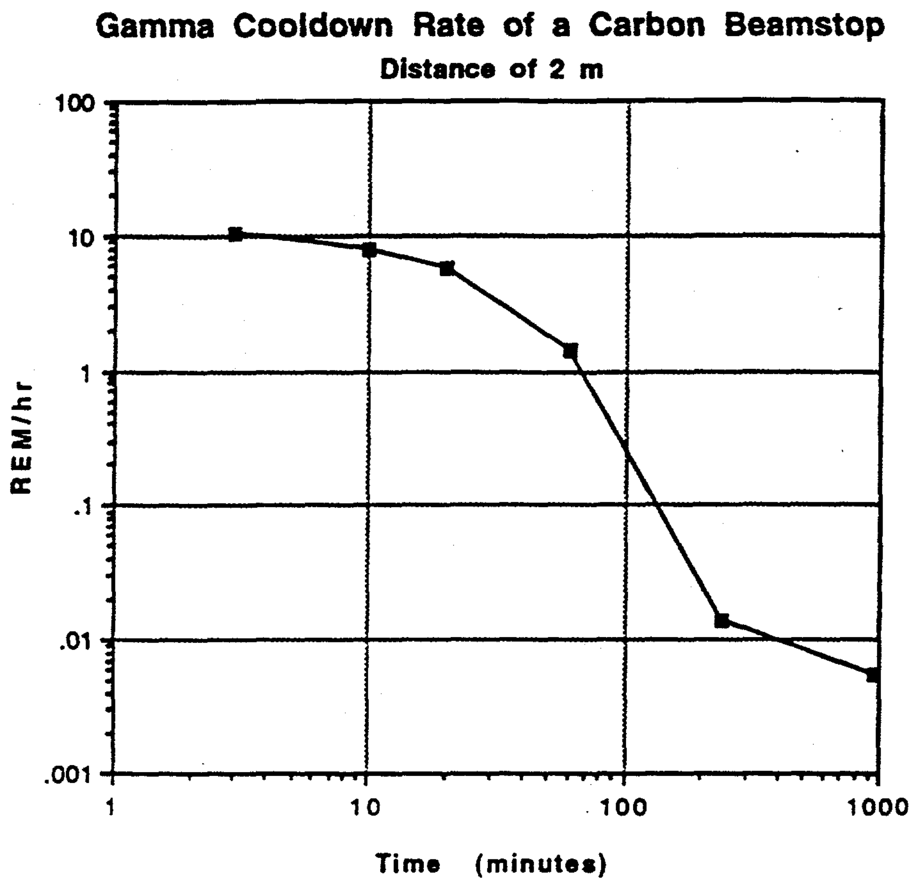
Thick Target Neutron Yields



from: Calculated Proton-Induced Thick-Target Neutron... Yields
Wilson, et al LA-UR 89-2788


Neutron Flux Density Giving 1 mREM/hr
1000
100
10
1
Neutron Flux Density (n/s/cm^2)
Data from Table II, page 16,
NCRP Report # 38
"Protection Against Neutron Radiation"
10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3}
Neutron Energy (MeV)

A calculation performed by Bill Wilson (documented in reference # 6) shows little dependence of carbon beamstop activation on run time or operational history. After beam shutoff, the predicted activation is shown below:



Air Activation
The estimated air activation is given in reference 2 for a 0.2%DF. Scaling those numbers up by a factor of ten to obtain 2% DF gives an estimated release from the stack of 8.4E-8 Ci/s. These numbers would apply for a 500 CFM air discharge rate, and no shielding immediately around the beamstop.

Miscellaneous
1 Sievert = 1 J/g = 100 REM
1 Becquerel = 1 dps (SI) [dps = disintegration /second]
1 Rad = 100 ergs
1 Gray = 1 J/kg = 100 Rads
1 REM = 1 Rad * QF

typical quality factors (QF)

alpha	= 20
beta	= 1
gamma	= 1

neutrons = 1--11

Activity	1 Curie	= ≈ 3.7E10 dps
absorbed dose	1 Rad	= 100 ergs/g of any material
exposure	1 Roentgen	= 2.082E9 ion pairs/ cc of air (X & gamma)

1 Roentgen ≈ 1 Rad for soft tissue.

Tenth-value layer thicknesses:

1 MeV neutrons	8 cm of water or tissue
	20 cm of concrete
1 MeV gammas	10 in (25 cm) of concrete
	4 cm of lead

Air Activation

Tunnel volume ≈ 2.4E5 ft^3 = 6.8E9 cc (473 ft long x 512 ft^2)
Tunnel air activation 3.5E-14 Ci/cc . Total = 3.5E-14 x 6.8E9 = 2.38E-4 Ci
(for 0.2 % DF)

Notes

Meeting with Bill Wadman, consultant to HS-12, on April 7, 1992.
He questions our source term for protons impinging on carbon. Production rate is 1.2E-4 n/p per Wilson's (Oct, 1990) memo, or 1.6E-3 n/p per graph. Although we initially believed the larger number to be correct, we later found that the larger value was based on extrapolation from data at 50 and 100 MeV. Measured data at 18--20 MeV, and high energies confirmed the smaller number. We will use a value of 0.0002 n/p for the nominal neutron production rate in carbon.

Bill agrees that a modified approach for beamstop ventilation is viable and preferred. Instead of exhausting air immediately from beamstop up the stack, allow the air to mix with other tunnel air.

LAMPF produces approximately 150,000 Ci/yr of activated air products. This results in approximately 8 mREM/yr at the site boundary. We can scale from this number. If we hope to contribute only 0.1 mREM/yr, we can release only 1875 Ci/yr.

Neutron streaming back through the waveguide basement tunnel should be only a minor problem. Assume a factor of 100 loss in each 90° bend. Total production of low-energy (thermal?) neutrons is given empirically by:

$\Phi_n = 1.25 * Q/S$ where:

Φ_n = Thermal flux in $n/s/cm^2$
Q = Neutron production rate in n/s
S = surface area in view (cm^2)

Meeting with Bill Wadman, consultant to HS-12, on April 22, 1992.

Also present was Kerri Kennedy, from the Radioactive Emission Air Monitoring (REAM) office. Bill's comments:

- Periodic sampling will be required, however continuous air sampling should be unnecessary.
- I will need to compile my computations and prepare a memo that will be submitted for EPA approval.
- HS-1 will provide the necessary air filters and monitoring. We can probably use part of the existing hardware.
- My calculations will show total Curies/hr and # of operating hours/ yr. I will include tunnel volume and exhaust rate of the tunnel air.
- Normal operation will be at 0.2% DF, but we will discuss 2% DF.
- We will investigate the possibility of using only closed-loop water-chiller units to simplify our handling of potentially radioactive water.

Information on Telescope Scrapers (Andy Jason, AT-3):

- Most probable location of the beam halo scrapers is about 8 m downstream of the telescope eyepiece.
- Sustained beam loss on these scrapers is ≤ 8%. Maximum is about 30%.
- In addition, there will be about a 1% beam lost due to gas stripping in the telescope.

Reference 2:
Addresses the air-cooled beamstop.
Appropriate shielding is 1–2 inches of lead.
A 2" lead shield permits immediate access after beam shutdown (for 0.2% DF).
A shutter (up to 2") will be needed when beam is not present and personnel access is needed.
Level during operation is 50--100 REM/hr.
Nuclide formation in carbon: 0.00044 ^{11}C/p & 0.000018 ^{13}N/p.
Approximate half lives are: ^{11}C = 20 minutes, ^{13}N = 10 minutes
Effective dose rate during operation (6" concrete shield, 2 m distance) is 204 REM/hr from neutrons and 363 REM/hr from gammas.
For purposes of radiation damage, we can infer a fluence dose of ≈ 8E6 REM 50 cm away from the beam stop.
Air activation was calculated to give a discharge activity flow of 8.4E-9 Ci/s. This may need to be increased by a factor of ten for 2% DF.

Ref 6
Provides a summary of the expected activation of a carbon beam stop.

Outstanding Issues

Design for what duty factor

During the October, 1991 Tiger visit, we were told that accelerator safety designs must use passive, absolute protection for personnel for machine operation at the highest possible production. It was one Tiger's opinion that we would have to design for cw operation. We must succeed in making the argument that maximum possible operation is at ≈ 2% DF on GTA. It would be very much to our advantage if we could acceptably limit beam operation at an even lower duty factor.

Action Needed:

More room for lead shielding

We may need to find space for 6 or 7" of lead around the beam stop. Earlier estimates may have ignored the large number of proton-induced gammas produced on carbon. If we assume that we must protect for 2% DF beam operation, we need about 52" of regular concrete or 42" of high-density concrete. We will need an additional 6 or 7" of lead to bring the gamma levels to the same effective dose. Reference 6 indicates that surrounding the beamstop with about 10" of lead will reduce the dose equivalent rate due to proton-induced activation to a negligable level.

Action Needed:

Herb Newman, MEE-13: What are our contingency plans for providing for more (thicker) lead shielding immediately around the beam stop(s)?

Tunnel Ventilation Rate

Early design work on the GTA facility made two incompatible assumptions:

1. The tunnel would be held at a slight negative pressure wrt the high-bay area.
2. The tunnel air exhaust would be off during beam operation.

Obviously, a negative pressure is impossible to maintain unless an exhaust fan is running. Also, air leaks between the tunel and high-bay are larger than originally suspected because of the many penetrations. We still need to design a system that maintains a slight negative pressure, low airflow and provides the required holdup prior to atmospheric exhaust.

Action Needed:

Marty Milder, AT-10: Determine the levels in cfm that the tunnel exhaust fans can be made to run effectively. What are the costs and implications of running at a lower rate?

Possible Equipment & Electronics Damage

With the recent changes of deliberately scraping a significant fraction (>25%) of the beam with output collimators, we need to reinvestigate the possibility that some more sensitive electronics may see some radiation damage. The equipment environment may be considerably more harsh than it would have been with the only operational beamstop located at the far end of the beam tunnel.

Action Needed:

Ralph Stevens, AT-10 & Dave Schneider, AT-10: Determine what electronics equipment will be present inside the beam tunnel during beam opeations. What are the damage threshold levels for this equipment? Prepare a document comparing the expected levels with the damage thresholds of all equipment.

This issue is only partly resolved, in that we have been unable to find radiation-damage thresholds for some of the electronics inside the high-voltage equipment dome.

References

1. memo T-2-M-3340, June 28, 1991, W. B. Wilson & R. J. LaBauve, Calculation of the Radiation Environmen near GTA final beamstops of Al or C; Activation of Beamstop, Beamline vessel, and $Sm_2 Co_{17}$ magnets.

2. Memo T-2-M-3254, October 30, 1990, W. B. Wilson & R. J. LaBauve, GTA 24-MeV In-Line Beamstop Shielding/Activation Studies.

3. memo AT-2:87-274, June 22, 1987, H. A. Sandmeier, RAD (Si) Neutron and Photon Does at the Beam Sensing Camera Electronics, and at the beam steering magnet from neutron and photon prouction in the GTA H_2O proton beam stop.

4. memo AT-2/88-29, Jan. 22, 1988, H. A. Sandmeier & M. E. Battat, Forward and Backward Neutron Streaming for 24- and 100-MeV GTA carbon beam stop concepts.

5. memo T-2-M-3080, W. B. Wilson, Sept 6, 1989, 24-MeV GTA Tunnel Flux, Annual Fluence and Dose-Equivalent Rate Calculations

6. memo T-2-M-1967, Feb 16, 1988, W. B. Wilson & R. J. LaBauve, Calculated Radiation Environments Following 24-MeV Operation with Beamstops of C, Al, and Cu.

7. memo T-2-M-3117, October 31, 1989, W. B. Wilson, 24 MeV GTA In-Line Beamstop Water Activation with LANL Tap Water and pure H_2O.