***** DRAFT *****

[Open issues are shown in brackets.]

INITIAL STRATEGY FOR SNS BEAM CONTAINMENT

1. INTRODUCTION

SNS will have several distinct operating modes, ranging from source conditioning to full-power neutron production. In the interest of overall availability, it is desirable that personnel be able to work safely in areas "downstream" of areas that are operating with beam. For example, tuning the linac should not prevent personnel from working in the ring tunnel. A critical aspect of having this capability is that there must exist a completely reliable means for containing the beam within the designated operating area. Safety systems must be provided to ensure that the beam cannot be accidentally routed to areas where people are working.

The project has yet to define the critical devices[1] that will be used to contain beam within designated operating areas. In fact, some of these devices may not even be in the project baseline yet. Being named as a "critical device for beam containment" has a big impact (e.g. cost, reliability, QA, interfaces, etc.), so it makes sense for the project to define these critical devices as soon as possible. Thus, the intent of this paper is to document the project's consensus on what critical devices will be provided for beam containment.

Of course there are other aspects of beam containment besides the critical devices used. For example, passive shielding plays an important role. This topic has been covered in the "SNS Shielding Policy" document and is therefore not repeated here. Other aspects (e.g. personnel access control, radiation monitoring) will be addressed elsewhere. The scope of this paper is deliberately limited to the selection of critical devices to be used for beam containment so we can arrive at a consensus as quickly as possible.

2. SNS BEAM CONTAINMENT POLICY

2.1 Accelerator-Related Regulatory Requirements

The authors have not been able to find any regulatory requirements that directly specify a required beam containment policy.

One source of guidance is the DOE "Draft Implementation Guide, Accelerator Safety Order" (Section III.C.3.d; dated May, 1998), which states the following:

> "Critical devices are specific accelerator or beam line components that are used to ensure that the accelerator beam is either inhibited or cannot be steered into areas

[1] See section 2.1 for definition of "critical device".

where people are present. Common examples are steering magnets, beam stops or collimators. Other examples are systems which operate on the injector or ion source to inhibit the beam.

(1) Two critical devices should be used in an interlock system if a whole-body very-high-radiation area, as defined in 10 CFR 835, can be produced.

(2) The status of each critical device should be monitored to ensure that the devices are in the "safe" condition when personnel access is permitted. If only one device is used, two separate indication systems should be provided. If the "safe" condition is lost, the beam should be inhibited by operation of other critical devices upstream. Critical device command systems should be independent of the monitoring systems."

2.2 Nuclear-Facility-Related Regulatory Requirements

The classic function of beam containment is to protect personnel from prompt radiation. For SNS, beam containment must provide an additional function: To protect the mercury target from beam during ring extraction tuning. This function is best illustrated by the following scenario.

First some background: The target facility is considered to be a nuclear facility due to the possible inventory of radioactive materials in the mercury and the potential for its release to the environment. The primary driver for a release is postulated to be the continuation of beam after the target has failed. This would ultimately cause radioactive materials to go out the stack. A Target Protection System (TPS) will monitor for target failures and cut off beam if failures are detected. The TPS will be a safety system and must meet stringent requirements dictated by DOE regulations for nuclear facilities.

Now consider the following scenario. Suppose ring extraction tuning is in progress and the mercury target is turned off. (e.g. The target is being worked on and there is no mercury flow). The TPS views no-flow as a target failure condition and tries to cut off beam. Therefore the TPS must be bypassed in order to tune with beam. (Note that this is true for all tuning modes, not just ring extraction tuning). Current plans are to allow a bypass of the TPS if the critical devices for beam containment during extraction tuning are in place. As long as these devices are in place, the target is protected from beam for any beam tuning mode.

By now the reader has probably guessed where this is heading: The TPS bypass function must be considered to be part of a safety system for a nuclear facility. The bypass function relies on detection of status of ring-extraction-tuning critical devices. Therefore the mechanisms used to detect the status of these particular critical devices are subject to regulations for nuclear facility safety systems. (Fortunately the critical devices themselves are exempt from these particular regulations). The regulations of concern consist primarily of DOE O 420.1 "Facility Safety" and related standards. The implications of being part of a safety system for a nuclear facility will be addressed in a separate white paper.

2.3 SNS Beam Containment Policy

The beam containment policy for SNS is simply that we will comply with the applicable guidance from the DOE "Draft Implementation Guide, Accelerator Safety Order" (Section III.C.3.d; dated May, 1998). The applicable text is presented in section 2.1 above.

[DOE says "should have 2 critical devices". For comparison, Kelly Mahoney of CEBAF says their beam containment policy is "3 methods, 2 of which are technically diverse". Any guidance from other facilities at our collaborator's labs?]

3. SNS NORMAL OPERATING MODES

[This is the only place I've seen the planned operating modes actually written down. Do we need more description here (or somewhere else) describing the operating modes in more detail?]

In order to establish beam containment requirements, one must first designate the areas where people will be allowed for the various normal operating modes. Towards this end, Table 1 below and the referenced figures establish the areas for which access will be prohibited for a given operating mode.

Table 1 – Accelerator Operating Modes and Access Restrictions

Operating mode:	**Prohibited access areas:**	**Ref. figures:**
Source conditioning	None[a]	
Front-end tuning	Area #1	Figs. 1A – 1B
Linac tuning	Areas #1 and #2[b]	Figs. 1A – 1B, 2A – 2D
Ring injection tuning	Areas #1, #2, and #3	Figs. 1A – 1B, 2A – 2D, 3
Ring extraction tuning	Areas #1, #2, and #3	Figs. 1A – 1B, 2A – 2D, 3
Neutron production	Areas #1, #2, #3, TBD target areas[c], and TBD instrument areas[d]	Figs. 1A – 1B, 2A – 2D, 3, (TBD target and instrument areas not shown)

[a] The front-end high-voltage cage will be locked for electrical safety, not beam containment, and is therefore outside the scope of this document.

[b] Potential radiation levels in the achromat require that personnel access be prohibited from this area when linac tuning is in progress. A gate at the downstream-end of the achromat will prevent access from the ring. Labyrinth-style shielding in the upstream-end of the achromat will be provided to protect personnel in the ring.

[c] Target building prohibited access areas have not been defined yet. Access the remote handling cell will be prohibited whether the accelerator is operating or not due to continuously-high radiation levels. The only access to this cell will be through heavy shield plugs. Consequently there is no need to provide an automatic interlock to protect a person in the cell from accidental radiation exposure due to beam on target. Administrative controls will be used to handle those rare occasions when the cell must be accessed. (During commissioning, access to the remote handling cell will be required while tuning is in progress. See section 5 for a description of how this will be handled).

There may be other areas in the target building that do require preventing beam on target while personnel are present. The utility vaults are probably one such area.

[d] Instrument prohibited access areas have not been defined yet. Most instruments will probably have relatively small chambers that must not be accessed when a neutron beam is present. Other instruments may actually have habitable space that must not be accessed.

4. BEAM CONTAINMENT MECHANISMS FOR NORMAL OPERATIONS

4.1 General

The critical devices used for beam containment for each operating mode are addressed in this section.

In order for a mechanism to be a candidate for "critical device for beam containment", it must meet certain criteria:

- It must be fail-safe
- It must be highly reliable.
- It must have a high availability.
- One must be able to automatically verify that the beam containment action really took place. (e.g. If locking out a magnet power supply is one of the actions, you must be capable of automatically detecting that the power supply really is locked out. In this case the breaker contacts and the actual lock position could be monitored by the PPS).

Since beam containment critical devices will serve a vital personnel protection function, stringent quality assurance requirements will be imposed on their implementation and maintenance. At this time the details of the QA plan are TBD. However it is likely that QA requirements will include:

- a reliability analysis
- independent design verification
- acceptance testing
- periodic testing after installation
- rigorous configuration control

4.2 Source Conditioning

Source conditioning will involve operating the source and possibly the LEBT. For example, plasma could be generated in the source, extracted, and then dumped to the source chopper.

The accelerator beam does not reach an energy level capable of generating neutrons until somewhere along the RFQ. As long as the RFQ is not operating (i.e. RFQ RF is turned off) it should be possible to operate the source and still allow personnel access to the area. (Access to the high voltage cage will be restricted, but this is on the basis of electrical safety rather than radiation protection).

During source conditioning, x-rays could conceivably be produced by the beam striking front-end components and/or by other phenomena that can occur when there is high-voltage in a vacuum. Local shielding will be used to eliminate x-ray exposures[2]. Configuration control over the local shielding will be managed via administrative control. No PPS monitoring of front-end shield positions (e.g. via limit switches) is planned. [Another option: Have PPS monitor the positions of shield components that are routinely removed during F.E. maintenance. Comments?] The PPS will provide radiation monitors in the vicinity of the front-end to verify that radiation levels are in compliance with regulatory requirements.

Table 4-1. Beam Containment Mechanisms For Source Conditioning

Mechanism #:	**Beam confinement mechanism:**
1	RFQ RF

4.3 Front-end Tuning

Front-end tuning will involve incrementally starting up sections of the front end, and will culminate in dumping beam to the end-of-MEBT beam stop. Since the beam is capable of generating neutrons in the RFQ and the MEBT, personnel access must be restricted during this operating mode. Figures 1A and 1B show one scenario for restricting access during front-end tuning. In this scenario the RFQ and MEBT would be behind a shield wall. A gate would prohibit access from the front end building during tuning.

It would be useful for personnel to be able to access the linac tunnel during front end tuning. Potential radiation levels preclude access to the upstream end of the tunnel. However, beyond some distance downstream of the front end potential radiation levels should be low enough to allow personnel access. The safe area is yet to be determined, but for now it is postulated to be downstream of the CCDTL-CCL junction. A gate would prohibit access from the downstream end of the tunnel during front end tuning. (See fig. 1B).

The end-of-MEBT beam stop will serve as one beam containment mechanism during front-end tuning. The second method will be to inhibit power to the DTL RF system. Even if the beam stop were to fail, in the absence of DTL RF the beam would disperse and not present a radiation hazard beyond the gates.

[John Staples says that if front-end components are not set up properly, beam can get focused to the point where it could burn a hole through the stop. If true, we will have to have a way to detect this. e.g. Could we design the beam stop's water cooling to spoil beam under these circumstances?]

Table 4-2. Beam Containment Mechanisms for Front End Tuning

[2] X-ray fields will be characterized by actual measurements taken during testing of front-end equipment at LBNL. The shielding design will be based on these measurements. The effectiveness of the shielding will be re-verified during initial operations at ORNL

Mechanism #:	Beam confinement mechanism:
1	End-of-MEBT beam stop
2	Inhibit DTL RF power

4.4 Linac Tuning

For linac tuning, access to Area 2 (as shown in figures 2A – 2D) will be prohibited.

Potential radiation levels require that personnel be restricted from accessing most of the achromat during linac tuning. A gate in the downstream section of the achromat (exact location TBD) will prevent access from the ring tunnel. Labyrinth-style shielding in the upstream end of the achromat will be provided to sufficiently mitigate any potential prompt radiation hazard downstream of the gate. This shielding coupled with beam containment mechanisms will prevent a person standing at the gate from receiving an unacceptable radiation dose.

The beam confinement mechanisms for linac tuning are listed in table 4-2.

Table 4-2. Linac Tuning Beam Containment Mechanisms

Item:	Beam confinement mechanism:
1	Inhibit AC power to the power supply for the 7.5^{o} dipole in the HEBT
2	Inhibit AC power to the power supply for the 82.5^{o} dipoles in the HEBT

4.5 Ring Injection Tuning and Ring Extraction Tuning

Given the potential radiation levels in the ring tunnel and RTBT during both ring injection tuning and ring extraction tuning, it is not practical to design for access to any portion of these areas during either ring tuning mode. Thus, access will be prohibited to all of the ring tunnel and all of the RTBT during ring tuning. (See figure 3).

The primary beam containment function during injection tuning and extraction tuning is to protect personnel in the target area (e.g. during target change-out). The system can be simplified by taking advantage of the fact that that any beam containment mechanisms used to protect personnel during extraction tuning will also provide protection during injection tuning. (Of course, during ring injection tuning the beam would not normally reach any protection mechanisms used during extraction. However, we can still claim that these mechanisms provide the required protection).

The beam confinement mechanisms for both ring-injection and ring-extraction tuning are listed in table 4-3.

Table 4-3. Ring Tuning Beam Containment Mechanisms

Item:	Beam confinement mechanism:
1	Inhibit AC power to power supply for extraction dump/RTBT 15.5^{o} bending magnet
2	Inhibit DC current from power supply to extraction dump/RTBT 15.5^{o} bending magnet
3	Combination of beam defocusing and beam diffuser (both located downstream of extraction dump / RTBT 15.5^{o} bending magnet): • Defocus beam by inhibiting AC power to focusing magnet power supplies • Install beam-stop-style diffuser downstream of focusing magnets

In theory the beam defocusing / beam diffuser combination would never actually be challenged with direct beam. None-the-less, since it is being designated as a critical device it must be capable of acting alone should the other critical devices fail. Thus the diffuser must be designed to sustain the fraction of power that is received after the full-power beam is defocused.

4.6 Neutron Production

There are at least two beam containment requirements in the Target building during neutron production:

1. The mercury target plug must be in place and the target full of mercury.
2. There must be no way for personnel to be exposed to neutron beams in the course of instrument operation and maintenance.

4.6.1 Target-Related Beam Containment

One can view the mercury in the target and the target plug as critical devices for beam containment during neutron production. (Their configuration can change under normal and common circumstances, and we have to make sure they are in a particular configuration before we can allow neutron production). Safety systems will not actually control the configuration of the mercury and the plug, but rather will monitor their status and disable beam accordingly.

A Target Protection System (TPS) is being implemented to shut off beam when there is the potential for loss of mercury containment. This system will monitor mercury flow, pressure, temperature, etc., to ensure that the mercury is able to safely receive beam. While the primary function of the TPS is to prevent the release of radioactive materials, it can also coincidentally serve to monitor the status of the mercury and the plug from the standpoint of beam containment. That is, the TPS will only allow beam when the target plug is in place and the target is full of mercury. (As a side note, The PPS need not carry out this particular beam containment function since the TPS is a safety system and is already doing it).

To serve as an additional monitor of beam containment, redundant radiation monitors will be installed downstream of the target to detect both loss of mercury and incorrect placement of the target. The PPS will provide an active shut-off of beam based on these monitors' readings.

4.6.2 Instrument-Related Beam Containment

Personnel must be protected from neutron beams during (a) instrument operation with beam, and (b) experiment changes and maintenance.

Beam containment during instrument operation is a concern because local shielding is frequently removed and replaced in the course of experiment changes (e.g. sample change-outs). In this context, local shielding serves as a critical device for neutron beam containment during instrument operation. An automatic protection system plus administrative controls will ensure that will local shielding is configured properly before neutron beams are allowed.

Beam containment during experiment changes and maintenance is a concern since personnel will be working in areas that could potentially be configured to receive a neutron beam. The neutron beam shutter for each beamline will serve as the critical device to contain beam during experiment changes and maintenance. Interlocks will insure that a given shutter cannot be opened unless the downstream instrument is in a safe state (i.e. clear of personnel, local shielding in place, etc.). Also, interlocks will shut off the accelerator beam and close the neutron shutter if local shielding is violated while the shutter is open.

Each instrument will be unique in terms of its radiation hazards and the corresponding beam containment system required. A radiation safety analysis will be performed for each instrument. Shield configuration control and access control systems will be designed to address the identified hazards. SNS management will review and approve the designs.

5. BEAM CONTAINMENT DURING COMMISSIONING

Where possible, the beam containment mechanisms used for normal operations will also be used for commissioning. This means that these mechanisms will have to be implemented in time to support commissioning, even if they are located downstream of the segment being commissioned.

The phased approach planned for linac commissioning requires that temporary beam containment measures be taken. Current plans are to terminate the beam tube segment being commissioned with a diagnostic commissioning plate (DCP). A temporary shield wall (e.g. stacked blocks) will be placed downstream of the DCP. In accordance with the SNS shielding policy, this temporary shield wall will be adequate to limit radiation doses to acceptable levels under worst-case conditions. Note that burn-through of shielding is not a credible accident due to the certain loss of beamline vacuum if the beam were to burn through the DCP. Workers will be able to continue installation downstream of the wall while commissioning is taking place on the upstream side. To insure compliance with regulations, a pair of temporary radiation monitors will be placed on the downstream side of the wall. These will be incorporated into the PPS logic to shut down beam if excess radiation is detected. If a labyrinth-style shield wall is used (e.g. to allow access for installation when not operating), a gate will be provided to prevent personnel from accessing the operating area. Gate interlocks will be incorporated into the PPS system to shut down beam if the gate is open.

Prior to CCL commissioning a section of beamline in the upper end of the achromat will be removed and the beamline capped. This precautionary measure can be justified during construction since risks are higher during this phase. The beamline section will be replaced prior to ring commissioning.

During ring commissioning, access to the remote handling cell in the target building will be required for construction. To protect workers in the cell, a section of beamline downstream of the extraction dump/RTBT bending magnet will be removed and the beamline capped. This, coupled with permanent shielding planned in the downstream end of the RTBT (to prevent neutron backstreaming), will protect construction workers in the cell.

Table 5-1 lists the commissioning phases planned and their corresponding prohibited access areas.

Table 5-1 – Commissioning phases and prohibited areas

Commissioning phase:	**Prohibited access areas:**
Source	None
Front-end	Same as for front-end tuning during normal operations
DTL phase 1	Between front-end-building-to-linac-tunnel sliding shield door and temporary shield wall downstream of DTL
DTL, phase 2	Between front-end-building-to-linac-tunnel sliding shield door and temporary shield wall downstream of DTL
CCDTL, phase 1	Between front-end-building-to-linac-tunnel sliding shield door and temporary shield wall downstream of CCDTL
CCDTL, phase 2	Between front-end-building-to-linac-tunnel sliding shield door and temporary shield wall downstream of CCDTL
CCL	Same as for linac tuning during normal operations
Ring injection	Same as for ring injection tuning during normal operations. Exception: Access to target building hot cells and utility vaults will be allowed.
Ring extraction	Same as for ring extraction tuning during normal operations. Exception: Access to target building hot cells and utility vaults will be allowed.
Neutron production	Same as for neutron production during normal operations.

APPENDIX A - ASSUMPTIONS NEEDING VERIFICATION

This document makes the following assumptions that remain to be verified.

1. X-ray production during source conditioning can be mitigated using local shielding.

2. Potential radiation levels are acceptable for habitation beyond some distance downstream of the front end during front-end tuning. If true, the actual safe distance needs to be determined.

3. Adequate shielding (e.g. a labyrinth) will be provided in the upstream end of the achromat to protect personnel in Ring and RTBT tunnels during linac tuning.

4. Regarding protection of personnel in target building:

   (a) During construction/commissioning: Adequate shielding will be provided to protect personnel working in the target building hot cells and utility vaults during simultaneous ring commissioning and target construction.

   (b) During normal operations, after commissioning: Adequate shielding will be provided to protect personnel in target building should an accident occur during simultaneous ring extraction tuning and target change-out. (e.g. Steering magnet fails "on" and beam strikes beam diffuser in RTBT. Or extraction kicker fails and beam strikes a magnet upstream of beam diffuser).

Contributors:

Jose Alonso
Ron Battle
Kent Crawford
Bill DeVan (editor)
Mike Harrington
Andy Jason
Jeff Johnson
Rod Keller
David Olsen
Ken Reece
Andy Soukas
John Staples
Bob Stevenson
Paul Wright

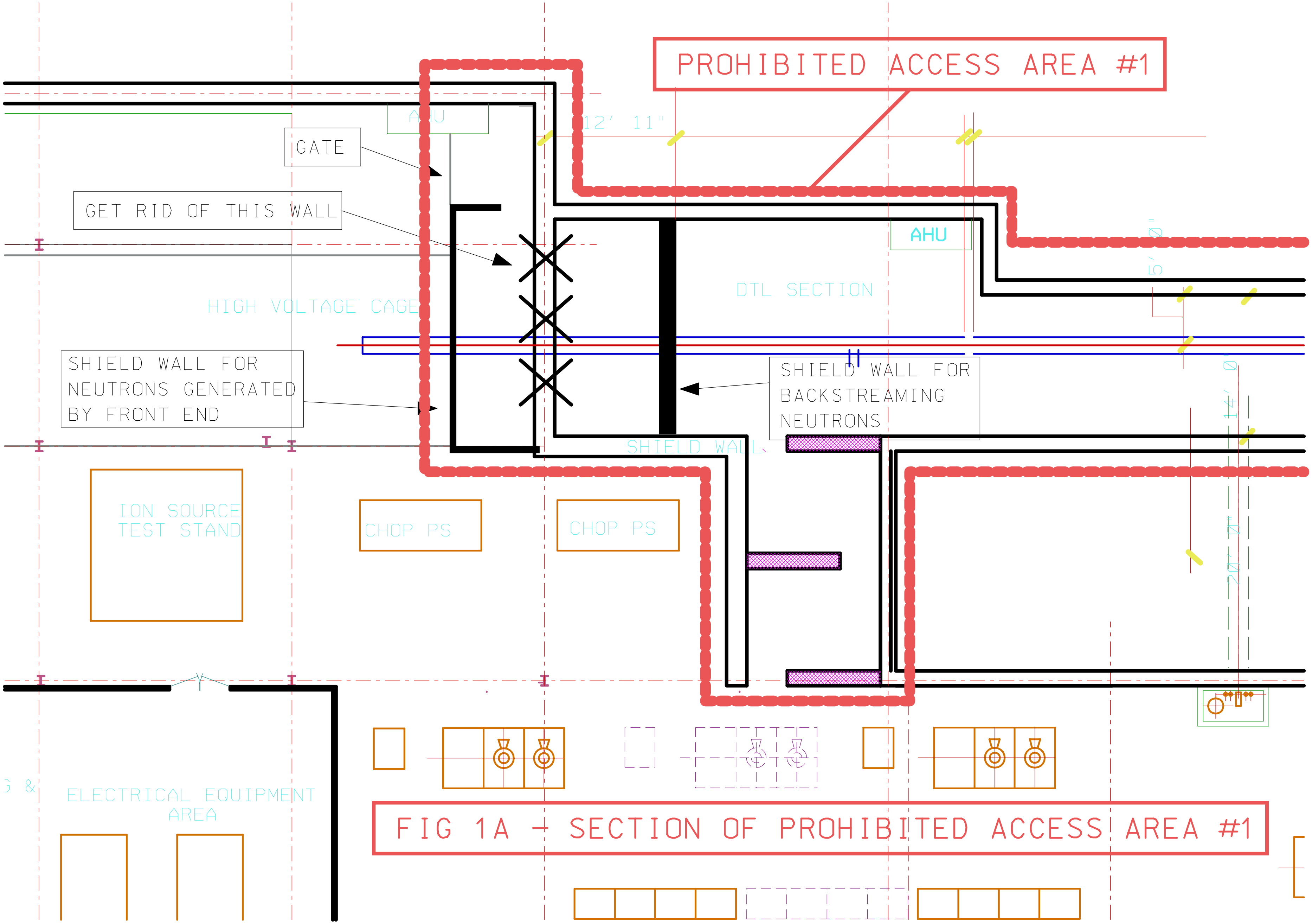


FIG 1A – SECTION OF PROHIBITED ACCESS AREA #1

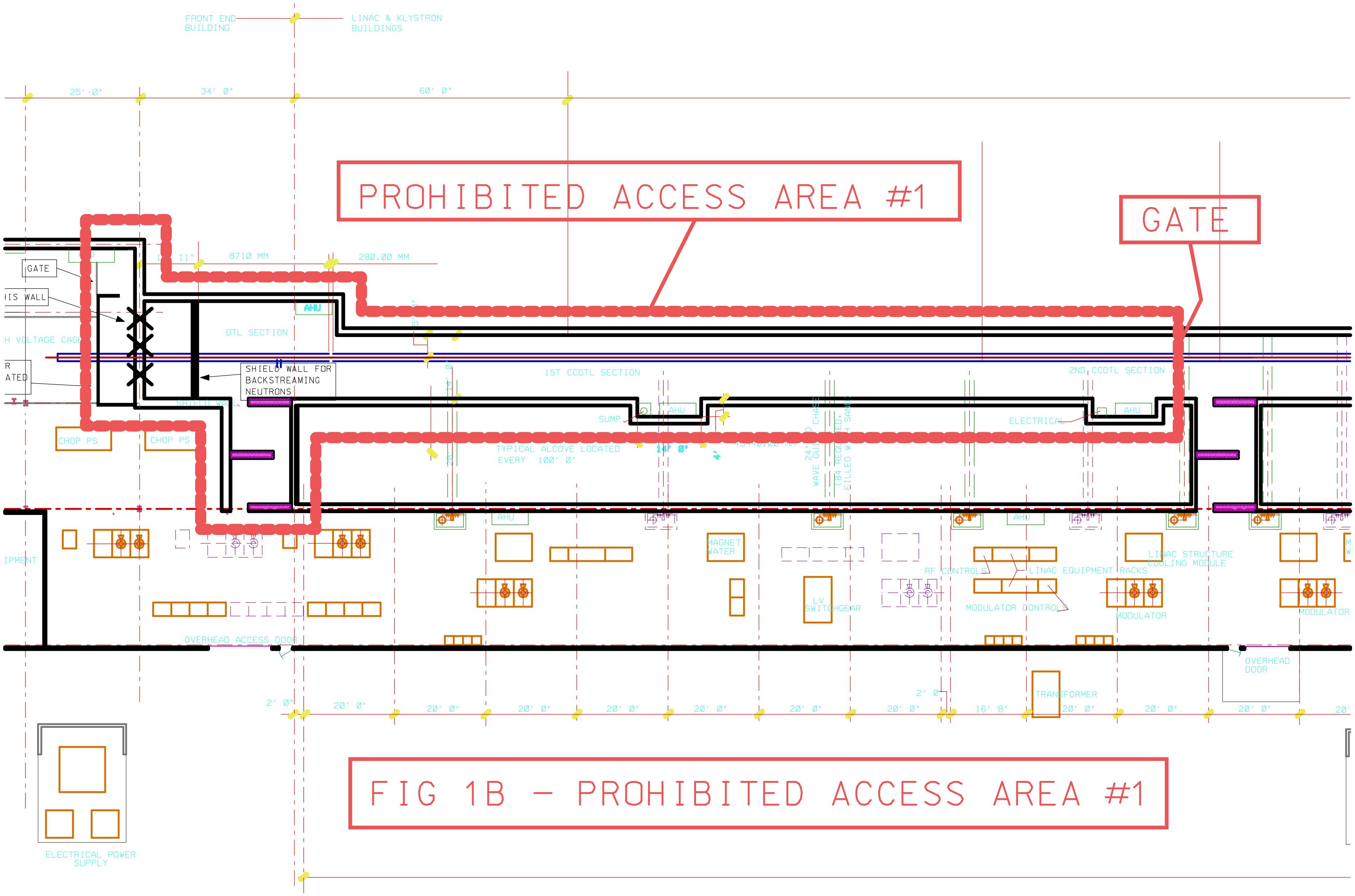


FIG 1B – PROHIBITED ACCESS AREA #1

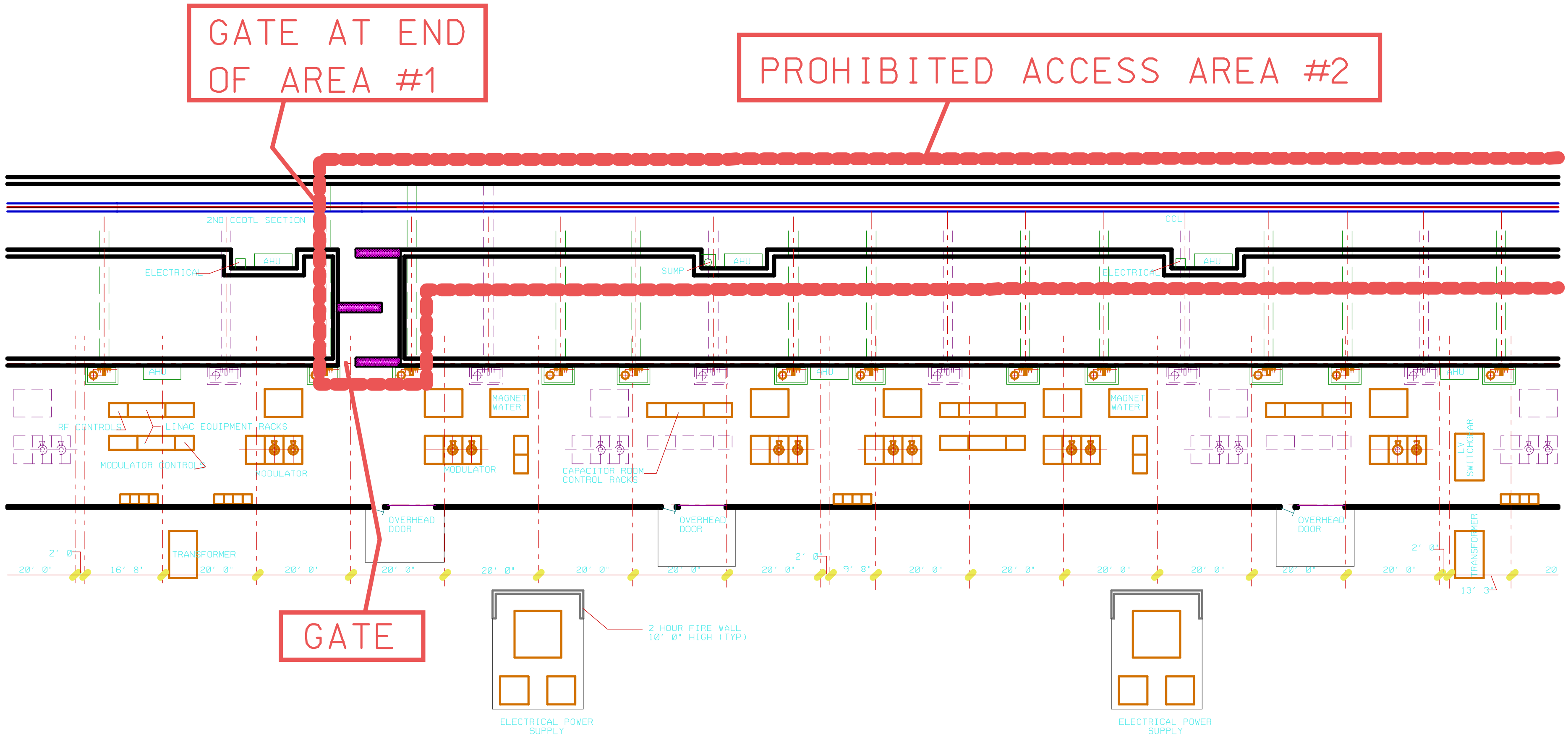
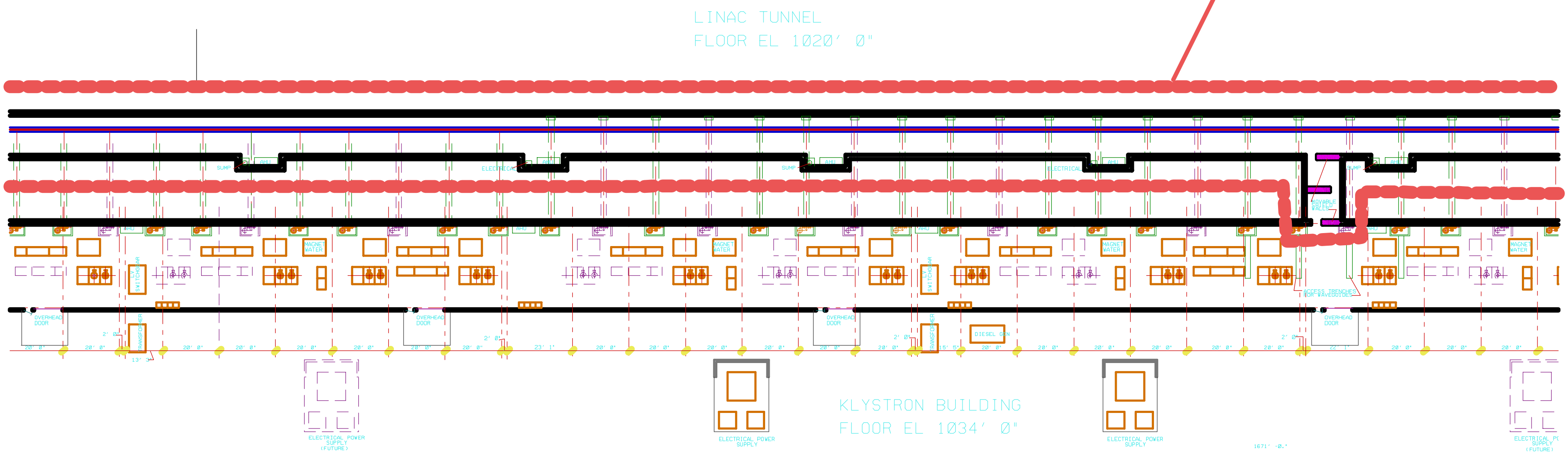


FIG 2A – SECTION OF PROHIBITED ACCESS AREA #2

PROHIBITED ACCESS AREA #2



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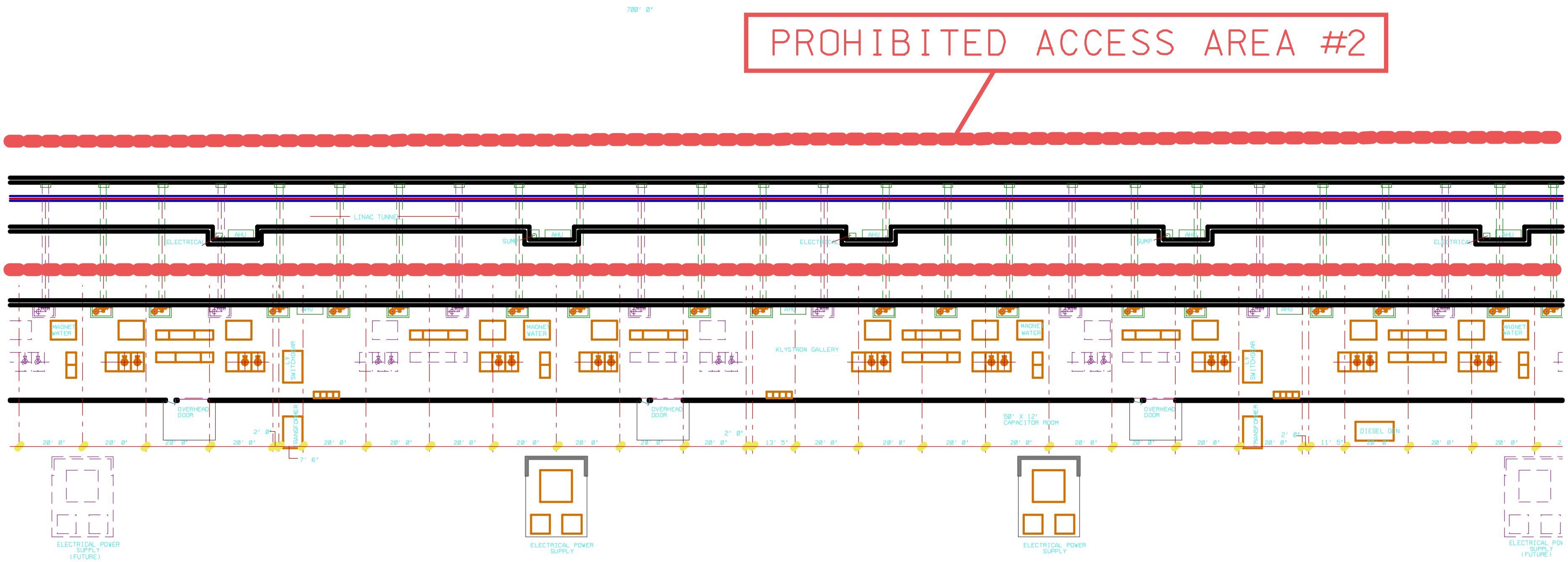

FIG 2C – SECTION OF PROHIBITED ACCESS AREA #2

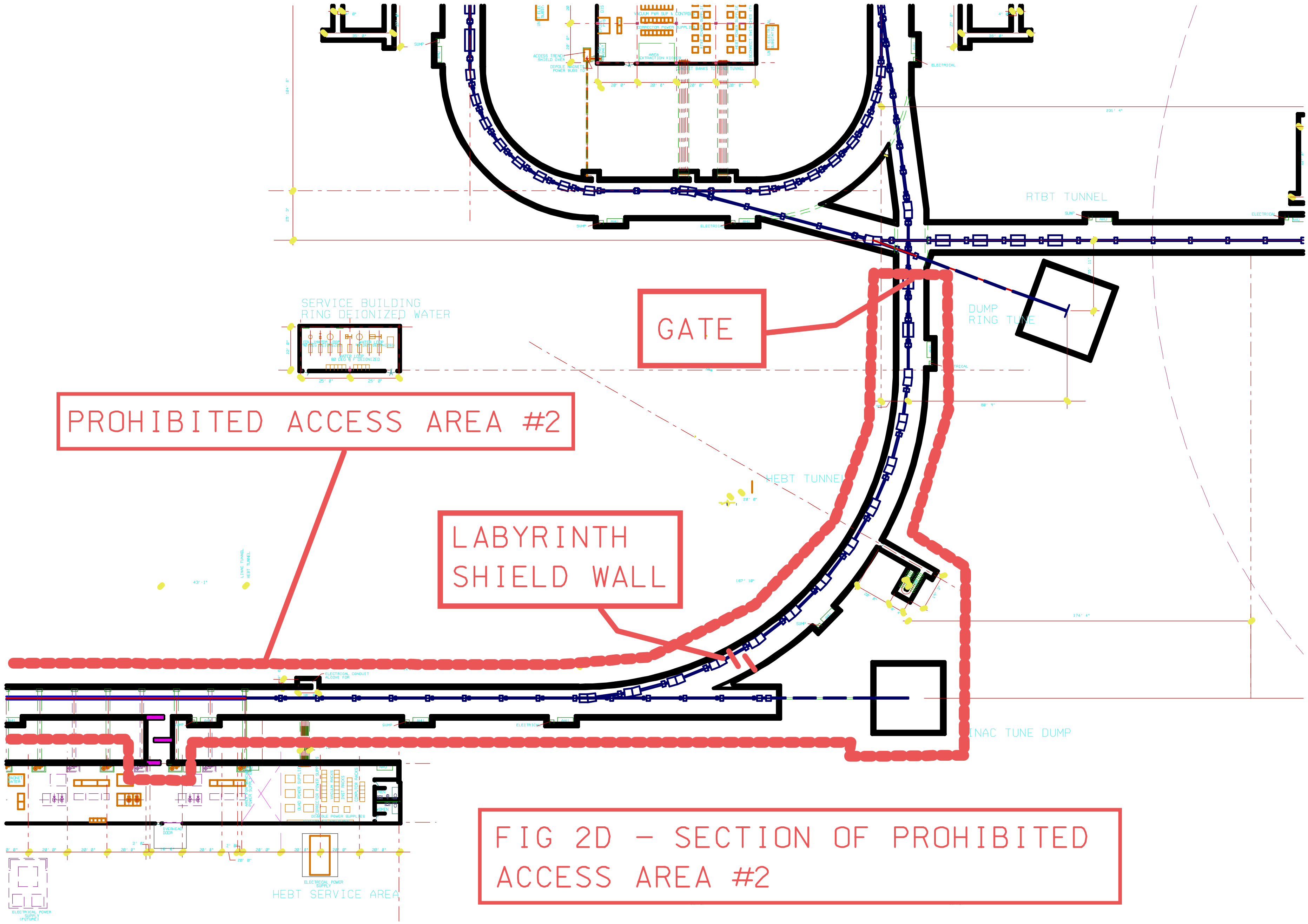

FIG 2D – SECTION OF PROHIBITED ACCESS AREA #2

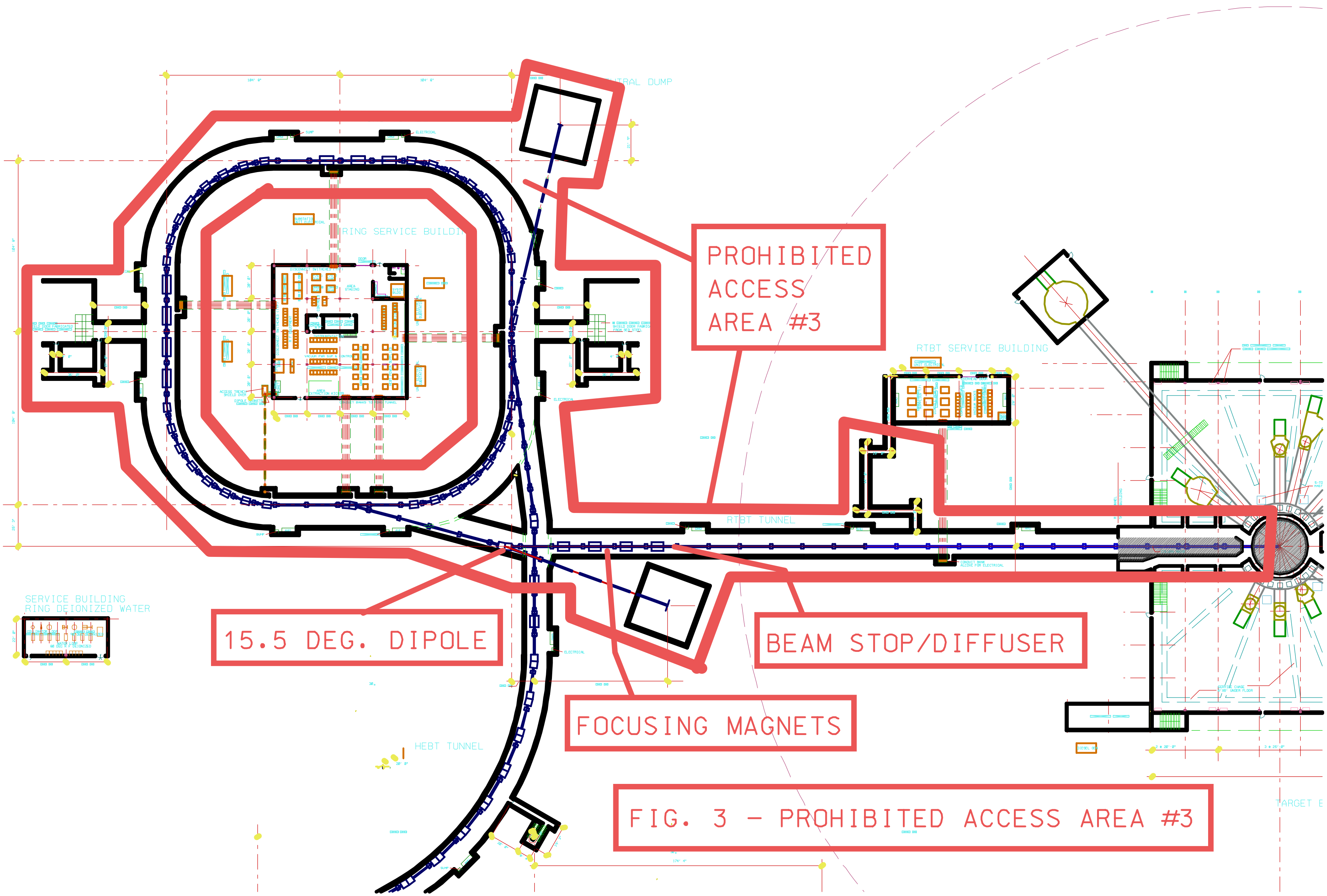

FIG. 3 – PROHIBITED ACCESS AREA #3