National Spherical Torus eXperiment Upgrade

NSTX-U Recovery Project Shielding Plan

NSTX-U-RQMT-PLAN-017-00

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Record of Revisions

Date	Version	Brief Description of Changes
4/4/18	Rev 0	Initial Release

References

[1] NSTX-U-RQMT-SRD-010: NSTX-U Test Cell System Requirements Document

1: Structure of the Shielding Plan

During the 2016 run campaign, measurements at locations around the NSTX-U Test Cell demonstrated the need to improve the Test Cell shielding. In particular, some doors and penetrations lacked sufficient shielding to reduce the neutron flux from the test cell to acceptable levels.[1]

As part of the NSTX-U Recovery Project Extent of Condition assessment, a number of chits were written regarding the need to improve the shielding. These chits are listed in Table 1-1. Remediation of these shielding deficiencies was identified as high-priority by the laboratory and the Extent of Condition committee.

Table 1-1: *DVVR chits related to NTC shielding that are addressed by this plan.*

Chit #	Chit text
RMS1	Data from the Radiation Monitoring System will need to be reviewed, as it becomes available, to determine if penetration shielding needs to be improved.
RMS3	Shielding, especially local shielding of penetrations may be insufficient for future operations. Restart design and analysis of local shielding around penetrations. A survey of penetrations could identify a few bad actors.
RMS4	Consider using D-T generator to assess which penetrations or features of the NTC walls/ceiling/floor are causing the worst dose (after appropriate review of course...)
RMS5	Please consider moving the card reader on the south door to the door to the south high bay.
RMS6	Continue process to identify and shield penetrations that are most problematic.
RMS10	Identify penetrations such as water, laser guides, fiber optic bundles, RF Feeds and shield the entry and exit sides of the penetration with additional shielding.
RMS11	Consider adding a labyrinth to the south high bay door to mitigate southeast gallery radiation issues.
RMS12	Consider ways to improve the shielding at the North door. Poly sheets, other concrete, or close the battleship door?

The shielding plan described here is based on a three phase approach. The first two phases include testing with the D-T neutron generator to identify the most problematic penetrations, followed by implementation of the engineering steps required to remediate those penetrations. This two-phase process is needed because the contributions of small or marginally shielded penetrations to the total neutron flux from the Test Cell can be difficult to identify in the presence of large or poorly shielded penetrations.

The final step of the plan is to assess the performance of shielding during plasma operation. This is described in Phase III below. It is possible that an additional phase of testing with the D-T neutron generator will be required following Phase III if the additional shielding implemented in Phases I and II

[1] Note: a staged approach to improving the test cell shielding had been envisioned before the 2016 run. It was envisioned that this would commence following the FY2016 campaign. The Recovery activity reset those plans.

does not adequately reduce the neutron flux from the Test Cell. The shielding shall be deemed to be adequate if:

- The NSTX-U dose component at the site boundary is sufficiently small to accommodate a total dose of 10 mrem/yr.
- Access to regions indicated as requiring unrestricted access[2] in Table 2.3-1 of Ref [1] meets this requirement.

2: Underlying Motivations

The requirements for the NSTX-U test cell are provided in Ref. [1]. High level shielding requirements are given in Section 2.3 of that document, including site boundary requirements and requirements for access to D-site locations in the vicinity of the test cell.

3: Phase I

3.1 Phase I Shield Wall Test Results

A survey of the test cell penetrations with a D-T neutron generator was performed in May 2017. This test was performed using procedure D-NSTX-IP-3931. The D-T neutron generator was placed at the 7 locations in the test cell listed in Table 3.1-1 and shown in Fig. 3.1-1. Readings were taken at various areas outside the test cell using calibrated ^{3}He proportional counter detectors. The data were recorded in surveys SS-2017-05-24-0020, SS-2017-05-26-0005, and SS-2017-05-24-0019.

The summarized data from these surveys are listed in Table 3.1-2. Penetration numbers can be found in drawing E-FA1030 sheets 1 and 2 and in the Appendix to this document.

Readings less than or equal to 100 microRem/hr during the D-T neutron generator test are not considered to be sufficiently significant to address in the first round of shielding, and are therefore not shown. Areas in red in Table 3.1.-2 will be addressed in Section 3.2. In general, areas in green in Table 3.1-2 are not considered to be significant and will probably not be addressed in Phase II. Areas in green that are greater than 100 microRem/hr have additional considerations that are listed in the notes to Table 3.1-2 and sometimes further addressed in Section 3.2

[2] Unrestricted access allowed for regions having a radiation field <50 µrem/hr.

Table 3.1-1: D-T neutron generator locations during May 2017 testing

Location No.	Description
1	109' near RF Bay F&G Pointing South East
2	100' SE Corner Pointing North East Corner
3	Top NB#2 Pointing North East Corner
4	Top NB#1 Cryo stand Pointing North West Corner
5	100' NE Corner Pointing South West
6	119' SW Corner Pointing North East Corner
7	S High Bay Scissor Lift Elevated to 10’ Pointing East

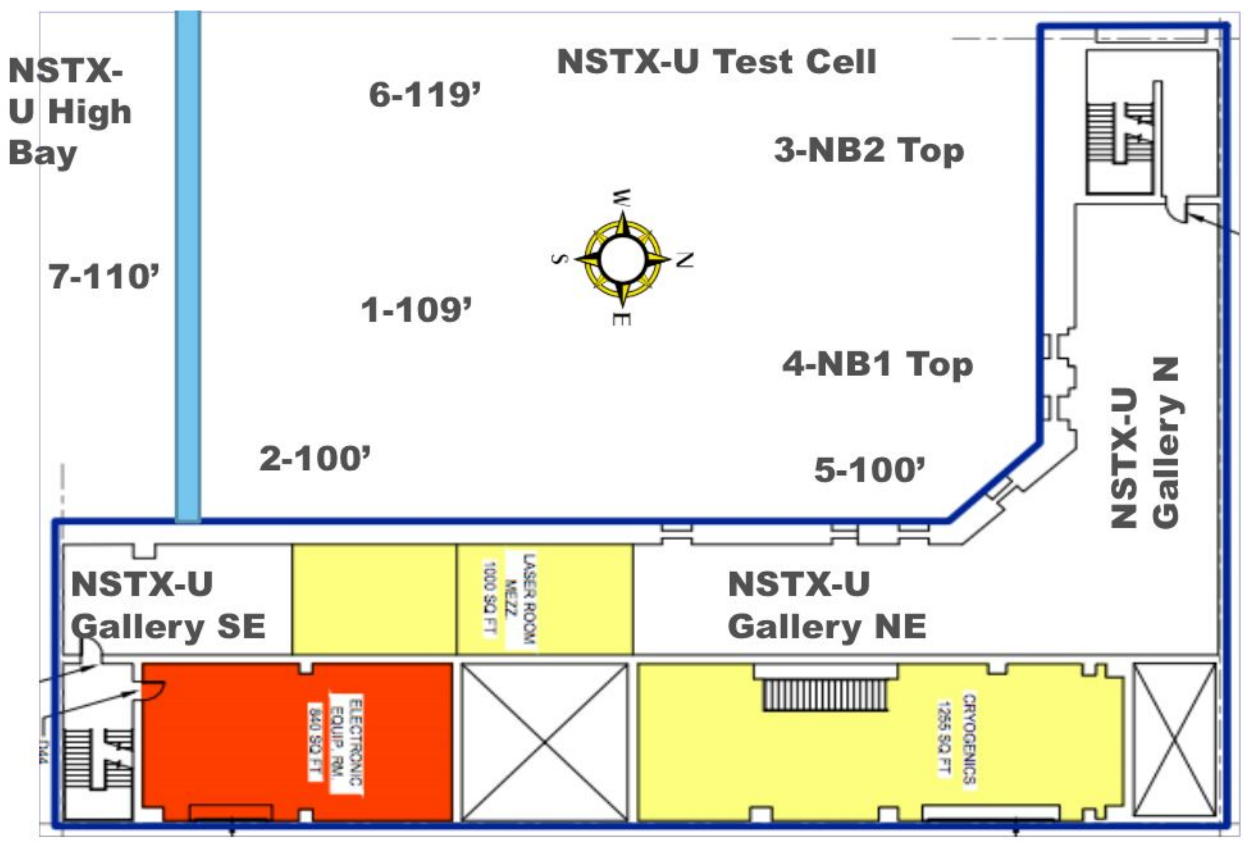

***Figure 3.1-1**: Schematic of the locations where the D-T neutron generator was placed during the May 2017 tests*

Table 3.1-2: *Significant test results from the May 2017 D-T neutron generator shielding assessment.*

	Location	Highest Reading Observed (μRem/hr)
1	NSTX Test Cell North Door and Vestibule	2,500
2	North Wall Center, Height 16 Feet, Lateral Distance 10 Feet Across From upper wall large windows 6500 and 6501 (NOTE 1)	100
3	RF Feed Thru #6111 - 6116 / Window 6502, Penetration 1616 and 1617	500
4	Penetration 1636 North Wall	100
5	Penetration 1594 North Wall	100
6	Penetration 1591 North Wall	100
7	Large Window behind Panel B-GIS-2A North Wall #6495 (NOTE 2)	300
8	Inside gas cylinder cage North Wall (NOTE 3)	200
9	North East Wall at 8' between large window 6497 and cable tray penetrations 1622 and 1623	700
10	Window 6497 Center Contact	400
11	Cable tray penetration 1623	400
12	Large Window 6503 Lateral Distance 10 Feet, Height 12 Feet	300
13	General Area 12 Foot High Penetrations 1622, 1623, 1624, 1625	200
14	Penetration 6360 East Wall	100
15	Penetration 6310 East Wall	400
16	Door 44-110A South East High Bay Door (I-31)	25,000
17	Laser Water Chiller storage tank and pump (NOTE 4)	1,000
18	NB Power Conversion Bldg Door D44-116 8 locations (NOTE-5)	100 - 900
19	South / East MER Mezzanine	700
20	Penetration 6136 Laser Mezzanine	600

NOTE 1: This reading is at the 100 microRem/hr threshold; however, it is considered to be significant because the measurements were taken at a distance of at least 10 feet from the target windows. The dose rate at the window is likely significantly higher. It is not possible to calculate the neutron flux at the windows due to neutron scattering.

NOTE 2: This measurement was taken when the D-T neutron generator was in a position almost directly behind that shield wall, between the HVEs[3] and Beam Boxes. It is likely this window will be well shielded during D-D operations.

NOTE 3: Same as NOTE 2.

NOTE 4: This data was taken with the D-T neutron generator located in the High Bay area. During that run the neutron dose rate in front of the South High Bay Door was more than 25 mR/hr. It is likely that readings taken as far down the east wall as the laser cooling skid are a result of scattering from neutrons that are coming from the unshielded south door. In all other tests no neutron dose rate could be detected at the laser cooling skid.

Note 5: This data was taken during the run with the D-T neutron generator located in the High Bay area. The door had a direct line of sight to the 14 MeV neutrons produced by the generator. During D-D plasma operation neutron dosimetry placed on various locations on the outside of the steel door did not show any significant readings. These measurements during the D-T generator neutron test should be discounted because they were primarily due to unmoderated high energy neutrons and therefore the shielding was not sufficient. D-D neutrons would be well-shielded by the door because they are well-moderated due to scattering inside the Test Cell. Additionally, this door is concrete filled, so no additional shielding should be required. For these reasons, this door will be assessed in Phase II.

3.2 Phase I Shielding Assessment Recommendations

This section describes the recommendations for Phase I improved door and penetration shielding, based on the D-T neutron generator studies.

3.2.1: South East Door

The entrance to the High Bay area is identified in red in row 16 of Table 3.1-2. The shielding of this door should be improved by the installation of additional dedicated shielding.

Because of the extremely poor (nonexistent) shielding provided by this door it is very likely that some readings taken in the general vicinity of this door should be considered to be impacted. Until this door is properly shielded and the areas re-tested, any other positive result around the vicinity of the door should not be considered accurate.

Action: Construct shielded enclosure around this door.

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[3] HVE: High Voltage Enclosures, the six large orange vessels which contain neutral beam power supply equipment.

3.2.2: South High Bay Tritium Seal Door to Neutral Beam Power Conversion Building

This door is identified in green in row 18 of Table 3.1-2 .

Initial assessments indicated that this door was hollow, and it therefore was included in the list of areas of interest. Since then, it was determined that this door is filled with concrete.

Per Note 5 above, this door should not be included in the first round of shielding (Phase I). It should be assessed during Phase II or when D-D operation plasma operations begin (Phase III) and a more representative neutron spectrum can be obtained.

Action: Develop methods to ensure the door is closed during operations. Defer further shielding assessments to Phase II.

3.2.3: North NSTX-U test cell door and vestibule

This area is identified as red in row 1 of Table 3.1-2.

Initial efforts to shield this area utilized an additional concrete wall in the north gallery. However, Phase I tests indicated that this step was insufficient, and that additional steps must be taken. Additional tests could involve the installation of additional concrete shielding.

However, after further investigation, it has been determined that closing the existing shield/sela door is acceptable, following appropriate modifications to procedures and related electrical installations.

Action: Develop procedures, and make necessary modifications, to close the large shield/seal door ("battleship door") during plasma operation.

3.2.4: Window 6497 on the east wall, 100' level

This window is identified in red in rows 9 & 10 of Table 3.1-2. This was the only accessible window along the east wall for which a direct reading could be obtained.

The surrounding windows 6498, 6499, 6503, 6504 and 6505 were not directly tested, and were not identified at the CDR. However, given their large size, similarity to the window that was determined to have a problem (6497), and in many cases direct line of sight to the machine, these additional windows should be shielded. This conclusion is further motivated by the readings in row 12 of Table 3.1-2, where strong readings were observed at a distance from window 6503.

Note that windows 6494 & 6495 are not included in the Phase I shielding plan; they did not register signal during D-T neutron generator testing, and are well shielded from the device by neutral beam components. They are included in the list of windows and penetrations to assess in Phase II.

Action: Install shielding on windows 6497, 6498, 6499, 6503, 6504, and 6505.

3.2.5: Penetration 6310 on the east wall, 100’ level

This penetration is identified in red in row 15 of Table 3.1-2.

However, this penetration was removed from the Phase I shielding list following further consideration. After reviewing the measurement data this penetration, positive radiation readings were seen on one of the tests and no detectable radiation on any of the other tests. The test that had a positive result had the D-T neutron generator in the direct line of sight of this penetration.

Hence, it is recommended to remove this penetration from the list and wait for Phase II or D-D plasma operation (Phase III) to make a recommendation for this penetration.

Action: Defer further assessment of this penetration to Phase II.

3.2.6: Penetration 6136 on the east wall, 109’ level

The 10” Penetration in the mezzanine laser room (Penetration 6136) is identified in red in row 20 of Table 3.1-2. Of all the penetrations measured in the mezzanine areas this was the only one that showed a positive result.

Action: Install shielding to reduce or eliminate neutron streaming down this penetration.

3.2.7: Penetrations 1622, 1623, 1624 on the east wall, 100’ level

Three cable penetrations on the north end of the east wall (1622, 1623, 1624) are red in rows 9, 11 & 13 of Table 3.1-2.

Additional penetrations adjacent to the ones noted here were omitted from the test. Based on similarity of size and geometry, the following penetrations should should also be addressed: 1618-1621, 1625, 1626-1632, 1587-1590, 1616, and 1617. During the radiation survey these penetrations were difficult to identify and see but their proximity to the measurement points may have had an influence on the overall reading.

Action: Install shielding on penetrations 1622-1625, 1618-1621, 1626-1632, 1587-1590, 1616, and 1617 as part of Phase I.

3.2.8: Area around the RF waveguide penetrations, northeast wall

The RF waveguide penetrations at the 119’ level on the northeast wall are identified in red in Row 3 of Table 3.1-2.

However, it is not possible to determine if the actual waveguide penetrations or Window 6502 is the source of detected neutrons during the D-T neutron generator tests.. The radiation survey could only determine that the general area around the waveguides is a problem, with increasing signals as the detector approached window 6502.

The entire area should be addressed, starting with window 6502 and penetrations 1616 and 1617. This should be accomplished by remediating window 6502 as part of Phase I and shielding around the waveguides as a potential step in Phase II.

Action: Install shielding in window 6502 and penetrations 1616 and 1617 for Phase I; assess and remediate as necessary the HHFW waveguide penetrations as part of Phase II.

3.2.9: Vicinity of windows 6500 and 6501 on the NTC north wall

The two large windows on the north end of the east wall (6500 & 6501) are red in row 2 of Table 3.1-2.

Action: Install shielding in windows 6500 & 6501.

3.2.10: NTC bakeout piping floor penetration (Penetration 515)

Penetrations for bakeout piping in the Test Cell floor to the South/East MER Mezzanine are identified in red in row 19 of Table 3.1-2. However, it is not practical to shield these penetrations for two reasons:

- The large pipes cannot be shielded on their interior, resulting in a an irreducible minimum penetration size.
- Any shielding material would need to be compatible with the high temperature of the helium piping or the hole in the Test Cell floor would need to be large enough to accomodate the insulation, which would further compromise the neutron shielding.

However, the MER is an underground room with concrete walls and is therefore an ideal location to capture neutrons.

For these reasons, the recommended path is to restrict access to the MER and MER mezzanine during plasma operation via engineering controls. This is similar to the access restrictions to basement areas that were in place during TFTR operation.

Action: Restrict access to the MER and MER mezzanine during plasma and beam operations. This will involve developing appropriate access controls on personnel doors as well as the mechanized MER air shaft access door.

3.2.11: NTC floor neutral beam penetrations (Penetrations 506, 504)

The NB water penetrations were identified as possibly requiring shielding at the CDR. However, no measurements were taken below these penetrations. That recommendation was largely based on judgement, as it is clear that these allow neutrons to enter the MER.

Based on the discussion in 3.2.10, the recommendation is to restrict access to areas beneath those penetrations.

Action: Restrict access to the MER and MER mezzanine during operations, as per 3.2.10.

3.2.12: NTC flow OH water heater penetration (Penetration 510)

There are unshielded penetrations associated with the OH water heater electrical power feed. While no D-T neutron generator tests were done for these penetrations, it is clear that these penetrations allow neutrons to pass from the test cell into the MER.

Action: Restrict access to the MER and MER mezzanine during operations, per 3.2.10

4: Phase II Overview

This details of this section will be completed once the Phase II DT tests are completed. The doors and penetrations listed in Table 4-1 may be found to require remediation as part of Phase II. This table lists all penetrations and doors that were identified during the Phase I testing but deferred to Phase II, as well as all other test cell penetrations of significant size that are not addressed in Phase I.

Table 4-1*: Doors and penetrations that may require remediation as part of Phase II.*

	Penetration Number	**Penetration Location & Notes**
1		NBPC Door from South High Bay
2	6310	East wall
3	6495	North Wall
4	6494	North Wall
5	1586	North Wall
6	1586A	North Wall
7	1636	Northeast Wall
8	1635	Northeast Wall
9	1634	Northeast Wall
10	6172	East Wall
11	6173	East Wall
12	6174	East Wall
13	1591	North Wall

14	1592	North Wall
15	1593	North Wall
16	1594	North Wall
17	6360	East Wall
18	6243	East Wall
19	6111-6116	Northeast Wall RF Waveguide Penetrations
20	---	Penetrations above the shield door between the south high bay and the neutral beam power conversion building

5: Phase III

The phase three plan will be based on measurements made during the FY2016 run, and refined based on the output of Phase I and Phase II activities. During the Phase III testing to be performed during plasma operation, the following activities shall be performed to further assess the effectiveness of the Test Cell shielding.

- Up to 10 mobile integrated ^{3}He neutron detectors will be used to monitor then neutron flux outside the Test Cell. They will be located in the similar positions as they were during initial NSTX-U startup operation. These locations include but may not be limited to the north and east galleries, the neutral beam power conversion building, and other areas adjacent to the NSTX test cell.

- A single neutron detector will be placed inside the north test cell door prior to daily plasma operation, and another integrating neutron detector will be placed outside the south high bay tritium seal door to make a comparison measurement of potential neutron exposure inside the test cell versus exposure outside the north door shield wall.

- Three integrating neutron monitors will be located in the existing North, East and South boundary trailer locations. Backup neutron monitors will be provided in each location.

- Passive dosimetry will be deployed in a 1’x1’ grid formation from ground elevation up to 10 feet above floor level along the North and East outside walls of the gallery. This data will be normalized and compared to data taken during the NSTX-U startup run.

Based on data taken during the original NSTX-U startup operation, access restrictions to the North and East gallery halls will not be in place and dosimetry will not be required in these areas.

Appendix: Penetration Drawings

In the drawings below, color coding is as follows:

Table A-1*: Color coding in Figs. A-1 through A-4.*

red	Penetrations to be addressed in Phase I, by either additional shielding or access restrictions
green	Doors where remedial action is required
black	Other penetrations

Figure A-1*: Penetrations in the test cell north wall*

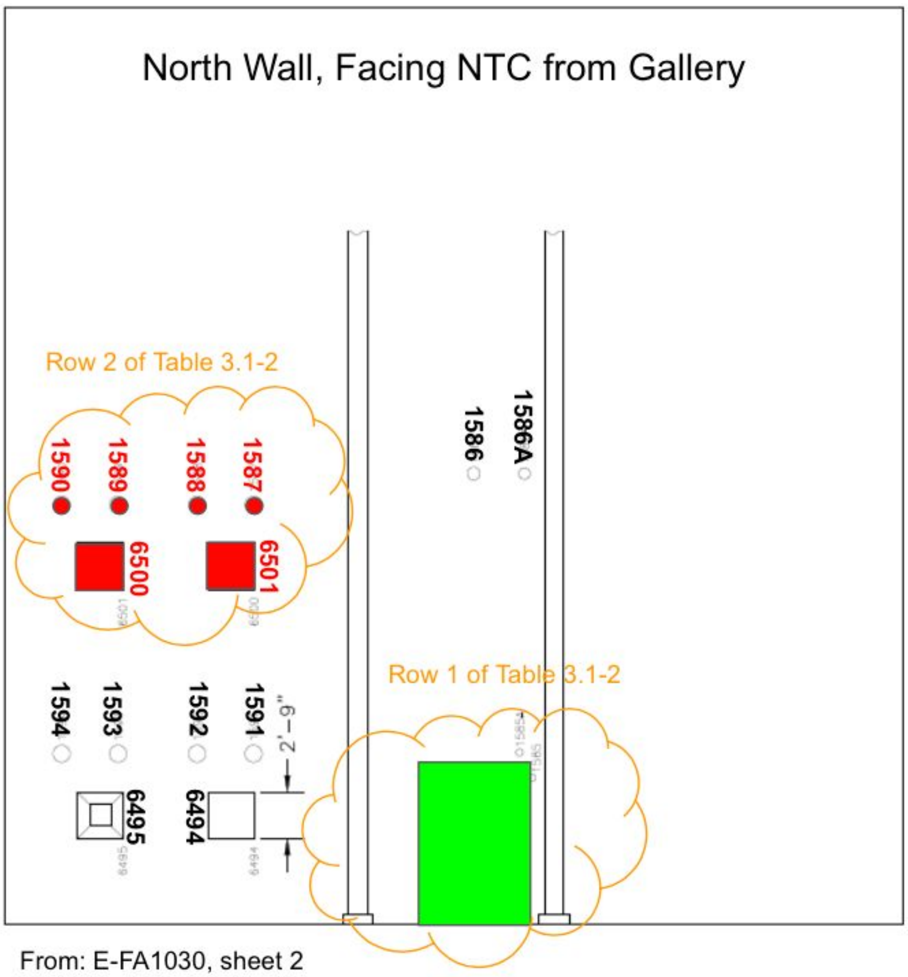

Figure A-2*: Penetrations in the test cell north east wall*

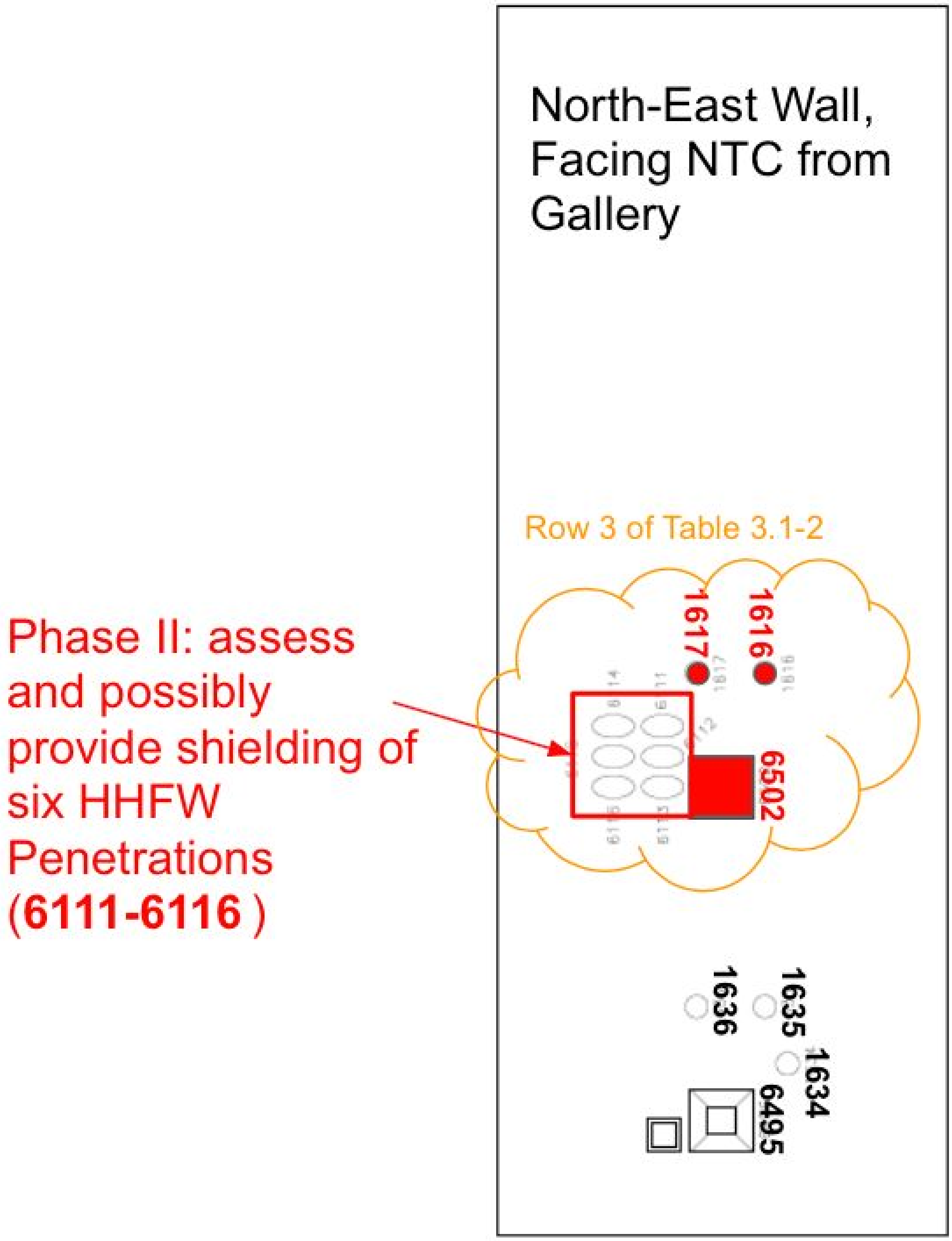

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***Figure A-3**: Penetrations in the test cell east wall*

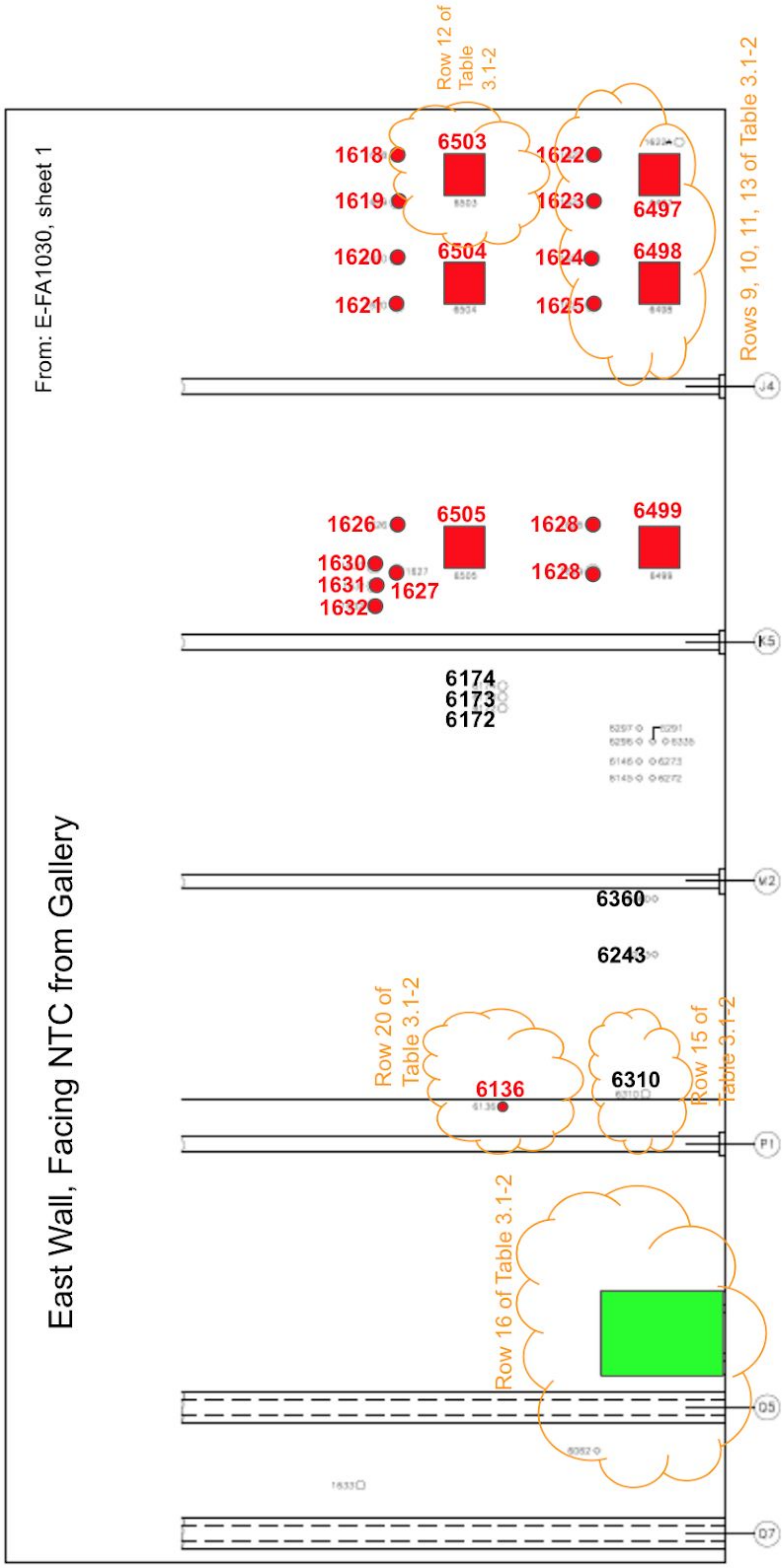
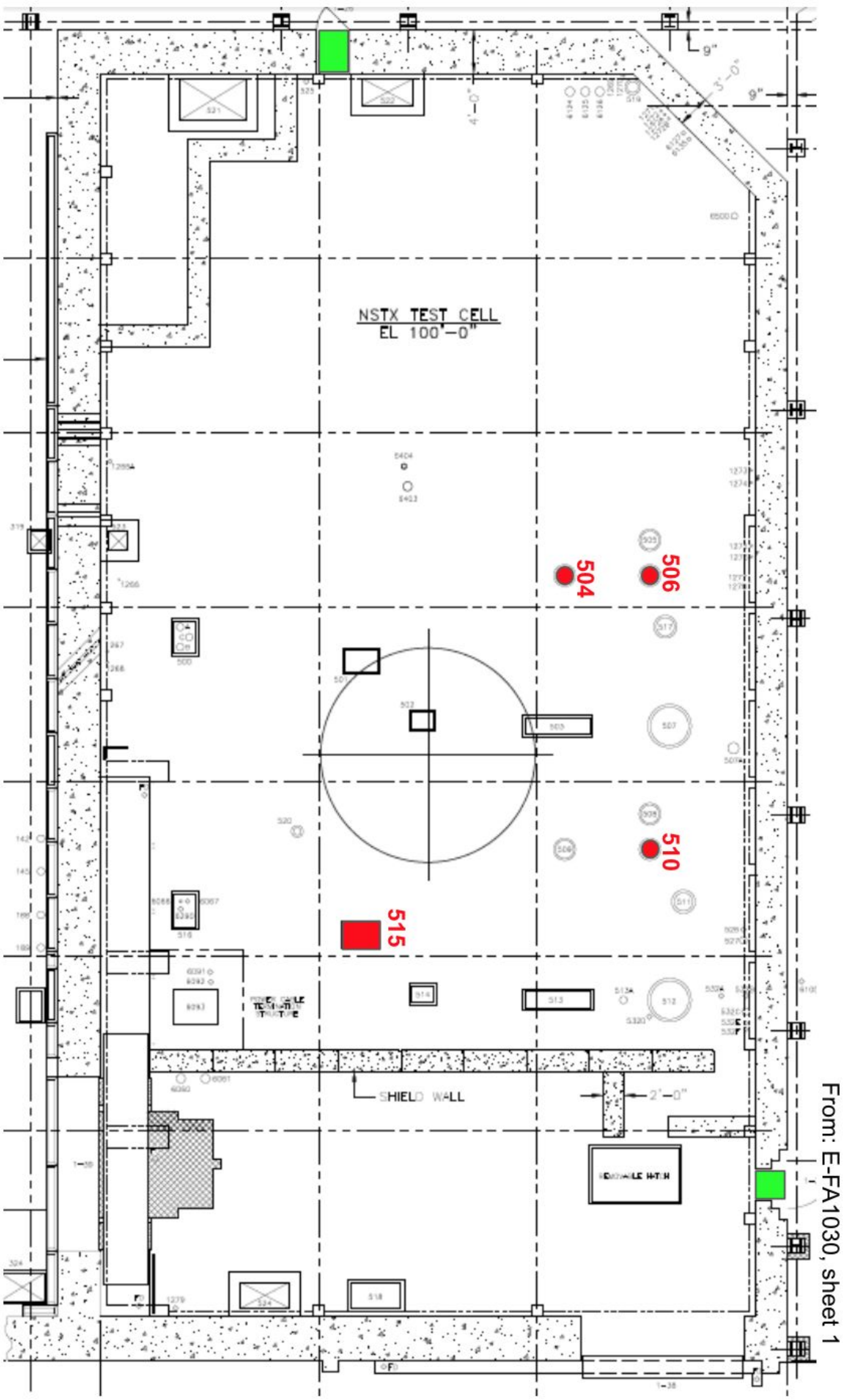


***Figure A-4**: Penetrations on the Test Cell floor. Note that the majority of penetrations in the Test Cell floor are already filled with concrete.*



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