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Seismic Performance Requirements for WETF

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Seismic Performance Requirements for WETF

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by Hans Jordan

Abstract

This report develops recommendations for requirements on the Weapons Engineering Tritium Facility (WETF) performance during seismic events. These recommendations are based on fragility estimates of WETF structures, systems, and components that were developed by LANL experts during facility walkdowns. They follow DOE guidance as set forth in standards DOE-STD-1021-93, *Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components* and DOE-STD-1020-94, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*. Major recommendations are that WETF institute a stringent combustible loading control program and that additional seismic bracing and anchoring be provided for gloveboxes and heavy equipment.

WETF Seismic Performance

1 Introduction

The Weapons Engineering Tritium Facility (WETF) at the Los Alamos National Laboratory (LANL) is currently upgrading its Safety Analysis Report (SAR) to comply with DOE-STD-3009-94, CN #1 [DOE, 1994a]. Part of this update addresses the consequences of the impact of natural phenomenon hazards (NPH) on the facility's ability to confine its hazardous material inventory, particularly tritium.

Of particular concern is the facility's response to a seismic event. This report addresses that issue by reviewing the current seismic vulnerability of WETF in comparison to its seismic performance requirements as dictated by DOE guidance, and by recommending upgrades and actions designed to bring the facility into conformance with DOE expectations.

2 Natural Phenomenon Performance Categories

Natural phenomenon performance categories (PCs) were devised by the DOE as a systematic way of quantizing (or binning) the requirement that structures, systems, and components (SSCs) continue to function under the impact from a given severity of a natural external event (such as earthquakes, high winds, floods, and so on). This DOE approach in application to seismic events is briefly described below.

DOE-STD-1021-93 [DOE, 1993] defines five performance categories for SSCs of nuclear facilities. These categories are based on the potential consequences attendant on their presumed failure as the result of the expression of an NPH. The PC definitions are reproduced in Table 1. In this table, the definitions are worded with the intention that the SSC in question is assigned the highest performance category that applies.

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Table 1. NPH Performance Category Definitions

SSC Performance Category	Definition
PC-4	Failure results in a release whose consequence exceeds that of an unmitigated release from a > 200 MW_t (class A) nuclear reactor.
PC-3	Failure results in a release whose consequences exceed that of the *Safety Class* (SC) evaluation guideline (25 rem TEDE to the MOI).
PC-2	Failure may result in loss of function and the function is one of the following: • Performs, or helps to perform emergency or mitigative function preserving health and safety of workers. • More than 300 people may be in room housing SSC. • The SSC is *safety-significant*.
PC-1	• The structure potentially houses people. • Failure may cause fatality or serious injury to immediate worker. • Failure can be prevented by cost-effective NPH design.
PC-0	None of the above apply.

DOE-STD-1021-93 also addresses any interactions among SSCs that result from the expression of an NPH. If the response of an SSC (the *source*) to the expression of an NPH leads to an interaction with a second (*target*) SSC of a higher PC, then the performance categorization of the source is upgraded to that of the target if the failure probability of the target as a result of the interaction is high. Another way of looking at this aspect is to place all SSCs with significant interaction potential in a group and to assign the highest PC of the SSCs of that group to the group as a whole.

Continued on next page

2 Natural Phenomenon Performance Categories, Continued

The PCs defined in Table 1 are picked up in DOE-STD-1020-94 [DOE, 1994b], Chapter 2, *Earthquake Design and Evaluation Criteria*, and associated with seismic event occurrence probabilities. That is, the requirement that an SSC function in a seismic event is made conditional on the *risk* associated with its failure caused by seismic impact.

This association of a PC with the occurrence probably of a seismic event is reproduced in Table 2. In this table, probabilities are expressed as annual exceedance probabilities and as return periods.

- Annual exceedance probabilities refer to events whose occurrence probabilities are greater than or equal to that specified.
- Return periods refer to the expected (mean) period between the largest seismic events associated with the corresponding exceedance probability.

Table 2: NPH PCs and Corresponding Seismic Occurrence Probabilities

Performance Category	Seismic Event Annual Exceedance Probability	Return Period (years)
0	-	-
1	2×10^{-3}	500
2	1×10^{-3}	1,000
3	5×10^{-4}	2,000
4	1×10^{-4}	10,000

3 SSC Seismic Response

The stress on an SSC associated with a seismic event is a function of the occurrence probability event. Seismic events with high peak ground accelerations (PGAs) occur less frequently than those with low PGAs–that is, the probability of a seismic event is inversely proportional to its magnitude. This relationship is expressed in the seismic hazard curve, which is dependent on geographical location and is determined by seismic evaluation for each DOE site.

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3 SSC Seismic Response, Continued

The latest seismic evaluation of LANL was performed by Woodward-Clyde in 1995 [WCFS, 1995]. Design basis earthquakes for LANL were developed from this evaluation by Goen, 1995, and give the following PGAs by PC:

- PC-1 – 0.15 g
- PC-2 – 0.22 g
- PC-3 – 0.31 g

PC-4 does not apply to WETF on the face of it – even an unmitigated release of all of the tritium permitted in WETF does not yield a consequence comparable to that of an unmitigated release from a 200 MW_t nuclear reactor PC-0 has no requirements.

4 WETF Safety-Related SSCs

The major WETF structures, systems, and components are listed below. In this listing, building envelopes (structures) are designated *systems* and components are indicated as subsystems. Thus, seven systems are called out.

System	Components
1. Tritium Gas Handling System (TGHS) (process equipment inside gloveboxes)	• Temperature controllers • Pressure relief valves • Rupture discs
2. Storage containers	
3. Tritium Gas Containment System (TGCS), or glovebox lines	• Double walled TGHS lines between gloveboxes • N_2 supply lines • Bubblers • Tritium Gas Waste Treatment System (TWTS) • Glovebox tritium monitors • Pressure relief/inerting system by sensor/controller

Continued on next page

4 WETF Safety-Related SSCs, Continued

System	Components
4. Building Structure	• HVAC isolation dampers + ducting from dampers to stack • Emergency Tritium Cleanup System (ETCS)
5. HVAC	
6. Room Fire Suppression System	
7. Room Tritium Monitoring System	

Following DOE-STD-1021-93, each SSC is associated with its safety function in Table 3.

Table 3: Safety System Function Matrix

System	Function			
	Contain-ment	Supports Contain-ment	Radiation Moni-toring	Industrial Safety/ Protection
1. Tritium Gas Handling System	X	-	-	-
• Temperature controllers	-	X	-	-
• Pressure relief valves	-	X	-	-
• Rupture discs	-	X	-	-
2. Storage containers	X	-	-	-
3. Glovebox Lines	X	-	-	-
• Tritium Gas Handling System lines between gloveboxes	X	-	-	-
• N_2 supply lines	X	-	-	-
• Bubblers				

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Table 3: Safety System Function Matrix (continued)

System	Function			
	Contain-ment	**Supports Contain-ment**	**Radiation Moni-toring**	**Industrial Safety/ Protection**
• Tritium Gas Waste Treatment System	X	-	-	-
• Glovebox tritium monitors	-	-	X	
• Pressure relief/inerting system by sensor/controller	-	X	-	-
5. HVAC	-	-	-	-
6. Room Fire Suppression System	-	-	-	X
6. Room Tritium Monitoring System	-	-	X	-

5 SSC Failure Consequences

The WETF is a hazard category 2 facility by virtue of its radionuclide inventory. It is useful to first identify maximum consequences from facility-wide release of this inventory, then look at releases by system.

The radionuclide inventory of WETF consists of tritium, which is administratively controlled to a maximum of 2 kg or 1.93×10^7 Ci, and three sealed ^{238}Pu heat sources totaling no more than 5 g or 86 Ci.

Continued on next page

5.1 Facility-Wide Failure Consequences

The dose conversion factor (DCF) for tritium depends on its chemical form. The highest value is that for either tritium oxide vapor, T_2O, or tritiated water, THO. For these, DCF = 95 rem TEDE/Ci for the combined inhalation and skin absorption pathways [DOE-94c]. For tritium gas, T_2, metabolic uptake by the body is much reduced, and the DCF is approximately a factor of 10,000 less [DOE, 1994c]. For ^{238}Pu as oxide, which is the case for heat sources, the DCF is 2.88×10^8 rem TEDE/Ci[1].

It is convenient to convert these inventories to *dose equivalent* inventories in order to facilitate consequence calculations in the following. Dose equivalent means the dose a person would receive if that person were to inhale (and absorb) the entire associated inventory[2]. In dose equivalents, the inventories of the two radionuclides are limited to:

- tritium oxide: 1.83×10^9 rem TEDE,
- tritium gas: ~ 2×10^5 rem TEDE
- ^{238}Pu oxide: 2.48×10^{10} rem TEDE.

Doses cannot be expressed unless the materials become airborne. While total release of tritium, which is a gas (or water vapor), is possible, it is highly unlikely that any of the ^{238}Pu can be released because it is contained in small, robust, sealed sources.[3] Even if a breach is assumed, the fraction of ^{238}Pu oxide content that is released and made airborne is minimal, as will be argued next.

For loose powder that is mechanically stressed, the DOE handbook on airborne release fractions [DOE, 1994d] gives a bounding ARF on the order of 10^{-3}. In fact, however, the ^{238}Pu of heat sources is in the form of sintered pellets. Experiments at LANL [LA, 1988], in which sealed sources were deformed by being impacted at 338 mph, showed fracturing of the pellet content to 10% respirable fines (but no breach). Using this value for the respirable fraction (RF), gives a respirable release fraction (RRF = ARF $\times$ RF) of 10^{-4}.

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[1] Actually, heat source plutonium is a mixture of isotopes with just 90% of the mixture being ^{238}Pu. Assuming all of it to be ^{238}Pu, as is done here, increases consequences by 10%.
[2] Since that is not generally possible, the dose equivalent inventory, while mathematically useful, has no physical significance.
[3] Sintered oxide pellet encased in double layer, welded steel ¼-in. x 1-in. or 2.5-in. ampoule. Stored in a *calcan* – a robust sealed container with bolted lid.

5 SSC Failure Consequences, Continued

5.1 Facility-Wide Failure Consequences (continued)

When applied to the above dose equivalent release, the assumed breach will at most lead to a dose equivalent release of 2.48×10^6 rem TEDE, or a factor of 740 less than the maximum tritium release. Because of the robustness of the ^{238}Pu sources and because their small size makes it unlikely that a seismic event can mechanically impact them, their risk to WETF is assumed negligible and they will be carried in the rest of the report for reference only.

It is shown in the consequence analysis of the WETF SAR [WSAR, 2000] that the 95th percentile atmospheric transport factor for the Maximally Exposed Offsite Individual (MOI) is 2.8×10^{-4} s/m^3, assuming a ground level-release and no building wake. Using this value, and the breathing rate, 3.333×10^{-4} m^3/s, of the *standard man*, gives an atmospheric transport reduction factor of

$$2.8 \times 10^{-4} \text{ s/m}^3 \times 3.333 \times 10^{-4} \text{ m}^3\text{/s} = 9.33 \times 10^{-8},$$

and thus the following unmitigated doses to the MOI from a total inventory release:

- tritium oxide: $1.83 \times 10^9 \times 9.33 \times 10^{-8} = 171$ rem TEDE,
- tritium gas: ~ $2 \times 10^5 \times 9.33 \times 10^{-8} = 0.019$ rem TEDE
- ^{238}Pu oxide: $2.48 \times 10^6 \times 9.33 \times 10^{-8} = 0.23$ rem TEDE.

It is seen from these results that only the 2-kg tritium release with at least 14% as oxide challenges the evaluation guideline (EG) of 25 rem TEDE to the MOI of DOE-STD-3009-94 [DOE, 1994a]. (Alternatively, a fully oxidized release of 292-g tritium does.)

There is no equivalent evaluation guideline for worker exposure, but one can estimate consequence as follows: assuming a typical room in WETF to have a volume of 500 m^3, instantaneous and uniform dispersal throughout the room, a worker breathing rate of 3.5×10^{-4} m^3/s, and the most favorable worker egress time of 60 sec, the factor analogous to the atmospheric transport reduction factor developed above is seen to be:

$$1/500 \text{ m}^{-3} \times 3.5 \times 10^{-4} \text{ m}^3\text{/s} \times 60 \text{ s} = 4.20 \times 10^{-5},$$

which is 450 times as high as that for atmospheric transport to the MOI.

Continued on next page

5 SSC Failure Consequences, Continued

5.1 Facility-Wide Failure Consequences (continued)

With this factor, worker doses from a total inventory release become:

- tritium oxide: $1.83 \times 10^9 \times 4.20 \times 10^{-5}$ = 76,860 rem TEDE,
- tritium gas: $\sim 2 \times 10^5 \times 4.20 \times 10^{-5}$ = 8.4 rem TEDE
- ^{238}Pu=: $2.48 \times 10^6 \times 4.20 \times 10^{-5}$ = 104 rem TEDE.

These doses are representative of lower limits. Higher doses are possible for the immediately involved worker. They show that a complete release of tritium, followed by its complete oxidation, presents a major worker hazard. Complete release of tritium without oxidation is a minor worker hazard. The release for ^{238}Pu is shown for reference only, as explained above.

5.2 System Failure Consequences

It is useful to group the SSCs of Table 3 by their role in the WETF containment system philosophy, which relies on a nested, tertiary defense-in-depth for the worker and the public:

Primary	TGHS–confines gas and protects product from loss, contamination, deflagration.
Secondary	Glovebox lines [Tritium Gas Containment System (TGCS)], the Tritium Waste Treatment System (TWTS), N_2 gas supply lines, associated piping, and bubblers–prevents tritium deflagration should primary confinement fail (gloveboxes are inerted with nitrogen). Secondary barrier to worker radiation exposure.
Tertiary	Building envelope, ventilation isolation dampers, Emergency Tritium Cleanup System (ETCS). • Passive: walls and roofs • Active: ventilation isolation dampers, ETCS • Final instance of barrier to public rad exposure.

Storage Area (Room-124) Containments

Primary	Inner storage container
Secondary	Outer storage container
Tertiary	Same as for process areas: building envelope, ventilation isolation dampers, Emergency Tritium Cleanup System (ETCS).

5.2 System Failure Consequences (continued)

Storage Area (Room-124) Containments (continued)

Administrative controls for WETF allow only 250 g of tritium outside the storage area (Room 124) of WETF at any time. These 250 g will be processed in the TGHS that is bounded by gloveboxes or their double-walled pipe connections, or in transit (in containers) between the storage area and the TGHS.

The storage area is administratively limited to 2-kg tritium, contained in special storage containers. The maximum content of a single container is administratively controlled to 24-g tritium. Two of these may be contained in a single outer container. The inner containers constitute the primary containment. The outer container constitutes the secondary containment.

The consequences of various system failures can now be estimated from the consequence calculations done above. They are presented in Table 4. In each case, it is assumed that the tertiary containment has failed.

If the tertiary containment (building envelope) can be assumed not to fail its function, then the dose to the MOI is near zero for each SSC failure mode. For this assumption to hold, it is essential that the ventilation isolation dampers function immediately in an accident and that, furthermore, the ETCS function efficiently. Without the ETCS functioning effectively, tritium would eventually and quantitatively leak from the building.

Table 4: SSC Failure Consequences

Failure Mode	Dose (rem TEDE) – Tertiary Containment Assumed Failed	
	MOI	Worker
TGHS breached; TGCS intact	0	0
TGHS & TGCS breached – tritium not oxidized	2.4×10^{-3}	1.1
– tritium fully oxidized	21	9,608
Single container* breached – tritium not oxidized	4.6×10^{-4}	0.20
– tritium fully oxidized	4.1	1,845
Max. stored inventory – tritium not oxidized	0.019	8.4
– tritium fully oxidized	171	76,860

5.2 System Failure Consequences (continued)

From Table 4, it is clear that only an event that breaches several storage containers challenges the DOE evaluation guideline for determining safety-class SSCs, and then only if the event involves oxidation of the released tritium gas. This conversion can occur either in a room fire, or if the tritium itself ignites, as it might, close to its source[4]. Uniformly dispersed in a 500-m^3 room, 2,000 g of tritium do not reach the lower flammability limit of 4 mass percent

6 WETF Seismic Vulnerability Assessment

In March 2000, a walkdown/screening seismic vulnerability assessment was performed for WETF [Goen, 2000]. The findings for the glovebox lines were revisited by Salmon in a follow-up walkdown (Appendix). Major findings of this screen and the follow-up can be summarized as follows.

6.1 Tertiary Containment

With completion of the seismic upgrades (now in process) to Building 205 of WETF, the facility envelope will be in PC-3. The ETCS was judged to be in PC-0 because of the lack of lateral support for rod-hung associated piping. If the lateral supports were added, the system components would fall into PC-2 and PC-3. Note, however, that the functional qualification for the ETCS, independently of its seismic qualification, is inadequate for its designation as a safety-class system.

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[4] Tritium gas is also converted to oxide (and retained on molecular sieves) in the TWTS and ETCS. In this report, these systems are assumed to either function or fail completely – that is, the failure mode in which tritium is oxidized but released, is not considered as this event is bounded by fire scenarios.

6.2 Secondary Containment

Gloveboxes were judged to be in PC-2. Salmon (Appendix) reviewed gloveboxes specifically and recommends minor fixes to *greatly increase their functional performance*. Among these are anchoring and cross-bracing, adding flexible couplings to penetrations, and securing nearby heavy components that are now free to interact with the secondary confinement.

High-pressure transients resulting from releases from the primary containment (TGHS) are absorbed by release through the bubbler. It and the stack monitor were judged PC-0.

The TWTS was placed in PC-2 or PC-3 on the proviso that the control cabinet anchorage be checked, and if found deficient, upgraded. The dryer of the TWS, which is part of the secondary confinement system, was rated PC-0 (insufficient bracing). Controls are needed to purge tritium from gloveboxes if the primary containment fails as a result of the seismic event. Tritium in the inerted gloveboxes cannot lead to an explosive mixture unless the secondary containment envelope fails.

There is no seismic experience with gas-confining gloveboxes that would allow qualifying the process area secondary confinement to PC-3.

Secondary containers in the storage area have not generally been certified. Their ability to provide containment (seal integrity) in a room fire, as might accompany a seismic event, can therefore not be guaranteed. Nor can their performance under mechanical insult.

Such insult can conceptually come from falling objects, although the ceiling of Room 124 is qualified to PC-3 and fixtures and piping that are attached to the ceiling, and are not seismically qualified, will not fail in free fall and will therefore probably not cause failure damage to the secondary containers. At the very least, a compelling argument could be made that a seismic event of PC-3 or less would only affect a fraction of the stored secondary cans in common mode failure.

Loose containers may also be compromised by being propelled against other objects. It is therefore assumed that the storage containers will be adequately restrained.

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6.3 Primary Containment

The TGHS has not been seismically qualified. It represents a defense-in-depth system from the point of view of worker and public dose, the TGCS being the main line of defense. Failure of the TGHS may lead to tritium release to gloveboxes and their subsequent purge. An explosive gas mixture cannot result unless the glovebox envelope fails, allowing air ingress.

Primary storage containers have not been seismically (fire, mechanical breach) qualified.

6.4 Fire Prevention System

The Fire Prevention System for WETF plays a separate and significant role in that it is only a fire at WETF that elevates the consequences to the MOI of releases of tritium to a challenge of the EG. The Fire Prevention System is judged to fall into PC-0 because it is one continuous system. Water supply vulnerability was not evaluated.

7 Conclusion

It was shown in Section 5 that the evaluation guide (25 rem TEDE to the MOI) for safety-class SSCs can be approached only by a release of tritium from the storage area into a room fire. The only candidates for a safety-class SSC that would prevent or mitigate that consequence are the storage containers themselves (primary and secondary), the facility envelope, and the Fire Suppression System. None of these is PC-3, as required of safety-class SSCs by DOE-STD-1021-94 (Table 1).

The intent of the evaluation guide threshold can nevertheless be accommodated with the following recommended actions:

- Implement a TSR-controlled combustible loading program that limits the combustible loading in the facility to values that prohibit fires of sufficient intensity to compromise container seals (or the containers themselves). Determine the limit values by detailed fire code modeling.

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7 Conclusion, Continued

- Designate the facility structure as safety-class. This is required to preserve the assumption that the ceiling of the storage area will not collapse onto the storage containers–an event that might breach the containers and release their tritium contents. Note that DOE-STD-1021-93 then requires the facility structure to qualify as PC-3–which it does.

The secondary confinement system (glovebox) provides defense-in-depth and worker protection and is therefore, by DOE-STD-3009-94, safety-significant. By DOE-STD-1021-94 (see Table 1), that system must qualify as PC-2. By the seismic vulnerability assessment (Section 6), it generally qualifies as such provided the following upgrades are effected.

- Anchor glovebox legs and cross-brace them.
- Add flexible couplings to glovebox penetrations.
- Anchor nitrogen supply tanks.
- Provide additional bracing to the TWTS dryer assembly.
- Secure (to PC-2) heavy components in the vicinity of the gloveboxes.

Additionally, it is defense-in-depth to ensure the mechanical integrity of the tritium storage containers by requiring them to be retrained from movement in a PC-3 seismic event.

Once the roof upgrades have been completed, the WETF structure itself will be PC-3. It will then satisfy the requirements of Table 1.

A beyond design basis earthquake is one whose consequences exceed those of the PC-3 defining event. For such an event, the WETF must be expected to collapse, posing an immediate danger to life for the worker, independently of any tritium release.

It must also be assumed that tritium storage containers will breach because of the falling ceiling, resulting in a quantitative release of the tritium inventory, which, since a building-wide fire cannot be excluded, will lead to a maximum dose to the MOI of 171 rem TEDE.

Continued on next page

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Appendix

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WETF Process Room 114 Glovebox Lines

A walkdown of the glovebox lines in the WETF building 205 process room 114 was conducted on Friday, November 17, 2000 for the purpose of describing upgrades needed to bring the glovebox lines into compliance with DOE-STD-1020 94 criteria for seismic performance category 3 (PC3) components. This memorandum describes the seismic vulnerability of the glovebox lines in their present configuration and presents general strengthening schemes needed for their upgrade.

Existing Configuration

A vulnerability assessment of the WETF structures, systems, and components was completed in March of 2000 (Ref. 1). The vulnerability assessment placed components into seismic category bins as a function of their ability to withstand strong ground motion. Items were placed into three capacity categories based upon their judged capacity to withstand ground motion. The three bins selected are shown below:

Table 1
Seismic Vulnerability Screens from Walkdown Evaluation

Seismic Vulnerability Bin	Judged Peak Ground Acceleration Capacity[5]
Low	≤ 0.15g
Medium	0.15g to 0.30g
High	≥ 0.30g

Reference 1 placed the gloveboxes in the medium category based on the observation that "all gloveboxes are supported similar to the Auxiliary Maintenance Glovebox (8 legs, 4 anchored with 3/8" diameter shell anchors). All have similar components mounted on framing above with similar attributes plus motor controls for pumps inside the gloveboxes.'

The walkdown conducted on 11/17/2000 confirmed this. The glovebox lines in the process room are typically mounted to a flexible frame. The flexible frame is supported on eight vertical legs that are made of angle iron. The legs are not all anchored. The gloveboxes are attached to each

[5] The acceleration capacity is the peak ground acceleration at which the component is stressed beyond its code limit.

other with stainless steel piping that is rigidly mounted to the glovebox with bolted flange connections. The photo below shows a typical glovebox configuration in the process room.

Figure 1
Typical Glovebox Anchorage

This mounting configuration results in a relatively flexible system. The lack of bracing in the glovebox legs introduces some flexibility into the system. In addition, all of the support legs are not anchored. Finally, it was noted that there are a large number of penetrations entering the gloveboxes. These penetrations are necessary for processes. The umbilicals entering the penetrations are generally attached to adjacent gloveboxes in the same line, or to remote locations.

There are a number of large unanchored components near the gloveboxes.

Desired Performance
It is desired that the gloveboxes provide containment of hydrogen gases during and after an earthquake at the PC3 level. Thus, deflections of the gloveboxes during strong ground motion should be minimized. The gloveboxes should not slide or tip over. Penetrations should be designed to accommodate expected anchor point motions and relative displacements.

General Recommendations

The gloveboxes are not able to maintain confinement at PC3 ground motions in their current configuration. The following recommendations are made to greatly increase their functional performance at the PC3 ground motion levels.

- Anchor all glovebox legs to the supporting floor with concrete expansion anchor bolts.
- Provide cross bracing in supporting legs in order to stiffen the system
- Add flexible couplings in penetrations that are susceptible to differential anchor motion
- Eliminate credible seismic interaction sources by anchoring heavy components near the target gloveboxes.

The implementation of these upgrades will not ensure the functional requirement (confinement of gas) of gloveboxes at PC3 levels of ground motion. There are little real earthquake experience data on the performance of gas-handling gloveboxes during and after earthquakes. Test data are not available to demonstrate the ability of glovebox-lines to maintain confinement as a function of seismic shaking. One possible way of ensuring confinement of gases following an earthquake is to provide a seismically qualified ventilation system on the glovebox lines to maintain negative pressure relative to the room.

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