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Evaluation of Natural Phenomena Hazards as Part of Safety Assessments for Nuclear Facilities*

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1 INTRODUCTION

The continued operation of existing U.S. Department of Energy (DOE) nuclear facilities and laboratories requires a safety reassessment based on current criteria and guidelines. This also includes evaluations for the effects of Natural Phenomena Hazards (NPH), for which these facilities may not have been designed. The NPH evaluations follow the requirements of DOE Order 5480.28, "Natural Phenomena Hazards Mitigation (1993) which establishes NPH Performance Categories (PCs) for DOE facilities and associated target probabilistic performance goals. These goals are expressed as the mean annual probability of exceedance of acceptable behavior for structures, systems and components (SSCs) subjected to NPH effects. The assignment of an NPH–Performance Category is based on the overall hazard categorization (low, moderate, high) of a facility and on the function of an SSC under evaluation (DOE–STD–1021, 1992). Detailed guidance for the NPH analysis and evaluation criteria are also provided (DOE–STD–1020, 1994). These analyses can be very resource intensive, and may not be necessary for the evaluation of all SSCs in existing facilities, in particular for low hazard category facilities. An approach relying heavily on screening inspections, engineering judgment and use of NPH experience data (S. J. Eder et al., 1993), can minimize the analytical effort, give reasonable estimates of the NPH susceptibilities, and yield adequate information for an overall safety evaluation of the facility. In the following sections this approach is described in more detail and is illustrated by an application to a nuclear laboratory complex.

2 APPROACH

To achieve the probabilistic NPH performance goals the evaluation approach combines probabilistic and deterministic methods. Thus the hazards are specified on a probabilistic basis, usually as mean (or surrogate mean) curves of annual probability of exceedance of a hazard level. On the other hand the response evaluation and comparison to acceptance criteria is conducted using deterministic methods with built–in conservatisms (DOE–STD–1020, 1994).

For existing facilities, a preliminary hazards assessment establishes the Nuclear Hazard Category, the NPH–Performance Category and thus the NPH performance goals. The actual NPH evaluation then starts with a detailed walkthrough screening evaluation of the facility, whose purpose is to identify vulnerabilities of structures, systems and components to NPH effects. The performance goals that are considered during these reviews may include the following: placing hazardous operations in a safe state, confinement of radioactive and other hazardous materials, continued operation of safety systems and emergency services, life safety and occupancy considerations, and damage control/recovery. In the detailed walkthrough screening emphasis is placed on equipment anchorage and supports (load path), structural integrity, seismic system interactions, and building structure evaluation. In some cases system operability or relay chatter may also be of concern. For nuclear facilities the release of radioactive materials is usually the primary concern, thus the review emphasis is on confinement systems, including exhaust ventilation and filter systems. Another concern is the direct impact of NPH effects on facility workers. Seismic experience data, which has been systematically collected and organized for the reevaluation of existing nuclear power plants (SQUG,. 1992), can be used to evaluate specific equipment and components in a nuclear facility.

Where vulnerabilities are identified analytical evaluations may become necessary. Similarly, the building structure evaluation will, in general, require some analysis. The type of analyses depends on the NPH–Performance Category (PC) of the facility (DOE–STD–1020–94). Thus for PC–2 or less (low hazard or general use facilities) static analysis using the base shear approach of the Uniform Building Code (UBC, 1991) may be used. For higher performance categories (i.e., more severe hazards) dynamic analysis is required. To minimize the effort, simple, but conservative modeling, or existing analyses and/or models can be used or adapted for the analyses.

If existing SSCs cannot meet the NPH evaluation criteria, backfit assessments should be performed. These may include: more rigorous (less conservative) analyses and possibly probabilistic assessments, strengthening of the SSCs, and change of their usage so they fall into a lower Performance Category. For existing SSCs some relief is also allowed in the NPH evaluation criteria, in that evaluations may be performed using NPH hazards which correspond to an exceedance probability of twice the value required for new designs.

If deficiencies or vulnerabilities are uncovered that can be easily remedied, it is usually more cost effective to implement upgrades than expand more analytical effort. On the other hand if NPH vulnerabilities cannot be readily reduced or eliminated, their effect should first be factored into the overall safety evaluation of the facility, to ascertain if the resulting risks are acceptable. Only then a reasoned judgment can be made if costly upgrades or other actions affecting the operation of the facility are warranted.

3 FACILITY EVALUATION

The approach outlined above is illustrated by the example of a nuclear laboratory complex with glovebox, hood and hot–cell operations used for nuclear material and waste characterization as well as for nuclear fuel processing and treatment experiments. Based on the nuclear material inventories and the complexity of operations the facility is classified as a low hazard facility which corresponds to an NPH–Performance Category 2 (PC–2) with a performance goal of 5×10^{-4} (DOE–STD–1021, 1992). The facility occupies two wings of a much larger building (see Fig. 1), each constituting a separate segment with its own nuclear material inventory and independent exhaust ventilation and HEPA filtration systems, which are located in the fan lofts of the wings. The wing dedicated mainly to glovebox operations (G–Wing), with support activities carried out in hoods, is constructed of moment resistant reinforced–concrete frames with masonry (concrete block and brick) curtain walls, and reinforced concrete floors and roof. Its fan loft is of similar construction. The wing is structurally coupled to adjacent building wings (common columns, etc.). K–Wing which houses the hot–cells, is not closely tied to the remainder of the building, is constructed of unreinforced masonry and has some very light roof structures. Its fan loft is of similar construction. The hot–cells themselves are very massive concrete and steel structures. Except for some nominal wind resistance, the structures were not designed for NPH effects.

At the site in question, the NPH Evaluation Basis (EB) Hazards for a PC–2 facility are as follows:

	EB – Hazards		Reduced EB – Hazards	
	Magnitude	Annual Frequency	Magnitude	Annual Frequency
Earthquake	0.12 g	1×10^{-3}	0.09 g	2×10^{-3}
Straight Wind	~75 mph (33.5 m/s)	1×10^{-2}	70 mph (31.3 m/s)	2×10^{-2}
Tornado	–	–	–	–

There is no flood hazard at this site and tornadoes and air borne missiles need not be considered for PC–2 facilities. The reduced hazards levels apply to existing facilities, when the standard EB Hazard cannot be met.

During an earlier safety assessment of the building, the extreme wind and tornado resistance of G–Wing and its adjacent wing was evaluated (Simon, 1975), using two–dimensional concrete frame models and a limit–load–type analysis. Using current procedures (DOE–STD–1020, 1994) and wind loads (ANSI/ASCE 7–88, 1990), together with the concrete frame and roof capacities established in the earlier analysis, it was determined that G–Wing can readily resist the effects of the Evaluation Basis Wind (EBW). Similarly, using current wind load determination procedures and analysis methods appropriate for masonry construction (ACI, 1993), it was determined that K–Wing can also sustain the combined effects of dead and wind loads resulting from the EBW, provided the roofs behave as diaphragms and offer lateral support to the walls at the top. This is a reasonable assumption for the undirectional wind loadings. An evaluation of the EBW generated differential pressures acting on the exhaust ducting and filters were also found to be acceptable. Thus, the wind loading is not a concern for the facility.

Extensive walkthrough screening evaluations of the laboratories, surrounding areas (including the basement service areas) and fan lofts identified a number of seismic vulnerabilities in the facility. The possibility of natural gas line rupture during an earthquake in the facility and immediately adjacent areas leading to fire/explosion was identified as a major hazard. Since these gas lines are in general not used it was recommended that they be disconnected. Inadequate lateral restraints of emergency power batteries and the diesel fuel day–tank anchorage are other deficiencies being remedied. Subject to resolving some issues of anchorage and vibration isolator mounting, the exhaust blowers in the fan lofts can be seismically qualified using experience data (SQUG, 1992). While the duct work and the HEPA filters in the fan lofts have reasonably good support structures they are not adequately anchored.

Finally, many of the glovebox support structures and their anchoring were judged to be inadequate. Since the gloveboxes are important confinement barriers for the radioactive materials, it is imperative that their survival during earthquakes be assured. Thus, a detailed analysis using the ANSYS finite element computer code (ANSYS, 1989) was undertaken for the representative glovebox shown schematically in Fig. 2. The analysis showed that the existing support structures are inadequate, leading to excessive displacements/deformations of the glovebox and stresses in the support legs which exceed allowables. Parameter studies were then conducted, using simple two– and three–dimensional frame models as well as some detailed ANSYS calculations, to determine the best support structure strengthening and minimization of anchor loads. The final recommended upgrades consist of diagonal cross–braces between all support legs and strengthened anchor brackets and bolts at each support leg.

Because of its unreinforced masonry load–bearing walls, the K–Wing structure appeared seismically suspect. Analysis, which employed the recommended base shear approach (DOE–STE–1020, 1994) as well as structural evaluations appropriate for masonry walls (FEMA–222, 1992; ACI, 1993), showed that the masonry will exceed its rupture strength, unless the roofs in K–Wing can develop their full diaphragm action and provide lateral support at the top of the walls. Based on the roof details, the diaphragm action assumption does not appear to be justified under the vibratory loading of an earthquake. Thus, significant damage to the main and fan loft structures in K–Wing can be expected.

The G–Wing structure was first seismically evaluated using the simple two–dimensional frame models and the column collapse capacities of the existing wind analysis (Simon, 1975). It was found that the demand for many of the columns exceeded their capacity even for the reduced earthquake hazard (0.09 g). This was confirmed by a two–dimensional elastic analysis using the ANSYS computer code. To eliminate the conservatism of these analyses, a final UBC–type three–dimensional analysis was performed using special purpose software (ETABS, 1992). The software is designed for the analysis of frame structures and includes the evaluation of reinforced concrete column and beam capacities and the treatment of eccentricity effects. Using the required load combinations (DOE–STD–1020–94), it was found that the columns capacities of the main G–Wing structure marginally meet the demands. However, for the fan loft, demands for many of the columns substantially exceed the capacities. Thus, substantial damage to the fan loft structure may be expected.

The results of the NPH evaluations were factored into the overall safety analysis of the facility, by assuming that in K–Wing both the fan loft and main structure would collapse. For G–Wing it was assumed that the main structure would survive the earthquake but the fan loft would collapse resulting also in a loss of exhaust ventilation and final HEPA filtration. It was also assumed that the shielded cells in K–Wing and the gloveboxes in G–Wing (after retrofit) would sustain no damage in the earthquake and that their local HEPA filters remain intact. The safety analysis then indicated that radioactive releases would be minor and that the risks to on–site workers would be acceptable and off–site negligible. Thus, any major risks to the public or workers is not related to the presence of radioactive materials, but to the direct effects of the earthquake.

4 CONCLUSION

In reassessing the overall safety of existing nuclear facilities NPH effects play an important and sometimes dominant role. Nevertheless, for low hazard nuclear facilities, where the safety evaluation is often semi–qualitative, detailed analyses of the NPH effects may not be warranted. Simplified methods, which rely on facility walkthroughs, existing analyses, and a minimum of new analytical effort, similar to the approach outlined here, may be adequate. If the overall facility risks to on–site personnel, the public and the environment are acceptable, in spite of seismic or other NPH vulnerabilities, no remedial actions may be required, unless these inadequacies pose too grave a risk to the safety of the facility worker.

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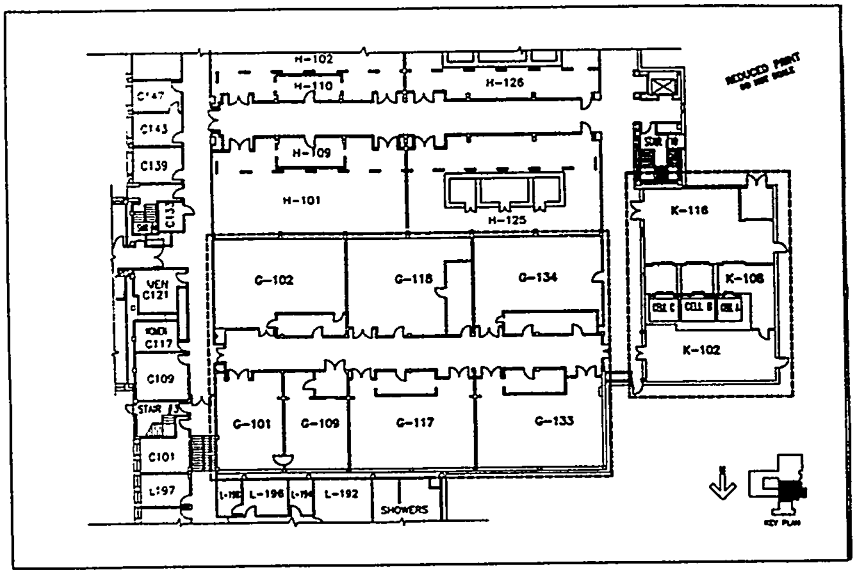

Fig. 1. Facility Floor Plan.

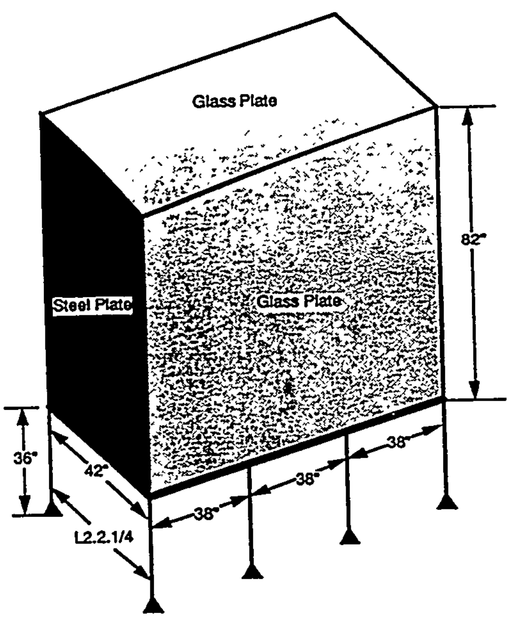

Fig. 2. Schematic of Glovebox and Support Structure.