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Preliminary Hazards Analysis for the National Ignition Facility

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October 1993

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Executive Summary

We have performed a Preliminary Hazards Analysis (PHA) for the National Ignition Facility (NIF), in accordance with DOE Order 5480.23 (DOE, 1992a), DOE Order 5481.1B (DOE, 1986), and Management Directive (MD) 5481.1A (DOE, 1989). The NIF is a laser fusion experimental facility, whose primary goal will be to demonstrate ignition and propagation of fusion burn in the laboratory. Based on the materials and operations described in this report, we classified the NIF as low hazard. The methodology we used to arrive at this classification is described in reference DOE (1992b), supplemented by the approach for classification on the basis of hazardous chemicals currently used at the Lawrence Livermore National Laboratory (LLNL). We assigned an initial classification of low hazard, nonnuclear by comparing estimated maximum facility inventories of radionuclides and hazardous chemicals with threshold values. The thresholds for radionuclides have been established by DOE; LLNL provided the thresholds for hazardous chemicals. We then confirmed the low hazard, nonnuclear classification by evaluating consequences of bounding accidents for radionuclides and for the chemicals presenting the most significant hazards.

The low hazard classification assumes that administrative controls will prevent inventories from exceeding the maximum values used in this analysis. Changes in operations, maximum inventories, materials, or release potential that could result in the bounding consequences being exceeded, or that could negatively impact the safety of the facility, will necessitate a reevaluation of the classification.

This PHA was prepared for siting the NIF at the Lawrence Livermore National Laboratory. The inventory of materials assumed in this analysis would not change for other DOE sites. The methodology for classification on the basis of radionuclide inventories has been standardized, and would apply at any other DOE site. The chemical hazard classification methodology is that currently used at LLNL, and may be different from approaches used at other DOE sites.

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1. Introduction

This report documents the Preliminary Hazards Analysis (PHA) for the National Ignition Facility (NIF). In summary, it provides:

- A general description of the facility and its operation;
- Identification of hazards at the facility; and
- Details of the hazards analysis, including inventories, bounding releases, consequences, and conclusions.

As part of the safety analysis procedure set forth by DOE, a PHA must be performed for the NIF (DOE, 1986; 1989; and 1992a). The PHA characterizes the level of intrinsic potential hazard associated with a facility, and provides the basis for hazard classification. The hazard classification determines the level of safety documentation required, and the DOE Order governing the safety analysis. The hazard classification also determines the level of review and approval required for the safety analysis report.

The hazards of primary concern associated with the NIF are radiological and toxicological in nature. The hazard classification is determined by comparing facility inventories of radionuclides and chemicals with threshold values for the various hazard classification levels and by examining postulated bounding accidents associated with the hazards of greatest significance. Such postulated bounding accidents cannot take into account active mitigative features; they must assume the unmitigated consequences of a release, taking into account only passive safety features. In this way, the intrinsic hazard level of the facility can be ascertained.

2. Description of Facility and Operations

The three primary goals of NIF are:

- Goal 1—to demonstrate ignition and propagation of fusion burn in a laboratory setting.
- Goal 2—to provide access to physics regimes of interest in nuclear weapons design and to provide nuclear weapons-related physics data. Upon achieving significant fusion energy yields, the NIF will provide capability for weapons-effects simulation.
- Goal 3—to develop laser fusion as a source of commercial power, providing enhanced understanding of target designs, driver requirements, and other technological aspects important to energy applications.

To achieve these goals, the NIF will require a laser with an output pulse energy of 1.8 MJ and an output pulse power of 500 TW. The laser will be comprised of several hundred identical beamlets. Each beam of light will be focused and directed onto a target suspended in the center of the spherical target chamber (Fig. 1). The facility will be operated in the indirect drive mode, which makes use of the hohlraum, a metal casing around the target. Upon illumination, the hohlraum material generates x rays, which compress and heat the target. The direct drive option, where laser light shines directly on the target, may be considered in the future. This option would be covered by this PHA provided the inventories during direct drive operation are maintained within the limits defined in this report.

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Figure 1. The NIF target chamber (cut-away shown) would be 4-7 m radius and 10 cm thick Al.

Targets will contain a mixture of hydrogen isotopes, which may be at room temperature or maintained at a low temperature through the use of a cryostat. Approximately 300 targets per year will contain the radioactive hydrogen isotope tritium, at a nominal level of less than 2 Ci per target. The laser energy will be delivered to the target over a short period of time (on the order of 10^{-9} s), causing compression and heating to thermonuclear burn conditions. Not all targets will achieve those conditions, but those that do will emit neutrons, energetic particles and debris, and x-rays. Unburned tritium will be exhausted to the collection system. The tritium inventory in this system will be limited to a maximum of 300 Ci. The inventory can be maintained below this limit by regular changeouts (approximately every 6 months) of the collection system.

The energetic particles, debris, and x-rays generated during a shot will be contained by the 4- to 7-m-radius aluminum alloy target chamber. We expect some ablation of first wall material as a result of shots and assume that it will form particulates in the chamber. The use of a protective coating (e.g., boron) would reduce this ablative process. We also assume the hohlraum, cryostat, and target positioning apparatus will form particulates as a result of shots.

The energetic neutrons may activate the target chamber, or they may travel through the target chamber structure, and the shielding, or through penetrations, and enter the target chamber bay. In the target chamber bay, they will activate the space frame (supporting structure for the target chamber), the concrete and rebar in the walls, or the gases in the air. The level of neutron activation is a function of the shot yield, the number of shots, and their frequency. Long-lived nuclides, which are more of an issue for waste disposal, will be produced at fairly low levels. Shorter-lived nuclides will present a greater hazard. These short-lived nuclides will decay significantly between shots, such that the inventories are primarily a function of shot yield. The inventories we assume in this analysis are based on a maximum shot yield of 20 MJ.

A significant number of diagnostics (>100) will penetrate the target chamber. These diagnostics will examine and measure specific aspects of the operation. We expect some ablation of the diagnostics during shots, which will contribute a small amount of particulates to the inventory in the target chamber.

The operation of the NIF will begin with no- to low-yield shots, building up to higher-yield shots after initial characterization and experimentation. The ultimate schedule will consist of a mix of shots with varying yield, none greater than 20 MJ.

3. Hazard Identification

Table 1 summarizes the hazard sources at the NIF. We determined these based on discussions with design team personnel, and reviews of proposed operations and design criteria, a draft environmental document (in preparation), and a hazard checklist (LLNL, 1991). Based on this table of information, we have characterized potentially hazardous events that could result from energy sources, materials, and natural phenomena. We determined the causes, identified appropriate safety features for design, and projected potential consequences. Table 2 summarizes the hazardous conditions that could arise during normal and abnormal operations at the NIF. Safety features in design, which can eliminate, control, or mitigate the hazardous conditions, may be supplemented by administrative controls. We have not identified such administrative controls at the present time, but they will be considered in the preparation of the safety analysis report.

Some of the hazards listed in Table 1 and events identified in Table 2 are common industrial hazards/events, which are adequately covered by OSHA regulations and therefore are not emphasized in this report. The primary nonradiological/nontoxicological hazards at the NIF are associated with electrical equipment and the use of lasers. Safe operation of electrical equipment is governed by such documents as the National Electric Safety Code and the National Electric Code (ANSI, 1993a and 1993b). Laser safety is covered by the relevant ANSI Z136.1 standard (ANSI, 1993c).

The most significant hazards that could affect people in the local area of the NIF, elsewhere on the LLNL site, and offsite, are associated with radiological and hazardous materials. These hazards are the focus of this report and are the basis for the facility hazard classification. The other hazards will be addressed in more detail in the safety analysis report.

Table 2 provides the basis for the bounding accidents hypothesized in Section 4.3. These accidents, however, do not take into account the identified mitigative safety features unless they are attributed to the inherent properties of a material or a process. In this way, the facility's intrinsic hazard can be evaluated. Other safety features may only function under certain conditions, or they may require electric power or operator intervention. These features can reduce the risk of operations and will be considered when the facility risk is evaluated in the safety analysis report.

Table 1. Hazards source list for the NIF.

Source category	Hazards list
Motion	Vehicles Mass in motion
Gravity-mass	Falling Falling objects Lifting Tripping, slipping Earthquakes
Cold	Cryogenic materials
Heat	Electrical equipment Flames Friction Chemical reactions
Pressure	Confined gases Chamber at vacuum Pressurized liquids Explosion
Electrical	Capacitors Transformers Static electricity Other high-voltage sources
Radiant	Lasers Magnetic fields Ionizing radiation
Chemical	Corrosive materials Flammable materials Reactive materials Oxygen deficiency Carcinogenic materials Toxic materials

Table 2. Hazard characterization at the NIF.

Postulated event description	Possible causes	Safety features in design	Potential consequences
Release of radioactive material			
Release from tritium collection system	Routine release, primarily during changeouts and cleanup; accidental releases may result from: natural phenomena (primarily earthquakes); failure of connecting piping or adjacent equipment (allowing air ingress); personnel error during changeout.	Ventilation system provides in-facility dilution and possible elevated release point; seismic design of tritium collection system; design for other natural phenomena according to DOE (1989b); doubly confined (equipment plus building); careful materials selection; materials QA; isolation valves; monitors; alarms.	Routine tritium release, worker exposure, and public exposure; accidental worker exposure; accidental tritium release from facility and public exposure; facility contamination; equipment damage.
Release from single target	Natural phenomena (primarily earthquakes); personnel error; equipment failure.	Doubly confined target (shell and cryostat wall); cryostat designed to withstand pressure of cryogenic target when raised to room temperature.	Accidental worker exposure to tritium; accidental tritium release from facility and public exposure; equipment damage.
Release of radioactive inventories from the target chamber	Natural phenomena (primarily earthquakes); pressure cycling leading to failure of target chamber; shrapnel impact leading to failure of target chamber; possible driving force out of chamber provided by vaporizing cryogen from failed cryostat.	Seismic design of target chamber; design for other natural phenomena according to DOE (1989b); pressure vessel design; design for shrapnel impacts; materials QA; limit cryogen inventory so that it (on its own) cannot pressurize the target chamber to a level that would result in a release of inventory; design shall allow personnel entry to target chamber without significant release of radioactivity; monitors; alarms.	Accidental worker exposure to radionuclides; accidental release of radionuclides from facility and public exposure; facility contamination; equipment damage.
Release of activated gases	Routinely generated during shots with yield and released at a slow rate; more rapid release may result from natural phenomena (primarily earthquakes) or through open doors.	Ventilation system operates at negative pressure during and shortly after shots with yield >1 MJ; ventilation system with exhaust rate that allows for significant decay and provides for possible elevated release point; seismic design; design for other natural phenomena according to DOE (1989b); interlocks on doors to prevent opening during and shortly after shots.	Routine release from facility and public exposure; accidental worker exposure; accidental radionuclide release from facility and public exposure; equipment damage.
Release from waste	Fire involving waste from target chamber cleanout; (see also Fire Event).	Minimize use of flammables; store flammable waste in approved combustible material containers; fire protection equipment (see also Fire Event).	Accidental worker exposure to radioactive material; accidental release of radionuclides from facility and public exposure.

Table 2. (Cont.)

Direct exposure to ionizing radiation			
Prompt radiation during shot	Shots with yield will produce radiation.	Shielding; interlocks; limited shot yield (<20 MJ).	Routine worker and public exposure.
Residual radioactivity	Routine exposure during maintenance and chamber cleanout; accidental exposure if worker enters before delay time has elapsed.	Shielding; limited shot yield; barriers to entry.	Routine and accidental worker exposure.
Release of hazardous material			
Release of solvents and/or optics treatment chemicals	Minor releases due to normal operations (cleaning and treatment); accidental releases may result from: spills due to personnel error, natural phenomena, equipment handling error, or container failure; fire (see also Fire Event); equipment failure or personnel error leading to pressurized release (ethanol is the only hazardous material used under pressure).	Ventilation system provides in-facility dilution and possible elevated release; use of approved hazardous and flammable material containers; use of appropriate storage cabinets for hazardous and flammable materials; spill containments; minimize use of hazardous materials and flammables; fire protection equipment (see also Fire Event); proper design of spraying device with pressure regulator and relief valves.	Operations result in negligible routine worker exposure to hazardous material; accidental worker exposure to hazardous material; accidental release of hazardous material from facility and public exposure; equipment damage.
Release of hazardous material from target chamber	Natural phenomena (primarily earthquakes); pressure cycling leading to failure of target chamber; shrapnel impact leading to failure of target chamber; possible driving force out of chamber provided by vaporizing cryogen from failed cryostat.	Seismic design of target chamber; design for other natural phenomena according to DOE (1989b); pressure vessel design; design for shrapnel impacts; materials QA; limit cryogen inventory so that it (on its own) cannot pressurize the chamber to a level that would result in a release of inventory; design shall allow personnel entry to target chamber without significant release of hazardous material.	Accidental worker exposure to hazardous or nuisance material; accidental release of hazardous or nuisance material from facility and public exposure; facility contamination; equipment damage.
Release from ignitron switches	Personnel error; equipment failure.	Materials and equipment QA; mercury in sealed units.	Accidental worker exposure to hazardous material; accidental release of hazardous material from facility and public exposure; facility contamination; equipment damage.

Table 2. (Cont.)

Fire	Electrical short; ignition of flammables; personnel error; improper maintenance; improper use of equipment.	Minimal use of flammable material for operation and in design; use of approved combustible material storage containers; electrical components in compliance with ANSI (1993a and 1993b); physical barriers; non-flammable construction; fire protection equipment.	Potential smoke inhalation or burns; accidental worker exposure to hazardous or radioactive material; accidental release of hazardous or radioactive material and public exposure; facility contamination; facility damage.
Explosion	Combustible material reaches explosive concentration in presence of ignition source.	Minimal use of flammable or explosive materials; electrical components in compliance with ANSI (1993a and b); concentration monitors; proper ventilation; design according to DOE (1999b).	Equipment damage; accidental worker exposure to hazardous or radioactive material; accidental release of hazardous or radioactive material and public exposure; facility contamination.
Electric shock	Electrical short; wiring failures; equipment failures; improper maintenance; personnel error.	Installations in compliance with ANSI (1993a and b); circuit breakers; grounded conduits; enclosures for high voltage equipment; interlocks; barriers.	Potential for burns and severe electrical shock; equipment damage
Exposure to laser light	Personnel error; equipment failure.	Physical barriers blocking light; physical barriers to entry to areas where exposure could occur; interlocks on laser system; limited duration laser pulse.	Personnel injury.
Exposure to cold	Personnel error; container failure; improper maintenance.	Limited cryogen inventory; design for temperature extreme; materials QA; barriers.	Personnel injury.
Exposure to heat	Personnel error; container failure; improper maintenance; fire (see also Fire Event).	Insulation; electrical installations designed in compliance with ANSI (1993a and 1993b); barriers; fire protection equipment; (see also Fire Event).	Personnel injury; equipment damage.
Exposure to magnetic fields	Personnel error; equipment failure.	Shielding; physical barriers; interlocks.	Personnel injury.
Falling, falling objects, mass in motion	Fall from equipment; fall of equipment; improper use of equipment; improper forklift operation; improper crane operation; improper maintenance.	Handrails; seismic restraints; equipment in compliance with standards; safety factors in equipment design.	Personnel injury; potential operator injury; accidental worker exposure to hazardous or radioactive material; accidental release of hazardous or radioactive material from facility and public exposure; facility damage.
Oxygen deficiency	Routine entry to confined space during chamber cleanout; accidental chamber entry without adequate airflow due to personnel error or equipment failure; failure of cryogenic equipment; failure of equipment using inert gas.	Design for adequate airflow during personnel entry to target chamber; ventilation in areas where cryogens or inert gases are used.	Unconsciousness or asphyxiation.

4. Hazards Analysis and Classification

We performed this PHA to determine the hazard classification of the NIF, as per DOE Order 5480.23 (DOE, 1992a), DOE Order 5481.1B (DOE, 1986), and SAN Management Directive 5481.1A (DOE, 1989). We based the PHA on the DOE's criteria (DOE, 1992b), and the approach for chemical hazard classification currently employed at LLNL. The methodology is summarized in Appendix A of this report.

This section provides the basis for our evaluation and how we derived the hazard classification of low hazard for the NIF. In summary it covers the following:

- A comparison of facility inventories of radionuclides and chemicals to threshold values, resulting in an initial hazard classification.
- Analysis of events presenting the greatest hazards.
- A comparison of the bounding consequences of these events to criteria outlined in Appendix A to determine the final hazard classification.

This evaluation assumes that operations are as described in Section 2 of this report. Additionally, it is assumed that administrative controls and operational restrictions will be in place so that maximum inventories will not exceed those assumed in this analysis. If there are operational changes or changes in maximum inventories of radionuclides or chemicals, a reevaluation of the facility for the purpose of hazard classification would be required.

4.1 Inventories

This section documents the maximum expected inventories of radionuclides and hazardous chemicals at the NIF and compares them to threshold quantities. The result is an initial facility hazard classification.

4.1.1 Radionuclide Inventories

Radioactivity will be present at the NIF in the following forms: (1) Tritium in targets, which may be consumed in fusion reactions, adsorbed onto the inner surface of the target chamber, captured in the tritium collection system, or present in waste; or (2) Neutron activation products, which may be in the form of particulates or debris in the target chamber, activation products in the target chamber area structures (including the target chamber, shielding, space frame, concrete walls/rebar, etc.), particulates or debris collected as waste, or activated gases in the target chamber room atmosphere.

Table 3 provides an estimate of the maximum inventories of radionuclides expected at the NIF. We did not include activation inventories in the target chamber structure, shielding, space frame, or walls, as these inventories are contained within structures and are not releasable under any credible circumstances. Although short-lived nuclides are listed in the table for completeness, we did not include inventory thresholds for nuclides with half-lives less than 10 minutes, as these are not available.

Tritium will arrive at the facility in individual targets, nominally containing 2 Ci each. We expect no more than 300 tritium shots per year. Unburned tritium will be exhausted and retained in a collection system. As indicated in Section 2 and documented in Table 3, the inventory in the collection system can be controlled and maintained at 300 Ci or less by periodically removing the collected material and transferring it to shipping containers for disposal or recovery offsite.

Activated debris will be created in the target chamber as a result of operation. During a shot, the hohlraum and target-positioning apparatus will be subject to a significant energy release and to a high neutron flux, which will result in their destruction and activation. As discussed in Section 2, we expect some ablation of first-wall material and diagnostics. The character of the remnants and ablated material in the chamber are not known, but we suspect they would be in the form of large pieces of debris, fine particulates, and recondensed material. Conservatively, for the purpose of this analysis, we assume all the material will exist as fine particulates. The material in the target chamber will be comprised of the SS316 portion of the target positioner, the copper cryostat, either a lead or gold

Table 3. NIF estimated maximum radionuclide inventories and Category 3 threshold values.

Isotope	Quantity (Ci)	Threshold value (Ci)	Ratio
Exhaust collection system			
H-3	300	1.0×10^3	0.3
Activated particulates^(a)			
Na-24	1.2	$3.0 \times 10^{2(b)}$	4.0×10^{-3}
Mg-27	77	N/A ^(c)	—
Al-28	1.1×10^2	N/A ^(c)	—
Al-29	7.0×10^{-2}	N/A ^(c)	—
V-52	1.6	N/A ^(c)	—
Cr-55	9.3×10^{-1}	N/A ^(c)	—
Mn-56	4.8×10^{-1}	$2.8 \times 10^{3(b)}$	1.7×10^{-4}
Co-60m	2	$5.8 \times 10^{7(b)}$	3.4×10^{-8}
Co-60	1.4×10^{-3}	2.8×10^3	5.0×10^{-6}
Co-62m	2.1×10^{-1}	$2.0 \times 10^{4(b)}$	1.1×10^{-5}
Cu-62	42	N/A ^(c)	—
Cu-64	5.1×10^{-1}	$1.5 \times 10^{5(b)}$	3.4×10^{-6}
Cu-66	2.5×10^{-1}	N/A ^(c)	—
Au-196	9.0×10^{-2}	$2.0 \times 10^{3(d)}$	4.5×10^{-5}
Activated air^(e)			
H-3	9.8×10^{-5}	1.0×10^3	9.8×10^{-8}
N-13	13	N/A ^(c)	—
N-16	1.8×10^3	N/A ^(c)	—
S-37	3.6×10^{-1}	N/A ^(c)	—
Cl-39	1.0×10^{-3}	9.0×10^3	1.1×10^{-7}
Cl-40	1.3	N/A ^(c)	—
Ar-41	4.6×10^{-1}	6.0×10^2	7.7×10^{-4}
C-14	7.8×10^{-6}	4.2×10^2	1.9×10^{-8}
Sum of ratios			0.305

^(a)At the end of year, after 20-MJ shot, prior to cleanup. The values correspond to a 4-m aluminum alloy target chamber.

^(b)Threshold does not appear in DOE (1992b); value obtained directly from DOE.

^(c)We did not include nuclides with half-lives less than 10 minutes for the inventory comparison, as thresholds were not available. See Section 4.3 for further evaluation.

^(d)Threshold does not appear in DOE (1992b). We calculated the value by scaling with dose conversion factors from another nuclide for which a threshold was available.

^(e)After 20 MJ shot. The values correspond to a room with dimensions of 38.1 m (L) $\times$ 38.1 m (W) $\times$ 30.5 m (H) (125 ft $\times$ 125 ft $\times$ 100 ft).

hohlraum, and first-wall material. We did not specifically account for the expected small contribution from diagnostics, but the conservative estimates of the other contributions should more than cover this amount. These materials will accumulate in the target chamber until the annual scheduled cleanup. Table 3 lists the prominent nuclides expected as particulates in the chamber.

We expect that the total inventory of activated, mobilizable material created in the chamber will be quite small, but we have included it here for completeness. For the first-wall material, we assumed the use of bare aluminum, a conservative assumption in terms of radioactivity. A thin protective layer of a material such as boron is also being considered for the first wall, because it is less susceptible to ablation. It would also be less subject to activation.

The NIF will routinely generate neutron activation products in the air surrounding the target chamber. The inventories listed in Table 3 are estimated maximum quantities generated during a 20-MJ-yield shot.

4.1.2 Chemical Inventories

Chemicals will be used at the NIF for a variety of purposes, including cleaning, optics treatment, first-wall protection, and in electrical equipment. Cleaning chemicals include sodium hydroxide solutions, organic solvents, and water-based cleaners. Optics treatment requires the use of hydrofluoric acid, ammonium hydroxide, and some organics. Table 4 lists the expected maximum quantities of these chemicals at the facility. Inventories of water-based cleaners and castor oil, which will be used in the capacitors, are not provided as these materials are nontoxic.

Materials inside the chamber include ablated first-wall material (aluminum or boron, if first-wall protection is used), hohlraum (lead or gold), target positioner (stainless steel), and cryostat (copper). The in-chamber inventories provided in Table 4 are conservative estimates (i.e., over-estimates) of the amount of material that would be present as particulates at the end of one year. As stated earlier, we conservatively assume the target debris and ablated material to be in the form of fine particulates. The remainder of the unablated first-wall material will be in the form of solid structure, which is not vulnerable to release under any credible circumstances.

The power for the NIF laser will be supplied by a discharging bank of capacitors, similar to the arrangement used for Nova. Part of this power supply system is a set of approximately 200 ignitron switches that contain mercury. Each ignitron contains about 0.125 gal of mercury. This makes a total of 25 gal of mercury at the facility, as listed in Table 4.

4.2 Initial Hazard Classification on the Basis of Inventories

Appendix A defines the hazard Categories 1 through 3. Category 3 is the designation given to the lowest hazard nuclear facility. Such a facility is expected only to result in significant localized consequences from bounding accidents. The thresholds provided in Table 3 distinguish between a nuclear and a nonnuclear facility. Some of these thresholds have been established in a Standard (DOE, 1992b). Others not listed in the Standard have been obtained directly from DOE, or by scaling using dose conversion factors from a known threshold for another nuclide. These thresholds correspond to inventories of radionuclides which, if released, would result in a dose of 10 rem at a distance of 30 m from the release point.

The DOE methodology (1992b) requires that if more than one nuclide is present in the facility, the sum of the ratios of the individual inventories to their respective threshold values be determined. If individual inventories are all below their Category 3 thresholds, but the sum of the ratios is greater than one, the facility would be considered a Category 3 (nuclear) facility.

Table 3 shows that in all cases, the nuclide inventories fall below the individual Category 3 threshold values. Further, the sum of the ratios of nuclides to their respective thresholds is less than one. Thus, the NIF would be classified as nonnuclear.

Hazard classification on the basis of chemicals utilizes a similar approach, where inventories are compared to threshold values. For low hazard facilities, the threshold, which distinguishes between an Excluded and a low hazard facility, is based on the Reportable Quantities provided in 40CFR302 and 40CFR355. The moderate hazard thresholds, which distinguish between a low hazard and a moderate hazard facility, are based on Threshold Quantities as specified in 29CFR1910.119 and

Table 4. NIF's estimated chemical inventories and hazard classification threshold values.

Chemical	Source	Quantity	Exposure criteria ^a	Low hazard threshold	Moderate hazard threshold
Acetone	Solvent for cleaning	10 gal (30 kg)	750 ppm (OSHA ^b) (1800 mg/m ³) 1000 ppm STEL ^c (2400 mg/m ³)	5000 lb	—
Aluminum	Particulates from first wall	420 kg	10 mg/m ³ (ACGIH ^d)	—	—
Ammonium hydroxide (50% wt)	Optics treatment	10 gal (~85 lb [38 kg] ammonia-equivalent)	25 ppm (ACGIH) (18 mg/m ³) (as ammonia) 35 ppm STEL (27 mg/m ³)	100 lb (as ammonia)	15000 lb (solution)
Boron (5% wt Hafnium)	Particulates from first wall	4 kg	10 mg/m ³ B (ACGIH) (as nuisance dust) 0.5 mg/m ³ Hf (OSHA)	—	—
Copper	Particulates from cryostat	<0.5 kg	1 mg/m ³ (ACGIH)	5000 lb	—
Ethanol	Solvent for cleaning and optics treatment	400 ^e gal (~1200 kg)	1000 ppm (OSHA) (1900 mg/m ³)	—	—
Hydrofluoric acid (50 gal at 1% wt, 5 gal at 52% wt)	Optics treatment	55 gal (~50 lb [22 kg] HF)	3 ppm ceiling limit ^f (ACGIH) (2.5 mg/m ³)	100 lb ^g at 100%	100 lb ^g at 100%
Lead ^h	Particulates from hohlraum	<1 kg	0.05 mg/m ³ (OSHA)	1 lb ^a	—
Mercury	Ignitrons	25 gal (~2840 lb ⁱ [1290 kg])	0.05 mg/m ³ (OSHA)	1 lb ^j	k
Methylene chloride ^l	Solvent for cleaning	5 gal (25 kg)	50 ppm (OSHA) (75 mg/m ³)	1000 lb	—

Table 4. (Cont.)

Sodium hydroxide (50 gal at 3% wt, 20 gal at 50% wt, or solid pellets)	Cleaner for debris shields	70 gal (~180 lb [82 kg] NaOH)	2 mg/m ³ ceiling limit (ACGIH)	1000 lb	—
Stainless steel	Particulates from target positioner	<0.2 kg	1 ^m mg/m ³ (OSHA)	100 lb ^m	—
Tetraethylorthosilicate ⁿ	Optics treatment	100 gal (353 kg)	10 ppm (OSHA) (85 mg/m ³)	—	—

^a All criteria are 8-h time weighted averages, unless otherwise stated.

^b OSHA: Occupational Safety and Health Administration.

^c STEL: Short Term Exposure Limit averaged over a 15-min time period.

^d ACGIH: American Conference of Governmental Industrial Hygienists.

^e Single container inventories will not exceed 50 gal.

^f Ceiling limit: The maximum concentration of an airborne substance to which a worker can be exposed at any time.

^g The low hazard and moderate hazard thresholds are the same. This actually means that there really is only a moderate hazard threshold, and none exists for low hazard.

^h Lead hohlraum is more toxic than gold hohlraum.

ⁱ Single ignitron inventories are approximately 14 lb (0.125 gal).

^j Some materials have a low hazard threshold, but do not have a moderate hazard threshold.

^k No threshold value has been recommended (see Appendix A). See Section 4.3 for further evaluation.

^l Methylene chloride has the potential to form phosgene, which has a TLV of 0.4 mg/m³ (OSHA). Phosgene has a low/moderate threshold of 10 lb.

^m Based on the elemental composition of stainless steel and the TLVs of each constituent, nickel was determined to present the greatest hazard. This TLV and threshold are those for nickel.

ⁿ Tetraethylorthosilicate can potentially form silicon dioxide, which has a TLV of 6 mg/m³ (amorphous form, OSHA).

^o Threshold applies only to lead particulate (particle diameter less than 100 µm).

Threshold Planning Quantities as specified in 40CFR355. Refer to Appendix A for further discussion of the hazard classification process. Many chemicals do not have hazard classification thresholds (Table 4). These are discussed further in Section 4.3. On the basis of those chemicals for which threshold quantities exist, mercury exceeds its low hazard threshold. Lead particulate just exceeds its low hazard threshold. The other chemicals fall below their respective low hazard thresholds. Thus, the hazard classification for the NIF on the basis of chemical inventories would be low hazard.

If we consider the radionuclide and hazardous chemical inventories at the facility (Tables 3 and 4), and the resulting initial classifications, the overall initial hazard classification for the NIF would be low hazard.

4.3 Postulated Bounding Accidents

In this section, accidents are postulated to bound the consequences of radionuclide releases and releases of the more hazardous chemicals at the NIF. The more hazardous chemicals are identified on the basis of relatively low hazard classification thresholds, relatively high inventories at the facility, and/or relatively low exposure criteria, as outlined below. Only those presenting the greatest hazards are examined in the context of a bounding accident. A release of all vulnerable radionuclides is considered to confirm the nonnuclear classification.

Of the chemicals with established hazard classification thresholds, we considered mercury since only a low hazard threshold is available and its total inventory is well in excess of this amount. We examined an airborne release of mercury to ensure that the consequences are consistent with the low hazard classification. The other chemicals with thresholds fall below their respective low hazard values and therefore do not warrant further analysis.

Chemicals without inventory thresholds that are expected to be present in relatively small quantities and those with relatively high exposure criteria (see Table 4) were not considered further. Most of the solvents, cleaners, and treatment chemicals listed in Table 4 could be eliminated from further analysis on this basis. Although methylene chloride falls well below its low hazard threshold, we selected it for further examination because of the potential formation of phosgene if this material were exposed to fire or elevated temperature.

Tetraethylorthosilicate (TEOS) is a combustible liquid. Although it may generate amorphous silicon dioxide fumes in a fire, we expect that only a small quantity could become airborne. Silicon dioxide in the amorphous form has a PEL of 6 mg/m^3 . Because of the small amount of silicon dioxide potentially released, and its low toxicity, we did not consider it further.

It is possible to mobilize the particulates in the chamber subsequent to a Loss of Vacuum Accident (LOVA), involving rapid air ingress to the chamber. A conservative dispersible solid release fraction of 10^{-3} would be applicable (DOE, 1992b). With the exception of aluminum, use of this release fraction would result in mobilized inventories of a few grams. Therefore, we did not further evaluate releases of these particulates from the chamber from a chemical standpoint, because the consequences would be minor. Several hundred grams of aluminum could become airborne in this event. We examine this release later, in section 4.3.2.

4.3.1 Radionuclide Release

We postulated a bounding event, which could result in the release of tritium, activated particulates, and activated gases from the NIF. An event such as a severe earthquake could damage the target chamber and collection system, and compromise the integrity of the building housing the facility. We assumed all vulnerable inventories would be released, without the benefit of any confinement barriers or the benefit of an elevated release through the roof vent or stack. We evaluated the consequences for a ground level release, with meteorological conditions corresponding to D stability and a wind speed of 4.5 m/s , in accordance with DOE (1992b). Table 5 provides estimated Committed

Table 5. NIF estimated maximum radionuclide inventories released and consequences for bounding event.^a

Isotope	Half-life	Quantity released (Ci)	Dose (at 30 m) (rem)
H-3	12.3 y	3.0×10^2	1.4×10^{-1}
Na-24	14.96 h	1.2×10^{-3}	1.8×10^{-5}
Mg-27	9.45 m	7.3×10^{-2}	1.6×10^{-4}
Al-28	2.25 m	9.4×10^{-2}	4.0×10^{-4}
Al-29	6.5 m	6.6×10^{-5}	2.3×10^{-7}
V-52	3.76 m	1.5×10^{-3}	4.5×10^{-6}
Cr-55	3.49 m	8.2×10^{-4}	5.8×10^{-8}
Mn-56	2.58 h	4.8×10^{-4}	2.8×10^{-6}
Co-60m	10.5 m	1.9×10^{-3}	3.6×10^{-8}
Co-60	5.27 y	1.4×10^{-6}	1.0×10^{-6}
Co-62m	13.9 m	2.0×10^{-4}	1.3×10^{-6}
Cu-62	9.74 m	4.0×10^{-2}	1.0×10^{-4}
Cu-64	12.7 h	5.1×10^{-3}	7.9×10^{-7}
Cu-66	5.1 m	2.3×10^{-4}	7.6×10^{-8}
Au-196	6.18 d	9.0×10^{-5}	5.8×10^{-7}
N-13	9.97 m	12	2.9×10^{-2}
N-16	7.1 s	3.6×10^2	2.5
S-37	5.05 m	3.3×10^{-1}	2.9×10^{-3}
Cl-39	55.6 m	1.0×10^{-3}	4.2×10^{-6}
Cl-40	1.38 m	9.8×10^{-1}	9.8×10^{-3}
Ar-41	1.82 h	4.6×10^{-1}	1.4×10^{-3}
C-14	5730 y	7.8×10^{-6}	8.0×10^{-8}
Total			2.7 rem

^aDecay of nuclides during holdup and transport is included in the above calculations; building wake effects and finite plume size are not accounted for.

Effective Dose Equivalents (CEDE)* at 30 m downwind. Appendix B provides the methodology for the dose calculations.

The postulated event assumes release of the entire 300 Ci in the collection system. This would bound the consequences of tritium releases from the NIF. Tritium in the oxide form is 25,000 times more toxic than the elemental form (ICRP, 1977). We evaluated consequences assuming the tritium to be in the more toxic oxide form.

As discussed earlier, we suspect that there may be fine particulates created in the target chamber as a result of the destruction of the hohlraum, target positioner, cryostat, and ablation of the first-wall material during a shot. Dose calculations assume the conservative case of a bare aluminum first wall. We considered the particulates to be mobilized in the bounding event, where there would be a large scale breach of the target chamber. A dispersible solid release fraction of 10^{-3} was applied to the inventory present in the chamber after the last 20 MJ shot** (DOE, 1992b). We did not consider any redeposition of mobilized material within the target chamber. After release from the chamber, no plate-out or deposition within the building was considered. We conservatively assumed the release to take place over a 3-minute period. Table 5 documents the inventories released from the facility and the dose at 30 m. We quote the dose for the gold hohlraum, as radiological consequences are greater for gold than for lead.

Activated gases would be produced in the bay surrounding the target chamber as a result of neutron interactions with the atmosphere. During the bounding event, these nuclides would be available for release from the facility. We conservatively assumed that the activated gases would enter the environment at ground level, over a 3-minute time frame. Table 5 summarizes the inventories reaching the environment and the resultant doses at 30 m. The table also provides the total dose from the release of all vulnerable radionuclide inventories.

We were very conservative in these calculations and have not included factors such as building wake effects or the finite size of the plume (relevant for cloudshine calculations). These considerations would reduce the doses in Table 5 by at least an order of magnitude.

4.3.2 Aluminum Release

A bare aluminum alloy first wall is currently an option for the target chamber. Ablation of the first-wall material will occur as a result of shots. We have estimated that a total of 420 kg of aluminum alloy will be ablated during a year. The character of the ablated material after the shots is unknown. It may redeposit on the first wall, forming a uniform and strongly adherent layer. Alternatively, it may recondense as particulates. For the purpose of this analysis, we have assumed that the entire quantity of ablated aluminum forms particulates in the chamber. The target chamber will be cleaned annually, so the quantity present at the end of the year would be the maximum inventory of aluminum alloy particulate present at any time. We considered the particulates to be mobilized in the bounding event described in the previous section, where there would be a large-scale breach of the target chamber.

The released mass is assumed to be entirely aluminum, although it makes up approximately 94 %wt of the alloy. Magnesium is present at about 4.4 wt%, and it presents no greater hazard than aluminum. The other constituents are present at less than 1 wt% and will not contribute significantly to the hazard. A dispersible solid release fraction of 10^{-3} was applied to the inventory present in the chamber at the end of the year (DOE, 1992b). We did not consider any redeposition of mobilized material within the target chamber. After release from the chamber, no plate-out or deposition within the building was considered. We conservatively assumed the release to take place over a 3-minute period.

* The dose is a 50-yr CEDE. It includes the inhalation and cloudshine pathways, in accordance with DOE (1992b). At a distance of 30 m from the facility, there would be no possibility of food production. Thus, we did not include the ingestion pathway.

** The last shot of the year (before chamber cleaning) will have a yield of 100 kJ. The inventory in the target chamber will be highest, however, after the last 20-MJ shot. Therefore, we based our evaluation of the consequences of the release of activated particulates on the inventory after the last 20-MJ shot.

In evaluating the consequences of this release, we did not take into account building wake effects or deposition during environmental transport. We assumed that release from the facility occurs at ground level. We evaluated consequences of the release using the EPICODE program (Homann, 1988), a model for atmospheric dispersion. The resulting aluminum concentration 100 m downwind, assuming a wind speed of 4.5 m/s and Class D atmospheric stability, is 12 mg/m³. This is below the ERPG-2 (Emergency Response Planning Guide, Level 2)-equivalent value for aluminum of 15 mg/m³.

4.3.3 Mercury Release

Mercury is used in the ignitron switches of the power conversion system supporting the laser. We postulated a scenario to bound the mercury release from the facility. The scenario involves the failure of a water-cooled tube as a result of repeated arc transfer with an eccentric anode (Cummings, 1991). This would allow water vapor to fill the ignitron tube, resulting in pressurization and failure.

This failure would provide a mechanism for a pressurized spray release of the mercury. Each ignitron contains approximately 0.47 L (0.125 gal) or 6,450 g of mercury. We used a release fraction of 10⁻² for the pressurized spray release (Mishima, 1993). This value corresponds to a release at higher pressure or through a smaller orifice than expected here, and should therefore be a conservative value. It accounts for all droplets 50 µm in diameter and smaller. Larger droplets have terminal settling velocities greater than 1 m/s, and would deposit in close proximity to the release point, never reaching the environment. We believe a 50-µm droplet size to be a conservative cut-off point. With a 10⁻² release fraction, 64.5 g of mercury could be released from the facility.

In evaluating the consequences of this release, we did not account for building wake effects or deposition during environmental transport. All of the mercury reaching the receptor, regardless of droplet size, was considered for potential impact. We assumed that the release from the facility occurs over 30 minutes at ground level. We evaluated consequences of the release using EPICODE (Homann, 1988). The resulting mercury concentration 100 m downwind, assuming a wind speed of 4.5 m/s and Class D atmospheric stability, is calculated to be 0.057 mg/m³. This is below the ERPG-2-equivalent value for mercury of 0.250 mg/m³.

4.3.4 Release of Phosgene Formed in a Fire Involving Methylene Chloride

Although methylene chloride (CH₂Cl₂) is not flammable, it may decompose at elevated temperatures (Genium, 1988). It is possible that the methylene chloride could become involved in a fire fueled by other flammable materials at the facility (e.g., ethanol). At elevated temperatures, methylene chloride is known to produce small quantities of the extremely toxic gas, phosgene (Genium, 1988). The composition of product gases from the combustion of chlorinated hydrocarbons has been studied under a variety of conditions (Lee et al., 1993; and Koshland et al., 1992). The chloroform experiments performed by Lee et al. (1993) under fuel-rich flame conditions most nearly approximate our situation. "Fuel-rich" is appropriate because the scenario assumes the presence of another flammable (e.g., ethanol), which starts the fire and is its primary fuel. Under these conditions, Lee et al. (1993) measured the maximum phosgene mole fraction to be 3 × 10⁻³. Considering the other chemical species present in the mixture, this corresponds to a molar fractional conversion of chloroform to phosgene of approximately 8 × 10⁻³. The work of Chang et al. (1991) indicates that under similar conditions, phosgene formation from methylene chloride would be less than phosgene formation from chloroform. However, for the purpose of this analysis, we assumed a conservative value of 1% converted to phosgene from methylene chloride.

The total inventory of methylene chloride (5 gal) is approximately 25 kg. A 1% conversion (on a molar basis) to phosgene under the fire conditions described above would produce about 293 g. Phosgene has a Moderate hazard threshold of 10 lb (4.5 kg). The estimated quantity produced is well below this value.

We evaluated consequences of the phosgene release using EPICODE (Homann, 1988). We did not account for building wake effects in the evaluation. The concentration 100 m downwind, assuming a wind speed of 4.5 m/s and Class D atmospheric stability, is calculated to be 0.29 mg/m³. This is below the ERPG-2 value for phosgene of 0.82 mg/m³.

4.4 Final Hazard Classification on the Basis of the Bounding Accidents

To determine the final hazard classification on the basis of bounding accidents, the consequences must be compared to the following criteria. For radionuclides, the criterion is a dose less than 10 rem at a distance of 30 m for a nonnuclear facility (DOE, 1992b). Table 5 summarizes the contributions to dose for the nuclides released in the bounding event from the NIF. As shown, the total dose at 30 m is 2.7 rem. This is less than the 10 rem criterion for a Category 3 facility. As noted earlier, this dose would be much lower if factors such as building wake effects and the finite size of the plume were accounted for. Thus, the nonnuclear classification for the NIF is confirmed.

Table 6 compares the consequences of the aluminum release, the mercury release and the phosgene release to ERPG-2 values or their equivalents. The criterion for distinguishing a low hazard facility from a moderate hazard facility is a concentration equal to the ERPG-2 value at 100 m from the release point. If the calculated concentration for the bounding release is below ERPG-2 at this distance, the classification would remain low hazard. The values in Table 6 are all below the ERPG-2 value. Thus, the low hazard classification of the NIF is confirmed.

On the basis of the low hazard, nonnuclear classification, the safety analysis for the NIF will be governed by DOE Order 5481.1B (DOE, 1986).

Although the NIF has been classified as nonnuclear, it is still considered a radiological facility due to the presence of radioactive materials. The facility will be subject to other orders governing safety associated with the use of radioactive materials, such as DOE Order 5480.11 (DOE, 1988c) and DOE Order 5400.5 (DOE, 1990).

Table 6. Consequences of bounding chemical release.

Chemical	Quantity vulnerable to release	Release fraction	Release duration	Concentration at 100 m (mg/m ³)	ERPG-2 ^a (or equivalent (mg/m ³))
Aluminum (particulates in chamber)	420 kg	0.001	3 min	12	15 ^b
Mercury (in ignitrons)	6450 g	0.01	30 min	0.057	0.25 ^c
Phosgene (from methylene chloride)	293 g ^d	1.0	30 min	0.29	0.82

^aERPG-2: As defined by the American Industrial Hygiene Association, this is the concentration level of hazardous material at which nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair their ability to take protective action.

^bERPG-2-equivalent: Set equivalent to EEGL (60-min) (Craig, 1992).

^cERPG-2-equivalent: Determined from TLV-TWA (ACGIH) $\times 5$, where TLV-TWA (ACGIH) = 0.05 mg/m³ for mercury (Craig, 1992).

^d Assumes 1% of methylene chloride is converted to phosgene (on a per mole basis).

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Acronyms and Glossary of Terms

ACGIH	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
ANSI	American National Standards Institute
CEDE	Committed Effective Dose Equivalent. In this report, this dose measure is the 50-yr integrated dose resulting from inhalation of radionuclides and external exposure to the cloud during plume passage. It is the weighted sum of doses to individual organs, with the weights determined by the stochastic risk factors for the generation of fatal cancers associated with the respective organs, as specified by the ICRP.
Ci	Unit of radioactivity equivalent to 3.7×10^{10} disintegrations per second.
DOE	Department of Energy
DOT	Department of Transportation
EEGL	Emergency Exposure Guidance Level
EPA	Environmental Protection Agency
EPICODE	Emergency Prediction Information Code
ERPG-2	Emergency Response Planning Guide, Level 2
FEMA	Federal Emergency Management Agency
hohlraum	The metal shell placed around an ICF target, which emits x-rays upon illumination with laser light. These x-rays then impinge upon the ICF target, indirectly compressing and heating it.
ICF	Inertial Confinement Fusion
ICRP	International Commission on Radiological Protection
LOC	Level of Concern
LOVA	Loss of Vacuum Accident
LLNL	Lawrence Livermore National Laboratory
NAS	National Academy of Sciences
NIF	National Ignition Facility
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PEL-C	Permissible Exposure Limit, Ceiling
PHA	Preliminary Hazards Analysis
TEOS	Tetraethylorthosilicate
TLV-C	Threshold Limit Value, Ceiling
TLV-TWA	Threshold Limit Value, time weighted average
yield	The fusion energy release from an ICF target.

Acknowledgments

The author wishes to thank Corrine Burgin, Mike Cable, Doug Larson, Jeff Latkowski, Jesse Lum, Larry McLouth, George Morris, Mike Singh, Mike Trent, Jon Yatabe, and the NIF Environmental Assessment working group. Comments from and discussions with these various people have been extremely valuable in the preparation of this document. Jeff Latkowski and Mike Singh are also acknowledged for their neutron activation calculations.

Appendix A

Hazard Classification Methodology

This appendix outlines the hazard classification methodology used to determine the hazard classification of the NIF. It is based on the methodology of DOE (1992b) and the approach for chemical hazard classification currently employed at LLNL.

An initial hazard classification is assigned to the facility on the basis of facility inventories. Figure A-1 illustrates the process. The facility radionuclide inventories are first examined to evaluate whether or not the facility is a nuclear facility. DOE (1992b) defines three hazard classifications for nuclear facilities:

- Category 3: Hazards analysis shows the potential for only significant localized consequences; this encompasses facilities with quantities of radioactive materials, which meet or exceed the Category 3 thresholds.
- Category 2: Hazards analysis shows the potential for significant onsite consequences; this encompasses facilities with the potential for nuclear criticality events or with sufficient quantities of radioactive material (in excess of Category 2 thresholds) and energy that onsite emergency planning activities would be required.
- Category 1: Hazards analysis shows the potential for significant offsite consequences; this encompasses Category A reactors and facilities designated by DOE.

Threshold values for radionuclides for nuclear classification are provided in DOE (1992b). The Category 3 thresholds are minimum values for the inventory of a radionuclide, which if exceeded, would cause a facility to be classified as Category 3. For nuclides that do not have a threshold listed, and for which no firm guidance on what should be used is provided, values are available in most cases from DOE. In certain instances, it may be necessary to calculate a threshold. This can be done by scaling from the threshold of another nuclide, using dose conversion factors.

When multiple nuclides are present at a facility, DOE (1992b) requires that the sum of the ratios of the individual nuclide inventories to their respective threshold values be calculated. If the sum of the ratios exceeds one, then the next higher classification, relative to that determined on the basis of single nuclide inventories alone, would be assigned. For example, if individual inventories at a facility fall below the Category 3 thresholds for all nuclides, but the sum of the ratios of the individual nuclide inventories to the Category 3 threshold values exceeds one, the facility would be classified as Category 3. Similarly, if individual inventories are greater than the Category 3 thresholds, but are below Category 2 thresholds, and the sum of the ratios of the individual nuclide inventories to the Category 2 threshold values exceeds one, the facility would be classified as Category 2. There are no threshold values for hazard Category 1. This classification is reserved for Category A reactors or any other facility deemed to be of this hazard level by DOE.

The top portion of Figure A-1 summarizes the initial nuclear classification process. The presence of significant quantities of radionuclides determines if a facility is classified as a nuclear facility. If so, it will be designated as Category 1, 2, or 3. If not, it will be classified as nonnuclear.

Knowing the nuclear classification, the facility chemical inventories should then be examined. DOE (1986) defines the following classifications, which apply to nonnuclear facilities:

- Low hazard: Hazards analysis shows the potential for only minor onsite and negligible offsite impacts to people or the environment; this encompasses facilities with quantities of hazardous materials which meet or exceed the low hazard thresholds.
- Moderate hazard: Hazards analysis shows the potential for considerable potential onsite impacts to people or the environment, but at most only minor offsite impacts; this encompasses facilities with significant quantities of hazardous material (in excess of moderate hazard thresholds) and energy.

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Figure A-1. Initial hazard classification process.

High hazard: Hazards analysis shows the potential for onsite or offsite impacts to large numbers of persons or for major impacts to the environment.

LLNL has adopted a set of threshold values for chemicals which meet the definitions of low and moderate hazard. We have not developed a set of thresholds for high hazard, as we do not expect to have any facility of this hazard level at LLNL. We use Reportable Quantities as specified in 40CFR302 and in 40CFR355 as our low hazard thresholds. The low hazard thresholds are minimum values for the inventory of a chemical, which if exceeded, would cause a facility to be classified as low hazard. We use Threshold Quantities as specified in 29CFR1910.119 and Threshold Planning Quantities as provided in 40CFR355 as our moderate hazard thresholds. The chemicals listed in 40CFR302, 40CFR355, and 29CFR1910.119 have been identified as being hazardous for one reason or another. Thus, the chemical inventory comparison will consider most extremely hazardous materials. Chemicals not on these lists are generally less hazardous, and are not considered in the initial hazard classification process. They may be examined, depending on the quantity at the facility and on the toxicity of the material, in the final hazard classification process.

The bottom portion of Figure A-1 summarizes the initial chemical classification process. If a facility does not have significant quantities of hazardous chemicals, its chemical classification will be "excluded."

The nuclear classification, based on inventories of radionuclides, and the chemical classification, based on inventories of hazardous chemicals, should be combined to provide an overall classification for the facility. The various combinations and the outcomes are provided in Table A-1. In most cases, the nuclear classification will be the ultimate designation given to the facility. However, in cases where the chemical classification is higher than the nuclear classification, the facility may be assigned a dual classification. For example, if a facility is assigned a nuclear classification of Category 3, and the chemical evaluation results in a classification of moderate hazard, the facility will have the designation, Category 3—moderate hazard. On the other hand, if a facility is assigned a nuclear classification of Category 2, and the chemical evaluation results in a classification of low hazard, the facility will be known as Category 2.

After assigning an initial hazard classification, the classification can be finalized based on an unmitigated release of available hazardous material. For the purpose of hazard classification, "unmitigated" means that material quantity, form, location, dispersibility, and interaction with available energy sources should be considered, but safety features that will prevent or mitigate a release should not be considered. Such additional analysis would provide the basis for the actual inventory at risk in a facility and would evaluate a credible release fraction based on physical and chemical form and available dispersive energy sources. The use of bounding accidents can lower the classification from that initially obtained or it can confirm the initial classification. Accidents can be selected to explore only the hazards of greatest significance, or those that were not part of the initial hazard classification process. For example, in the case of chemical hazard classification, not all chemicals have hazard classification thresholds. In some instances, it may be useful to explore accidental releases of some of the other chemicals, particularly those present in large quantities at the facility or those that are known to be relatively toxic.

A final hazard classification is assigned on the basis of bounding analyses of potential accidents. Figure A-2 illustrates this process. The facility radionuclide inventories are first examined to assess releasable inventories on the basis of material form, location, and available energy sources. The consequences of the release determine the final nuclear classification. DOE (1992b) defines nuclear classifications on the basis of consequences of releases as follows:

- Nonnuclear: Total dose at 30 m from the facility is less than 10 rem.
- Category 3: Total dose at 30 m from the facility exceeds 10 rem.
- Category 2: Total dose at 300 m exceeds 1 rem.

As was the case before, Category A reactors or other facilities deemed to be of similar hazard level by DOE will be classified as Category 1.

All calculated scenarios should use Class D atmospheric stability and a wind speed of 4.5 m/s, in accordance with DOE (1992b).

Table A-1. Matrix illustrating the outcomes of combining nuclear and chemical classifications.

	Nonnuclear	Category 3	Category 2	Category 1
Excluded	Excluded	Category 3	Category 2	Category 1
Low hazard	Low hazard	Category 3	Category 2	Category 1
Moderate hazard	Moderate hazard	Category 3— moderate hazard	Category 2	Category 1
High hazard	High hazard	Category 3— high hazard	Category 2— high hazard	Category 1

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Figure A-2. Final hazard classification process.

If an accident scenario is developed for the release of chemicals, the LLNL criteria for hazard classification are as follows:

- Low hazard:** Individual concentrations of chemicals released all fall below the ERPG-2 level (or its equivalent) at 100 m from the facility.
- Moderate hazard:** Any individual concentration of a chemical released exceeds the ERPG-2 level (or its equivalent) at 100 m from the facility.

We have not yet established a criterion for facility exclusion on the basis of postulated bounding accidents involving hazardous chemicals at a facility. And, as discussed earlier, we have no criterion for high hazard facilities, as we do not expect facilities of this hazard level at LLNL.

The bottom portion of Figure A-2 summarizes the final chemical classification process. Not all chemicals need to be evaluated in the context of a bounding accident. Only those which are present in significant quantities, or which are particularly toxic, should be considered. If there are no chemicals presenting particular concerns, then an accident evaluation may not be necessary, and the initial chemical classification can be maintained.

The ERPG-2 level is a toxic exposure level developed by the American Industrial Hygiene Association (AIHA) for emergency planning purposes. At the ERPG-2 concentration level of a hazardous material, nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair their ability to take protective action. ERPGs are only available for a limited number of chemicals. In the absence of an actual ERPG value, the following hierarchy of alternatives is suggested to determine an ERPG-2-equivalent (Craig, 1992):

1. EEGL (60 min), NAS
2. LOC, EPA/FEMA/DOT
3. PEL-C, OSHA
4. TLV-C, ACGIH
5. TLV-TWA $\times$ 5, ACGIH

The acronyms are defined as follows:

ACGIH	American Conference of Governmental Industrial Hygienists
DOT	Department of Transportation
EEGL	Emergency Exposure Guidance Level
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
LOC	Level of Concern
NAS	National Academy of Sciences
OSHA	Occupational Safety and Health Administration
PEL-C	Permissible Exposure Limit, Ceiling
TLV-C	Threshold Limit Value, Ceiling
TLV-TWA	Threshold Limit Value, Time Weighted Average

Appendix B

Radiological Dose Calculation Methodology

We calculated doses from releases of radionuclides using a Gaussian plume dispersion model. This approach is commonly used for modeling of releases. The Gaussian model is more appropriate for predicting impacts at distances greater than 100 m from the release point; at closer distances, it has been found to overpredict concentrations (Brown, 1988). We used the Gaussian model to evaluate doses at 30 m from the release point. These doses should be conservative estimates.

In accordance with DOE (1992b), the dose calculations include inhalation and direct exposure during plume passage. Groundshine is not included, as it is expected to be small. Ingestion is not included, as there is no possibility of food growth at the point of interest. The doses were calculated according to the following equation.

$$\text{Dose}_i = \frac{\lambda}{Q} (Q_i) (\text{IDCF}_i \times \text{BR} + \text{CSDF}_i), \quad (1)$$

where

i = nuclide of interest,

Dose_i = dose at point of interest from nuclide i (rem),

$\frac{\lambda}{Q}$ = relative concentration at point of interest (s/m^3),

Q_i = source term of nuclide i (Ci),

IDCF_i = inhalation dose conversion factor (50-yr dose commitment) for nuclide i (rem/Ci),

BR = breathing rate (m^3/s),

CSDF_i = cloudshine dose conversion factor for nuclide i $\left(\frac{\text{rem} \cdot \text{m}^3}{\text{Ci} \cdot \text{s}} \right)$.

The relative concentration is a function of distance from the release point. It can be evaluated as follows:

$$\frac{\lambda}{Q} = \frac{1}{\pi \times \sigma_y \times \sigma_z \times u}. \quad (2)$$

DOE (1992b) assumes atmospheric stability class D for dispersion calculations. Under these conditions, the diffusion coefficients at a distance less than 100 m from the release point can be described as (Napier, 1988):

$$\sigma_y = 0.1471(x^{0.9031}), \quad (3)$$

$$\sigma_z = 0.079(x^{0.881}), \quad (4)$$

where

σ_y = horizontal diffusion coefficient (m),

σ_z = vertical diffusion coefficient (m),

u = wind speed (m/s),

x = distance downwind from release point (m).

For a wind speed of 4.5 m/s, as specified by DOE (1992b), the relative concentration at 30 m becomes 1.41×10^{-2} s/m³. Assuming a slightly elevated breathing rate of 3.5×10^{-4} m³/s, the expression for the dose from a given nuclide at 30 m from the release point becomes:

$$\text{Dose}_i = 1.41 \times 10^{-2} \times Q_i (3.5 \times 10^{-4} \times \text{IDCF}_i + \text{CSDF}_i). \quad (5)$$

To calculate the dose, the quantity of the nuclide to be released must be known, and the dose conversion factors must be available. For the purpose of calculating doses for this PHA, DOE (1988a) served as the primary reference for the inhalation dose conversion factors; DOE (1988b) served as the primary reference for the external dose conversion factors. When dose conversion factors for a nuclide were not available from these sources, we consulted Fetter (1988) and Fetter (1991).

With this information available, the dose from an individual nuclide can readily be calculated. The total dose at a point from all nuclides released is the sum of the doses from the individual nuclides.

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