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NATIONAL IGNITION FACILITY: IMPACTS OF CHEMICAL ACCIDENTS AND COMPARISON OF CHEMICAL AND RADIOLOGICAL ACCIDENT APPROACHES

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ABSTRACT

An environmental assessment was conducted to estimate potential impacts or consequences associated with constructing and operating the proposed National Ignition Facility (NIF). The multidisciplinary assessment covered topics ranging from radiological and chemical health and safety to socioeconomic and land-use issues. The impacts of five chemical accidents that could occur at NIF are compared, and the extent of their consequences for workers and off-site populations are discussed. Each of the five accident scenarios was modeled by a chemical release and dispersion model with a toxicological criterion for evaluating potential irreversible human health effects. Results show that most of the chemical release scenarios considered will not impair the general public in taking protective actions in the event of an accidental release. The two exceptions are the mercury release (equipment failure) scenarios for the conceptual design and the enhanced design. In general, the predicted maximum threat zones are significantly less than the distance to the point of nearest public access.

I. INTRODUCTION

The U.S. Department of Energy (DOE) has proposed the construction and operation of a National Ignition Facility (NIF) to achieve fusion ignition in the laboratory. Five candidate locations at four DOE sites are being considered for the facility. The preferred location is Lawrence Livermore National Laboratory (LLNL) in Livermore, California. The other candidate locations are Los Alamos National Laboratory (LANL), Sandia National Laboratories (SNL), the Nevada Test Site (NTS), and the North Las Vegas Facility (NLVF). In evaluating the five locations, it is necessary to compare the impacts of nonradiological accidental releases among the sites.[1] This paper considers five nonradiological accident release scenarios for the conceptual design and the enhanced design at the five candidate sites (Table 1). In addition, the approaches for nonradiological accident modeling and radiological accident modeling are compared.

For each of the five candidate locations, health effects on both workers and the general public must be considered for each nonradiological accident scenario. To predict health effects in both populations, it is necessary to identify chemicals of concern at each candidate facility, accident scenarios that could cause the release of these chemicals, and the probability of the occurrence of such accidents.

II. CHEMICAL ACCIDENT SCENARIOS

Five chemicals and five associated accident scenarios were identified and modeled for four candidate locations. Table 2 summarizes the chemical accident release scenarios. Chemical inventories for both the conceptual design and the enhanced design were examined to determine which chemicals are toxic and could cause toxic inhalation effects. In general, the NIF would maintain large inventories of low-hazard-classification or low-exposure-criteria materials. Most chemicals were eliminated from consideration on the basis of a joint weighting of those two factors. The five chemicals identified for consequence modeling were mercury, carbonyl fluoride, hydrogen fluoride, alumina, and silica. For NTS, a propane tank failure accident scenario was also modeled because propane is used for backup utility service for boilers and heaters.

III. EVALUATION METHODOLOGY

Many consequence models are available for predicting the effects of a chemical accident. The choice of a particular model depends on the characteristics of the release scenario, scale of the problem, level of data available for input, and level of accuracy required. The greater the desired accuracy, the more detailed the model inputs must be. The two models selected for the NIF project were Areal Locations of Hazardous Atmospheres[2] (ALOHA) and FIREPLUME.[3]

TABLE 1 Accident Scenarios

Initiator	Release/Source
Equipment failure	Mercury release from ignitron switches
Earthquake	Combined release of alumina and silica from the target chamber
In-facility fire	Carbonyl fluoride release from the optics treatment area
In-facility fire	Hydrogen fluoride release from the optics treatment area
Aircraft crash/fire	Mercury release from ignitron switches
Tank failure	Propane gas leak (modeled for NTS)

The ALOHA model uses a Gaussian-type dispersion approach to describe the movement and the spread of a neutrally buoyant gas and a heavy-gas dispersion model to describe the movement and spread of a dense gas. The ALOHA model estimates plume extent and concentrations for short-term chemical releases. It is commonly used in conjunction with the appropriate health criteria for emergency response planning. It does not consider topography.

The FIREPLUME model consists of two components: a Monte Carlo code that estimates the dispersion of both buoyant and nonbuoyant chemical releases in the atmospheric boundary layer and a puff dispersion code based in part on a Monte Carlo code. The FIREPLUME model predicts ground-level concentrations resulting from the release of a hazardous material within an instantaneously discharged thermal (i.e., a fireball), a fire, or a smoldering fire before it is fully extinguished. The FIREPLUME model was used to simulate the release of mercury from the ignitron switches resulting from an aircraft accident and subsequent fire at the NIF site.

Several bounding conditions were identified for meteorology. For five of the six cases, wind speed was assumed to be 1 m/s (3.3 ft/s), with a stability class of F, extremely stable. Under these conditions and for these release types, "worst-case" dispersion and conservative impacts can be expected. For the aircraft crash and fire, the mercury release was modeled by using stability class A and a wind speed of 2.0 m/s. For this release, these conditions yielded the most conservative impacts. Emergency Response Planning Guideline-2 (ERPG-2) values were chosen as the health criteria. ERPG-2 values are defined as "the maximum airborne concentration below which it is believed that 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 an individual's ability to take protective action." Within the contour defined by the maximum threat zone (as predicted by the models), individuals who are outdoors would be exposed to concentrations that would impair their ability to take protective action. Outside the maximum threat zone, individuals should be able to take adequate protective action. Individuals who are within the maximum threat zone but are indoors would experience different concentrations from those who are outdoors.

ERPG-2 surrogate values were used whenever an ERPG-2 value had not yet been determined. For example, surrogate ERPG-2 values could be determined by multiplying the threshold limit value, time-weighted average for the chemical of concern by a weighting factor of 5. For the combined alumina/silica accident release, the impacts of the exposure to both chemicals are combined (by weighting their associated health indices) to account for health effects associated with simultaneous downwind exposures. Five of the six cases involve releases at ground level. Mercury resulting from an equipment failure was modeled by assuming a release from the top of the building at a height of 17 m.

IV. MODEL RESULTS

Tables 3 through 6 present the modeling results for the mercury, alumina/silica, carbonyl fluoride and hydrogen fluoride chemical accident scenarios at each of the five candidate sites. Indoor and outdoor chemical concentrations were predicted with the ALOHA model. Distances predicted by the ALOHA and FIREPLUME models for the maximum threat zone are less than the distance to the nearest public access for all cases, except the equipment failure mercury release scenarios at NLVF and LLNL. Although atmospheric concentrations resulting from an accident would exceed the ERPG-2 values outdoors at the two facilities, workers who were indoors would be protected. Indoor concentrations depend on specific building ventilation rates. Details of each building within the threat zone are necessary for quantitative evaluation of indoor chemical concentrations. Typically, single-storied structures show concentrations of a factor of 5 or more below the outdoor levels.

Table 3 presents the results of the modeling for the mercury release resulting from an aircraft crash and fire at the five candidate sites. Outdoor concentrations of mercury were predicted with the FIREPLUME model. Model results indicate negligible mercury concentrations for all distances from the site of the aircraft crash and fire. Predicted concentrations of mercury are significantly less than the ERPG-2 value, 0.125 mg/m^3, for all distances from the accident site.

On the basis of results from the ALOHA and FIREPLUME models, most of the chemical accident scenarios considered will not impair the ability of a member of the general public to take protective action in the event of such an accident. The two exceptions are the equipment failure mercury release scenario for the conceptual design and the enhanced design at NLVF and LLNL. Figure 1 shows three accident release scenario plumes, simulated with the ALOHA model, superimposed over the proposed LLNL-NIF site map.

V. COMPARISON OF CHEMICAL AND RADIOLOGICAL MODELING

It is difficult to compare directly the results from chemical and radiological modeling because of differences in models and health endpoints. Radiological modeling predicts the probability of long-term cancer fatalities among the general public, while chemical dispersion modeling, as used for chemical accidents, predicts a "threat zone" on the basis of a single human health endpoint associated with acute exposure to a chemical. The "endpoint" associated with radiological exposure is delayed; the "endpoint" associated with chemical exposure is immediate.

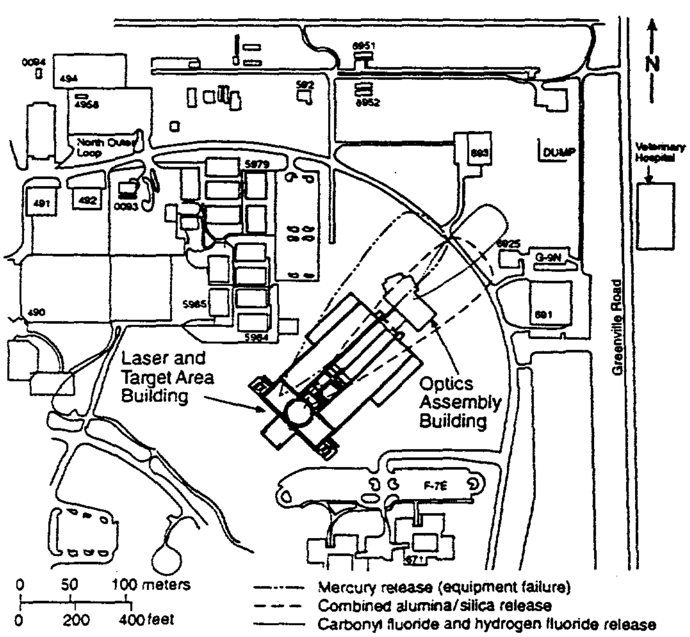

FIGURE 1 Overlay of Three Chemical Accident Plumes on the NIF Site at LLNL

The GENII program[4] was used to model radiation doses to workers and the general public at the five candidate sites. Radiation doses were converted to health effects on the basis of the 1990 recommendations of the International Commission on Radiological Protection. The results of that program led to predictions of radiation doses and cancer fatalities for a separate set of radiological accidents for the NIF. The results of the radiological accidents are presented in Ref. 5.

VI. CONCLUSIONS

On the basis of the results of the chemical accident release modeling for the NIF facility, the NIF presents minimal chemical exposure hazard. The maximum threat zone for each nonradiological accident scenario examined is within the site boundaries of each proposed site. The two exceptions are the equipment failure scenario involving a mercury release for the conceptual design and the enhanced design at NLVF and LLNL. Chemical and radiological modeling results cannot be compared easily because of differences in models and health endpoints.

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TABLE 2 Summary of Chemical Accident Release Scenarios for the National Ignition Facility

Release Scenario	Vulnerable Inventory[a] (kg)	Release Fraction	Total Quantity Released (g)	Release Duration	Release Height
Mercury					
Equipment failure	6.5	1.0×10^{-2} [b]	65	30 min	17 m
Aircraft crash	51.5	1.0	51,500	16 min	Grn. level
Alumina	6.7 (29.6)	1.0×10^{-3} [c]	6.7 (29.6)	7.6 min[d]	Grn. level
Silica	2.1 (4.4)	1.0×10^{-3} [c]	2.1 (4.4)	7.6 min[d]	Grn. level
Hydrogen fluoride	273 fluorinert (151 L)	1.0×10^{-4} [e]	27.3	1 h	Grn. level
	3 kg Teflon	3.8×10^{-1} [e]	1,145		
Carbonyl fluoride	3 kg Teflon	3.8×10^{-1} [e]	1,890	1 h	Grn. level
Propane	56,780 L	1.0	56,780 L	1 h	Grn. level

[a] Values are the same for conceptual design and the enhanced design except for vulnerable inventory and total quantity released for alumina and silica. Values in parentheses for those two materials are for the enhanced option.

[b] Ref. 6

[c] Ref. 7

[d] Corresponds to a wind speed of 1 m/s.

[e] Ref. 8

TABLE 3 Summary of Mercury Release Scenarios Predictions at the Five Candidate Sites[a]

Site	Nearest Public Access	Concentration [c] Equipment Failure Outdoor/Indoor (mg/m^3)	Concentration [b] Airplane Crash/Fire (mg/m^3)	Maximum Threat Zone [d] (m)
LLNL	245 m ENE	0.124/0.025	$< 10^{-5}$	237
NTS	20,000 m SSW	Negligible	2.47×10^{-5}	237
NLVF	210 m W	0.165/0.033	$< 10^{-5}$	239
LANL	1,620 m NNE	Negligible	$< 10^{-5}$	237
SNL	1,864 m N	0.0204/0.0035	$< 10^{-5}$	237

[a] Results are the same for the conceptual design and the enhanced design.

[b] The ALOHA model chooses a neutrally buoyant or a heavy-gas treatment for dispersion, depending on which modeling approach is most appropriate. The mercury release from the equipment failure was modeled as a heavy gas. The FIREPLUME model accounts for fire heat generation and simulates buoyant plume rise.

[c] Predicted concentrations at nearest point of public access.

[d] The maximum threat zone corresponds to the distance from the source beyond which concentrations are below the ERPG-2 value. Because of plume rise, the FIREPLUME-estimated concentrations did not exceed the equivalent ERPG-2 value for mercury.

TABLE 4 Summary of Alumina/Silicate Release Scenario Predictions at the Five Candidate Sites for the Conceptual Design and the Enhanced Design

Site	Nearest Public Access	Dispersion Type [a]	Outdoor/Indoor Concentration[b] (mg/m^3)	Maximum Threat Zone[c] (m)
Conceptual Design				
LLNL	800 m E	Neutrally Buoyant	0.0509/0.0001	171
NTS	20,000 m SSW	Neutrally buoyant	Negligible	171
NLVF	210 m W	Neutrally buoyant	0.296/0.002	171
LANL	1,620 m NNE	Neutrally buoyant	Negligible	171
SNL	1,864 m N	Neutrally buoyant	0.0123/0.0001	174
Enhanced Design				
LLNL	800 m E	Neutrally buoyant	0.11/0.0017	231
NTS	20,000 m SSW	Neutrally buoyant	Negligible	231
NLVF	210 m W	Neutrally buoyant	Negligible	231
LANL	1,620 m NNE	Neutrally buoyant	Negligible	231
SNL	1,864 m N	Neutrally buoyant	0.0268/0.0001	234

[a] The ALOHA model chooses a neutrally buoyant or a heavy-gas treatment for dispersion, depending on which modeling approach is most appropriate.

[b] Predicted concentrations at nearest point of public access.

[c] Differences in predictions among the various sites (171 compared with 174 m or 231 compared with 234 m) are not important and are due to the atmospheric differences (elevation) among the sites.

[d] The maximum threat zone corresponds to the distance from the source beyond which concentrations are below the ERPG-2 value.

TABLE 5 Summary of Carbonyl Fluoride Release Scenario Predictions at the Five Candidate Sites for the Conceptual Design and the Enhanced Design

Site	Nearest Public Access	Dispersion Type [b]	Outdoor/Indoor Concentration[c] (mg/m^3)	Maximum Threat Zone (m)
LLNL	120 m ENE	Heavy gas	18.9/4.14	99
NTS	20,000 m SSW	Heavy gas	Negligible	75
NLVF	210 m W	Heavy gas	4.83/1.02	75
LANL	1,620 m NNE	Heavy gas	0.198/0.0324	70
SNL	1.864 m N	Heavy gas	0.608/0.114	70

[a] Identical accidents are proposed for the conceptual design and enhanced design, so no differences exist between these options.

[b] The ALOHA model chooses a neutrally buoyant or a heavy-gas treatment for dispersion, depending on which modeling approach is most appropriate.

[c] Predicted concentrations at nearest point of public access.

[d] The maximum threat zone corresponds to the distance from the source beyond which concentrations are below the ERPG-2 value.

TABLE 6 Summary of Hydrogen Fluoride Release Scenario Predictions at the Five Candidate Sites for Conceptual Design and Enhanced Options[a]

Site	Nearest Public Access	Dispersion Type [b]	Outdoor/Indoor Concentration[c] (mg/m^3)	Maximum Threat Zone (m)
LLNL	120 m ENE	Neutrally Buoyant	11.2/4.66	99
NTS	20,000 m SSW	Neutrally Buoyant	$<10^{-2}/10^{-2}$	75
NLVF	210 m W	Neutrally Buoyant	3.98/1.54	75
LANL	1,620 m NNE	Neutrally Buoyant	0.095/0.027	70
SNL	1,864 m N	Neutrally Buoyant	0.076/0.020	70

[a] Identical accidents are proposed for the conceptual design and enhanced design, so no differences exist between these options.

[b] The ALOHA model chooses a neutrally buoyant or heavy-gas treatment for dispersion, depending on which modeling approach is most appropriate.

[c] Predicted concentrations at nearest point of public access.

[d] The maximum threat zone corresponds to the distance from the source beyond which concentrations are below the ERPG-2 value.