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SAFETY OVERVIEW OF THE NATIONAL IGNITION FACILITY

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ABSTRACT

The National Ignition Facility (NIF) is a proposed U.S. Department of Energy inertial confinement laser fusion facility. The candidate sites for locating the NIF are: Los Alamos National Laboratory, Sandia National Laboratory, the Nevada Test Site, and Lawrence Livermore National Laboratory (LLNL), the preferred site. The NIF will operate by focusing 192 laser beams onto a tiny deuterium-tritium target located at the center of a spherical target chamber. The NIF mission is to achieve inertial confinement fusion (ICF) ignition, access physical conditions in matter of interest to nuclear weapons physics, provide an above ground simulation capability for nuclear weapons effects testing, and contribute to the development of inertial fusion for electrical power production.

The NIF has been classified as a radiological, low hazard facility on the basis of a preliminary hazards analysis and according to the DOE methodology for facility classification. This requires that a safety analysis be prepared under DOE Order 5481.1B, Safety Analysis and Review System. A draft Preliminary Safety Analysis Report (PSAR) has been written, and this will be finalized later in 1996.

This paper summarizes the safety issues associated with the operation of the NIF. It provides an overview of the hazards, estimates maximum routine and accidental exposures for the preferred site of LLNL, and concludes that the risks from NIF operations are low.

I. INTRODUCTION

To achieve the NIF mission, the facility 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 192 identical beamlets. Each beam of light will be focused and directed onto a target suspended in the center of the spherical aluminum alloy target chamber, as shown in Figure 1. The target chamber will be housed inside a cylindrical, reinforced concrete target bay with 6-ft thick walls for radiation shielding. This will be located within the Laser and Target Area Building (LTAB), the main experimental building of the NIF. As shown in Figure 2, the LTAB will consist of 2 laser bays, 2 optical switchyards, a target bay, a diagnostics area, 4 capacitor bays, a mechanical room, a master oscillator room (MOR), and operational support areas.

Not all experiments will be "burn" shots, perhaps 25% of 1200 annual shots. These experiments release neutrons, debris, and x-rays. Unburned tritium will be exhausted from the target chamber to the tritium processing/collection system. Emitted neutrons will activate the target chamber, or they will travel through the target chamber structure and shielding, or through penetrations, and enter the target bay. Here, they will activate the supporting structure for the target chamber, the concrete and rebar in the walls, and the gases in the air. Small quantities of routinely generated activated gases will be released to the

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The facility will initially be operated in the indirect-drive mode, where a small metal cylindrical shell, known as a hohlraum (less than a centimeter high and wide), will surround the target. Upon laser illumination, the hohlraum material will generate x-rays, which compress and heat the target. Indirect-drive targets will contain no more than 1.5 Ci of tritium. The facility will be able to perform direct-drive experiments after a conversion time period of around 6 months. In the direct-drive mode, the target will be compressed and heated by direct exposure to laser light. Direct-drive targets will contain up to 15 Ci of tritium.

II. SAFETY ANALYSIS PROCESS

A draft PSAR has been prepared for the NIF LTAB. The process began with identification of hazards. A systematic review of planned LTAB operations and existing design and safety documentation was carried out. Safety documentation prepared for other fusion facilities was also reviewed. This was supplemented by the use of hazard checklists. Additionally, project personnel and a team of health and safety professionals were consulted.

The hazard evaluation and systematic review of the planned operations at the facility generated a comprehensive list of hazardous events for the construction, start-up, and operational phases of NIF. It included hazards associated with normal facility operation, as well as accidental occurrences. Internal operational events, external events, and natural phenomena were considered.

The unique hazards at the facility (i.e., other than standard industrial hazards) primarily consist of the laser, tritium handling, use of chemicals, prompt radiation during shots, and neutron activation of air and structures in the target bay. In addition to hazards encountered during normal operations, nearly 50 accidents that could occur at the facility were identified. Each hazardous event was reviewed to identify potential causes, preventive and mitigative design features, and preventive and mitigative administrative features. These are documented in PSAR.

Each event was also reviewed to gain a better understanding of event frequency and potential consequences. A qualitative descriptor of event likelihood and consequences was assigned to each event. This assignment was based on evaluations already done, the estimated magnitude of the source term, studies for other fusion facilities, and judgment. The frequency and consequence assignments were only broad estimates at this stage, sufficient to place an event into a frequency and consequence category range. The event frequencies and consequences were combined using a qualitative risk matrix, so that each event ultimately had a risk label associated with it. Details on the methodology for performing the qualitative risk assessment are provided in the PSAR. The outcome was a relative risk ranking of the events, and those presenting higher risk were identified for further study. In some areas, for example chemical exposures, the risk from all identified events was similar. In this case, an event was selected for further study on the bases of highest projected consequences.

The NIF LTAB has been classified as a low hazard, radiological facility, on the basis of facility inventories and hazard classification methodology. The analysis for NIF was carried out only to the level necessary to provide a convincing argument that the facility can be operated safely, with minimal risk to workers, the public, and the environment. Thus, it largely takes the form of a qualitative hazards analysis, with only the consequences of bounding accidents evaluated quantitatively. When impacts can easily be shown to be small, the use of bounding assumptions and less-detailed physical modeling and accident analysis is appropriate. This is consistent with the “graded approach” to safety analysis.

III. INVENTORIES OF RADIOACTIVE AND HAZARDOUS MATERIALS

Radioactivity will be present in the NIF facility in the following forms:
1. Tritium:
   - in targets
   - adsorbed/implanted into surfaces
on the vacuum pumps
- in the tritium processing/collection system
- in decontamination gloveboxes
- in waste.

(2) Neutron Activation Products:
- as particulate, created in the target chamber
- in target chamber area structures
- as activated gases in the target bay atmosphere.

The tritium inventory will be monitored and controlled such that the total quantity within the facility does not exceed 500 Ci. The quantity of activated particulate created in the target chamber is quite small, and most species are short lived. This material is derived from ablated first wall, debris shields, diagnostics, and the target positioner. The inventories created in target chamber area structures present a worker re-entry hazard; they do not present a hazard outside the facility, as they are not releasable under any credible circumstances. The activated gases created as a result of 1200 MJ of annual yield are provided in Table 1.

| Table 1: Inventories of Activated Gases at NIF |
|---|---|---|
| Nuclide         | Half-Life | Annual Quantity Produced (Ci/yr) | Annual Quantity Released (Ci/yr) |
| H-3             | 12.3 yr   | 5.4e-3                           | 5.4e-3                           |
| N-13            | 9.97 min  | 6.8e+2                           | 8.6e+1                           |
| C-14            | 5720 yr   | 1.5e-3                           | 1.5e-3                           |
| N-16            | 7.1 s     | 9.7e+4                           | 1.7e+2                           |
| S-37            | 5.1 min   | 2.0e+1                           | 1.4                              |
| Cl-40           | 1.4 min   | 7.4e+1                           | 1.4                              |
| Ar-41           | 1.82 h    | 8.8e+1                           | 5.4e+1                           |

IV. ROUTINE IMPACTS FROM NIF OPERATIONS

The relative risk assessment performed in the PSAR indicated that the majority of the risk to workers and the public was associated with routine operations. Based on the consequences associated with the routine activities, it can be readily concluded that the risks associated with NIF operations are low.

When fully operational, the NIF will produce up to 1200 MJ/yr of fusion yield, with routinely scheduled individual shots having yields of up to 20 MJ. Yield shots will generate prompt radiation. Exposures to prompt radiation are minimized through shielding of the target chamber itself (approximately 30 cm thick concrete), and shielding of the target bay, the cylindrical reinforced concrete building which houses the target chamber (6 ft thick walls, 4 ft thick roof). The shielding reduces prompt radiation levels to approximately 0.16 mrem/yr at the site boundary (340 m away). In addition to prompt radiation, activated gases are created in the target bay atmosphere. These nuclides are short-lived. A slow release to the environment provides considerable opportunity for decay. Released inventories are given in Table 1. Based on calculations using the CAP-88-PC code, these gases add about 0.1 mrem/yr to the site boundary dose.

It is expected that there will also be some routine release of tritium as a result of cleaning and maintenance activities. This was estimated to be approximately 30 Ci/yr. CAP-88-PC results indicate that this adds another approximately 0.0042 mrem to the site boundary dose, making the total maximum offsite exposure approximately 0.26 mrem/yr.

The design goal for NIF worker exposures is 0.5 rem/yr, one-tenth of the occupational exposure limit. This will be met by shielding design, use of temporary shielding as needed during maintenance, delay time before access, work time constraints, remote operations, personal protective equipment, training, and proper procedures.

Small quantities of cleaning solvents, such as methanol, ethanol, and acetone will be used in the LTAB. This is expected to generate a small amount of airborne effluent, but this will have a negligible impact outside the facility. Worker exposures will be minimized by proper ventilation and respiratory protection as needed.
The NIF will utilize a very powerful laser with an associated large electrical energy storage and discharge system. These present significant electrical and optical hazards. Laser exposures during normal NIF operations should not occur. Controls to prevent accidents from laser operation include: physical barriers, interlocks, protective eye equipment, visual and audible alarms, video surveillance, personnel accountability, training, and specific procedures.

V. ACCIDENTAL OCCURRENCES AT NIF

The safety analysis process identified the highest risk and/or consequence credible accidents that could occur in the LTAB. These events are briefly discussed here. Analytical details and further discussion can be found in the PSAR.2

A. Tritium Release From the Processing System

The tritium processing system is comprised of a gas expansion tank, a preheater, catalyst beds, a chiller, molecular sieve storage beds, and interconnecting piping. Tritium could be released from the system as a result of operational failures (random failures, material flaws, cycling, maintenance errors), or as a result of an earthquake. Since the tritium processing system is only operating for a short period out of the year, it is extremely unlikely that a random failure or an earthquake would occur during processing hours. Thus, this is a very low probability event.

The event assumes that the entire tritium inventory (500 Ci) is assumed to be released from the system in the more hazardous oxide form, over a 30 minute period. A ground level release of the inventory under conservative weather conditions using the GENII code3, results in a dose of 53 mrem at the site boundary.

Workers in the area would also incur a dose. The room activity concentration is a function of the competing effects of the source into the room and the discharge of air from the room4. A simple model describing the room concentration and the worker’s exposure can be derived. Assuming the worker leaves the area within 10 minutes, the estimated dose would be about 320 mrem.

B. Unplanned Worker Exposure in the Target Bay

Prior to a shot, a series of events will take place to ensure that the target bay has been cleared of people. These include a sweep of the area, announcing the shot, activation of warning lights, review of the personnel accountability system, and setting the interlocks to preclude further access. Given all of these controls, it is extremely unlikely that an individual would be present in the target bay during a shot. However, unplanned worker exposures have occurred at facilities with interlock systems and other preventive controls.5

The scenario evaluated considers an individual to be present in the target bay during a 45 MJ shot6. During the shot, the individual would be exposed to prompt neutrons and prompt gamma radiation. Depending on the individual's location in the target bay, the dose incurred will vary. Analysis indicates that prompt dose levels would range from approximately 4000 rem to close to 60,000 rem.7 These are lethal dose levels. Clearly, the interlock system and other controls are critical in preventing such exposures.

After the shot, any individual who enters the target bay would be exposed to decay radiation from activated structures and activated gases. A dose of 1 rem was estimated, assuming the individual is present for one hour.2

C. Spill of Methanol

Solvents will be used for miscellaneous cleaning activities throughout the NIF LTAB. The maximum anticipated single inventory at the facility is currently estimated to be 32 L. An anticipated scenario that might occur during solvent use is a spill of liquid.

The spilled material is assumed to form a pool on the ground, and is subsequently allowed to evaporate. The evaporation rate and consequences outside the facility were estimated using the ALOHA code.8 Under conservative weather conditions, the site boundary concentration was estimated to be 47 mg/m³. This concentration is negligible falling well below the ERPG-19 concentration of 262 mg/m³.

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4 Note that if the earthquake results in a power outage, both the processing system and the ventilation system would be non-functional, and both in-facility and ex-facility consequences would be lower than indicated here.

6 Although the maximum planned yield shot is 20 MJ, the impact of this event is evaluated for the maximum credible yield of 45 MJ.

9 ERPG-1: Emergency Response Planning Guide, Level 1, as established by the American Industrial Hygiene Association, is the concentration below which nearly all individuals could be exposed for up to one hour, without
A potentially hazardous concentration could exist in the room where the methanol was spilled. The concentration is a function of the evaporation rate, the room volume, and the discharge rate. A simple model can be derived to describe the room concentration as a function of time.\textsuperscript{2} Using this model, the methanol concentration in the room would have reached a level of 7,750 mg/m\textsuperscript{3} in 10 minutes. This concentration is approximately at the level of the IDLH\textsuperscript{4} (7,800 mg/m\textsuperscript{3}). It is expected that the worker would safely escape the area.

D. Aircraft Crash

A small aircraft crashing into the NIF LTAB was found to be an extremely unlikely, but credible event.\textsuperscript{2} From a safety analysis standpoint, it is of interest to know whether or not the crash could release radioactive or other hazardous material. The target bay is constructed of 6 ft thick concrete walls, which would protect this area from the aircraft impact. The tritium processing system is located in the basement of the diagnostics building, beneath a 6 inch concrete floor, and is likely invulnerable to the event. However, if an aircraft did penetrate, the resulting tritium release would be no more severe than the bounding release already analyzed in section V.A. The only area that could result in significant release of hazardous material subsequent to the crash would be the outer capacitor bays. The mercury containing ignitor switches could be damaged in an aircraft crash, and mercury could be released to the environment.

This event was analysed in the PSAR.\textsuperscript{2} It was assumed that 8 switches, containing a total of 1 gallon of mercury, were severely damaged in the event. The aircraft is assumed to spill its fuel over the area, and this is subsequently assumed to ignite. Because mercury boils at 356°C and because the fire temperature is expected to be well in excess of this value, a substantial amount of mercury vapor is expected to be generated.

The estimated plume rise for the fire under all combinations of atmospheric stability class and wind speed observed at LLNL was determined. Offsite consequences of the release of mercury were evaluated using the ALOHA code, under various weather conditions and using the associated plume rise. The maximum offsite mercury concentration was found to be 0.16 mg/m\textsuperscript{3} at 4.2 km downwind, under E atmospheric stability and 3 m/s wind speed. This condition exists for only 10 minutes (assumed release duration), and thus, corresponds to a mercury dose of 1.6 mg-min/m\textsuperscript{3}. The ERPG-2* of 0.1 mg/m\textsuperscript{3} corresponds to a one hour exposure, or a mercury dose of 6 mg-min/m\textsuperscript{3}. Thus, the total mercury exposure from this event would actually be less than that corresponding to the ERPG-2 level.

Because of the lofting of the plume, onsite airborne concentrations of mercury would be very low. NIF workers could be harmed by the incoming aircraft, or from the heat or mercury vapor generated in the immediate vicinity of the fire.

VI. SUMMARY

The hazards and spectrum of hazardous events that might occur at the NIF LTAB have been identified. Based on the associated low consequences, routine operations present a low risk. Offsite consequences of postulated accidents are low, and thus these present a low risk to the public. In some cases, worker impacts from accidents could be severe, but these events are extremely unlikely. Thus, the risk to NIF workers from accidents is also low.

REFERENCES

5. U.S. Department of Energy, "Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis

\*ERPG-2: Emergency Response Planning Guide, Level 2, as established by the American Industrial Hygiene Association, is the concentration below 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.