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The National Ignition Facility: Inertial Fusion Energy Applications, Waste Management, and Environmental Impacts

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THE NATIONAL IGNITION FACILITY: INERTIAL FUSION ENERGY APPLICATIONS, WASTE MANAGEMENT AND ENVIRONMENTAL IMPACTS.

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Abstract

The proposed design of the National Ignition Facility (NIF) is reviewed from the standpoint of the involvement of both radioactive and hazardous materials. Detailed analyses of these factors indicated that minimal environmental impacts are expected to occur, and very low exposures are predicted for both workers and the general public.

I. Introduction

This century's explosion in technology has been made possible by the availability of abundant, inexpensive fossil fuels and the relative resilience of the Earth's biosphere to their localized use. It is now clear that sustainable development (e.g., economic, agricultural, social, technical, and environmental) over and beyond the next century cannot be supported by existing and projected supplies of fossil fuels. It is generally agreed that early in the next century, the challenge will be to find a new, clean, and sustainable energy source.

Although many energy sources have been suggested, inertial confinement fusion (ICF) has been demonstrated as scientifically feasible and deserves support for continued development. The National Ignition Facility (NIF), proposed by the U.S. Department of Energy (DOE), is a next step in that direction. The NIF would use ICF technology to achieve ignition and energy gain that would allow the development and continued support of national security and other civilian applications, including inertial fusion energy (IFE) power plants. Furthermore, NIF would guarantee U.S. leadership in ultra-high-density plasma research.

Potential environmental impacts associated with the construction and operation of NIF are being evaluated, and four sites are under consideration for NIF. An environmental impact evaluation was performed for all of the proposed sites. This paper provides results of the waste management analyzes conducted as part of these site evaluations.

Waste management is of particular interest because of the unique character of the facility. The waste impact analyses considered waste generation and handling during construction, two levels of operation, and decommissioning. The laser and target area in particular requires complex waste handling procedures, both during operation and decommissioning, due to activation of the target chamber material, the presence of leftover unburned tritium fuel, and the periodic decontamination of the chamber walls and optics with solvents, which would generate mixed waste.

The current waste treatment, storage, and disposal capacities at the proposed sites were reviewed, and comparison tables have been developed. Waste-handling capabilities for decommissioning of the NIF laser and target area after 30 years of operation were also examined.

Overall, the environmental study has shown that the proposed construction and operation of NIF would result in only minor on-site and negligible off-site environmental impacts. At the same time, NIF would provide a major long-term environmental benefit as a key step in the development of clean and safe IFE power plants.

II. Description of the National Ignition Facility

The NIF would be the first facility capable of achieving fusion ignition by the ICF process. The NIF design would consist of three main components: a laser generator and optical focusing array made up of neodymium solid-state glass lasers; a target chamber; and an advanced integrated computer system to control the lasers and diagnostic equipment.

The NIF lasers would consist of 192 independent infrared laser beams (beamlets). Each beamlet would have a square aperture of ~ 40 cm. The 192 beamlets would require more than 10,000 discrete optical components. The laser pulses would be propagated through various beam transport and amplification stages to the target area. When the laser pulses reached the target area, they would be converted to the ultraviolet region of the spectrum (wavelength = 0.35μm) and focused on a fusion target located at the center of the target chamber. The energy in one pulse would be about equal to the caloric energy in one candy bar (1.8 MJ or 400 food calories). However, the peak power for a few nanoseconds would be equal to about 500 TW (500×10^{12} watts), instantaneously exceeding the steady-state power capacity of the entire United States by approximately a factor of 1,000.

The NIF target area would provide the experimental facility for performing the target experiments and also provide for the confinement of tritium and activation products. Shielding would provide protection from neutron and gamma radiation.

The NIF target chamber would be a 10 m internal diameter spherical aluminum shell with walls 10 cm thick. The exterior of the chamber would be encased in 40 cm of concrete to provide neutron shielding.

The computer control system would be an integrated network of conventional computer systems providing the hardware and software needed to support the complex laser optical system and would have to meet security requirements to handle classified information.

Two design options for the NIF target chamber have been proposed. The conceptual design option would use an ICF approach called *indirect drive*. In this option, laser beams would illuminate and heat the interior surfaces of a metal hohlraum case containing a deuterium-tritium-filled capsule. The beams would cause the case of the hohlraum to emit x-rays that would in turn strike the fusion target capsule and drive the fusion reaction. An enhanced design option would include the above indirect drive operations, plus a second approach called *direct drive*. The enhanced option would also provide the ability to perform an increased number of experiments to accommodate greater user needs. No hohlraum would be used in the direct drive ICF method. Instead, the laser beams would impinge directly on the outer surface of the capsule containing the tritium-deuterium target.

III. Waste Generation and Non-Waste Radiological Impacts

Potential environmental impacts associated with the construction, operation, and decommissioning of NIF are being evaluated by DOE at five locations on four sites: Lawrence Livermore National Laboratory in California (the preferred site), Los Alamos National Laboratory and Sandia National Laboratory in New Mexico, and Area 22 and the North Las Vegas Facility associated with the Nevada Test Site in Nevada. Since the environmental impacts would be similar for all five locations and for clarity of presentation, the remainder of this discussion focuses on the preferred alternative, Lawrence Livermore National Laboratory (LLNL).

Construction wastes created during the building of NIF would be nonhazardous (e.g., sanitary liquid, 14,000 m^3, sanitary solid, 500 m^3, and approximately 900 m^3 each of other nonhazardous liquids and solids) and would be handled under conventional construction procedures.[1]

The operation of the NIF would produce small quantities of waste in three basic categories: low-level radioactive waste, low-level mixed waste containing both radionuclides and hazardous chemicals, and hazardous chemical waste.

Low-level radioactive waste generated during NIF operations would consist of molecular sieves from the tritium processing system, personal protective equipment (PPE), wipes and general cleaning equipment, HEPA filters, and hardware from the target chamber. Mixed wastes would consist of vacuum pump oil, PPE, and general cleaning materials. Hazardous wastes would consist of oil-filled capacitors and general chemicals.

Table 1 lists the types and quantities of wastes generated by category for both the conceptual and enhanced design options. Waste handling methods would be the same for both the conceptual and enhanced design options. While total waste quantities would be somewhat higher for the enhanced option, no changes in handling methods would be necessary.[2,3]

Table 1. National Ignition Facility Waste Estimates for Low-Level, Mixed, and Hazardous Waste for Both the Conceptual Design and the Enhanced[a] Options (per year of NIF operation)

	Low Level		Mixed		Hazardous			
					LTAB[b]		OAB[b]	
Source of Waste	**Solid (kg)**	**Liquid (L)**	**Solid (kg)**	**Liquid (L)**	**Solid (kg)**	**Liquid (L)**	**Solid (kg)**	**Liquid (L)**
1. Vacuum pump oil				200				
Chamber pump down				***200***				
2. Molecular sieves	100							
Tritium processing systems	***264***							
3. PPE and wipes	820	600	135	400				
General cleaning	***2,032***	***1,560***	***351***	***1,040***				
4. Pre and HEPA filters	30							
Chamber ventilation	***30***							
5. Hardware from chamber	1,600							
Diagnostics target positioner	***1,600***							
6. Debris shield	1,920 ***4,992***			1,400 ***3,744***				
7. Capacitors, oil filled					3,000 ***3,000***		200 ***200***	
8. General chemicals						500 ***500***		1,800 ***4,100***
Conceptual design total/yr	4,470	600	135	2,000	3,000	500	200	1,800
Enhanced total/yr	***8,918***	***1,560***	***351***	***4,984***	***3,000***	***500***	***200***	**4,100**

[a] Numbers in bold italics refer to waste estimates for the enhanced option.
[b] LTAB: Laser and Target Area Building; OAB: Optics Assembly Building.

Table 2. Estimated Amounts and Types of Radioactive Emissions from NIF

Isotope	Half-Life	Enhanced Option Annual Release (Ci)
Tritium	12 yr	30
N^{13}	10 min	86
N^{16}	7.1 sec	170
S^{37}	5.0 min	1.4
Cl^{40}	1.4 min	1.4
Ar^{41}	1.8 hr	54
C^{14}	5,700 yr	1.5×10^{-3}

The types of radioactive releases associated with the operation of the NIF are detailed in Table 2. The general public living in areas surrounding the LLNL site and workers at LLNL may be exposed to small quantities of radionuclides released and radiation emitted (skyshine) from routine NIF operations. These exposures will stem from the operation of the NIF and not be the result of wastes generated by the NIF. The expected level of exposure from radioactive releases and radiation emissions from routine NIF operations would be well within regulatory limits.

Table 3 summarizes the potential impacts of radiation exposures from the conceptual and enhanced design options of NIF at the preferred site (LLNL). At these levels of exposure, the total impact to the exposed population would be indistinguishable from the average natural background radiation intensity in the Livermore area, which is 300 mrem/yr. Based on current regulatory standards, low-level emissions resulting from the operation of NIF are not considered significant and would not pose a substantial impact to the public or environment.

The health effects of exposures to the NIF chemical wastes generated during normal operations are expected to be at least an order of magnitude less than those estimated for the radiological exposures. As a result, no human health impacts from hazardous chemicals should occur.

Table 3. Radiological Impacts from Normal Operations of the National Ignition Facility at Lawrence Livermore National Laboratory.

Receptor	Conceptual Design Option	Enhanced Design Option
Maximally exposed individual		
Dose (mrem/yr)	0.04	0.1
Percent of natural background	0.01	0.03
30-year fatal cancer probability	6×10^{-7}	2×10^{-6}
Population within 80 km		
Dose (mrem/yr)	0.07	0.2
Percent of natural background	3×10^{-6}	8×10^{-6}
30-year fatal cancers	0	0
Workers on site		
Dose (person rem/yr)		
Non-NIF workers	0.06	0.2
NIF workers	10	10
30-year fatal cancers	0	0

IV. Possible Waste Management during Operation

The proposed sites currently generate waste streams that are similar to those that would be produced by NIF, and there are established procedures for disposal at the Nevada Test Site. (Nevada Test Site accepts wastes from the other sites for disposal). Mixed waste would be sent to an appropriately licensed commercial mixed waste disposal site.

The proposed NIF locations currently have contracts with commercial handlers for disposal of certain mixed waste streams that meet the waste acceptance criteria, and these agreements would include NIF mixed wastes. In addition, the proposed sites currently have well established systems for the disposal of hazardous wastes using on-site consolidation and shipment to commercial facilities. The NIF-generated solid hazardous wastes would be shipped to an approved commercial RCRA treatment, storage, and disposal facility.

In addition to the established procedures for managing the small amounts of NIF waste streams, steps would be taken to reuse or recycle waste material. Furthermore, several actions or technologies have been identified that, if successfully implemented, could significantly reduce or even eliminate certain forms of waste now projected for the NIF. The proposed technology and procedures are briefly described here. These waste reductions assume successful development of various new methodologies that are proposed to minimize the waste streams. These methodologies could reduce the waste stream volumes by a factor of 2 to 10. As such, it represents an optimistic lower limit of waste generation at NIF.

The following discussion identifies some important aspects of the minimization plan. The life span of a molecular sieve (used to trap unburned tritium) could be extended if subatmospheric chamber flushing was employed. The use of the lower flushing pressure would reduce vapor loading. Further reductions might be achieved if chamber tritium (following laser beam target strikes) was pumped directly to liquid helium cryo panels.

Minimizing the scrap hardware removed from the chamber would be accomplished by concentrating on three design areas: utilizing activation-resistant materials, minimizing weight and volume of structures, and discouraging the use of temporary experimental setups.

Implementation of an oil-less vacuum roughing pump system would eliminate 200 liters of liquid mixed waste per year. Such pumps have only recently become available and would be evaluated for use at NIF.

Cleaning the debris shields with CO_2 pellets could remove the anti-reflective (AR) coating and the neutron-activated particulate matter. If successful, this procedure could significantly reduce or even eliminate the production of radioactive NaOH, which is currently listed as liquid mixed waste.

A large fraction of the general chemical waste derived from the optics coating process would involve the AR coating solution. One method for reducing this waste would be to distill the ethanol from the waste solution and reuse it as a cleaner.

In addition to reducing or eliminating the liquid LLW from debris shield cleaning, CO_2 might also further reduce solid LLW. Far fewer wipes would be needed for general decontamination purposes if a "general decontamination CO_2 station" was developed and functional. Other liquid LLW streams, as well as solid-mixed and liquid-mixed streams, might also be reduced with such a system, because CO_2 could possibly remove activated particulates, as well as tritium contamination, and therefore eliminate the need for these solvents.[3]

Capacitors in the Laser and Target Area Building would be the predominant source of hazardous waste. This source could be reduced by purchasing advanced capacitor units with a longer service life. This decision, however, would depend on the development of such capacitors.

V. Waste Management during Decommissioning

The decontamination and decommissioning activities for the NIF would not add a significant burden to operations at the preferred site. This type of activity is common throughout the DOE complex. The major activated/contaminated components would be located in the target area. Two issues dominate the complexity or ease with which structures in the target area would be decommissioned at the end of the NIF operation: 1) the extent of tritium contamination, and 2) the contact dose due to long-lived activation products induced in large structures, such as the target chamber, mirror support frames, and concrete.

Semipermanent facility features that contain materials of concern for neutron activation, such as cable runs and diagnostics, would be maintained during NIF operation in such a way that contact dose rates would allow their reuse in other facilities. This condition would be achieved through a combination of periodic change-out, radioactive decay time, and shielding.

Frequent cleaning of equipment and inner chamber surfaces exposed to tritium and activated debris would significantly reduce (if not virtually eliminate) the need for major end-of-life decontamination. NIF operations would be designed to both minimize the quantity and extent of contamination and to reduce the hazard level of wastes.

NIF decommissioning operations would be designed to maximize, reuse, and recycle all components of the target area. For present estimates, it is conservatively assumed that the tritium decontamination levels required to allow material to be reused in uncontrolled areas or to be scrapped is 10 dpm/cm^2 of removable tritium or 50 dpm/cm^2 of removable and fixed tritium. Material from NIF would be decontaminated to this level before being disposed of or reused in an uncontrolled area. It is assumed that items useful at other DOE facilities that contain or use tritium would be packaged and shipped to those locations rather than undergo extensive decontamination, pending cost/benefit safety analysis.

VI. Summary

The proposed design of NIF has been presented. NIF operations would involve both radioactive and hazardous materials. No cancer fatalities are expected in the region as a result of the operation of NIF. Radiological doses to the general public from NIF operations would be less that one-millionth (0.0001 percent) of the dose to the population from normal background radiation. The preferred site (Lawrence Livermore National Laboratory) has the plans and capacity to handle wastes from NIF operations without facility expansion and resultant cumulative effects on the site or at regional waste management facilities.

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