

# Time and Motion Study for the National Ignition Facility Target Area

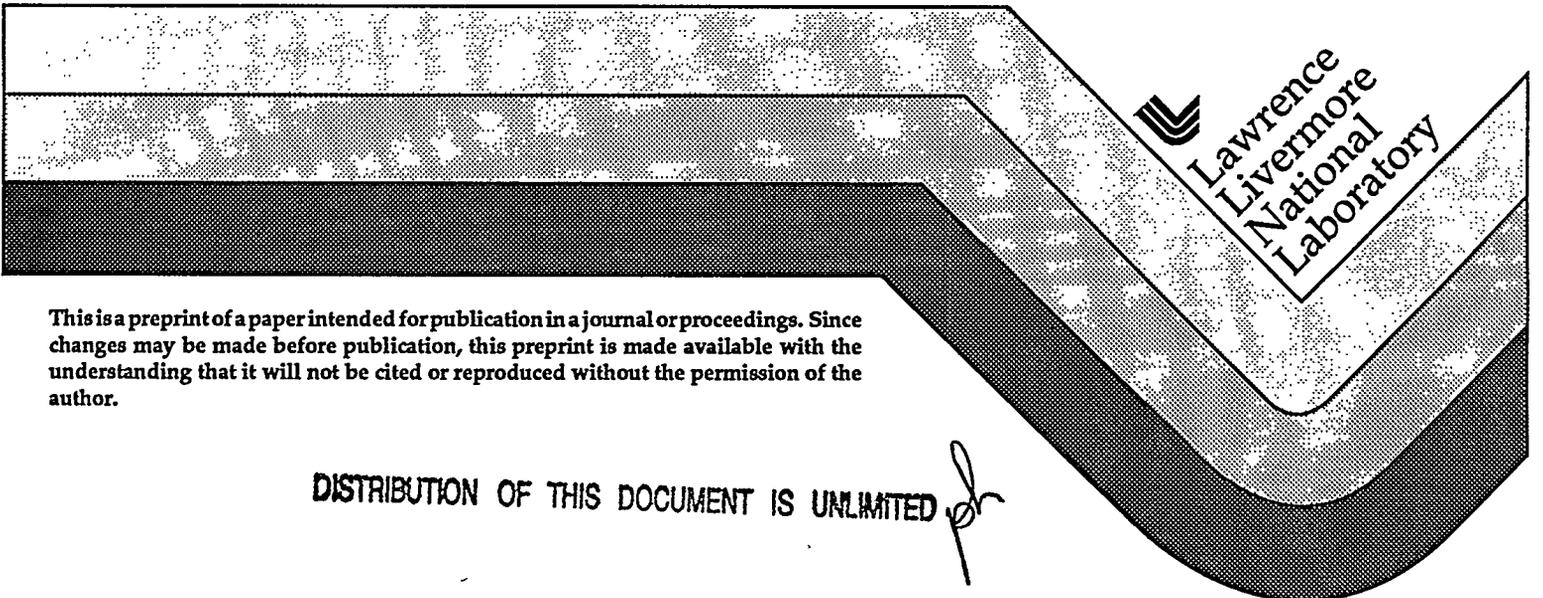
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## TIME AND MOTION STUDY FOR THE NATIONAL IGNITION FACILITY TARGET AREA

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### ABSTRACT

The Department of Energy (DOE) is proposing to construct the National Ignition Facility (NIF) to embark on a program to achieve ignition and modest gain in the laboratory. With annual fusion yields of up to 1200 MJ/year, neutron activation of nearby components is an important issue. Calculations must be performed to ensure that Target Area structures are designed and activities are planned in a way that ensures that such activities can be completed at the required times while meeting all requirements for occupational exposure to radiation. These calculations are referred to as "time-motion" studies. In the present work, key Target Area activities are identified and a detailed time-motion study has been completed for the task of debris shield change-out. Results of a preliminary time-motion study for debris shield change-out were used to influence the design. Subsequent analyses have been completed for several point designs of the NIF Final Optics Assembly (FOA). For each FOA point design, a total annual occupational dose equivalent, in person-Sv, has been estimated. Estimates range from 0.19 person-Sv/year (19 person-rem/year) for a composite FOA with a polyethylene plug to 1.38 person-Sv/year (138 person-rem/year) for the baseline FOA design.

### I. INTRODUCTION

For the first time in the history of inertial confinement fusion (ICF), enough D-T fusion neutrons will be produced to cause significant activation of nearby materials. In the NIF, as many as  $7 \times 10^{18}$  (14 MeV) neutrons will be released in a single experiment. Chapter 10 part 20 of the Code of Federal Regulations (10CFR20) limits occupational radiation dose equivalent to 50 mSv/year (5 rem/year).<sup>1</sup> DOE regulations require that facilities be designed to 1/10 of the 10CFR20 regulations.<sup>2</sup> Thus, occupational radiation dose equivalent in the NIF will be limited to 5 mSv/year (500 mrem/year).

Occupational exposure in the NIF will be dominated by activities that are performed within the Target Area and

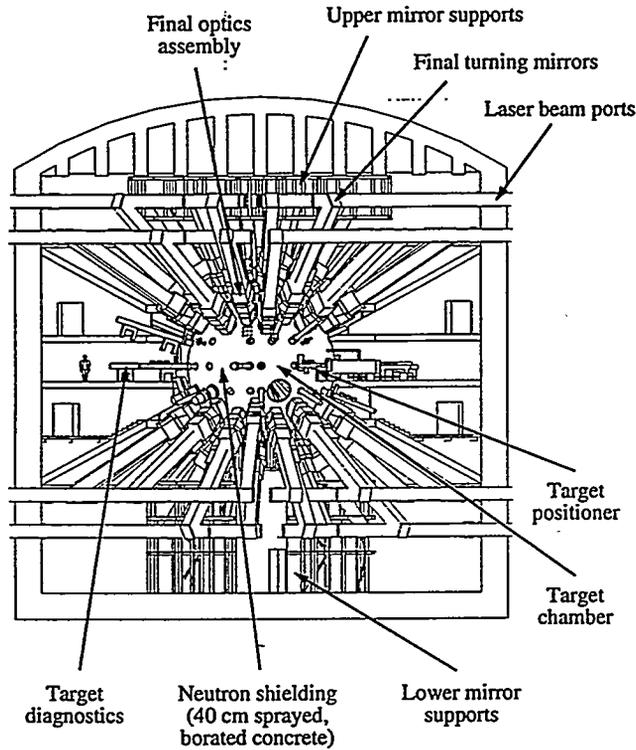
especially near the target chamber. Some tasks that will need to be performed in the vicinity of the NIF target chamber include target characterization, target insertion, diagnostic installation, diagnostic removal, and debris shield change-out. At this time, the level of definition required to allow detailed time-motion analyses to be performed is not available for each task. Sufficient definition is available, however, for a detailed time-motion analysis of the task of debris shield change-out. Results of the time-motion study for debris shield change-out for the baseline FOA design have been incorporated into the design process and several design iterations have resulted. A time-motion study has been performed for each FOA point design.

Figure 1 is an elevation view of the NIF Target Area. The Target Area will be a cylindrical building, 30.5 m in diameter and 32.9 m in height, with 1.8-m-thick concrete walls. In addition to the building structure, the figure shows the target chamber, concrete shielding, target positioner, final turning mirrors, upper and lower mirror supports, target diagnostics, and laser beam penetrations. Forty-eight FOAs will be mounted onto the target chamber.

The target chamber will be 10-cm-thick sphere made of an aluminum alloy. The outside of the chamber will be coated with 40 cm of "shotcrete" -- a sprayable form of concrete. The target chamber will have forty-eight rectangular penetrations, each of which will allow a two-by-two array of laser beams to enter the chamber through one of the FOAs.

During NIF operation, 192 laser beams will deliver a total of 1.8 MJ of 0.35  $\mu\text{m}$  laser light to the center of the 5-m-radius target chamber. An ICF capsule will be ignited and will release up to 20 MJ of fusion energy. As many of 1200 experiments will be conducted per year with up to 335 of them having significant neutron yields. Annual yields as high as 1200 MJ/year are expected.

**Figure 1:** An elevation view of the NIF Target Area shows several key components and systems.



**Figure 2** shows a cut-away view of a single FOA. The figure shows the vacuum barrier, the frequency conversion crystals, the focus lens, and the debris shield. The main function of the debris shield is to protect the remaining optics, which would be expensive to replace.

In high laser-energy (with or without significant fusion yield) experiments, however, the debris shields themselves may be damaged by debris or coated with materials ablated from other surfaces within the target chamber (e.g., vaporized material from the target assembly). Deposition of foreign material onto the surface of a debris shield or destruction of the anti-reflection coatings may decrease total debris shield transmissivity or may lead to laser-induced damage during the next experiment. Thus, it is anticipated that each debris shield may have to be changed-out as often as once per week. The annual radiation dose equivalent that will be received has been calculated for the task of debris shield change-out.

## II. COMPUTATIONAL METHODS

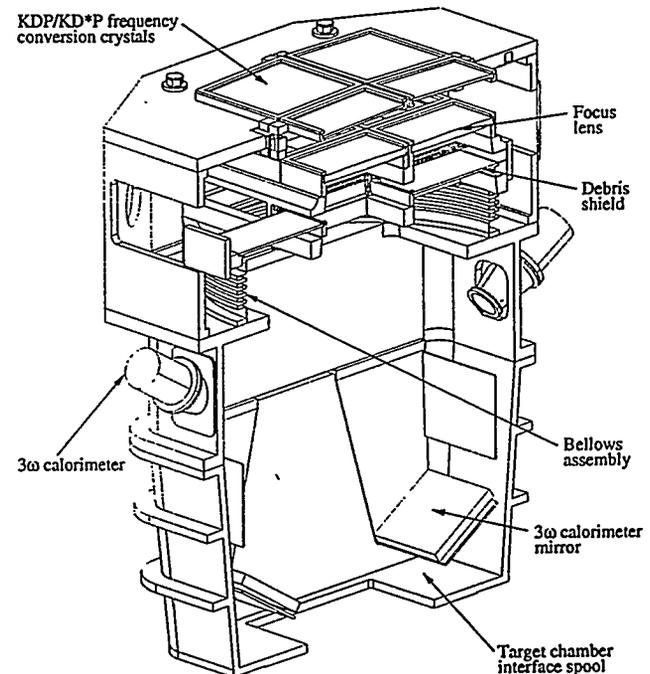
A description of the computational methods that have been used for these analyses must include not only the

system of computer codes and data libraries, but it must also include details of the geometric model that has been used. A general model was developed for the baseline FOA design. This original model was subsequently modified to allow analysis of alternate FOA designs and to consider alternate materials.

### A. Computer Code System

All calculations for these analyses began with a geometric model created for use with the TART95 Monte Carlo transport code and its associated data libraries.<sup>3-5</sup> A three-dimensional transport model was created for a single FOA. Such a complicated model was possible due to use of the TARTCHEK geometry checking code.<sup>3</sup> TART95 calculates the energy-dependent neutron pathlengths in each of 175 energy groups. These pathlengths are converted by the TARTREAD code into energy-dependent fluences, which are used in subsequent neutron activation calculations.<sup>6</sup>

**Figure 2.** A cut-away view of a final optics assembly shows the major optical components as well as the support structures.



Activation calculations were performed with the ACAB radionuclide generation/depletion code using the EAF3.1 neutron cross-section library.<sup>7,8</sup> Once radionuclide inventories were determined for each subcomponent,

photon transport calculations were performed for significantly contributing radionuclides and key subcomponents to determine energy-dependent photon fluences at locations of interest. Photon fluences were converted to doses using conversion factors recommended by the International Commission on Radiological Protection (ICRP) and adopted by the American National Standards Institute (ANSI).<sup>9</sup>

### B. Geometric Model of an FOA

Although an FOA has a shape that is largely rectangular, its shape has been approximated using cylinders of equivalent area. Care has been taken to ensure that the correct fractions of materials are exposed to line-of-sight neutrons (as opposed to being shielded by the target chamber and/or the concrete shielding). The use of cylindrical approximations greatly simplifies the neutron and photon transport models.

The three-dimensional transport model has included other components likely to contribute to the total dose equivalent rate. Such components include the target chamber and the 40 cm of borated concrete shielding. The FOA itself has been subdivided into many subcomponents and sections of subcomponents. These subcomponents include the FOA structure (subdivided into ten pieces), optics support (subdivided into three pieces), bellows and flanges, lead screws, and motors (1 kg of copper and steel assumed). Iterations of the baseline FOA design included several types of interior shielding.

Note that only a single FOA has been modeled -- in reality, a worker that is removing and installing debris shields will be exposed to neighboring FOAs in addition to the one that is being serviced. The time-motion portion of this analysis attempts to correct for this by conservatively assuming a factor of three increase in the dose equivalent rate contributions from the FOA. This factor of three increase is probably a good approximation due to the close proximity of one FOA to another. Some FOAs are so close to one another that a worker would have to stand between two neighboring FOAs in order to replace the debris shields on an FOA immediately in front of him/her. An additional contribution to the total dose equivalent rate would come from the FOA behind the worker.

All dose equivalent rates are reported at a distance of 30 cm from the surface of the uppermost spool of an FOA (the structural section that contains the optics). The 30 cm stand-off is intended to approximate the distance that a worker's body would be away from the surface if his/her hands were being used to replace the debris shields. Since

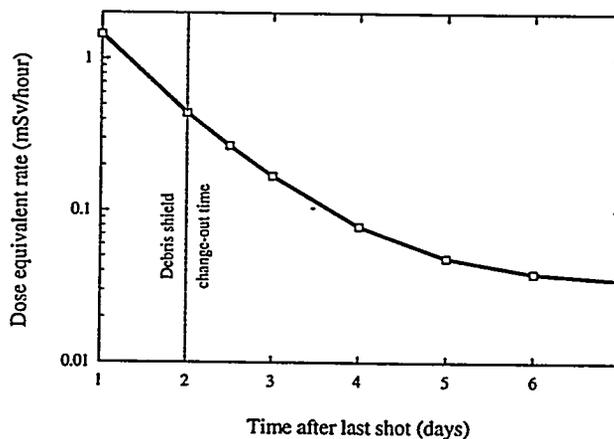
the worker's entire body would not be at that location, the reported whole-body dose equivalent rates are conservative.

## III. RESULTS

### A. Baseline FOA Design

The baseline FOA design includes an aluminum alloy structure that results in the creation of large quantities of <sup>24</sup>Na and high residual dose equivalent rates. Figure 3 shows the total residual dose equivalent rate for a single FOA, the target chamber, and the 40 cm of concrete shielding. The results shown in Figure 3 are for 10 years of Expanded Baseline operation (1200 MJ/year) plus a final, 20 MJ yield. The times are those following the final experiment.

Figure 3. The residual dose equivalent rate from a single FOA, target chamber, and concrete shielding falls to about 0.45 mSv/hour (45 mrem/hour) by 2 days after a 20 MJ yield.



In order to achieve 1200 experiments per year and up to 1200 MJ/year, NIF debris shields will have to be changed-out approximately 2 days after a 20 MJ experiment. At this time, the aluminum alloy FOA structure dominates the residual dose equivalent rate from a single FOA. Table 1 gives a breakdown of the residual dose equivalent rates by subcomponent. Correcting for contributions from neighboring FOAs, a dose equivalent rate of 1.11 mSv/hour at 2 days after a 20 MJ yield is obtained.

It has been estimated that it will take approximately 30 minutes to service a single FOA (replace its four debris shields).<sup>10</sup> Given this estimate, the dose equivalent rate at the time of change-out, and the frequency of change-out that will be required (weekly), a total annual occupational

dose equivalent of 1.38 person-Sv/year (138 person-rem/year) is obtained. In order to meet DOE regulations, this would require a crew size of 276 (each person receives the maximum of 5 mSv/year). Clearly, such a large crew would be undesirable.

**Table 1.** The contribution from the aluminum alloy FOA structure dominates the residual dose equivalent rate at the time of debris shield change-out.

Subcomponent	Dose equivalent rates at 2 days after 20 MJ	
	(mSv/hour)	% of total
Aluminum alloy target chamber	0.093	21
Concrete shielding	0.018	4
FOA structure	0.314	71
Bellows/lead screws	0.018	4
TOTAL	0.442	100
TOTAL for three FOAs	1.105	N/A

### B. Alternate FOA Designs

The results for time-motion study for the baseline FOA design have been incorporated into the design process. Based upon the contributions from the various subcomponents, redesign has occurred. Advanced FOA designs have internal shielding and alternate materials.

The first FOA modification required relocation of the  $3\omega$  calorimeter mirror (see Figure 2). This relocation made space available for up to 40 cm of internal shielding. Although analysis simply assumed that internal shielding would be added, the shape of the target chamber interface spool would probably be modified instead. In either case, the result would be the same — added shielding for the many of the key structural components. Calculations were performed for the addition of 20 cm of concrete shielding inside the target chamber interface spool (calculations were completed before it became clear that as much as 40 cm of shielding would be possible).

Since over seventy percent of the residual dose equivalent rate is due to the FOA structure, a second design iteration considered its replacement with a carbon-composite (C/C) material. Such a material could exceed the strength of an aluminum alloy while having a low residual dose equivalent rate.<sup>11</sup> Calculations were performed after replacing the aluminum alloy with C/C on a one-for-one volume basis.

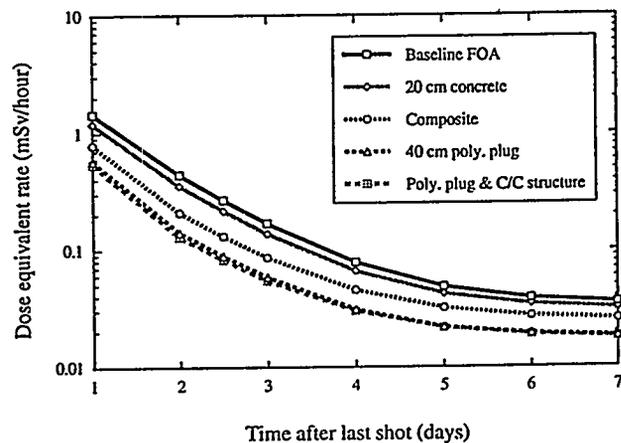
In order to maximize the quantity of shielding for structural components and minimize the activation of the shielding itself, the concept of using a polyethylene insert or "plug" was analyzed. Such a plug would subtend as

much of the FOA penetration as possible — it would fill all but the beamlines and a small gap for beam steering. In actual use, a polyethylene plug would need to be clad to decrease outgassing and eliminate ablation of organics by stray laser light.

The final design iteration considered is a combination of the C/C FOA structure along with the polyethylene plug. The C/C would eliminate dose equivalent rate contributions from the FOA structure, and the polyethylene plug would shield workers from the target chamber decay radiation.

Figure 4 shows the dose equivalent rate, as a function of time after the final experiment, for each of the FOA design concepts. The results in Figure 4 include contributions from a single FOA, the target chamber, and the concrete shielding. Clever redesign of the FOA can reduce residual dose equivalent rates by more than a factor of three.

**Figure 4.** The dose equivalent rate from a single FOA, the target chamber, and the concrete shielding can be reduced by more than a factor of three by the redesign of the FOA.



Once corrections are made for the fact that a worker will be exposed to multiple FOAs, the advantages of the alternate designs become even more pronounced. Table 2 gives the dose equivalent rates, for each design, for a single FOA as well as for three neighboring FOAs. The FOA design utilizing a polyethylene plug and C/C structure is better than the baseline FOA design by nearly a factor of seven. Use of the polyethylene plug and a C/C structure would reduce the total annual occupational dose equivalent to 0.20 person-Sv/year (20 person-rem/year). This would reduce the required debris shield change-out crew size to forty-one.

Table 2. The benefits from the alternate FOA designs become even more pronounced once neighboring FOAs are considered.

FOA design	Dose equivalent rate at 2 days (mSv/hour)	
	Single FOA	Multiple FOAs
Baseline	0.442	1.105
20 cm of concrete shielding	0.356	0.765
C/C structure	0.210	0.232
40 cm poly. plug	0.142	0.242
40 cm poly. plug & C/C structure	0.130	0.164

#### IV. Conclusions

The baseline FOA design would produce high residual dose equivalent rates and would require a large crew size. Several modifications can be made in order to reduce the occupational doses and the crew size. Minor design modifications would allow shielding to be placed inside the FOA structure. Such shielding would be beneficial but might not be sufficient without the use of alternate structural materials as well. Of the FOA designs that have been examined, a C/C structure used in conjunction with a 40-cm-thick polyethylene shielding plug resulted in the lowest residual dose equivalent rates.

The use of a polyethylene plug (or one made of a similar material) has dual advantages. Such a plug shields the FOA structure from 14 MeV neutrons and shields workers from  $\gamma$ -rays from the activated target chamber. The design of the plug may be improved by increasing its thickness or by altering its composition to include some high-Z material that has better  $\gamma$ -ray shielding characteristics relative to the pure material. A polyethylene plug is also potentially attractive as it does not need to be a part of the original FOA design -- it may be added later in the life of the NIF once significant neutron yields are being obtained on a regular basis.

C/C structures are attractive due to their low activation and high strength relative to aluminum alloys. It may not, however, be cost effective to replace all aluminum structures within the FOA with composites. The biggest contributors to the residual dose equivalent rate are the last spool of the FOA and the optics support frames. These two subcomponents are responsible for nearly one-half of the residual dose equivalent rate. Replacement of these subcomponents with a low activation material is probably cost effective and can probably be deferred until necessary.

A recent design iteration has produced an FOA design that would not require bellows.<sup>12</sup> In the baseline FOA

design, bellows were responsible for only about four percent of the residual dose equivalent rate. In the FOA design with the polyethylene plug and C/C structure, however, the bellows are responsible for thirteen percent of the total dose equivalent rate from a single FOA. Once neighboring FOAs are considered, elimination of the bellows reduces the total residual dose equivalent rate by about twenty percent. This would result in a total annual occupational dose equivalent of 0.16 person-Sv/year (16 person-rem/year). The crew size would be reduced to thirty-two.

Other design modifications could potentially aid in the reduction of the debris shield change-out crew size. Any design change that decreases the time required to service an FOA will decrease the required crew size. The crew size scales roughly linearly with the time required to service an FOA. The use of some type of "tool" to assist in the servicing of an FOA could also reduce the required crew size. Such a tool would could increase the worker's distance from an FOA thereby decreasing the dose equivalent rate to the worker. If the tool would be used from a platform suspended by a crane, auxiliary shielding could be used to significantly reduce the doses received by workers.

Finally, the thickness of the concrete shielding could be increased. Increasing the thickness from 40 cm to 60 cm would reduce both target chamber and shielding contributions to the residual dose equivalent rate by as much as fifty percent. An increase in the shield thickness is not desirable, however, as it may pose operational constraints that have not yet been explored.

Future work in the design of the FOAs should concentrate on the cost effective replacement of key subcomponents with low activation materials and the possible use of a shielding plug. Additional investigation should be made into the possible use of auxiliary shielding and the reduction of the time required to service an FOA.

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