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Streamlining NIF Design Engineering Processes

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Streamlining NIF Design Engineering Processes

Steven's Institute of Technology
Homework Assignment
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1.0 Executive Summary

As a new project and facility, the National Ignition Facility (NIF) located a Lawrence Livermore National Laboratory (LLNL), adopted a design standard that incorporated a safety criteria process that all equipment was to be designed with thorough design documentation and a level of safety evaluation that guaranteed tractability and success in the commissioning of this new asset. The documentation is in the form of a Mechanical Engineering Safety Note (MESN) or Engineering Note (EN), which is a complete stand-alone review document of each design, with backup support, detailed analysis, drawings and a full review committee signoff. The design safety review process was given conservative Factors of Safety (FS) and guidance to evaluated design adequacy, leading to robust support structures. The MESN, EN, FS and guidance requirements were primarily driven by a need for confidence in the early success of the facility and the importance of personnel safety concerns. As the NIF facility and operations have matured and design loads, usage and risks have been become well defined and empirically validated, and we now have an opportunity to streamline the design process by not requiring such strict adherence to historical practice, specifically for non-personnel safety related requirements. This streamlining helps support a congressional review that was performed on NIF to determine cost saving opportunities in all areas of operation and development. This proposed NIF design guidance design approach would save design time, schedule and material costs.

The new design approach includes reductions in FS and reduction in formal documentation, and will be implemented through the release of a NIF Design Guidance Document. This document will be used actively by designers, project engineers, structural analysts, safety engineers, scientists and engineering management to prepare, evaluated and approve designs for NIF experiments. This document will also be used as a general supporting reference for all design reviews involving the active stakeholders. The active stakeholders will gain through a faster design cycle time, from requirements, to concept, to final design, using less expensive materials and fewer design iterations. The passive stakeholders will gain through lighter weight equipment, easier to acquire materials, easier to manufacture parts and shorter schedules to get equipment in the hands of the user.

2.0 Mission

2.1 Background For Mission

The National Ignition Facility NIF) is a state-of-the-art experimental facility used for evaluation of extreme states of matter. The foundation of this experimental capability is the world's most energetic laser, which is comprised of 192 lasers housed within the NIF building. The lasers can deliver 2MJ of energy to Target Chamber Center (TCC) that delivers an intense amount of energy to a single small volume. Along with the scientific results of these events are the harsh consequences to the experimental equipment and supporting diagnostic structures, which include Holhraums, support packages, target positioners, diagnostic equipment, and laser optics. Of these, the holhram and support arms are typically quickly vaporized and are transformed into a spherically expanding shell of high-hypersonic gases referred to as Debris Wind. The impulse delivered by this expanding shell of gas is converted to an equivalent pressure time history for application to structural components in analysis, as shown in Figure 1. In cases where not all of this mass is vaporized, the remaining material is referred to as Shrapnel, which is traveling at ballistic speeds, which are of primary concern to the laser final optics and possible creation of secondary projectile through impact to other structures within the chamber.

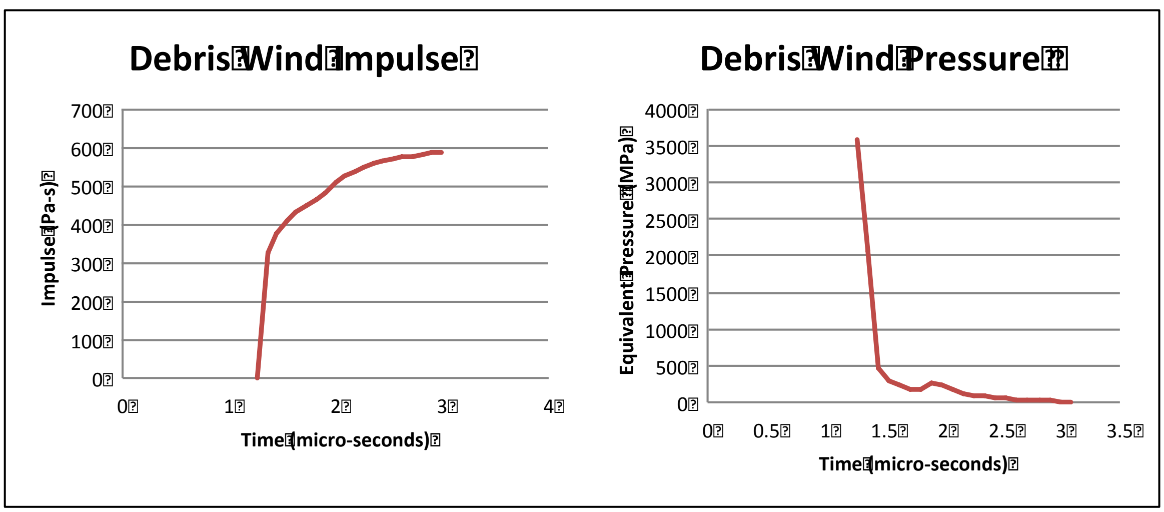
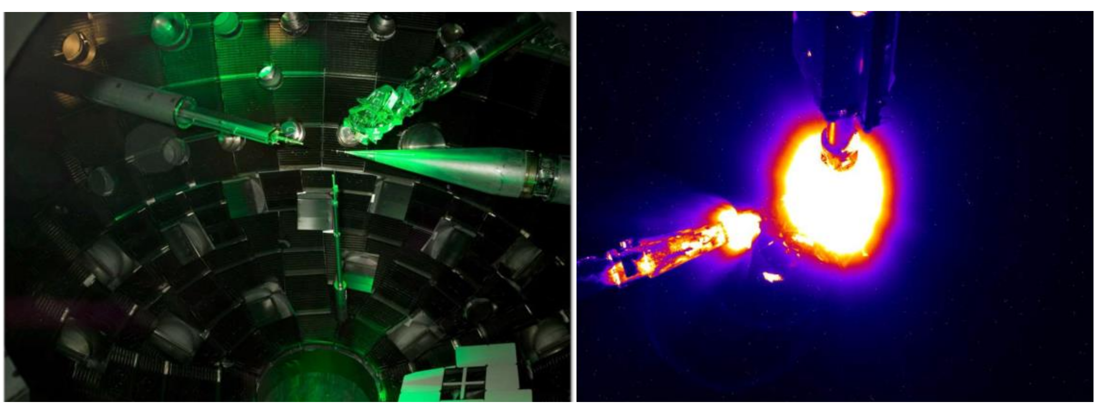


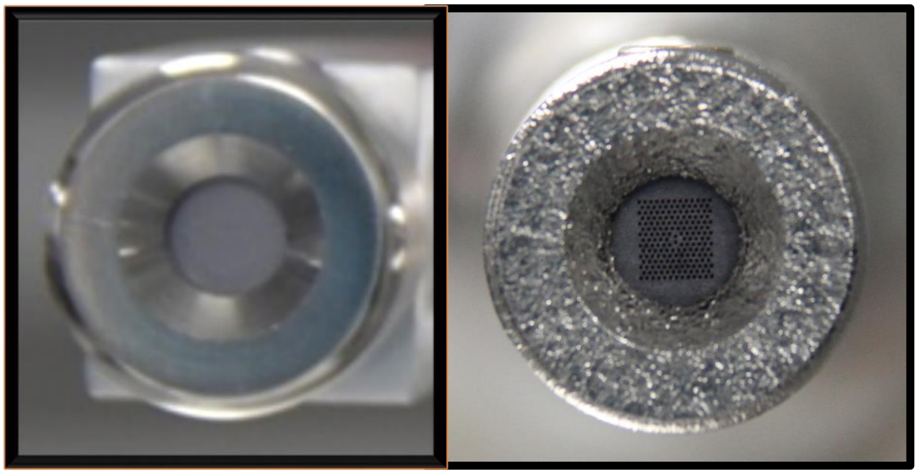
Figure 1 – Typical Debris Wind Profiles

This paper speaks to the target positioning and diagnostic equipment, which can be as close as 50mm from TCC. Of these, the diagnostic equipment is the most delicate, because it is holding and positioning sensitive and expensive electronics. Figure 2 shows a photo of and example of diagnostics deployed within the NIF chamber, and an actual laser shot showing the expanding blast wave which impacts the diagnostics. As diagnostics are positioned closer to TCC, the pinhole nose caps and other components in proximity to the pinhole stack are becoming more likely to be at or above the yield strength of the materials commonly used. Currently, the common 304 Stainless Steel nose caps, which are located at the tip of the diagnostic, see surface yield damage due to the Debris Wind impact and X-ray ablation, as seen in Figure 3. This has been determined to be acceptable through experience and review, based on this components regular inspection for gross deformation and damage after each laser shot. Surface and local yielding is common in components, which directly see Debris Wind and X-ray at distance of 300mm or closer to TCC. The loads generated by the target event are highly dependent on the distance from TCC. For example, at 360mm the Debris Wind load and X-ray energy is $1/50^{th}$ the load than that seen at 100mm. At distances closer than 100mm, even high strength materials will see surface damage. As mentioned, in addition to the spherically expanding shell of gas that causes direct loading on components, there is also an ablative loading generated through the heating of material surfaces, which also adds to the damage seen to exposed surfaces and in generation of added force into the components. This ablative load is out of time phase from the Debris Wind and is typically an order of magnitude lower than the Debris with physical load.



View Of The Inside of the NIF Chamber   Laser Shot and Resulting Blast Wave

Figure 2 – NIF Chamber Center With Diagnostics Deployed



Before Experiment **After Experiment**

Figure 3 - 300 Series Stainless Steel Nose Cap Re-use

Components which are shadowed from Debris Wind and X-ray by the nose cap or other features on the diagnostic are protected from the direct damage from Debris Wind and X-ray loading, however, the resulting shockwave that is transferred from the components directly impacted by target loading onto the secondary structures can be significant enough to make meeting high factors of safety difficult. These design conditions have lead the engineers to situations where they must propose multiple paths forward with varying risk assessments for each path. These paths include increased structure, higher strength materials, and requests for experimental relief and management review of requirements, all of which delay schedule and add cost. In many cases, the stakeholders appear to be pulling in opposite directions, but in fact there is one common goal, to field and conduct a successful experimental campaign.

The need for the experimental diagnostic equipment is driven by the experimental scientists and engineers, but involves a group of stakeholder from many disciplines. These stakeholders have consistently provided their feedback and concerns during the formal design reviews that have been held since the commissioning of the NIF facility. The feedback and concerns have helped drive the motivation for a change to the current design practice. Many of the comments from those involved were with the concern that we are spending too much time reviewing and analyzing designs which are vary similar to designs that have already been fielded. Also, that based on experience with currently fielded NIF designs, we appear to be too conservative in our approach to designing, which causes more effort than would appear is necessary. The stakeholders that are involved with deciding on and implementing a change to the current NIF design practice are shown in Figure 4. These active stakeholders are derived from the current design review process list. It is from these areas from which representatives are required to attend each of the formal design reviews. These formal design reviews are the Conceptual Design Review

(CDR) and Final Design Review (FDR). Those passively affected by this proposed guidance document will be those whom use or implement the use of the designs, such as technicians, facility leads, operation engineers, manufacturing and purchasing. They are considered passive, since although they will interact with the designed equipment, the guidance will not directly affect their contribution to fit or function of the equipment.

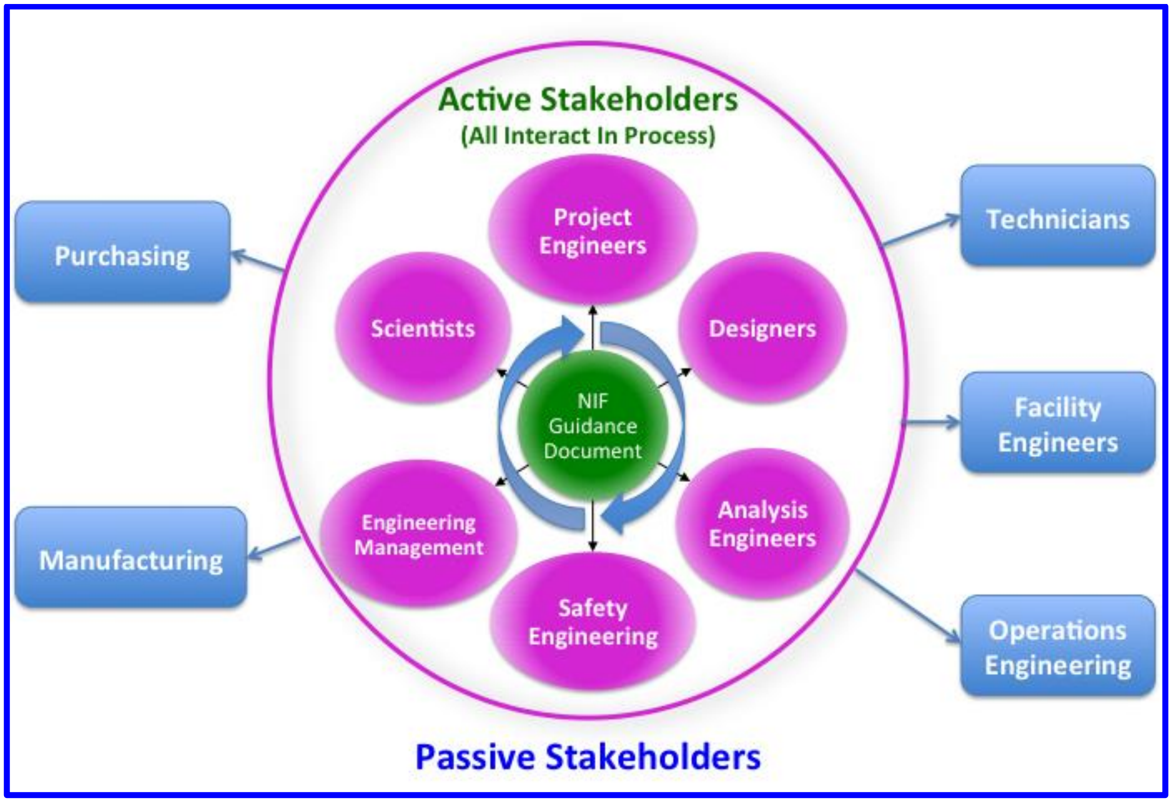


Figure 4 - Stakeholder Diagram

Discussions were held with the key active stakeholders to determine their specific expectations once the NIF guidance document is implemented. Each stakeholder has a very specific needs related to the fielding of new NIF experimental equipment, although they show that they are aware of the needs of the other stakeholders. In the discussions, only the comments directly associated with their specific needs were noted, with the assumption that other stakeholders will cover the needs in each of the other critical areas. The following is a List of Stakeholder and their duties. Appendix B contains a summary of the interview findings based on discussions held with several representatives from each stakeholder area.

2.1.1 Active Stakeholders

Project Engineers: Primary responsible engineer; duties include design coordination, requirements adherence, documentation, cost, schedule and fielding
Designers: Responsible for generating concept drawings, performing layouts and working with the project engineer on requirements and concept features
Analysts: Performs necessary analysis to show compliance to the design requirements
Scientists: Works with Project Engineer to provide experimental requirements, adjust concepts with design limitations, schedule and fielding
Safety Engineer: Responsible for verifying that design does not pose personnel safety risks
Engineering Management: Provides budget, staff, project priority assessment, risk acceptance, and support to new work proposals

2.1.2 Passive Stockholders

Instrument Technicians: Works with and operates designs
Facility Lead: Verify the designs are integrated successfully into the facility
Operations Engineer: Assures designs are available and ready for schedule needs
Manufacturing: Schedules, cost, defines manufacturing processes, build and assembly of designs
Purchasing: Procures sub-contracts, materials, vendor components and parts in support of designs

The inputs from the stakeholders were very diverse, but discrete enough to help define a path toward an acceptable guidance document. The response to changing the restrictive aspects of the current design process was received well and supported by all stakeholders, especially in the areas of reducing time-consuming practices. Based on the information provided by the stakeholders, the key common threads were extracted and used to generate a Mission Statement/Description. The other more stakeholder specific comments would initially be tracked for possible inclusion into the final product when determined to be appropriate and consistent with the primary mission.

2.2 Mission Statement

The mission of this effort is the generation of a NIF Design Guidance Document to update and improve the current design process to provide a more streamlined process that incorporates a more aggressive and risk based evaluation of the NIF inner chamber specific designs. The design guidance document will be written in a way to provide relief over the current design process restrictions, and will reduce many of the process step burdens to the engineers. Additionally, the new design guidance will reduce the design cycle time and overall cost to the fielding of new equipment.

2.2.1 Mission Concept Review

On November 4, 2014, a review of a preliminary outline of the guidance was performed with several active stakeholders, which at that time was referred to as "A Graded Approach To Snout Engineering". Snout Engineering is a slang term used within the diagnostics department to refer to the diagnostic structure, because of a typical diagnostics cone shape. In attendance were Scott Winters(Safety), John Celeste(Lead Engineer), Robin Hibbard(Lead Engineer), Brian Felker(Lead Engineer), Justin Galbraith(Project Engineer), and the presenter Cal Smith(Analysis Engineer). The presentation was a basic "Straw Man" with the initial ideas of how guidance could be provided to quickly access design risks, lower factors of safety and allow engineers to understand rough sizing of bolts and plates based on the distance from the target event. This preliminary outline is in Appendix A, as a reference only, since it was abandoned later in favor of a more comprehensive document. The stakeholders liked the ideas of providing simple and clear guidance based on proximity to the critical design loads and the idea of providing a distance at which the target loads no longer dominate the design.

As a more detailed outline was initiated, it was clear that the original Stakeholder chart in Figure 4 didn't represent the method that the guidance document would be implemented. The current design process has a "Project Engineer Centric" view of how new designs must be managed. So as to not change the organizational structure, a new view of the active stakeholder chart and interaction was generated to show how this new design guidance document would be implemented, as shown in Figure 5. In this new revised stakeholder figure, the Project Engineer controls the use of the NIF Design Guidance Document, and disseminates the guidance in order to manage its usage. All stakeholders then work through the Project Engineer to assure continuity. This may drive the need for several stakeholder group meetings, but will still allow substantial gain in the reduction of redesign iterations. The current process has many stakeholder group meetings to resolve open issues, and it is anticipated that this new design guidance will likely reduce the need for the number of these meetings needed. This is because the guidance will be clear and aggressive in its applications, allowing early determination of critical issues.

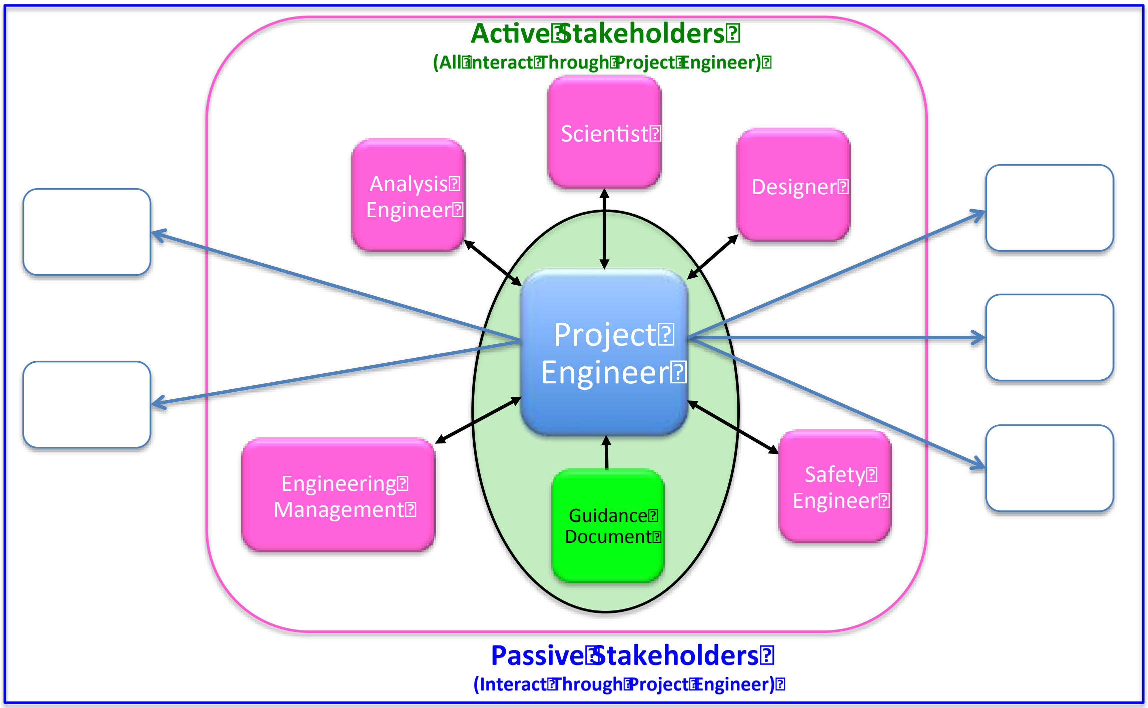


Figure 5 – Revised Stakeholder Diagram

Although the initial format of the guidance outline was well received, when beginning the work on the details of how to define the areas of interest and levels of engineering evaluation, the necessary format did not fit into the framework of the original over simplified outline. This is because there became too many situations where the guidance couldn't be written in such a generic form, and it was often failing the "What If?" question for various usage scenarios and actually was not as aggressive as stakeholders later appeared to expect. Maintaining the general ideas put forward in the initial guidance outline, a more detailed evaluation of loads, material, geometry, analysis, past designs and sensitivity studies provided a more robust and aggressive guidance solution. The result will be a guidance that aggressively pushes the limits without passing them.

3.0 Detailing the Guidance Outline

3.1 History

Factors of safety are a common method of determining how close to failure a component is, based on its loading and the material it is manufactured from. For diagnostic equipment near TCC, a factor of safety of 3.0 or higher is difficult for common materials such as welded and un-welded aluminums and annealed stainless steels. In the past, using high strength materials and increasing structural cross-sections have compensated for this. Referring back to the stakeholder interviews, it was clear that management was willing to accept risk if they were given enough background on what was driving the risk assessment.

As we have gained higher confidence in our NIF target Debris Wind and X-ray load derivations and in our structural analysis techniques, the uncertainty that may have once existed has been reduced. Based on this wealth of information, it is recommended that we may now allow lower factors of safety for target shock induced loading conditions. This includes being even as aggressive as allowing yield damage of replaceable parts. This is true for directly loaded components, as well as for secondary structures, which support the primary loaded structures, which directly see the target loading or that have a direct line of sight to TCC.

Currently there is a practice of attempting to maintain a factor of safety of 3.0 or greater for all structural diagnostic components, until it is determined that it can not be achieved. This NIF engineering document proposes a graduated factor of safety or load environment scheme, which will allow local and surface yielding for components near TCC and with a line-of-sight to TCC and provide rules as distance from TCC is increased. Components shadowed from a direct line-of-sight to TCC, but with contact to components with direct line-of-sight to TCC would be allowed to approach but not exceed yield, with a minimum factor of safety to yield of as low as 1.5.

Consistent with the mission of this effort, the NIF Design Guidance document will serve its purpose of streamlining the design process to reduce weight, schedule and cost impacts that have been growing due to legacy restrictions. The guidance document will provide clear direction for determining non-personnel safety related structural adequacy, through a combination of historical based sizing and an aggressive approach to analytical Factors Of Safety (FS) based on risk, requirements, location in the chamber and extent of usage. Personnel safety is associated with structures that are handled or can directly contact support personnel. Personnel safety related structural equipment would remain at the currently level of 3.0, which is based on LLNL Design Safety Standards (DSS).

Current direction in the LLNL DSS for non-personnel related structure allows for designs to request relief to lower the required FS after several iterations on design solutions have not achieved LLNL DSS standards, or cost have become excessive. This is done on a case-by-case basis that requires management review, which historically is granted in favor of scientific needs over possible equipment damage. As the NIF experiments become more technically demanding, these design challenges and reviews are becoming more common and costly. By creating a streamlined NIF structural design process and FS guidance document, there will be specific instruction for how to assure structural integrity in a less restrictive and knowledge based manner, without requiring management reviews. The management review will effectively be integrated into this document, using the criteria that are generally used to accept aggressive designs and experimental needs.

The current design assumptions and FS have driven NIF designs to become heavier in weight and requiring more expensive and difficult to machine high strength materials. This trend will be reversed by the new guidance. Further, as the design guidance is implemented, there is an expectation for there to be an improved design cycle time as the design concept to final design will be achieved with as-few-as 1 design iteration to meet the new more detailed and aggressive criteria. It is also expected that the purchase of more common raw stock materials, manufacturing times and final equipment delivery will all lead to lower labor cost and faster fielding schedule times. The components and structures most impacted by this guidance will be those operating within the NIF target chamber, as they are the most expensive and highly loaded. It also allows the guidance to be related only equipment survivability risk to the NIF experimental equipment and chamber and not that of a personnel safety risks.

3.2 Moving Forward

The primary and expectations of the guidance document will be that it provides relief over the current design process, while providing little process burden to the engineers involved. These two expectations are sacred in that if these are not met, then the purpose of the document loses its significance. Some lesser expectations are that the guidance will be over-riding of current practice, self contained, easy to use, doesn't disrupt current organizational roles, covers most commonly seen challenges and does not generate high risk applications. These expectations, the planned objectives and planned measurable attributes are covered in Table 1. This table provides a baseline and focus to the effort of generating a comprehensive and practical document that will become a standard for technical excellence in NIF design.

STAKEHOLDER EXPECTIONS/GOALS FOR MISSON DISCRIPTION		
EXPECTION/GOALS	**OBJECTIVES**	**MEASURABLE ATTRIBUTE**
Provides relief over the current design process	Lower factor of safety required	Record number of times that legacy factors are still used
	Reduce need for formal Documentation	Record number of formal documents released for new designs
Is of little process burden to the engineers	Creates fewer steps in the current process	Record number of design iterations required to reach final design
	Reduces the number of meetings to be held between stakeholders	Record number of group meeting held
Reduction in Design Cycle time	Designs are fielded sooner than pervious designs of similair complexity	Track design start and fielding dates
Material Cost Savings	Common low cost materials are use more often	Track number of special material orders associated with strutural strength requests
Manufacturing Cost Savings	Manufacturing schedules are relaxed with few Red-Lines	Record manufacturing lead times and drawing change requests
Is over-riding of current practice	No conflicting guidance preceived	Track questions on guidance objective
Is self contained	Few questions need to be answered to implement guidance	Record amount of time engineer uses to research guidance to be self assured
Is easy to use	No complaints on the meaning of guidance	Track number of complaints
Doesn't disrupt current general practice	Doesn't change organization or personell roles	Track the number of people that are displaced due to guidance
Covers most commonly seen challenges	Fewer requests for management review	Record number of time management is requested to make a decision on guidance direction
Does not generate high risk applications	Guidance does not allow high risk applications that clearly would not be approved by management	Track failure in the field

Table 1 – Stakeholder Expectations

The stakeholder expectations were compared against the other most likely options. The other options are considered, because they are expected to have little functional change over the current organization and practices. These options follow a trend of an evolutionary approach to change. A Kepner-Tregoe Technique was use to verify that the proposed solution to stakeholder expectations had the best possibility of success over other options. Table 2 indicates that a NIF Design Guidance Document would best serve the stakeholders expectations.

Decision Statement										
Evaluation Criteria		**NIF Design Guidnace Document**			**Provide A Dedicated Reviewer**			**Add Options To Current Process**		
Musts (Go/No-Go)										
Provide relief to existing design process		Go			Go			Go		
Is of little burden to the engineers		Go			Go			Go		
		Score			Score			Score		
Wants	Weight	Comments			Comments	Row	R/W	Comments	Row	R/W
	(W)		Rating (R)	(R)x(W)						
Reduction in design cycle time	10	Provides early selection criteria	0.8	8	Provides second opinion on design decisions	0.2	1.6	Simplification to current practices steps	0.4	0.64
Material Cost Savings	6	Lowers FS Guidance	0.9	5.4	May allow reduction in FS	0.5	2.7	Little change expected	0.4	1.08
Manufacturing cost savings	6	Provides path to easier machined materials	0.7	4.2		0.7	2.94	Little change expected	0.4	1.176
If over-riding of current design processes	4		0.5	2		0.2	0.4		0.2	0.08
Self Contained	8		0.8	6.4		0.1	0.64		0.1	0.064
Easy to use	8		0.7	5.6		0.6	3.36		0.3	1.008
Doesn't disrupt current design practice	8		0.7	5.6		0.8	4.48		0.9	4.032
Covers commonly seen challenges	10		0.9	9		0.6	5.4		0.7	3.78
Doesn't generate high risk applications	10		0.7	7		0.6	4.2		0.5	2.1
Maximum Score (80):										
Total Score:				53.2			25.72			13.96

Table 2 – Decision Criteria Statement

3.3 Plan For Implementation

Once the NIF Design Guidance Document is available to the NIF engineering staff, a short training coarse will be provided to briefly cover how the document meets the needs of NIF as we move forward. The concept of the NIF Design Guidance usage would be to follow the general design flow, where the guidance document resides within each of the process steps as shown in Figure 6.

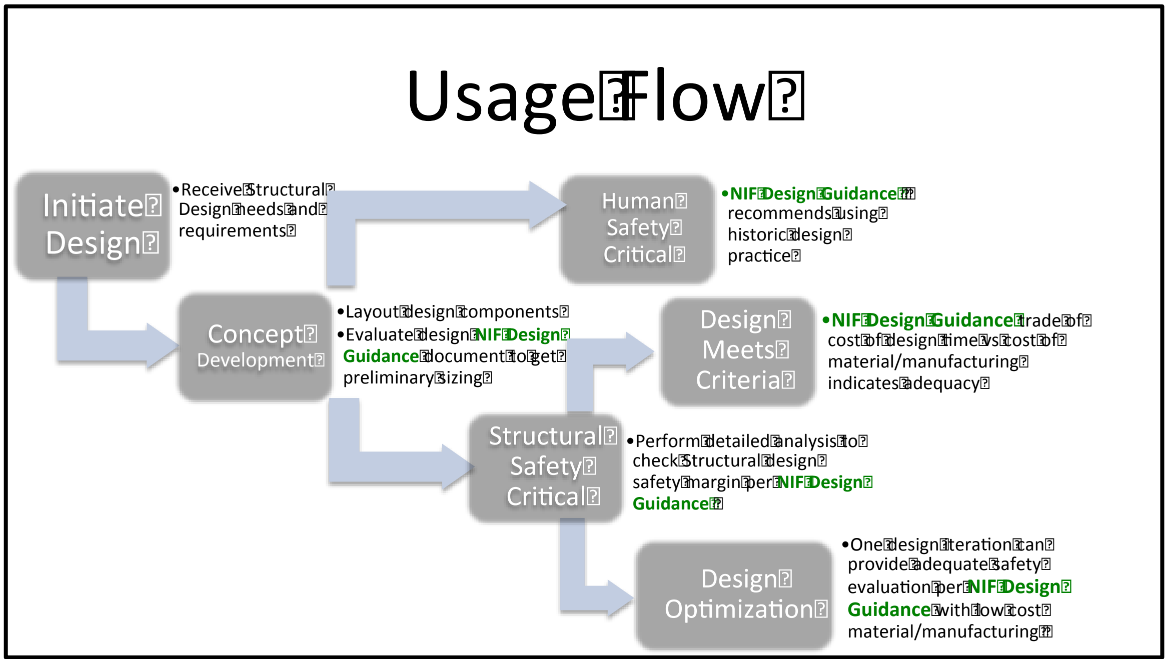


Figure 6 – Concept Of Operation Utilizing The NIF Design Guidance

Although figure 6 shows how the design guidance is embedded into the design process, it does not clearly show a view of its application and impact. In this flow, the guidance appears, as another step in the design process that engineers will need worry about. To clarify the positive impact of this change, it seemed a high level cartoon of the vision that is held by the stakeholders, best shows the usage expectation. In this view, shown in Figure 7, the guidance document is a tool that the engineer feeds ideas into and the guidance document sorts those ideas into tangible bins that can be used to make quick and meaningful evaluations on the design and path forward. The NIF Design Guidance Document is shown as a computing machine that takes input in the form of requirements, concepts and designs and breaks them down into risk categories.

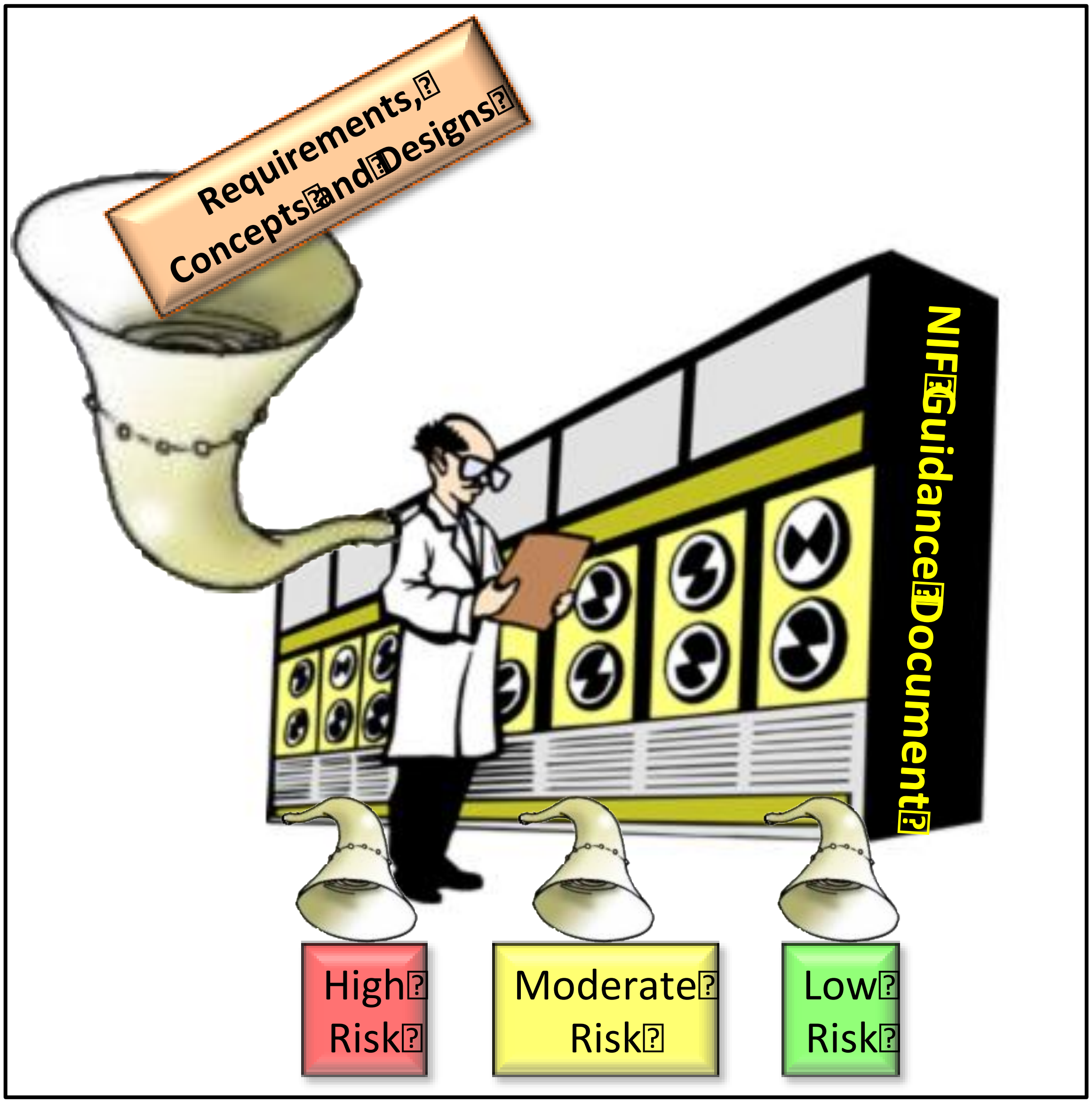


Figure 7 – High Level View Of the Expectation For The NIF Design Guidance

This idea of defining level of risk in the application of new NIF designs is key to this document, and has become more commonplace as the scientific experimentation becomes more challenging to both science and engineering. These levels of risk will be given specific definitions that will provide information on areas like reliability, component life, expected damage, and reuse potential. In this scheme, high risk does not necessarily mean unacceptable, but rather that the component may be consumable, or allowed to be damaged and replaced before the next experiment. This concept of utilizing the NIF Design Guidance to bin components into risk level allows Moderate and Low risk components to pass though the process faster, because the decision matrix for each bin will provide a basis for acceptance based on analysis, historical acceptance and risk to high value assets. High-risk components will contain sub-categories that follow a logic-based matrix to determine acceptance, controls, design change potential, and mitigating steps.

4.0 Plan For Documentation

Based on this overview, primarily driven by expectation of the active stakeholders, a V-Model for the creation of the NIF guidance document was created as shown in Figure 8.

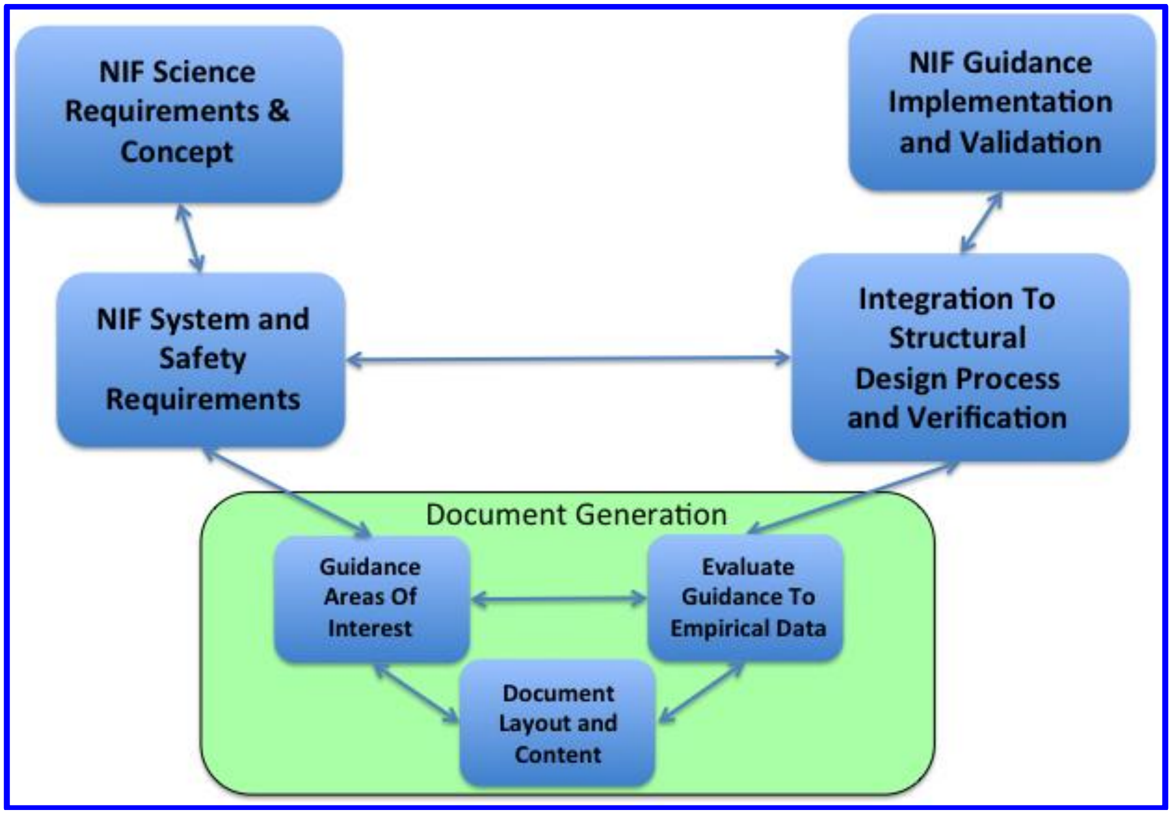


Figure 8 - V-Model Of Guidance Plan

This V-Model will begin with the current NIF processes in mind, and then take a close look at the system and safety/design approach, with a close tie as to how the design implementation will proceed, once the guidance is developed. The specific "Document Generation" box is the most complex area, because it must use empirical, analytical, engineering practice and engineering management to achieve its goal as a self-contained design guidance source. It is not expected that interactions of guidance criteria and determination will iterate out of this box until a logical justification matrix exists for each of the critical design areas. At this point the document will be release for review to the stakeholders to determine if integration of the new guidance process is in line with expectations. After review, the comments will be checked against overall expectations, NIF system and safety requirements and allowed to pass into the Document Generation cycle again.

There will be an effort to maintain this Model, however, pieces of the guidance have already been pulled from the Document Generation cycle, because of critical needs in the NIF experimental schedule.

4.0.1 Recent Unscheduled Applications Of Preliminary Guidance

Several designs in the last month have reaffirmed the idea that acceptance of some clear limitations of the current process will allow the new guidance to be more aggressive against the material allowable, as long as clear statements as to the risk assessment and the level of risk are provided with respect to the proposed usage of the component and its location with respect the experimental target event.

The first design needing this preliminary guidance was a new Solid Rad/Chem diagnostic design. The design had been through the design process, but when parts were scheduled for manufacturing, the need for high strength steels were causing extensive schedule slip. Analysis that had been performed showed that stresses were high, yet still below the strength of many common steels. By choosing highly ductile lower strength steel, the risk of ultimate failure was determined to be low. The factor of safety to yield was accepted at 1.5, which effective means there should be no damage to the part if all the assumptions remained valid. In conclusion, the design that was becoming a challenge due to high strength material needs was determined to be of Low risk to the NIF system using lower strength materials. The design is in the manufacturing process now.

The second design needing this preliminary guidance was the DIXI PPD, which was an existing design, but was to be used on a higher energy laser shot. This results of this experiment were important to the scientific community and was to be used with 3 days. A review of the supporting analysis and materials used, it was determined that the weakest component in the support structure would be at the yield strength of the material. Again, the evaluation would indicate that no damage is expected, but there is a possibility of damage. The material again was a highly ductile material, which for this dynamic loading condition means there is little risk of ultimate failure, only bending of parts. This risk assessment was that this was a Moderate risk. Based on the scientific need and its rating as a Moderate risk, the design was allowed to be used in the upcoming shot. The shot was performed and the diagnostic performed well with no damage.

4.1 Technical Support For Guidance

4.1.1 Empirical Support

Empirical data has been reviewed as lessons learned, but without a plan to change the practices or processes. With this effort, the goal is to improve the design process and meet as many of the Stakeholder expectations as possible. To this end a more detailed evaluation of lessons learned and test observation has started. The Debris Wind load generated by the vaporized target has recently gone through a detailed statistical evaluation, based on empirical observations of component surface damage, to adjust the predicted loads to be used for new designs. Nathan Masters', the lead of the NIF Debris and Shrapnel Group in NIF, generated a report titled "Re-assessment of NIF Debris Wind Loads" dated March 2014, which has allowed for reduction in the Debris Wind loads for equatorial located components. Polar located components were confirmed to be at the level used previously. Currently, structures internal to the NIF chamber reside at either the polar position (vertical) or at the equatorial position (waist) of the chamber. This is because of the inherent characteristics in the experimental data, where the information of interest is primarily available at these locations and additionally because the laser ports for the 192 lasers coming into the chamber are located in the majority of the other areas of the chamber walls. The equatorial Debris Wind load levels have dropped by a factor of 2 over previous values, and of those seen at the Polar location. The reason for this is complex, but can be related to the orientation of the targets (Holhraums). This, on its own, provides a great opportunity for a more aggressive design approach for equatorially mounted equipment. In addition, a more detailed physical review of components and analytical predictions after experimental test has begun. Similar to photographs like that shown in Figure 1, pre and post-shot photos and measurements have started to be reviewed and compared to analytical predictions of expected post-shot conditions. This, in combination with loosely verified anecdotal evidence from diagnostic alignment data, material depositions, post-shot fastener torques and component re-use before replacement, has provided reasonable confidence in past engineering decisions on Moderate to High risk applications. Several examples show how the empirical data will be used to support the NIF Design Guidance Document.

The first example is off a pinhole plate, which sits in the nose cap near TCC. The pinhole functions much like an old fashion camera lens system that projects an image onto an image plate set behind it. In the NIF the image plates can be set back far enough to get magnifications as high as 15X, and can be projected on to either image plates or digital cameras. These pinhole plates in NIF are composed of an array of holes in various patterns in the center of a uniform plate. These plates can see direct Debris Wind loading leading to permanent damage, but are usually sandwiched between two collimator plates, which add some structural support.

Figure 9 shows before and after photos of a pinhole plate than was not able to have collimator plates used for support. The upper picture shows a flat pinhole plate and the small pinhole array pattern at the center of the plate. The lower picture shows scorch marks from the target plasma and the yielded cupped section in the center. This Moderate shot configuration was approved, because it has been shown that the Tantalum material is highly ductile, even at high strain rates, and analytical simulations show that we a below 50% of the allowable maximum elongation. The biggest unknown is the effect of the pinholes on stress concentration. Experience has shown that maintaining a distance between pinholes that is equal to or greater than 4:1 will not cause intra-hole fracture. Lessons learned from the experience will be added to the guidance document.

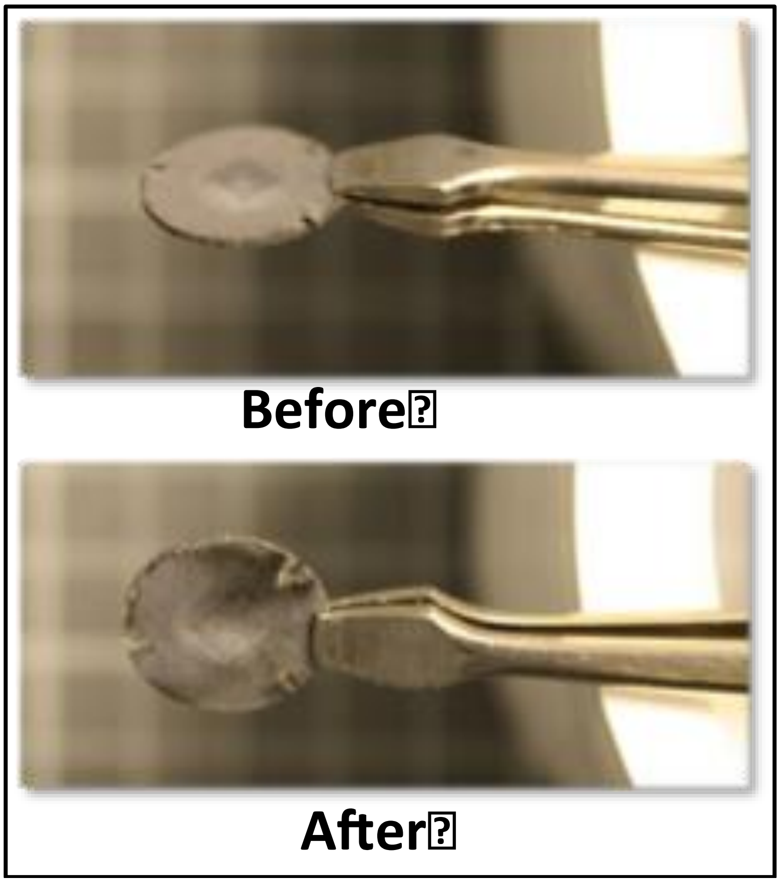


Figure 9 – Moderate Risk Accepted Component

The second example shown in Figure 10, illustrates a commonly disregarded loading condition in the highly loaded structures. Although the picture would initially been seen as an example of failure, this test was actually a success. In this test, the target was in direct contact to a metallic support structure designed to capture debris from the target. The damage at the tip was predicted and shown not to produce critical secondary debris hazards. The primary purpose of showing this photo example is not to show the damaged section, but the motion of the cap with respect to the base support. Analysis had predicted that there would be substantial spring-back of the front cone assembly that would need to be carried by the bolted interface. Rather than attaching the cone with axial bolts, as was in the original concept, the bolts were positioned on the sides with slotted holes. Axial bolts would have had direct loading of the spring-back force, and generated a High risk of failure. By positioning the bolts to the side and allowing the part of have small motion during the spring-back event, the load was attenuated enough that the bolts could safely carry the applied load, and the design could be considered a Moderate risk. This motion can be seen as the residual gap between the two parts. It has been shown that although the very high compressive load must be supported, it is as important to consider the secondary effects of these high loading events. Two lessons learned in this test are that the very high compressive stresses are best carried through direct contact of two components in the direct load path, and that compliance in the spring-back direction can attenuate loads to level that can be carried by the desire small size bolts.

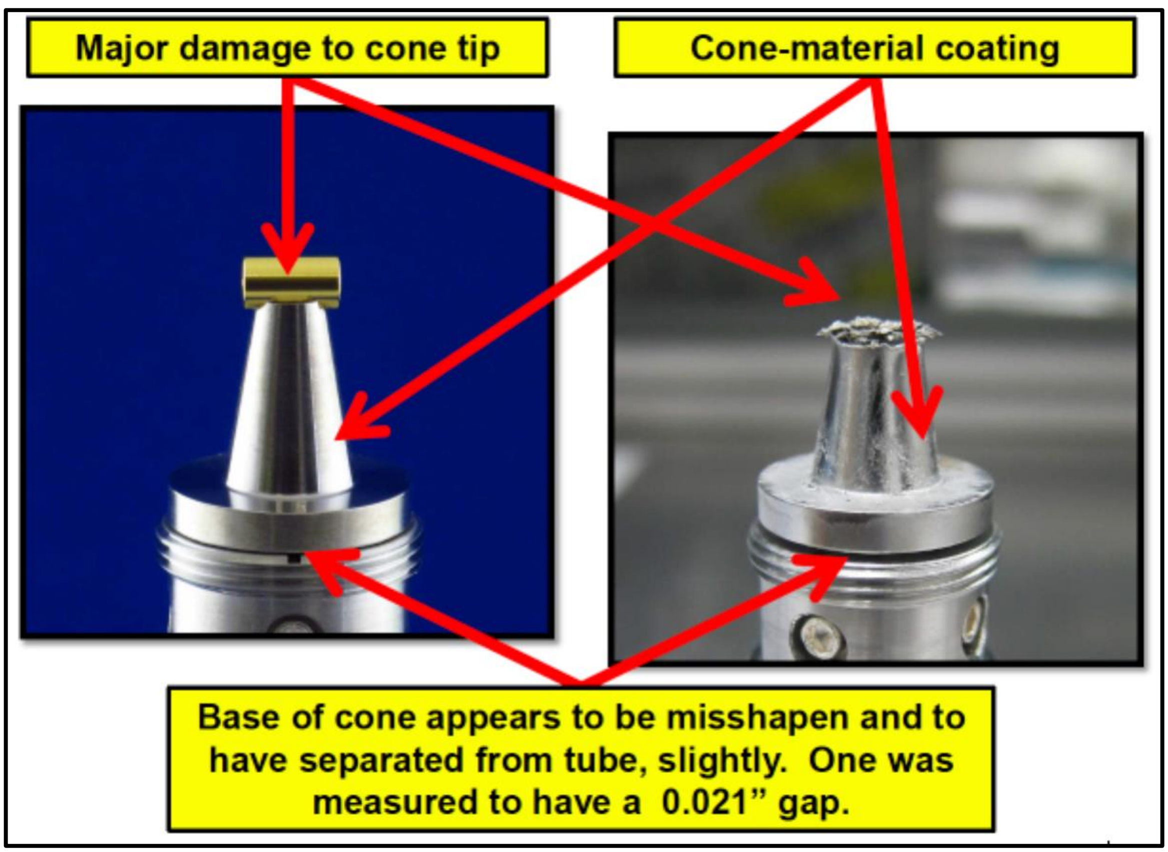


Figure 10 – Moderate Risk Accepted Component

The next design provides an example of how we can use Moderate risk to our advantage for cost savings. In Figure 11, a Polycarbonate window was placed at the aperture of a diagnostic to carry the damaging Debris Wind, without damaging the pinhole plate directly behind it. By sizing the Polycarbonate thickness to yield and absorb the Debris Wind impulse, the components were completely protected from loading. This inexpensive Polycarbonate window can then be easily removed and replaced for the diagnostic to be used for a second laser shot. The experiment was run and the results, also shown in the figure, indicate that the analytical predictions matched very well. This idea of allowing bending without breaking has wide-ranging potential for diagnostic protection, faster turn around of experimental structures and substantial cost savings. This solution cannot be indiscriminately used, because the Polycarbonate will generate some experimental data filtering that is not acceptable in some cases. This is a newly developed concept that will have detailed guidance associated with it, including several layers of risk assessment.

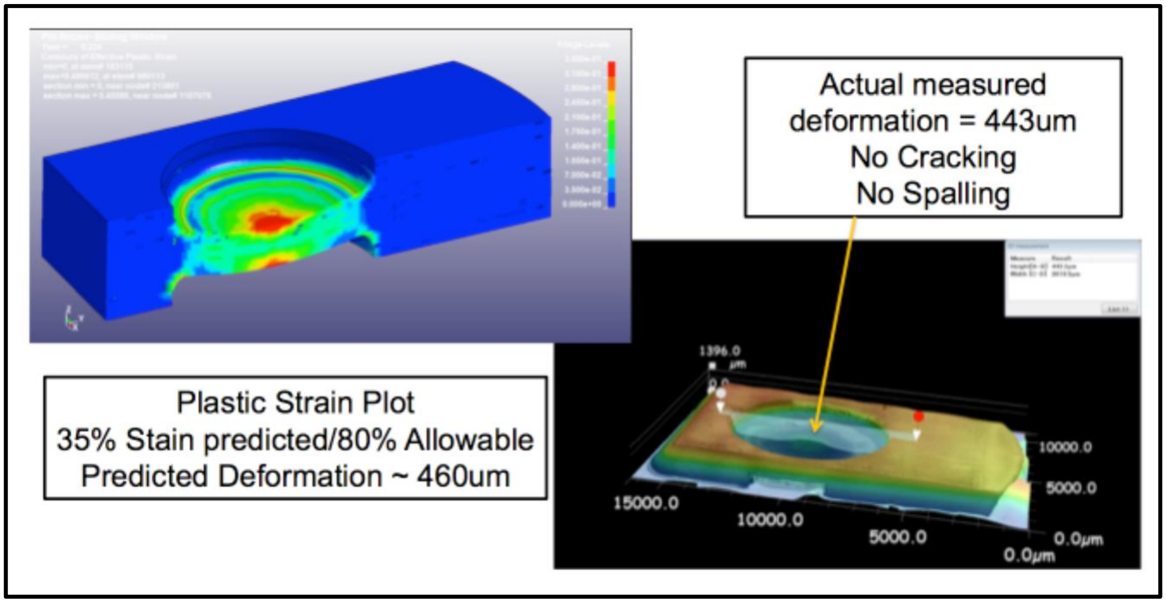


Figure 11 – Moderate Risk Accepted Component

The final example is that of what is referred to as a High-risk application. Figure 12 shows a catastrophic failure of a pinhole plate. This failure was shown analytically possible, but not fully anticipated. It was rated as having a High-risk of damage, because this was the thinnest pinhole fielded to date and the effects of the pinhole stress concentration had not been pushed this far in the past. To protect the sensitive cameras behind the pinhole, an analytical study was performed to size a Polycarbonate catcher to mitigate any transmission of secondary fragments. The Polycarbonate was spaced back from the pinhole so that it would not be contacted if failure did not occur. As discussed earlier, the pinholes role in stress concentration and crack initiation is unknown, but here we have gained a wealth of information. We see that the Tantalum pinhole plate did not fail away from the pinholes, again due to its high ductility, however crack initiation did occur at the pinhole array. The pinhole does have fracture along the pinhole array edge, but does not appear to have failed to the point that a complete separation of secondary fragments was generated. The backings Polycarbonate shows burn marks, but does not show any cracking or yielding. This experience gives even greater confidence in our understanding of the loads, materials and analytical capabilities. This may have pushed guidance to the limits, but will be key in future assessments and guidance.

Figure 12 – High Risk Accepted Component

The empirical data assessment, once completed will provide significant justification of the NIF guidance criteria.

4.1.2 Material And Geometry Support

In highly dynamic events, structural material and geometry are of highest importance in determining the response of the structure and the difference between pass and failure. This has been an area of research for years, and will continue to be. Using the wealth of publish data, LLNL data, NIF data and analytical results, these factors can be captured with very good precision and used to provide critical engineering information.

Aluminums are commonly used in NIF for the secondary support structures for the components not directly impacted with the dynamic loads, as long as they are sufficiently shadowed from directly line of sight to TCC. The general guidance for keeping aluminums shadowed is due to its relatively low melting point, making highly susceptible to X-ray ablation damage. This choice of material has often been made in an attempt to reduce mass, its characteristic of not easily being activated by radiation, reduction of cost and ease of manufacturing. Steels are used in areas of high X-ray level and where high ductility and strength are needed. The use of steel is limited due to its mass and activation characteristics. Material activation is the ability of the material to become radioactive after exposure to the highly radioactive events occurring within the NIF chamber. This material activation generates handling cost for components to be disposed of or reused. Currently the NIF chamber has not achieved neutron yields for this to become a major concern, but future breakthroughs in atomic fusion could make this a critical criterion. Since there is a desire for components to be reused as much as possible with little required inspection, a factor of safety on yield that would sufficiently prevent the possibility of permanent structural degradation is of great importance. A factor of safety of 1.5 on steels typically will provide infinite life for fatigue loading and because of its ductility will have high factors to ultimate failure. In highly dynamic impact events, the time it takes for the material and structure to respond will dictate how much plastic strain is achieved. Because plastically straining of a material takes time, it is often seen that the load has been attenuated long before significant plastic strain is achieved. For aluminums, a factor of safety of 2.0 will typically provide approximately 10^6 cycles (Ref. Figure 13), which can be referred to as a quasi-endurance limit for aluminums in non-high cycle applications such as NIF related usage. Also, because aluminums do not have the same ductility available in many steels, this higher factor compensates for the lower strain to failure in this material. This same logic can be used for other materials commonly used in NIF experiments such as Tantalum and Polycarbonate, which are highly ductile, and Tungsten and Fused Silica which are much more brittle.

The use of FS at the level will be consistent with those used in the Moderate Risk designs reviewed and approved by management in the past. The definition of when a material will be considered ductile or brittle will be defined such that most common material used in NIF will clearly fall on one side or the other. The material that will reside closest to the threshold will likely be Aluminums, which NIF would like to continue treating as a brittle material, not only because of its low static ductility, but also because of its sensitivity to strain rates. By choosing of threshold value 15% maximum elongation for brittle materials, the intension of these new factors of safety will be satisfied. Other criteria in the guidance document, besides factor of Safety, may limit the usage of various materials. For example, when a component of High or Moderate risk is identified, where plastic yield is expected, a proportion limit value of (Maximum Elongation/Expected Plastic Strain) reaching 2.0 or 4.0, respectively, will be imposed.

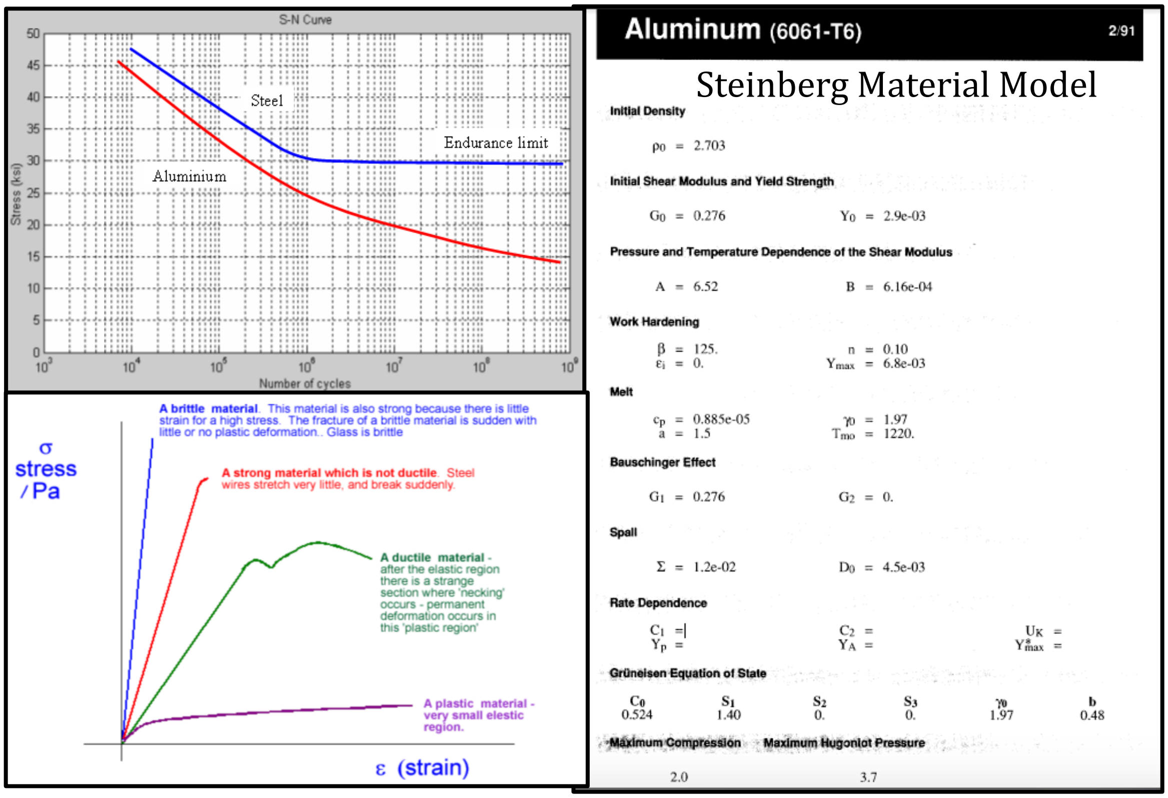


Figure 13 – Typical Material Data Used In Analysis

Secondary structure, defined as structure supporting the primarily loaded structures, will usually need to be of low risk. Since the secondary support structures must carry the resultant shock loads, this drives the need for a reasonable factor of safety, but must be tempered by the severity of the shock event. It is important to remember that the Debris Wind loads, although comprised of high amplitude loads, is vastly dominated by very high frequency contend, higher than 100,000Hz. These high frequencies have difficultly traversing even short distances through materials and structures, and especially across compliant regions. Similar to the ductile material response to impact loads, it is also true in structural bending, where the time to fully bend a component to achieve peak stress takes more time than the load is present. The secondary support structures have this inherent load attenuation, relative to their physical distance from the Debris Wind impacted surfaces and geometric compliance. This attenuation effectively filters out the high frequencies, transferring much of the energy to lower frequencies, which the material can transmit, while some of the energy is lost due to damping and heating. Although the analytical models are capable of determining some of this attenuation due to material damping structure and the structures geometric details, the models have not been shown to accurately determine attenuation from material crystal and grain structure, heating, bolted joints or contact surfaces. It is common for the Army

Research Laboratory (ARL) to use filters in analysis and testing of their high frequency ballistic shock testing and analysis events. These filters best represent secondary structure responses, even those directly adjacent to the ballistic impact surface through a bolted interface. A value of 1000Hz has been used successfully for design applications of the military armor panel attachments and supports developed at or for ARL. Structural components further from the ballistic impact surface are referred to as remote structures, and can see an additional order of magnitude reduction in frequency content in the load, to a filter level of 100Hz. In simple terms, the reduction in higher frequencies has the effect of lowering amplitudes and lengthening the time of application, eventually reaching levels often referred to as static equivalent loads. As much as possible, static equivalent loads will not be used this design guidance document, because they may lead to unrealistically low loads because of the loss and accumulation of error in transforming of these initial high frequency loads.

4.1.3 Analytical Support

Figure 14 shows a typical diagnostic and surfaces impacted by Debris Wind. Since the experimental target is small, the nose cap typically shadows the remaining diagnostic support from direct Debris Wind loading. This diagnostic has additional diagnostics referred to as Solid Rad/Chem units, which are further back and cantilever out from the shadowed volume, and therefore are subjected to direct Debris Wind loading. The burn marks seen on the shadowed forward portion of the diagnostic is due to high temperature plasma, which does not generate significant structural loading.

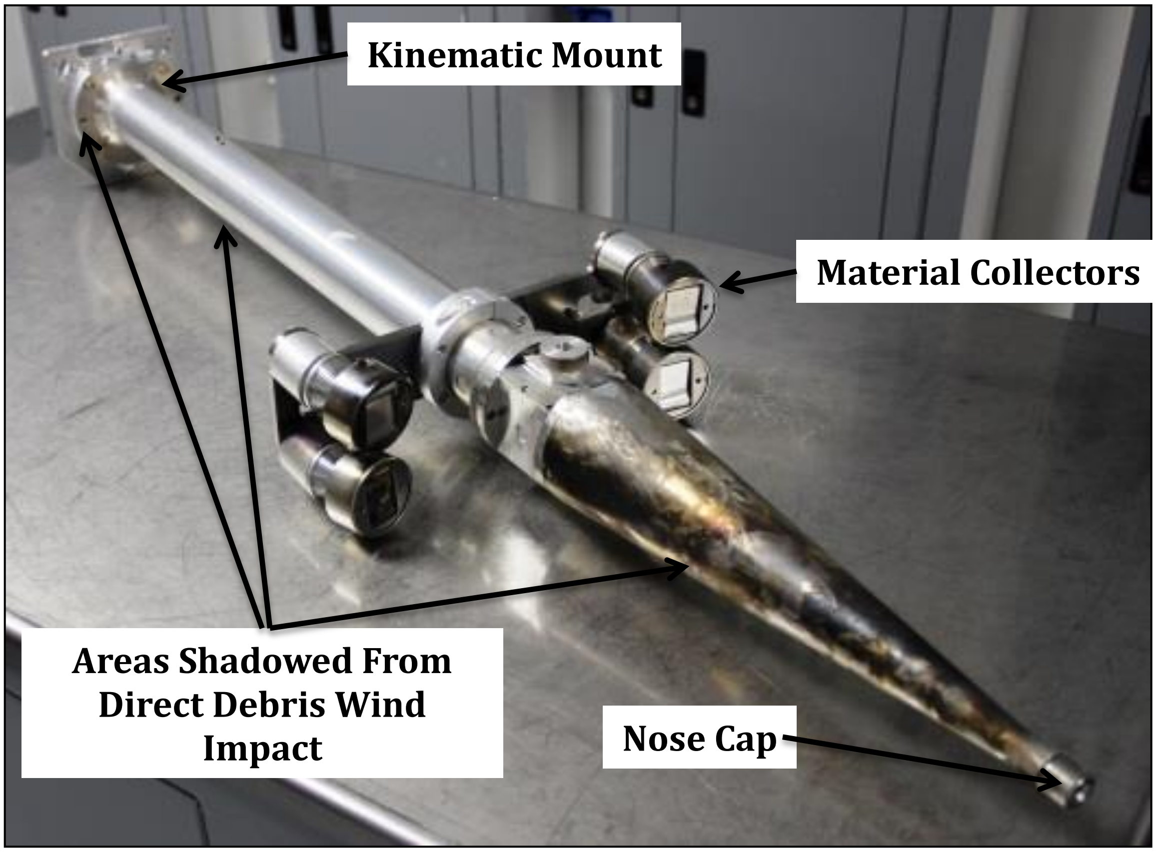


Figure 14 – Typical ~800mm Long Diagnostic

An analytical study, shown in Figure 15, illustrates how analytical models simulate some of the effective filtering discussed earlier, which is dominated by the bending response of the structures. Initially it would seems the loading is all axial, but with the dynamic response of the system, the reaction loads quickly disperses to directions of least resistance, making the lateral compliance dominate the system response. Frequency content consistent with the ARL filtering schemes can be seen for 3 general areas of the structure. Good rules of thumb are that the directly impacted surface sees up to 10,000Hz of frequency content, the direct secondary support structure, defined as structure out to 300mm from impact surface, sees up to 1000Hz, and finally structures further than 800mm from impact surface can see a reduction to 100Hz or less. No filter less than 50Hz will be used for NIF diagnostic structures. 10,000Hz transmission is highly material dependent and likely only seen on the impact surface and not inside the material. This is why the damage is only seen to shallow depths in the material, similar to shot peening.

Attenuation level at various distances along the diagnostic, purely due to system compliance dominated by bending

Transmission of load spectral content is determined by distance from load application point

- 100Hz Attenuation at 800mm from impact
- 1000Hz Attenuation at 300mm from impact
- 10000Hz Attenuation at 110mm and closer

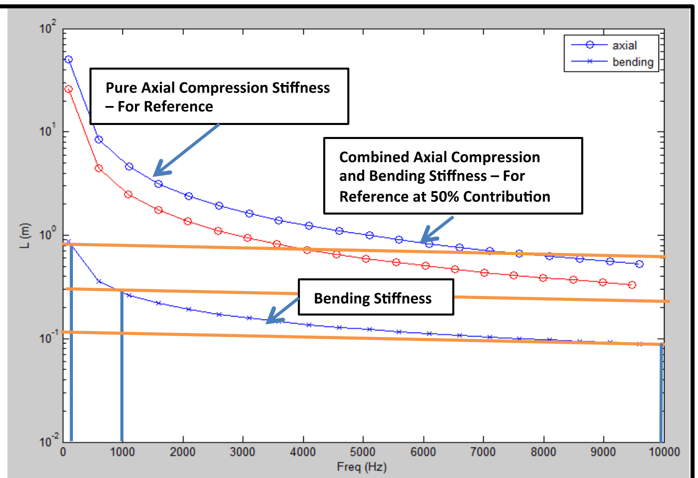


Figure 15 – Structural Attenuation In Long Structures

The numerical material models used in analysis, for example the Steinberg formulation (Ref. Figure 13), accounts for the shock effect on materials and provides variable yield strength based on the shock rate and micro-strain hardening. While providing an accurate representation of the material state, this does not lead itself to a simple factor of safety calculation. Many base line yield strengths based on static pull testing may underestimate the actual yield strength under shock loading by 3 times or more. Using a factor of safety on the static yield strength of material provides the minimum factor if the load was static, but for the dynamic strengths it is likely underestimating the true factor of safety. It will be proposed to use the minimum Steinberg yield value as the criteria for determining the factor of safety.

Welded aluminum components are especially susceptible to low factors of safety, due to the reduction in strength in the heat-affected annealed zone. For components, which see direct shock or secondary shock loading, ductility is as important as strength, therefore strain to failure, or maximum elongation, becomes one of the most critical parameters. The predicted plastic strains for new design must be developed using non-linear dynamic models, and are used to provide high confidence in the proportional factor to fracture or failure for highly ductile materials. Welded joints, especially in aluminums, have an effectively annealed heat affect zone, which provides additional ductility, however, a weld factor of 1.5 to account for weld flaws and precocity will likely drive the factor of safety for welded aluminums in a secondary shock back to the current factor of safety of 3.0.

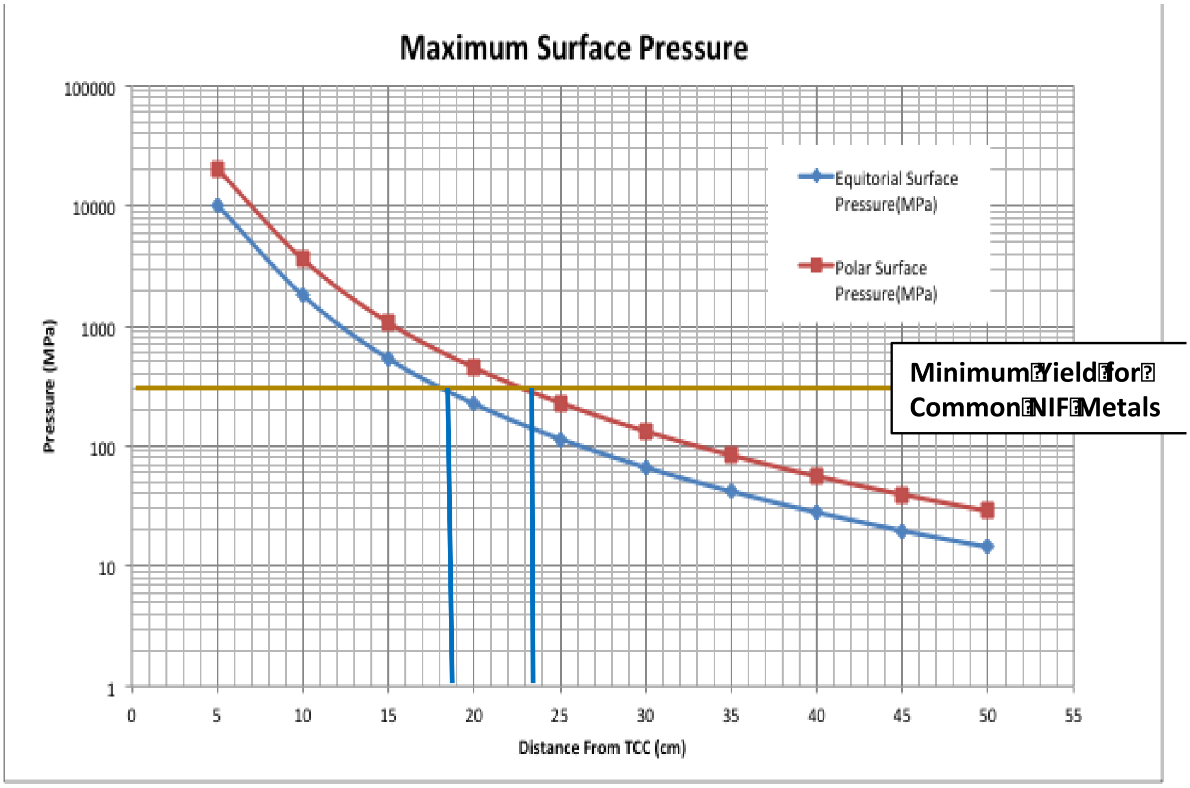


Figure 16 – Blast Pressure Surface Yield Distance

Debris Wind levels are dependent of whether the structure will be located in a polor oriientation or equitorial orientation. As can be seen in the graph in Figure 16, polar loading is twice as high in amplitude as in the equitorial orientation. Dynamic analysis is usually required, however, if the component can carry the maximum Debris Wind load amplitude statically, with a factor of safety of 1.0 on yield, then no further analysis would be needed. This would only be likely for components near the interior first wall of the NIF chamber. It is possible to provide a conservative guidance for some structure, where not analysis is required based on simple analysis studies.

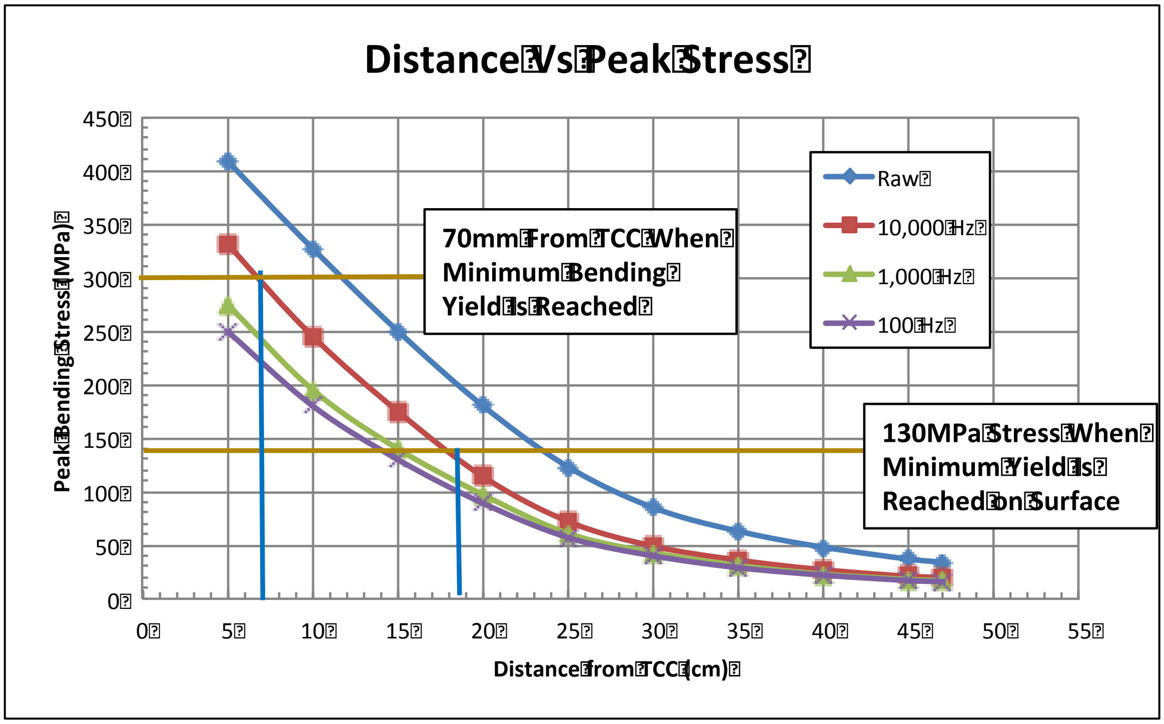


Figure 17 – Flexural Bending Yield Distance

Figure 17 presents a study showing the sensitivity of small compliance to stress. Components with a cantilever, which has a 4:1 or less length to thickness ratio, can be used at distances from TCC of 70mm or greater without the need for analysis for a factor of safety of 1.0 or greater on yield. At a distance of 130mm or greater a factor of safety of 1.5 can be assured without need for analysis. For bolted connections, a spring back tension load equal to 50% of the maximum compressive load evaluated at the interfaces within 110mm of surfaces impacted by Debris Wind load, and be used statically without need for more detailed simulation. This was verified in the empirical support section 4.1.1, Figure 10.

To reach some stakeholder expectations for guidance base on location of the structure with respect to TCC, analysis can provide a good value and basis for these distances. For components within 110mm of TCC subject to direct Debris Wind loading, a high strength and highly ductile material is recommend, such as Tantalum-10%Tungsten. For directly impacted surfaces at 110mm or greater, 300 and 400 series stainless steels are recommended, because of their high ductility and strain hardening characteristics. For structures supporting these directly load surfaces aluminum components are recommended. Welded aluminum components can be used but will need to use annealed material properties and a weld factor of safety of 1.5.

Components with at least two bolted interfaces between the direct shock loaded surface and at least 300mm from TCC, should use a low risk criteria as a goal, because a significant amount of attenuation will have been accumulated across the interfaces and distance. This includes fasteners and structural members. Shock loading is highly dependent on reflected shock waves and transmission of the shock waves energies, where pure surface to surface contact, like bolted joints, are very inefficient at transmitting higher frequency loads.

For components at or greater that 800mm from TCC, seismic loading will dominate the structural analysis and not require the labor-intensive non-linear dynamic analysis. Seismic loading is covered under another LLNL and NIF document, with allows for either static equivalent hand calculations or low frequency dynamic analysis. Appendix C gives an example of a simplified guidance matrix that may accompany the full guidance document.

Direction is also to be used as design criteria, as Polar and Equatorial positioned structures will see different loads. In cases where a diagnostic can be used in either location, the component must meet the higher loaded position, or have controls can be put in place allow shot energy limits for Polar location usage.

5.0 Chamber Position Preliminary guidance

These sections only provide an example of how the guidance outline has changed from the initial outline presented earlier to the stakeholders.

5.1 Polar Location

- For nose cap design, use of an existing nose cap design or a scaled version of the existing nose cap is an acceptable option requiring no analysis based on past usage. This is also true for the bolts number and size supporting the nose cap.
    - Nose caps shall be positioned such that the transfer the peak compressive load through a shoulder into the secondary support structure
    - Shear forces do not transfer well, so using 50% or less of the peak load from Debris Wind loading is adequate to qualify a joint, depending on if slotted holes are use
    - Ductile material must be used
- Components at 110mm or less from TCC are allowed to have surface yielding to as much as 25% of the maximum elongation.
    - True for ductile materials having greater than 15% maximum elongation
    - May not be available for re-use
    - Ductile material must be used

- Factors of safety for secondary structure shall be 1.5 on yield for ductile materials and 2.0 for brittle materials
- Components at 235mm or less from TCC are allowed to have surface yielding to as much as 10% of material depth
- Components at 300mm or less from TCC, which are directly impacted by Debris Wind, are allowed to have surface yielding and X-ray ablation damage
    - True for ductile materials having greater than 15% maximum elongation
    - May not be available for re-use
- Components with cantilevered or unsupported spans with a length over thickness ratio of less than 4:1 and having a line of sight to TCC of greater than 110mm do not need to be analyzed for Debris Wind
- Components shadowed from TCC line of sight and at 800mm or greater from TCC are structurally sized by seismic loading and not Debris Wind loading

5.2 Equatorial Location

- For nose cap design, use of an existing nose cap design or a scaled version of the existing nose cap is an acceptable option requiring no analysis based on past usage. This is also true for the bolts number and size supporting the nose cap.
    - Nose caps shall be positioned such that the transfer the peak compressive load through a shoulder into the secondary support structure
    - Shear forces do not transfer well, so using 50% or less of the peak load from Debris Wind loading is adequate to qualify a joint, depending on if slotted holes are use
    - Ductile material must be used
- Components at 110mm or less from TCC are allowed to have surface yielding to as much as 25%
  of the maximum elongation.
    - True for ductile materials having greater than 15% maximum elongation
    - May not be available for re-use
    - Ductile material must be used
- Factors of safety for secondary structure shall be 1.5 on yield for ductile materials and 2.0 for brittle materials
- Components at 300mm or less from TCC, which are directly impacted by Debris Wind, are allowed to have surface yielding and X-ray ablation damage
    - True for ductile materials having greater than 15% maximum elongation
    - May not be available for re-use
- Components at 185mm or less from TCC are allowed to have surface yielding to as much as 10% of material depth

- Components with cantilevered or unsupported spans with a length over thickness ratio of less than 4:1 and having a line of sight to TCC of greater than 70mm do not need to be analyzed for Debris Wind
- Components shadowed from TCC line of sight and at 800mm or greater from TCC are structurally sized by seismic loading and not Debris Wind loading

6.0 Project Schedule, Release and Integration

The current schedule being followed is shown in Table 3. The first items in the schedule have been completed. The effort is on schedule and there do not appear to be any obstacle to maintaining the release date.

PROJECT SCHEDULE AND MILESTONES			
Date	**Task**	**Status**	**Comments**
Year 2014			
November 4	Kickoff Meeting With Key Stakeholders	Completed	Positive Feedback, may need to re-evaluate guidance format
November 21	Complete Interviews with Active Stakeholders	Completed	Modify Stakeholder Chart To Better Represent Design Organization
November 23	First NIF Test Using Risk Assessment Guidance Methodology - Moderate Risk	Completed	Test was successful with no signs of damage
December 1	Design Approval for Vador Diagnostic with NIF Guidance Criteria - Low Risk	Completed	Management approved and fully supports new guidance methodology
December 23	Complete Analysis Studies to characterize Debris Wind Responses in Diagnostic Structures	Completed	Results are consistent with expectations and past experience
Year 2015			
January 30	Generate Simplified Guidance Matrix For Management Review		
Febuary 20	Complete Gathering NIF Empirical Data		
March 27	Complete Draft NIF Design Guidance Document		
April 10	Receive Feedback From Active Stakeholder On Draft Document		
April 24	Incorporate Feedback From Active Stakeholders And Release Document Into NIF System		
May 4	Begin Tracking Measurable Data To Track Compliance To Stakeholder Expectations		

Table 3 – Schedule and Milestones

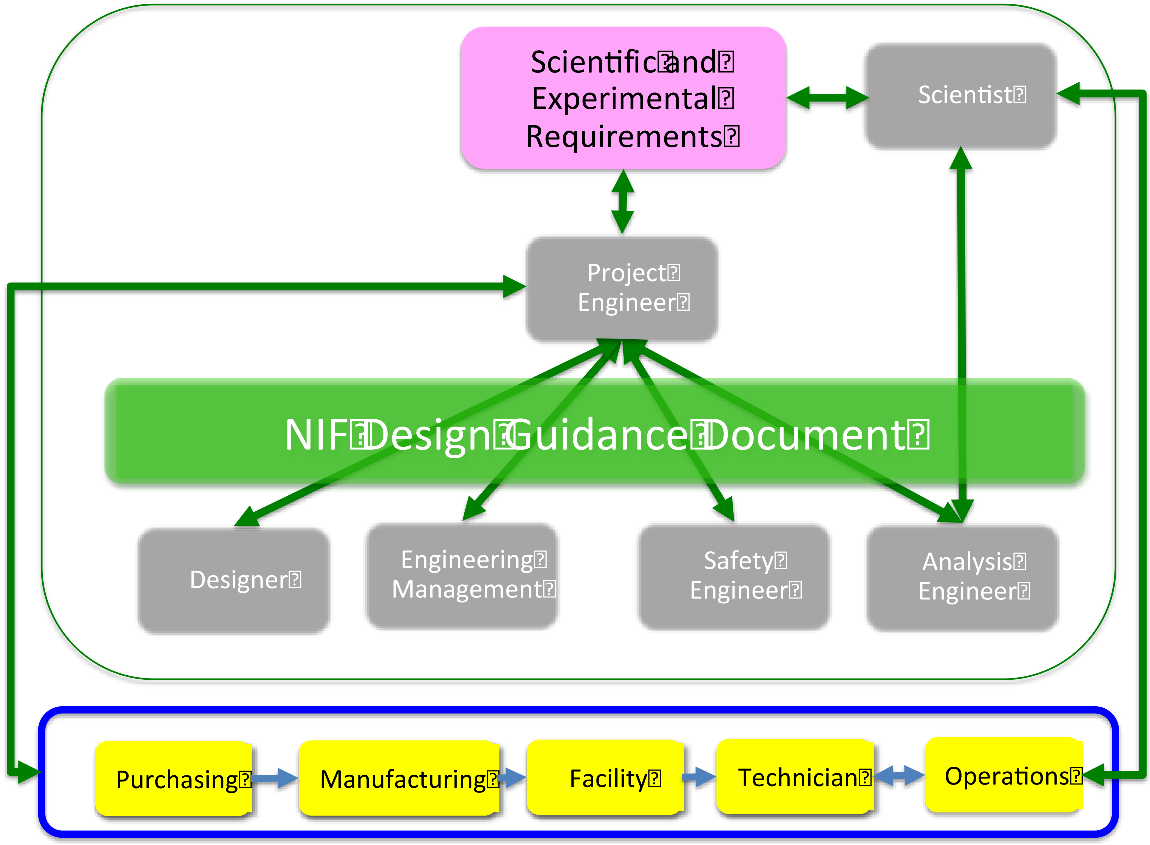


Figure 18 - Operational Scenario Context Diagram

The system operational scenario will follow the process shown in Figure 18, where the project engineer maintains control of the NIF Design Guidance usage. This is done to provide traceability, consistency and optimized use of the aggressive approach's available. The initial process with allow the scientist to work not only through the Project Engineer, but also through the Analysis Engineer, because the state of matter and energy in the scientific experiment will be used to assess the Debris Wind loading on the designs. In addition, the Project engineer will work directly with the passive stakeholders, with out the need of the NIF Design Guidance Document. As the guidance document implemented, data will be tracked as shown in Table 1, and provide again here for convince.

STAKEHOLDER EXPECTIONS/GOALS FOR MISSON DISCRIPTION		
EXPECTION/GOALS	OBJECTIVES	MEASURABLE ATTRIBUTE
Provides relief over the current design process	Lower factor of safety required	Record number of times that legacy factors are still used
	Reduce need for formal Documentation	Record number of formal documents released for new designs
Is of little process burden to the engineers	Creates fewer steps in the current process	Record number of design iterations required to reach final design
	Reduces the number of meetings to be held between stakeholders	Record number of group meeting held
Reduction in Design Cycle time	Designs are fielded sooner than pervious designs of similair complexity	Track design start and fielding dates
Material Cost Savings	Common low cost materials are use more often	Track number of special material orders associated with strutural strength requests
Manufacturing Cost Savings	Manufacturing schedules are relaxed with few Red-Lines	Record manufacturing lead times and drawing change requests
Is over-riding of current practice	No conflicting guidance preceived	Track questions on guidance objective
Is self contained	Few questions need to be answered to implement guidance	Record amount of time engineer uses to research guidance to be self assured
Is easy to use	No complaints on the meaning of guidance	Track number of complaints
Doesn't disrupt current general practice	Doesn't change organization or personell roles	Track the number of people that are displaced due to guidance
Covers most commonly seen challenges	Fewer requests for management review	Record number of time management is requested to make a decision on guidance direction
Does not generate high risk applications	Guidance does not allow high risk applications that clearly would not be approved by management	Track failure in the field

Table 1 (Reference Only)

The measurable attributes to stakeholder expectations will be a part of the Project Engineers responsibilities, but will also be supported by survey forms distributed to the other stakeholders to evaluate whether the guidance document was meeting their expectations. Based on the measures and evaluations, a lessons learned review of the document will be performed every 6 months, with appropriate document updates and releases occurring when necessary.

7.0 Final Comments

The foundations for this guidance utilize existing and accepted techniques, and can be integrated easily into the current design process flow. The completion and integration of the NIF Design Guidance document will provide an aggressive approach to design processes and practices utilizing advanced analytical techniques and studies, empirically based decision-making, and reduced need for documentation and review. This aggressive approach will lead to cost saving, schedule improvements, less management intervention and more optimized designs.

APPEDNDIX A

Initial Design Guidance Outline

I Graded Approach To Snout Engineering

A) DIM Engineering Loading

1) Much of the DIM is engineered based on "Design Margin" and on "Safety Factor"
    a. Define "Design Margin" to be the reasonable factor above the yield and ultimate strength of materials to assure structural integrity and component protection
    b. Define "Safety Factor" to be a required value need to protect personnel from injury
    c. The highest localized loading occurs from the high velocity dynamic target debris and shrapnel, and typically effects components as a design driver within 36cm of TCC
        i. Offset loading is not a critical parameter because of the short duration of the loading, compared to the lateral stiffness of the DIM components
    d. Seismic loading is a low velocity load with can be run statically or dynamically, and typically effects DIM components as a design driver further than 36cm from TCC
2) End Cap, Pinhole and Snout loads
    a. Shock Loading propagation attenuates quickly through materials and bolted interfaces
        i. Shock propagation through the DIM is complex and is typically not directly related to the initial shock
        ii. Rather, the transfer of loading through bolts and contact interfaces will reflect and scatter the initial shock at lower levels
    b. Debris Wind Loads drop quickly as distance from TCC increases
        i. Nominal Pinhole distance from TCC is 10cm
        ii. At 22cm the Debris Wind Load is $1/10^{th}$ of the load at 10cm
        iii. At 36cm the Debris Wind Load is $1/50^{th}$ of the load at 10cm
    c. Shrapnel impact is a function of its line of sight to TCC, and is not a function of distance from TCC and therefore must be shielded from sensitive components
3) Beyond 36cm from TCC, DIM structures are predominately driven by "Design Margin" on Seismic loading
    a. Debris Wind and Shrapnel Impact loads have a load duration of only several micro-seconds
        i. The DIM structural response at best will be at levels within several thousand Hz, which means there will be high levels of attenuation

ii. Analysis has shown bolted joint load reductions of 1 to 2 orders of magnitude beyond 36cm from TCC

B) DIM Engineering Materials
1) End Caps, Pinhole and Collimators have a line of sight to TCC and therefore carry direct Debris Wind and Shrapnel loading
    a. The material that these components are manufactured from must be capable of low ablation(X-Ray vaporization), high strength and high ductility, to survive is extreme environment
    b. Higher mass density materials also have a added advantage of being initially capable of resisting
    c. Typical NIC targets do not produce shrapnel, as they effectively vaporize all target mass which generates the Debris Wind
    d. Shrapnel loading is not common, and is highly influenced by the target shielding
2) Secondary DIM structure that is shadowed from a line of sight to TCC, typically do not have ablative issues and do not carry direct shock loading
    a. With much of the DIM having low natural frequencies, such as cantilevered bending, micro-second are not on the structure long enough to accelerate the mass to excite these low natural frequencies and therefore are not transferred to the supporting structures
    b. Since shock waves attenuate quickly, much of the DIM components will there for be drive by static loading conditions such as gravity, seismic and handling.
    c. Material choices for these components allow a greater range to choose from, including less ductile lower strength material

C) Safety Factor and Design Margin Determination
1) The LLNL DSS is the initial source for determination of what factor of safety or design margin is needed for structures, however, these are general guidance and do no always cover specific loading or design scenario's
    a. The DSS allows for engineering to use judgment on application of the final design margin to be applied to designs that are not related to personnel safety
2) As discussed in previous sections, components close to TCC will be subjected to loading environments which cannot be protected against, such as X-ray ablation and Debris Wind pressures which themselves exceed the strength of any material available

a. In these cases NIF has already informally allowed yield and surface damage to structures in the NIF chamber
b. A more formal design margin guidance can be determined from empirical and simulation evaluation, which will allow for safe yield cost effective design solutions to be implemented on NIF structures

3) Four zones of interest exist on the DIM for design margin determination
   a. The first zone represents the components that directly see ablative X-rays and Debris Wind within 22cm of TCC
      i. Within this sphere of loading, surface yield and damage is expected, but through thickness yield and damage is unacceptable
   b. The second zone represents the components that are secondarily loaded by attenuated shock and shadowed from direct Debris Wind and X-ray ablation
      i. These components have at least one bolted joint between the directly loaded components and are at a distance between 22cm and 36cm from TCC
      ii. These components, although still in a highly loaded environment have detailed simulation support and empirical basis for indicating a design margin of 2.0 on yield will provide sufficient structural confidence
   c. The third zone represents the components between 36cm and 600cm from TCC, which see very little shock loading from Debris Wind load or X-ray ablation
      i. In this zone, seismic loading becomes equal to or greater than the Debris Wind loading
      ii. Seismic loading requires a design margin of 1.0, while the Debris Wind loads will need to meet and likely have the ability to meet a design margin of 3.0
   d. The fourth zone represents components further than 600cm from TCC, which do not need Debris Wind evaluation or X-ray evaluation
      i. At 600cm and further that components will completely be driven by their design margin to seismic loading.

D) By providing design margin guidance, there will be opportunities to save time and money on structural designs within the NIF chamber

APPEDNDIX B

Stakeholder Interview Summary’s

Active Stakeholder Interview Summary

Designers:
Ron Bettencourt - Designer
He always felt that sticking to the LLNL standard design guidelines was one of their main goals, and weight and cost were ways to achieve these. The idea that they can get relief on design standards to meet design requirements would be of great help. Also, having easier access to previous similar accepted design features would allow them to not have to re-invent the wheel over and over would be a big help.

Project Engineers:
Justin Galbraith - Project Engineer
He just wants to get the design out per the requirements, manufactured and fielded in a timely manner. He has seen too many times where the project has gotten stuck in design and analysis, and having to ask for experimental requirements relief or management risk acceptance. He see this guidance document as a good change, where NIF can put the priority on the science, even if it is at the expense of a limited usage design life, or a possible bent part.
Jay Ayers – Project Engineer
He relies a lot on others to provide direction in the detailed technical areas, and tries to organize and pull together a workable solution to the requirements of the new design. He looks for inconsistencies in an effort to not generate overly conservative approaches to the design solution.

Engineering Management:
Robin Hibbard - Engineering Lead/Supervisor
He would like to have a simple matrix to help engineers know early on if their concept will require extensive analysis and what to do to avoid structural problems or the need for detailed evaluation. He believes that analysis is finding problems too late in the design cycle, and causing delays in schedule, and the need for expensive materials and manufacturing.
Greg Tietbohl - Chief Engineer/Manager
He has always been willing to accept low to medium risk given enough supporting evidence. If this guidance can give designers and engineers a better feel for when and how they can push the design limits, then this will help us meet our congressional mandate to save cost and schedule for NIF operations.

Analysts:
Nathan Masters – Lead Debris and Shrapnel Analysis Team
With analytical capabilities improving everyday, the accuracy of the structural simulations is such that we have very high confidence in our predictions. With this, except for uncertainty in the loading event for new experimental events, having a component close to mechanical yield or even locally plastic doesn't necessarily mean the design is unacceptable. It seems difficult to make general statements

about whether a design is acceptable based only on a few guidance inputs, without being very conservative.

Scientists:
Charles Yeamans – Engineering Scientist
The experimental results are the most important thing in the operation of the NIF, and whatever it takes to get the equipment ready on time, they are all for it. The target they design and test will be destroyed, so having the test support equipment possibly get damaged doesn't seem like much risk to them. The design of diagnostic equipment should not cause changes to essential experimental expectations.

Safety Engineer:
Scott Winters – Deputy Director/NIF Safety Reviewer
He is primarily interested in personal safety and trust engineering to determine if the structure will survive its intended use. The guidance document should help designers and engineers identify if something has a possibility to have personnel safety concerns. Other than that, they would like the term "Factor of Safety" used for personnel safety items and a term like "Design Margin" used for other design concerns.

Passive Stockholders Summary (Casual Discussions)

Instrument Technicians: As a user of the equipment, they expect the components to work, be easily be assembled and disassembled and for engineering to be responsible for whether it is structurally adequately designed.

Facility Lead: As a user of the equipment, they expect the components to work, and for engineering to be responsible for whether it is adequately designed. Design weight is a concern for facilities, in that the NIF building and floor strengths have limits, which we are approaching with new designs implementations.

Operations Engineer: Scheduling the use of the equipment, they expect the components to work, and for engineering to be responsible for whether it is adequately designed and delivered on time.

Manufacturing: Machining the high strength materials not only takes longer, but also requires additional maintenance time to sharpen or replace bits. Anyway to get designs made from materials that are easier to machine they will support.

Purchasing: With lead times on obtaining orders for the more exotic materials being 8-12 weeks, they will be happy not being the bearer of bad news to the engineers when materials are not available on time or do not meet specifications.

APPEDNDIX C

Preliminary Simplified Guidance Matrix

Location From TCC/ Characteristics	Polar Surfaces With Direct Line-Of-Sight To TCC	Polar Structural Appendages/Cantilevered With Direct Line-Of-Sight To TCC	Polar Surfaces Shadowed From TCC	Polar Structural Appendages/Cantilivered Shadowed From TCC	Polar Bolted Joints	Equitorial Surfaces With Direct Line-Of-Sight To TCC	Equitorial Structural Appendages/Cantilivered With Direct Line-Of-Sight To TCC	Equitorial Surfaces Shadowed From TCC	Equitorial Structural Appendages/Cantilivered Shadowed From TCC	Equitorial Bolted Joints
50mm	Current Compton Radiography nose caps and fastener can be used without additional analysis or review, including faster sizing					Current Compton Radiography nose caps and fastener can be used without additional analysis or review, including faster sizing				
	Scaling of current Compton Radiography nose cap design is acceptable without additional analysis or review, including faster sizing					Scaling of current Compton Radiography nose cap design is acceptable without additional analysis or review, including faster sizing				
70mm						Surface Compressive Yield is Expected, but is exceptable	4:1 Canitliver Component is at Yield, Nose Cap Lip			
						Current 304SS nose caps and fastener can be used without additional analysis or review, including faster sizing				
						Scaling of current 304SS nose cap design is acceptable without additional analysis or review, including faster sizing				
100mm	Surface Compressive Yield is Expected, but is exceptable	4:1 Canitliver Component is at Yield, Nose Cap Lip								
	Current 304SS nose caps and fastener can be used without additional analysis or review, including faster sizing									
	Scaling of current 304SS nose cap design is acceptable without additional analysis or review, including faster sizing									
120mm										
150mm									8:1 Canitliver Component is acceptalbe	
180mm			[illegible]	8:1 Canitliver Component is acceptalbe		Surface Compressive is at Yield, but is exceptable	4:1 Canitliver Component is acceptalbe			
220mm	Surface Compressive is at Yield, but is exceptable	4:1 Canitliver Component is acceptalbe								
300mm										
330mm										
420mm										
800mm	Siesmic Drives Strucural Sizing	Siesmic Drives Strucural Sizing	Siesmic Drives Strucural Sizing	Siesmic Drives Strucural Sizing	Siesmic Drives Strucural Sizing	Siesmic Drives Strucural Sizing	Siesmic Drives Strucural Sizing	Siesmic Drives Strucural Sizing	Siesmic Drives Strucural Sizing	Siesmic Drives Strucural Sizing

Table 4 – Simplified Guidance Matrix