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LLNL-TR-856839

National Ignition Facility Opacity Time Resolved Spectrometer Systems Engineering Final Project

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November 2, 2023

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

LLNL-TR-856839

Lawrence Livermore National Laboratory

National Ignition Facility Opacity Time Resolved Spectrometer Systems Engineering Final Project

Georgetown University

Design Thinking and Systems Engineering SYSM-5620

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Unclassified

October 5, 2023

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Table of Contents

1 Executive Summary

The National Ignition Facility (NIF) is the world's largest and most energetic laser facility. The NIF system is designed to produce high energy density (temperature and pressure) conditions through the application of its 192 laser beams. One of the users of NIF is the opacity platform developed to study the opacities at temperatures and densities relevant to the solar interior and stellar evolution. The platform was developed to study iron (Fe) opacity at temperatures relevant to the solar interior.

The opacity campaign uses spectrometers to gather data. Spectrometers utilize crystals to produce x-ray spectra that are recorded on time-integrated and time-resolved detectors. The opacity spectrometer (OpSpec) currently fielded and in use at NIF uses a time integrated film channel to collect data. The opacity spectrometer time resolved (OpSpecTR) will utilize novel hCMOS detectors to capture time resolved images of spectra of interest.

The key stakeholders identified for OpSpecTR included the physicists responsible for OpSpec and OpSpecTR ,the Target Area Science and Engineering (TASE) department at NIF, the NIF and Photon Science (NIF & PS) Opacity program, the Nevada National Security Site (NNSS) Physics and Engineering program, the Sandia hCMOS manufacturing and testing program, and the Los Alamos National Laboratory (LANL) program sponsor. The Target and Experimental Operations (TEXOPS) was identified as a key stakeholder because the group includes the individuals that will physically interact with the OpSpecTR system as it participates in NIF experiments.

The opacity platform collects data in a unique orientation relative to the existing diagnostics fielded at NIF. The existing infrastructure at NIF uses a diagnostic manipulator (DIM) to insert the diagnostic near the target chamber center to collect data during a NIF shot. Existing diagnostics collect data through the center line of the DIM axis and collect relevant data perpendicular to this axis. The opacity platform requires crystals mounted in a specific orientation which requires data collection parallel to the DIM axis. This deviation from standard NIF practices was a key factor in developing requirements.

The key stakeholders identified the following acceptance criteria for OpSpecTR:

1. The system shall achieve a primary X-Ray energy range goal 1-1.8keV.
2. The system shall be timed for hCMOS with minimum of 1 temporal frame with full width half maximum temporal width of less than 2ns centered within 0.3ns.
3. The system shall be fielded in the Polar DIM.
4. The system shall maintain hCMOS to board ribbon cable electrical connection at all times.
5. The system shall support the same orientation as the current OpSpec.
6. The system shall be compatible with a 3 shot campaign.
7. The system shall use a single set of sensor packages across a back-to-back shot series to reduce overall cost to procure multiple sensors.

A systems engineering evaluation was performed for OpSpecTR. Several concepts were considered including: a fixed based hCMOS and snout with removable line replaceable units (LRU's) for key components such as crystals, mirrors, filters and film, a sliding hCMOS detector with a standard DIM snout interface, and a system made up of a fixed hCMOS with a novel DIM kinematic snout interface. The fixed hCMOS with novel kinematic interface system was determined to be the superior solution, as it requires the least impact on the hCMOS interface and electrical connection, provides the operators with an easier connection when installing the hardware compared to existing designs, and requires the least amount of operator training. A concept of operations diagram for the proposed OpSpecTR system is shown below.

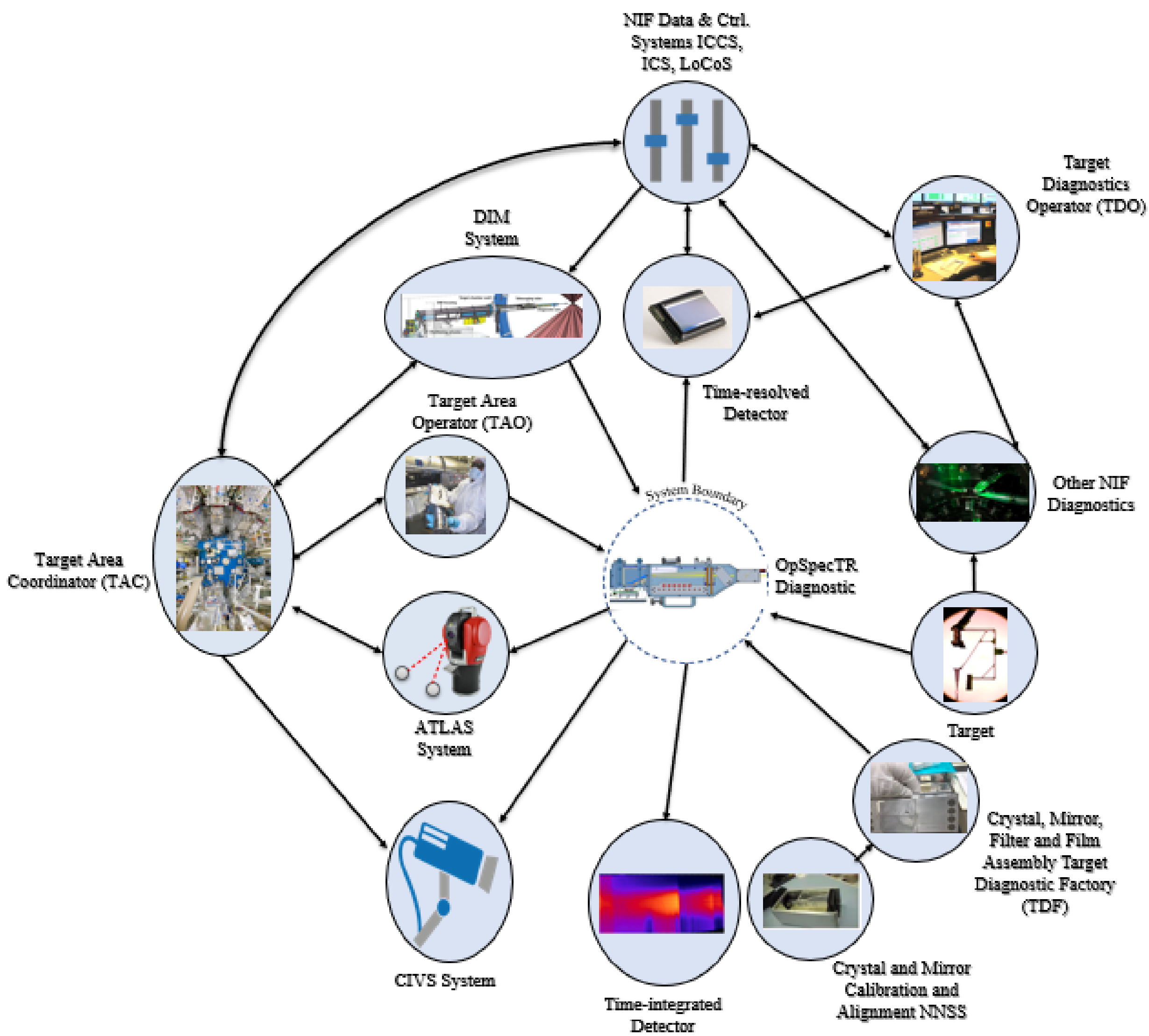

Figure 1. Concept of Operations Diagram for the OpSpecTR system.

2 Mission Description

2.1 Mission Goals, Objectives, and Rationale

The NIF system, shown in Figure 2, has been fully operational since 2009, and is designed to produce high energy density (temperature and pressure) conditions through the application of its 192 laser beams.

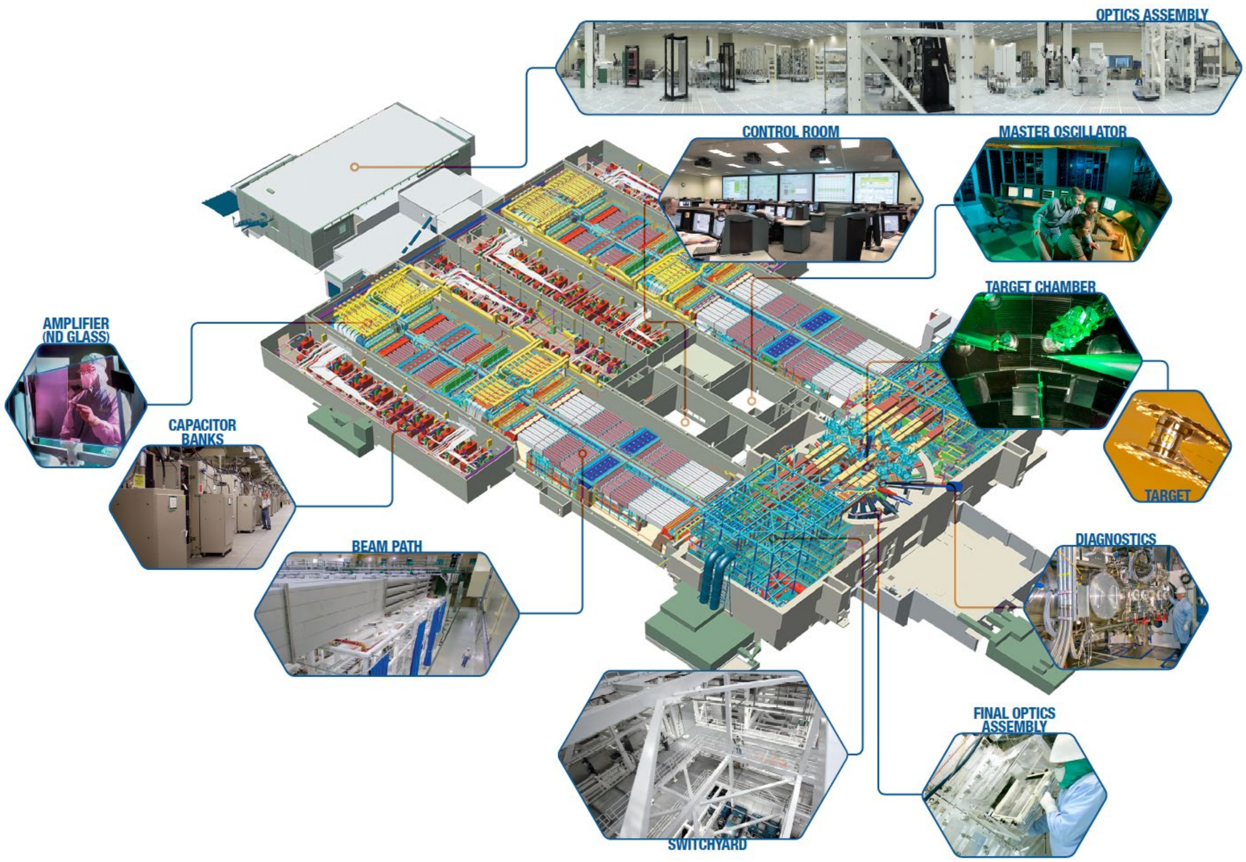

Figure 2. The National Ignition Facility. Image credit LLNL.

The facility is funded by the U.S. Department of Energy's (DOE) National Nuclear Security Administration (NNSA) and is operated by the NIF & Photon Science principal directorate of the Lawrence Livermore National Laboratory (LLNL). One of the users of NIF is the opacity platform developed to study opacities at temperatures and densities relevant to the solar interior and stellar evolution. Opacity is defined as the material property characterizing the x-ray absorption of a material. The energy from the NIF laser is converted to x-rays with the use of a backlighter. The x-rays then shine through a capsule containing the material of interest. The data is gathered opposite the material on a detector platform. The current opacity spectrometer OpSpec fielded at the NIF utilizes a film channel to capture NIF shot data. The film reports a time integrated data set which becomes dominated with background emission noise at higher temperatures of interest. As the NIF capsule is imploded late in time capsule self-emission saturates the film resulting in a loss of data. OpSpec has primarily been fielded on a Diagnostic Instrument Manipulators (DIMs) located directly above the target with data collected on time integrated film. Figure 3 below shows the basic schematic of a NIF opacity target.

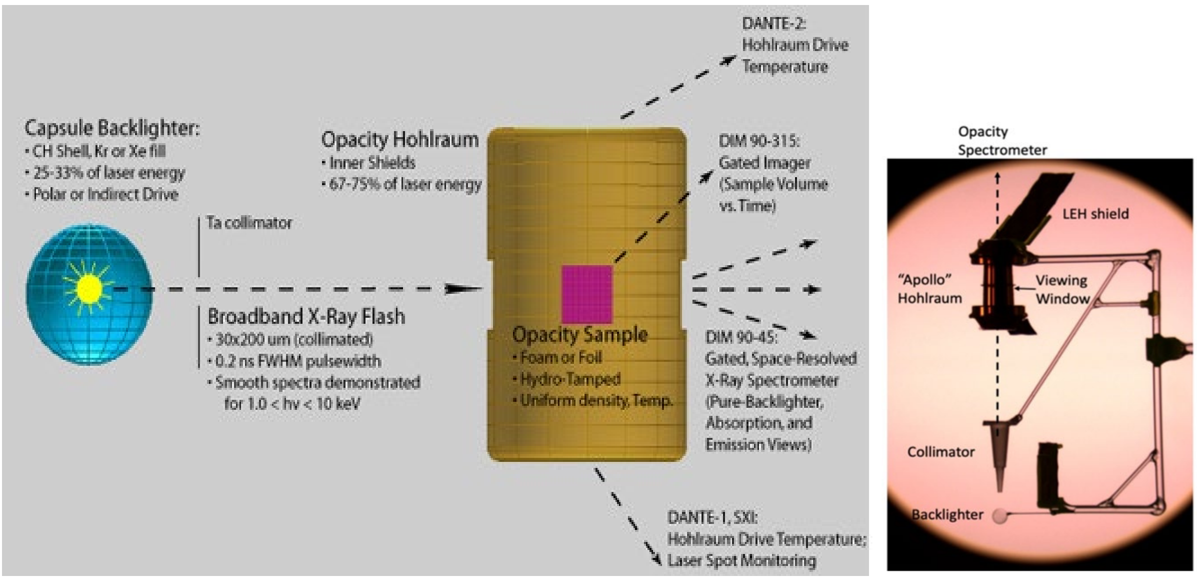

Figure 3. NIF lasers driving the backlighter though a capsule. Image credit LLNL.

A variety of diagnostic instruments are used to monitor the experiment by measuring the temperatures and performance of the experiment. Magnified images of x-ray emissions from the target are generated using pinhole arrays and are recorded on detectors. The images may be time-integrated, representing the full duration of the experiment, or time-resolved, representing very short durations at different instances of time. Spectrometers utilize crystals to produce x-ray spectra that are recorded on time-integrated and time-resolved detectors. The pinholes, crystals, filters and other components of a diagnostic are contained within a "snout" that is inserted in to the chamber, often mounted on the front of a DIM-mounted detector commonly known as an airbox. The snout is precisely aligned relative to the target located at Target Chamber Center (TCC) using a variety of alignment systems, such as laser-trackers using a system known as ATLAS and optical telescopes. A diagram of a typical experimental setup is shown in Figure 4.

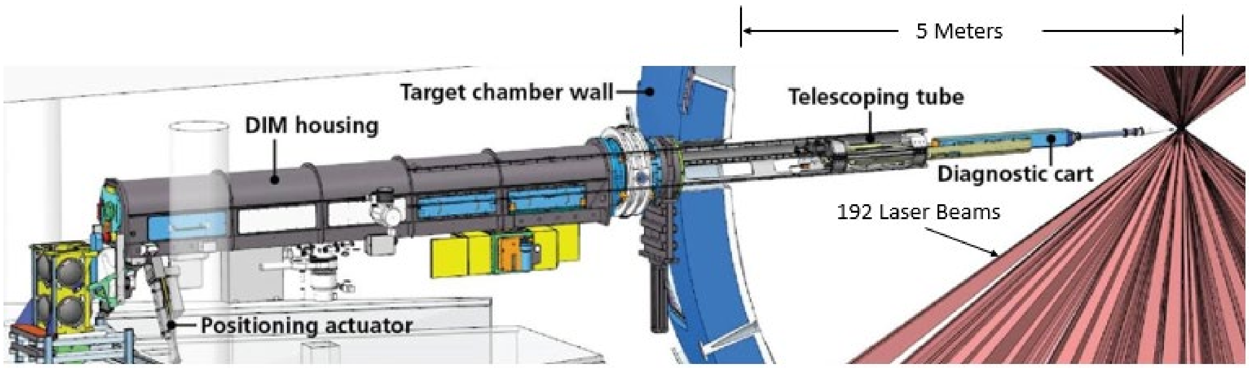

Figure 4. A snout diagnostic is inserted to target chamber center (TCC) by use of a Diagnostic Instrument Manipulator (DIM) shown above. The snout is able to precisely point toward TCC by bipod motion and a gimbal at the target vacuum chamber wall interface. The above image is shown in the equatorial position, OpSpecTR will be mounted on the Polar DIM which is oriented vertically facing down toward TCC.

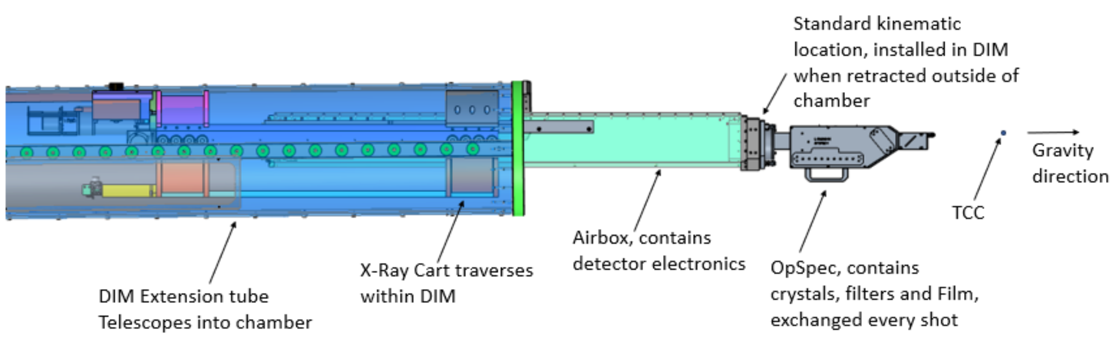

Figure 5. A close up view of the snout mounted to a standard kinematic base (KB) interface inserted into the chamber toward TCC.

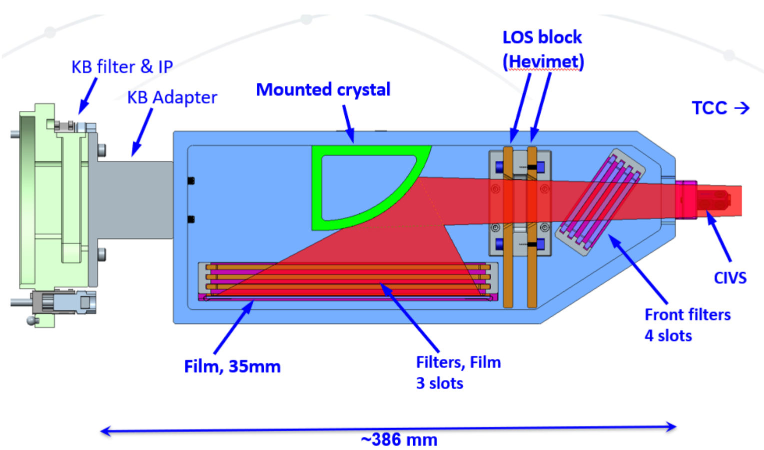

Figure 6. The OpSpec Opacity Spectrometer with a time integrated data collection channel.

2.2 Need Statement

Problem – The opacity campaign is a joint NNSS, LLNL and LANL effort to better understand opacities of elements. Higher temperature electron energy experiments are required to fully characterize the elements of interest and these energies are currently at the saturation limit of the film dominated by background noise self-emission.

Need - There is a need to upgrade the opacity spectrometer diagnostic to a time resolved capability allowing time gated images which would gate out late time capsule self-emission, thus greatly reducing the background noise data at higher temperatures.

Picture of Success - The ideal solution would gate out late time background noise with a nominal gate time of 1ns thus resulting in >80% rejection of background noise self-emission.

2.3 Stakeholders Identification

The stakeholders for this mission were identified and are included below in a satkeholder diagram shown in 7. Refer to Appendix A for the definition of any acronyms.

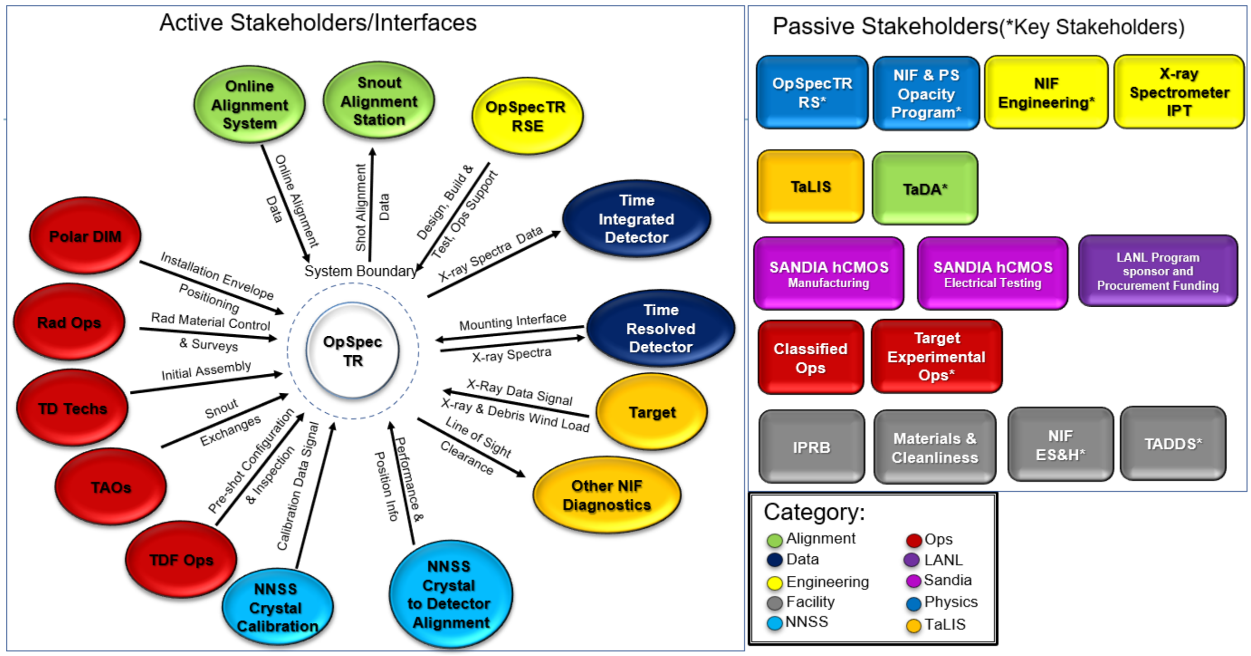

Figure 7. Stakeholder diagram for the OpSpecTR system. Active, passive, and key stakeholders identified. The stakeholder color indicates which category it belongs to. Interactions between the OpSpecTR and the active stakeholders are identified, and the arrow indicates the direction of exchange.

The stakeholders were grouped into ten categories. The alignment group handles snout alignment activities both offline and online inside the target chamber. The data group handles all data collection following a NIF shot. The engineering group handles all engineering and design of the system including developing system requirements, fielding the system and integrating the project team for various spectrometers in the spectrometer integrated project team (IPT). The facility represents the group of individuals dedicated to the facility infrastructure. NNSS is the Nevada National Security Site group handling the design and crystal testing for the snout. Due to this project being a multi-laboratory effort NNSS is handling the snout design due to their previous experience in snout design for the legacy OpSpec snout. Ops stand for operations and is the group that handle the snout and detector in the facility. LANL is Los Alamos National Laboratory and is responsible for portions of the procurements and funding. Sandia is another national laboratory that has designed and tested the sensor packages OpSpecTR plans to use. Physics represents the scientists interested in the data that can be collected from OpSpecTR. TaLIS stands for Target Area Laser Interaction Sphere and represents the group dedicated to machine and laser safety and all adjacent diagnostics at target chamber center.

The key stakeholders for OpSpecTR are the stakeholders that have the most at stake for the capabilities of the system. The key stakeholders identified for OpSpecTR included the physicists responsible for OpSpecTR known as the responsible scientist (RS). The NIF and PS opacity program for determining the experimental priorities for NIF. The NIF engineering group is a key stakeholder in determining the system requirements and scope of the project in order to deliver a working diagnostic on schedule and on budget. The TaDa or Target Area Diagnostic Alignment group part of the alignment team represents any alignment activities and is keenly interested in any new diagnostics to confirm compatibility with existing infrastructure and processes. The target experimental operations group is dedicated to the handling of the diagnostic in NIF and any diagnostic fielded in the polar DIM brings with it a number of challenging infrastructure and transport and handling constraints. The TADDS group represents a subset of the facility group which specifically deals with DIM based diagnostics and this group will interface with OpSpecTR specifically due to the time resolved detector that will require new infrastructure cabling. Finally, the NIF ESH or Environmental Safety and Health teams is interested in the safety of the people handling the diagnostic prior and follow the shot to confirm no radioactive activity or contamination is present.

2.4 Stakeholder Expectations Capabilities and Characteristics

Interviews in a voice of the customer fashion were conducted with the OpSpecTR stakeholders to collect expectations for the system. The significant expectations are included in Table 1 and Table 2. The expectations were categorized as capabilities or characteristics. Capabilities are those expectations that reflect functions or behaviors desired by the stakeholders. Characteristics are expectations that reflect system attributes or properties.

Stakeholders	Capabilities	Characteristics
OpSpecTR RSE	The system shall allow crystal exchanges for different capabilities and configurations The system shall be fielded in the Polar DIM The system shall be compatible with hCMOS detector, Image plate, and film The hCMOS ribbon cable connection shall maintain connection between sensor and sensor boards at all times The system shall use removable filters, film and image plate The system shall support the same orientation as the current OpSpec snout The system shall actively cool electronics	The system shall be timed for hCMOS with minimum of 1 temporal frame with full width half maximum temporal width of less than 2ns centered within 0.3ns The system shall constrain the maximum photon fluence to 1.5M photoelectrons/pixel The system shall have a field of view no less than 5mm diameter at TCC The system shall operate in NIF environment at 1e -7 torr
Time Integrated Detector Data	The system shall meet standard NIF image plate and film processing	
Time Resolved Detector Data	The system should meet standard NIF control software The system shall have a commissioning plan for timing verification The system shall use existing triggers The system should verify timing prior to a shot	The system shall allow data acquisition on a 5 mintues cycle time
Target TaLIS	The system shall protect the hCMOS detectors from damage	The system shall be designed to with stand 2.1MJ 0.5g debris wind load
Other NIF Diagnostic TaLIS	The system shall maintain machine safety clearance between adjacent diagnostics	
NNSS Crystal to Detector Alignment	The system shall allow for offline alignment of the snout to the detector	The system shall use crystal mounts shall maintain same methodology of mounts per OpSpec with 0.1mm repeatability The system shal be designed such that the snout to detector shall maintain repeatability of 0.3mm
NNSS Crystal Calibration	The system shall use crystal configurations shall be compatible with NNSS x-ray sources(Manson or Hinke)	
TDF Ops	The system shall allow for LRU crystal, filter, image plate and film exchanges per NIF configuration management	
TAOs	The system shall allow for LRU configurations in DIM for image plate and film exchanges	
TD Techs	The system shall allow for detailed assembly procedures at time of assembly	
Rad Ops	The system shall allow transport for radiological material	The system shall survive <1e13 neutrons
Polar DIM Ops	The kinematic interface should be reconfigured for Polar DIM for better ease of install The system shall allow for crystal, filter, image plate and film exchange between consecutive shots	The snout shall weigh no more than 25 lbs
Online TCC Alignment	The system shall be aligned with ATLAS	The system shall nominally operate at a standoff from TCC not less than 0.6m The system shall maintain +/- 0.5 mm pointing precision The system shall be aligned at TCC < 2 hours
Snout Station Alignment	The snout shall be compatible with the ATLAS snout station	

Table 1. Active Stakeholder expectations

Stakeholders	Capabilities	Characteristics
OpSpecTR RS	The system shall achieve: Primary X-Ray energy range goal 1-1.8keV Secondary X-Ray energy range goal 0.5-2keV The system shall be compatible with a 3 shot campaign The system shall include a photoconductive detector within line of sight of x-rays to provide aide for post-shot timing	Sensor spatial size sufficient to record 3 specific regions of interest relative uncertainty between sensors of 1%
NIF and PS Opacity Program	The system shall achieve long term x-ray energy range goal 0.5-15keV	
NIF Engineering	The system shall be designed to survive seismic events per DSS standards	
X-Ray Spectrometer IPT	The system shall allow for crystal calibration at LLNL spectrometer calibration station	
TADA	The system shall utilize existing alignment controls at NIF	
Sandia hCMOS Manufacturing	The system shall use existing IV2 sensors The system shall not preclude use of future DV2 sensors	
Sandia hCMOS Testing	The system shall use existing IV2 sensors The system shall not preclude use of future DV2 sensors	
LANL Program Sponsor	The system shall be in operation for milestone data collection in FY25 The system shall use a single set of sensor packages across a back to back shot series to reduce overall cost to procure multiple sensors	
Classified Ops	The system shall collect classified data	
Target Experimental Ops	The system shall interface and operate in the existing NIF environment The system shall be compatible with existing cabling in DIM The system shall maintain EMI shielding The system shall be properly grounded to operate in NIF DIM	The system DLP shall weigh no more than 400 lbs for polar DIM
IPRB	The design and documentation for OpSpecTR shall follow NIF IPRB standard process	
Material and Cleanliness	The system shall maintain NIF cleanliness controls	
NIF ES&H	The system shall allow transport for radiological material	
TADDS	The system shall reduce the operator strain during install and removal in polar DIM	

Table 2. Passive Stakeholder expectations

One of the challenges of OpSpecTR is introducing multiple hCMOS sensors into a single diagnostic. The IV2 hCMOS sensors are in their infancy with fielding at NIF, all previous diagnostics contained single sensor packages. The region of interest of the opacity platform requires more than one sensor and is planning up to 3 sensors initially for full coverage. Timing and calibrated sensors together poses a significant design challenge and risk to the function of the system. The program sponsor requires limiting the total number of sensors to procure to reduce overall project cost as the sensors themselves are long lead ~ 12 months and high value items.

The other challenge of the OpSpecTR system is the location of the sensor package relative to the DIM interfaces, specifically the kinematic connection of the snout to the airbox. The sensor package will be oriented parallel to the to the DIM axis and directly adjacent to the to the kinematic interface. The sensor package must remain electrically connected to the airbox at all times due to the extreme delicacy of the ribbon cable connection which contains 100+ connections per sensor. Due to this requirement, the sensor package will obstruct access to the DIM for snout install. This obstruction to the already limited access DIM snout install operation poses a risk to the sensor package from damage and to ergonomic challenges for the operator installing the snout.

2.5 Stakeholder Requirements

Stakeholder Requirement No.	Stakeholder	Requirement
SR1	OpSpecTR RSE	The system shall allow for crystal exchanges
SR2	OpSpecTR RSE	The system shall be fielded in the Polar DIM
SR3	OpSpecTR RSE	The system shall maintain hCMOS to board ribbon cable electrical connection at all times
SR4	OpSpecTR RSE	The system shall support the same orientation as the current OpSpec
SR5	OpSpecTR RSE	The system shall be timed for hCMOS with minimum of 1 temporal frame with full width half maximum temporal width of less than 2ns centered within 0.3ns
SR6	OpSpecTR RSE	The system shall constrain the maximum photon fluence to 1.5M photoelectrons/pixel
SR7	Time Integrated Detector Data	The system shall allow data acquisition on a 5 mintues cycle time
SR8	Time Resolved Detector Data	The system shall use existing triggers
SR9	Time Resolved Detector Data	The system should verify timing prior to a shot
SR10	Time Resolved Detector Data	The system shall allow data acquisition on a 5 mintues cycle time
SR11	Target TaLIS	The system shall protect the hCMOS detectors from damage
SR12	NNSS Crystal to Detector Alignment	The system shall allow for offline alignment of the snout to the detector
SR13	NNSS Crystal Calibration	The system shall use crystal configurations shall be compatible with NNSS x-ray sources(Manson or Hinke)
SR14	Rad Ops	The system shall allow transport for radiological material
SR15	Polar DIM Ops	The kinematic interface should be reconfigured for Polar DIM for better ease of install
SR16	Polar DIM Ops	The system shall allow for crystal, filter, image plate and film exchange between consecutive shots
SR17	Online TCC Alignment	The system shall be aligned with ATLAS
SR18	Online TCC Alignment	The system shall maintain +/- 0.5 mm pointing precision

Table 3. Stakeholder Requirements

Stakeholder Requirement No.	Stakeholder	Requirement
SR19	Snout Station Alignment	The snout system shall be compatible with the ATLAS snout station
SR20	OpSpecTR RS	The system shall achieve: Primary X-Ray energy range goal 1-1.8keV Secondary X-Ray energy range goal 0.5-2keV with phased crystal configuration changes
SR21	OpSpecTR RS	The system shall be compatible with a 3 shot campaign
SR22	OpSpecTR RS	Sensor spatial size sufficient to record 3 specific regions of interest relative uncertainty between sensors of 1%
SR23	NIF and PS Opacity Program	The system shall achieve long term x-ray energy range goal 0.5-15keV
SR24	NIF Engineering	The system shall be designed to survive seismic events per DSS standards
SR25	Sandia hCMOS Manufacturing	The system shall use existing IV2 sensors
SR26	Sandia hCMOS Manufacturing	The system shall not preclude use of future DV2 sensors
SR27	LANL Program Sponsor	The system shall be in operation for milestone data collection in FY25
SR28	LANL Program Sponsor	The system shall use a single set of sensor packages across a back to back shot series to reduce overall cost to procure multiple sensors
SR29	Classified Ops	The system shall collect classified data
SR30	Target Experimental Ops	The system shall be compatible with existing cabling in DIM
SR31	Target Experimental Ops	The system shall maintain EMI shielding
SR32	Target Experimental Ops	The system shall be properly grounded to operate in NIF DIM
SR33	Target Experimental Ops	The system DLP shall weigh no more than 400 lbs for polar DIM
SR34	IPRB	The design and documentation for OpSpecTR shall follow NIF IPRB standard process
SR35	Material and Cleanliness	The system shall maintain NIF cleanliness controls
SR36	TADDS	The system shall reduce the operator strain during install and removal in polar DIM

Table 4. Stakeholder Requirements Continued

The above tables 3 and 4 represents the culmination of requirements based on the voice of the customer feedback from the stakeholders pulled from the capabilities and characteristics. There are many known constraints that dictate a DIM based design at NIF. These constraints cross many stakeholder groups however the selection of the key acceptance criteria are specific to requirements that cannot be bargained or modified. The next section represents these key acceptance criteria for the OpSpecTR system.

2.6 Key Acceptance Criteria

1. The system shall achieve a primary X-Ray energy range goal 1-1.8keV.
2. The system shall be timed for hCMOS with minimum of 1 temporal frame with full width half maximum temporal width of less than 2ns centered within 0.3ns.
3. The system shall be fielded in the Polar DIM.
4. The system shall maintain hCMOS to board ribbon cable electrical connection at all times.
5. The system shall support the same orientation as the current OpSpec.
6. The system shall be compatible with a 3 shot campaign.
7. The system shall use a single set of sensor packages across a back-to-back shot series to reduce overall cost to procure multiple sensors.

3 System Concept Generation and Selection

The key acceptance criteria dictate the location the diagnostic must be fielded as well as the suite of sensor packages to be deployed. These are known constraints we cannot modify. OpSpecTR must also participate on back to back shots to full each shot campaign. Typically at NIF back to back shot campaigns are performed by exchanging snouts with the DIM while leaving the larger airbox in the DIM for the subsequent shot to come. The OpSpecTR system will be both a snout and a diagnostic load package which contains the OpSpecTR airbox with hCMOS related electrical boards and components as well as the hCMOS sensors. This matches the typical configuration at NIF for airboxes and snouts. Where OpSpecTR deviates from this configuration is the location of the sensor package relative to the airbox and snout. Figure 8 below shows this typical configuration.

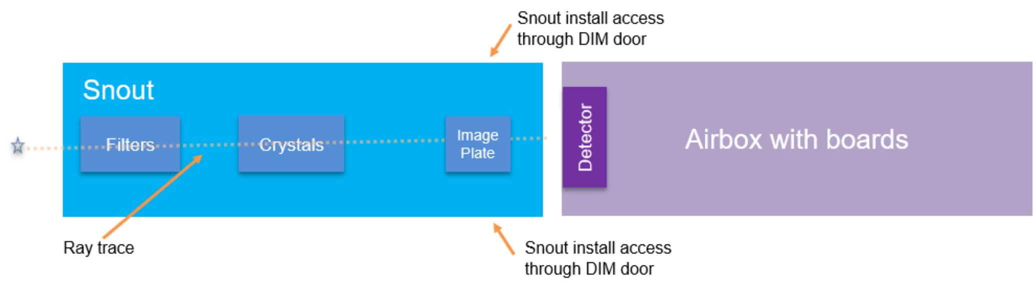

Figure 8. Typical Snout and Airbox Configuration

Figure 9 below however shows the off-normal configuration for OpSpecTR. The OpSpec crystal configuration and physical constraints on a DIM based diagnostic require the crystal orientation such that the image is thrown as shown below. The DIM detector parallel to the DIM axis poses a significant obstruction to the DIM snout install location. The required orientation also reducing the access to the kinematic connection to the airbox.

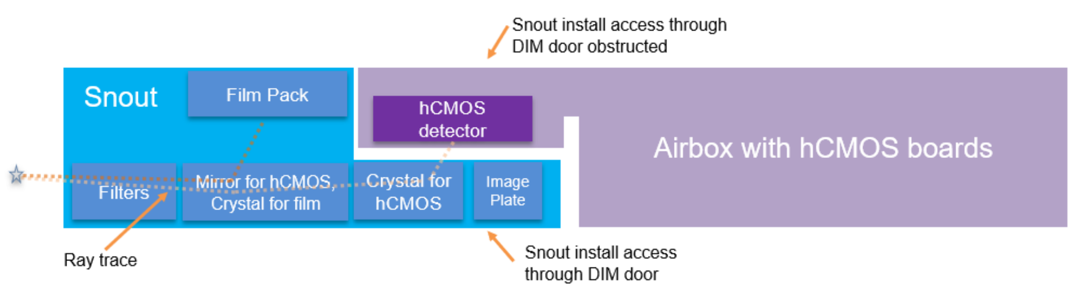

Figure 9. OpSpecTR Sensor Configuration at Snout and Airbox Interface

Figure 10 below shows this kinematic connection as OpSpec is installed into the Polar DIM. The snout is held in place to the airbox with a 3-point kinematic connection for repeatable installation.

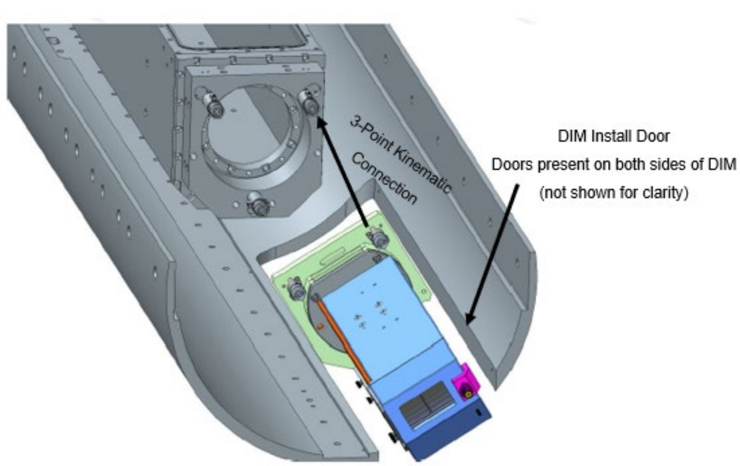

Figure 10. Snout Kinematic Connection to Airbox

3.1 Concepts for OpSpecTR

The concepts proposed are described in the following section with benefits and costs for each weighed against each finally in the Pugh Matrix to discuss the best viable concept for OpSpecTR.

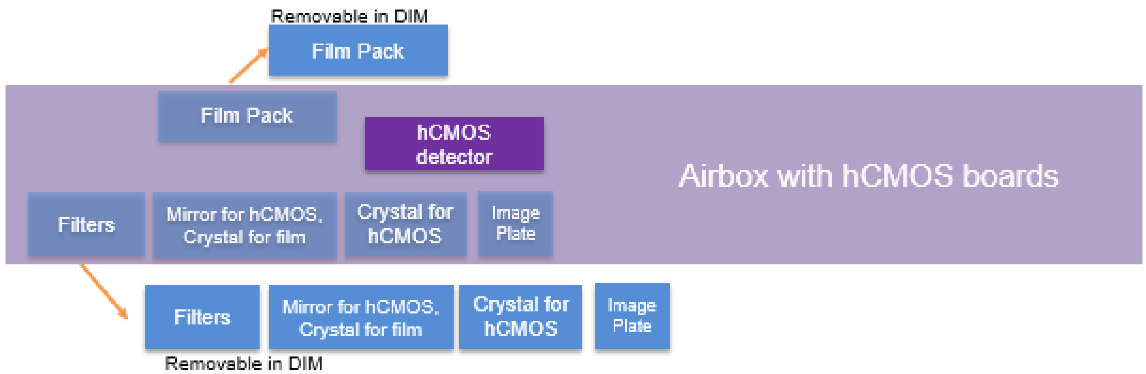

Figure 11. Fixed airbox and Snout with Removable Replaceable Crystal, Mirror, Filters and Film.

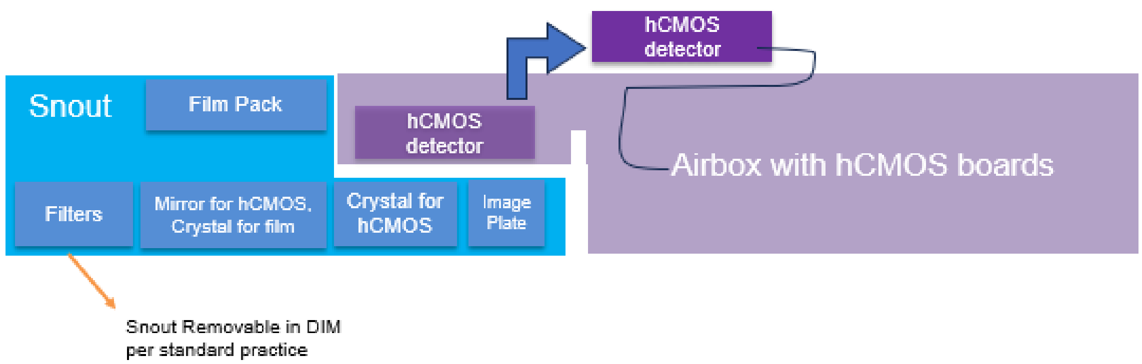

Figure 12. Sliding hCMOS Airbox Connection for better DIM access with removable snout

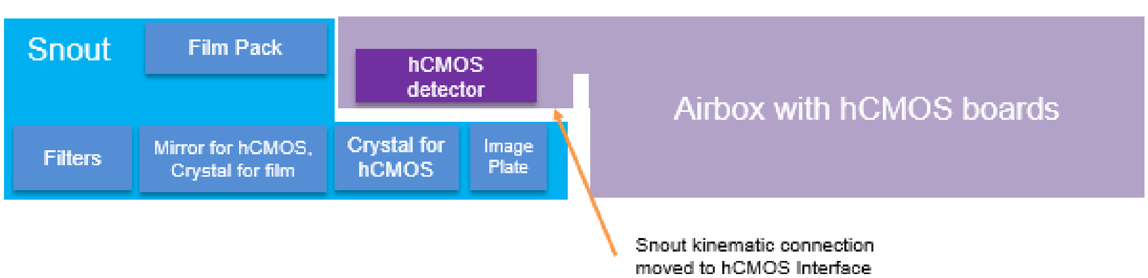

Figure 13. hCMOS fixed to Airbox with Novel Kinematic Snout to Airbox Interface

3.2 Concept Pugh Matrix

Stakeholder Expectation #	Criteria	Weight	hCMOS Fixed, Fixed Snout Removable LRU's [crystals, mirror, filters, film]	Sliding hCMOS Standard DIM kinematic interface	hCMOS Fixed Novel kinematic snout interface
SR1	The system shall allow for crystal exchanges	0.10	1	5	5
SR2	The system shall be fielded in the Polar DIM	0.10	3	4	5
SR3	The system shall maintain hCMOS to board ribbon cable electrical connection at all times	0.20	5	1	5
SR11	The system shall protect the hCMOS detectors from damage	0.20	5	1	3
SR21	The system shall be compatible with a 3 shot campaign	0.20	3	5	5
SR36	The system shall reduce the operator strain during install and removal in polar DIM	0.20	5	5	5
	Sum	1	4	3.3	4.6

Table 5. OpSpecTR Pugh Matrix

The above Pugh matrix weighs the concepts against each other based on stakeholder requirements. All of the concepts must satisfy the key acceptance criteria, however some of the concepts achieve certain stakeholder requirements more effectively. The concept matrix is weighted based on importance of the stakeholder requirement based on a percentage and the concepts are scored on a scale of 1-5 with 5 being the best score. The hCMOS fixed with novel kinematic snout interface scored the highest out of the 3 options. However, this option poses a deviation from standard NIF practices with the deployment of a new kinematic connection. Because of this, the Pugh matrix above must be discussed in detail with stakeholders to highlight any possible concept selection inadequacies reflected in the Pugh Matrix.

The details of the Pugh matrix are not apparent without careful consideration of each stakeholder requirement. The hCMOS fixed with fixed snout best protects the hCMOS, the hCMOS electrical connection and reduces operator strain because there is no snout to install. However, exchanging optics such as crystal and mirrors within the DIM poses a great risk to high dollar items. The limited access in the DIM would pose a drop risk to these optics, so this option scored poorly for stakeholder requirement 1.

The sliding hCMOS with standard kinematic interface scored the worst out of the three concepts. The risk to the hCMOS ribbon cable held within a sliding mechanism poses a damage risk to the electrical ribbon cable and connection. In moving the hCMOS sensors for every snout exchange, the hCMOS is at risk for damage in the move sequence. Because of these 2 key requirements this option scored poorly.

The hCMOS fixed with novel kinematic snout interface scored the best across all options. The polar DIM operators have requested improvements to the standard kinematic snout interface in the past. The interface requires and operator to reach out and hold a snout while connecting the 3-point kinematic. This operation puts strain on the operator and poses a drop risk for the snout. By relocating and improving the kinematic connections, OpSpecTR can ease the install ergonomics and reduce the snout drop risk. This option however does have some risk for damaging the hCMOS with the kinematic interface moved to the hCMOS sensor face parallel to the DIM axis. With that risk weighed, the best viable option remains the hCMOS fixed in place with a novel kinematic snout interface.

4 System Context and Concept of Operations

4.1 System Context Diagram

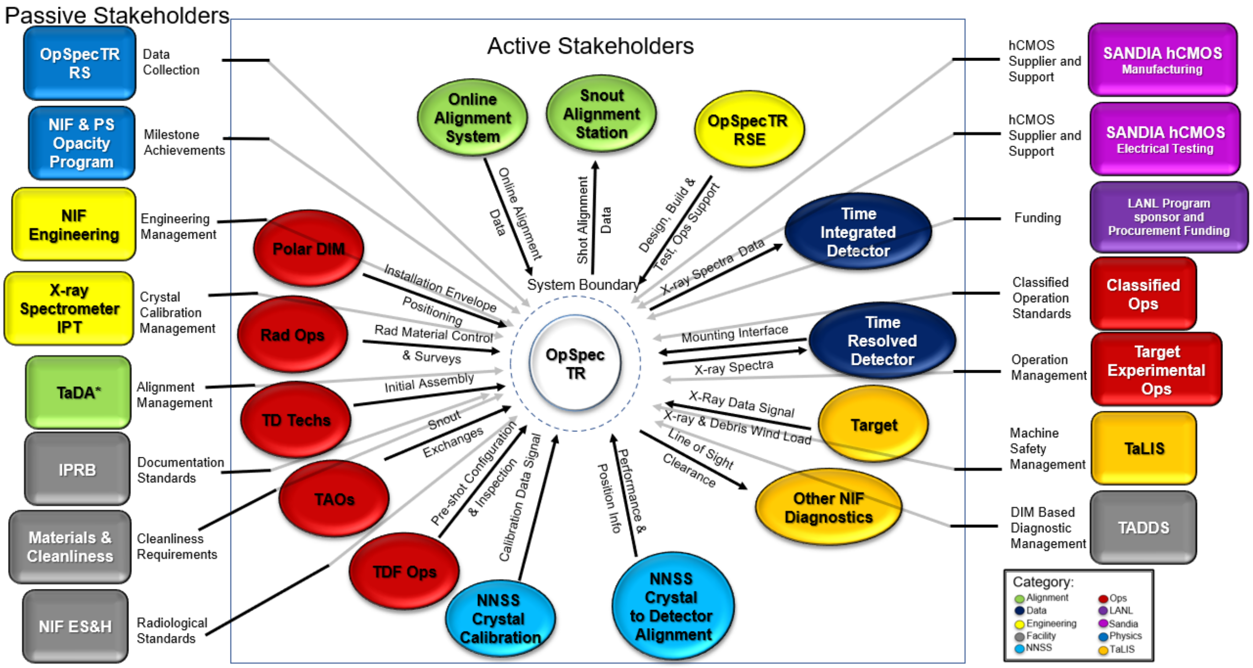

Figure 14. System Context Diagram

The system context diagram is shown above in figure 14. The passive stakeholders and active stakeholders are listed according to their interactions with the system. The active stakeholders physically handle and interact with the system as it operates. The passive stakeholders are interested in the performance of the system but do not physically interact with the system. The system requires frequent handling at NIF to prepare for a shot as well as for recovering data following the shot. The complex facility of NIF requires careful coordination of manpower and scheduling to field a snout and airbox specific to a shot campaign such as the Opacity program. More coordination is required for OpSpecTR because the system is combined with an OpSpecTR dedicated airbox that is solely used for OpSpecTR. Typical snout configurations fielded at NIF mount to airboxes that remain in the DIMs for extended use. OpSpecTR requires an airbox transaction removing a standard airbox and installing OpSpecTR for every campaign. Optic calibrations and alignments are performed prior to campaigns as well to ensure quality data.

4.2 System Concept of Operations Diagram

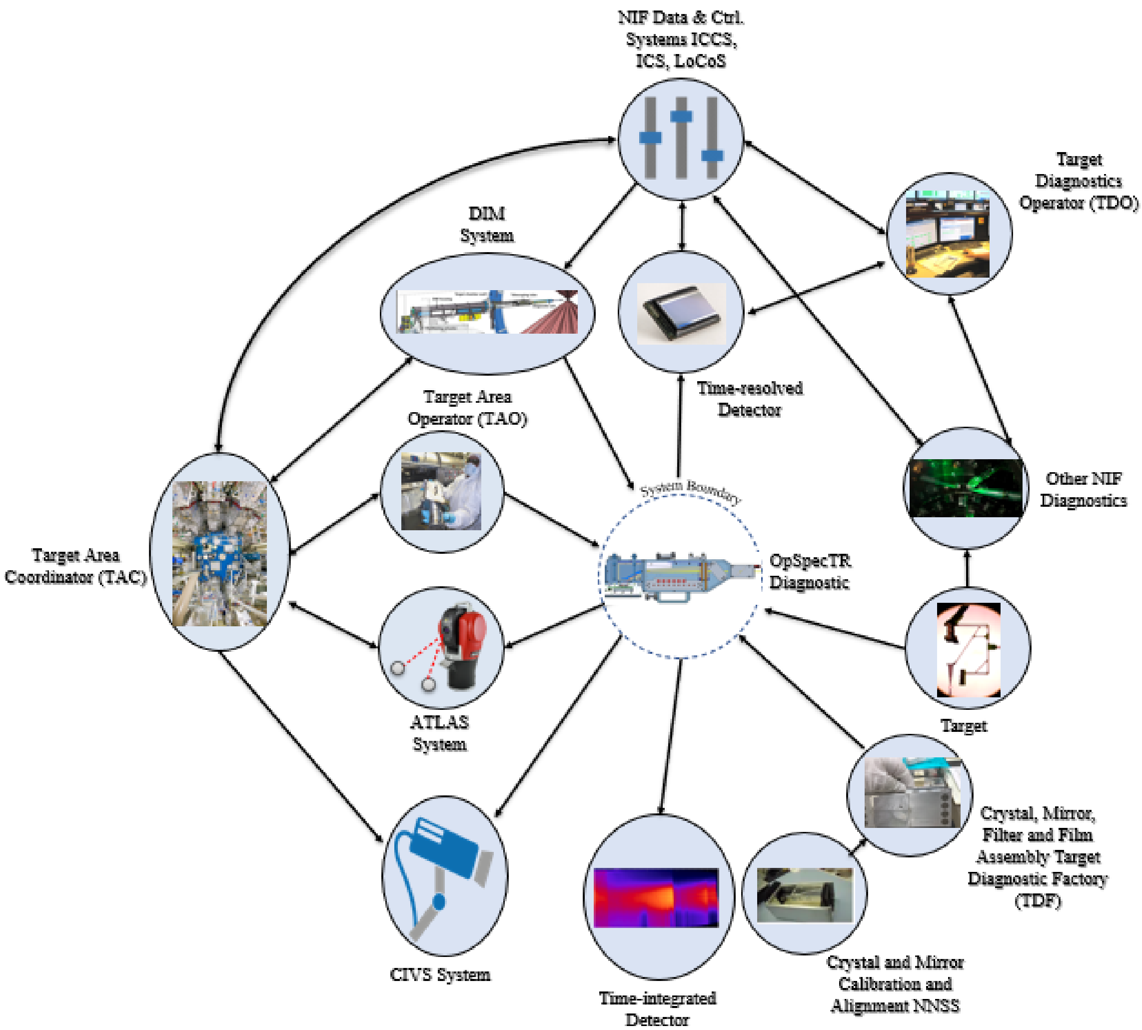

Figure 15. System Concept of Operations Diagram

The concept of operations diagram above reflects the complex interactions of the many groups at NIF. OpSpecTR adds more complexity to this operational diagram with the addition of outside groups such as NNSS and Sandia. The multi-lab project model allows for collaboration across different lab experiments. This added complexity requires careful coordination and integration into NIF. The goal for all snout designs is to provide the target diagnostic factory with all components required to ready a snout for a NIF shot. Similarly the diagnostic airbox is tested by TDO's and TAC's to ensure functionality prior to installation in a DIM to ensure that the facility is not affected by downtime during the airbox transaction. Once the system is installed at NIF, further groups become involved to ready for the shot including the alignment group to align the snout, target and any other diagnostics present on the shot. When the shot is taken, data recovery and snout and airbox transactions begin as needed. In the case of OpSpecTR, the snout will be transacted 3 times for a 3 shot campaign and the airbox will be removed following the campaign.

4.3 System Use Case Diagram

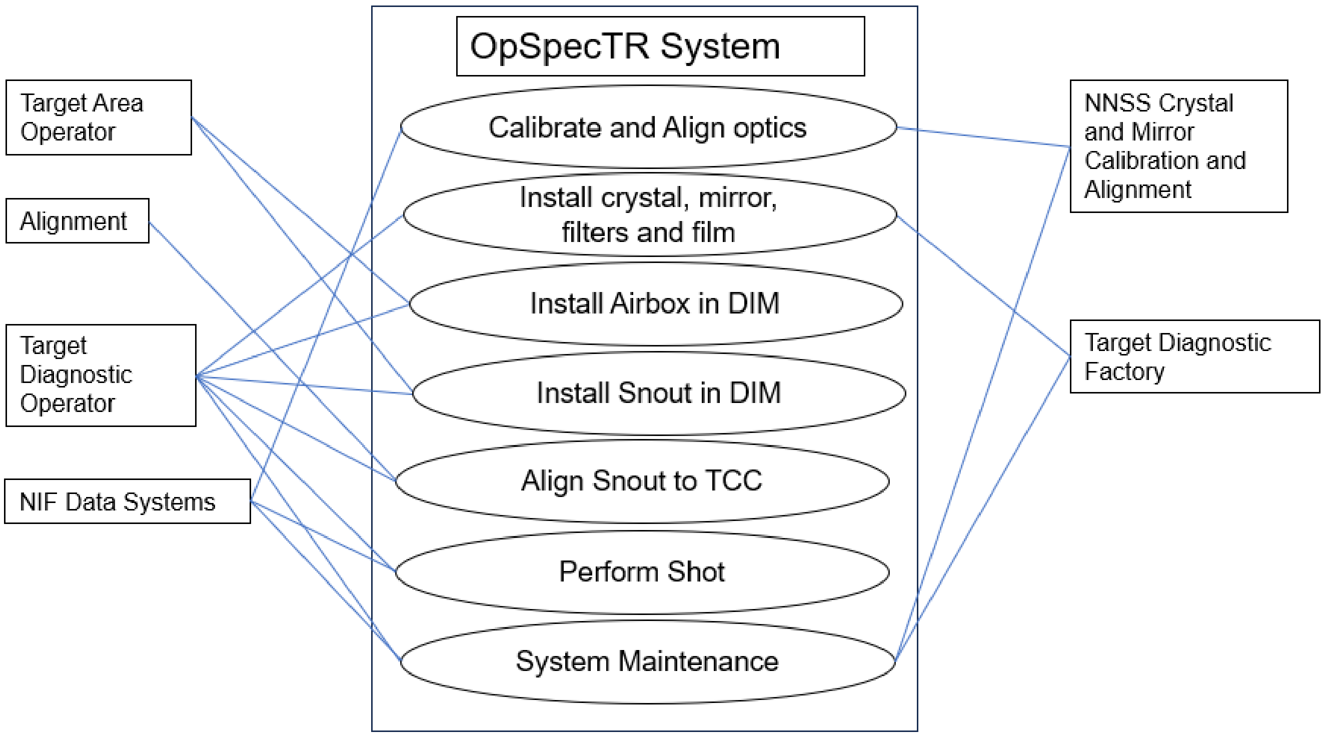

Figure 16. System Use Case Diagram

The system use case diagram reflects the planned use cases of the system. Every snout will need to have calibrated and aligned optics ready for install into the snout. This effort is performed by NNSS with their alignment and x-ray sources and the data from the calibration is sent to the NIF data systems for storage. The target diagnostic factory is physically involved in assembling the snout. Upon completion the target diagnostic communicates to the diagnostic operator that the snout is ready for the shot. In parallel with this effort is the installation of the airbox in the DIM. This effort is performed physically by the target area operators in coordination by the target diagnostic operator. When the airbox is installed in the DIM the snout can be installed. The snout install is also performed by the target area operator in coordination with the target diagnostic operator. Once installed the DIM is inserted into the chamber for alignment to TCC. The alignment is performed by the alignment group with use of the ATLAS tracker system in coordination with the target diagnostic operator. Following alignment the system is now ready for the shot. This effort is in coordination with the target diagnostic operator and the NIF data system ready for data recovery. The complex system requires maintenance following each campaign to ensure the integrated electronics are timed and function as needed as well as crystal and other optic replacements for future shots as needed. The maintenance of the snout and airbox are performed across several groups including NNSS, the target diagnostic factory, the NIF data system and in coordination with the target diagnostic operator.

4.4 System Sequence Diagrams

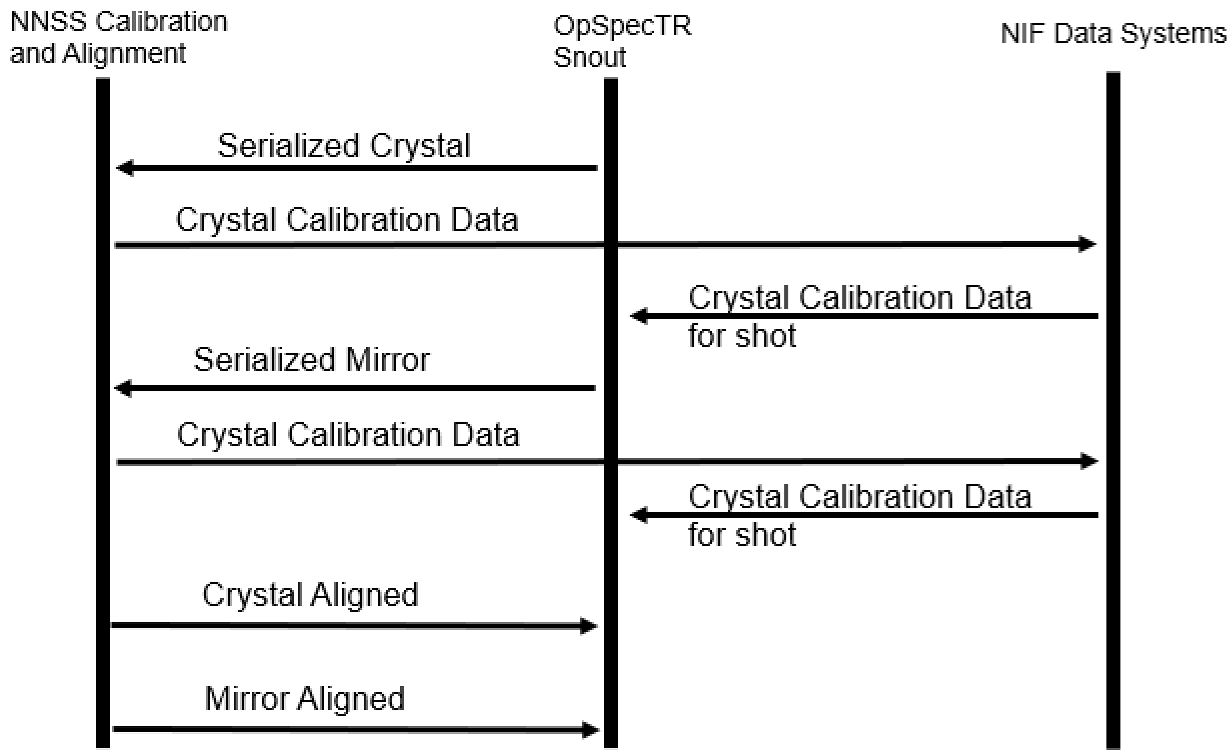

Figure 17. Sequence Diagram for Calibrate and Align Use Case

The sequence diagram above breaks down the sequences for the calibration and alignment of the snout optics. Serialized crystal and mirrors are provided to NNSS and the calibration data performed at NNSS is sent to the NIF data systems. Following calibration the crystal and mirror are aligned ready for installation into the snout for the next sequence.

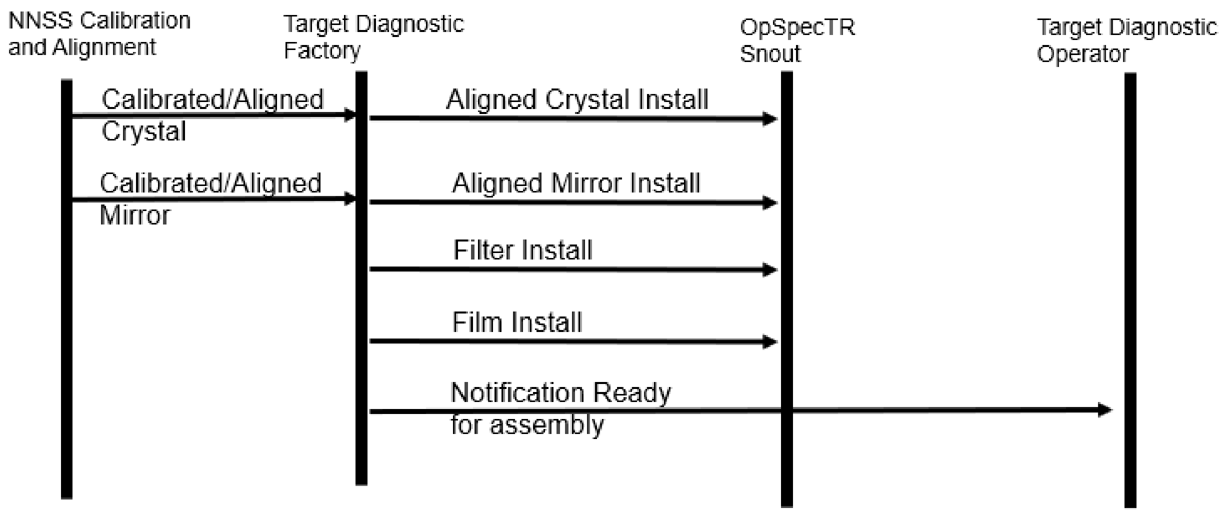

Figure 18. Sequence Diagram for Crystal, Mirror, Filter and Film Install Use Case

The sequence diagram above breaks down the sequences for the crystal, mirror, filter and film install into the snout. The target diagnostic factory procures the filters and film and maintains inventory for each. NNSS provides the factory with aligned and calibrated optics for install into the snout. When complete a notification is sent to the target diagnostic operator.

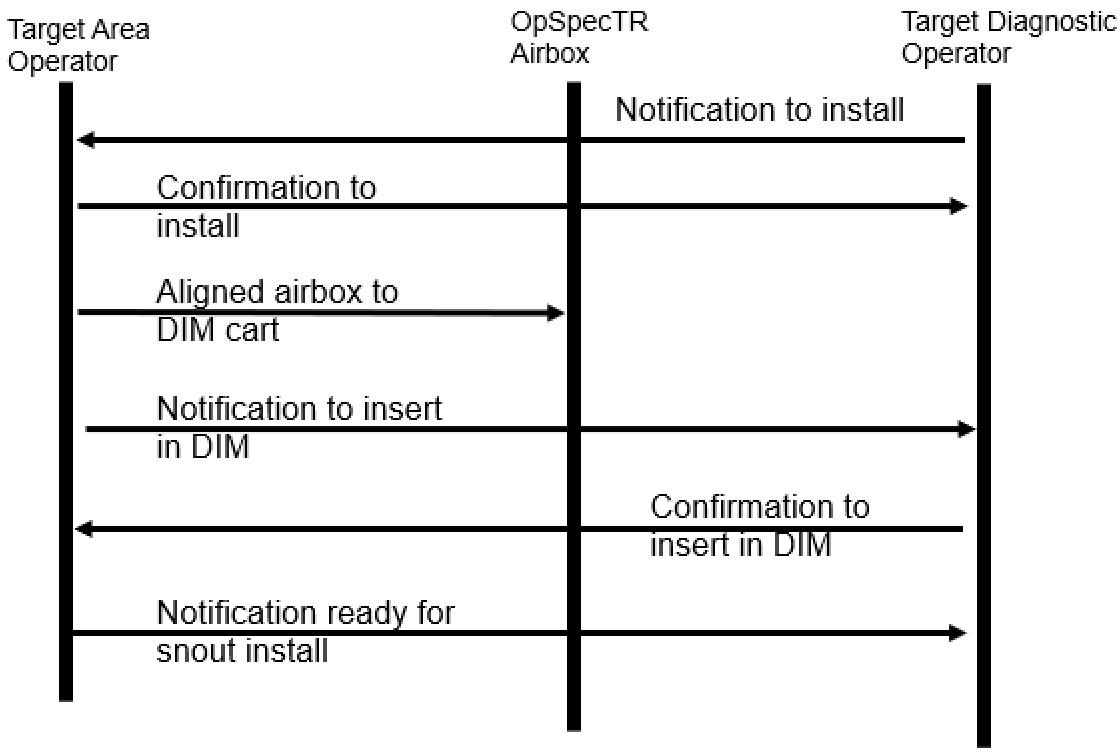

Figure 19. Sequence Diagram for Airbox DIM Install Use Case

The sequence diagram above breaks down the sequences for the airbox installation into the DIM. The target diagnostic operator communicates to the target area operator when it is time to install the airbox. The target area operator confirms the install request and begins the airbox installation and alignment process into the DIM. When aligned the airbox insert request is sent to the target diagnostic operator. The target diagnostic operator confirms the insert request. Finally the target area operator inserts the airbox in the DIM and sends a notification to the target diagnostic operator that the airbox is ready for snout installation.

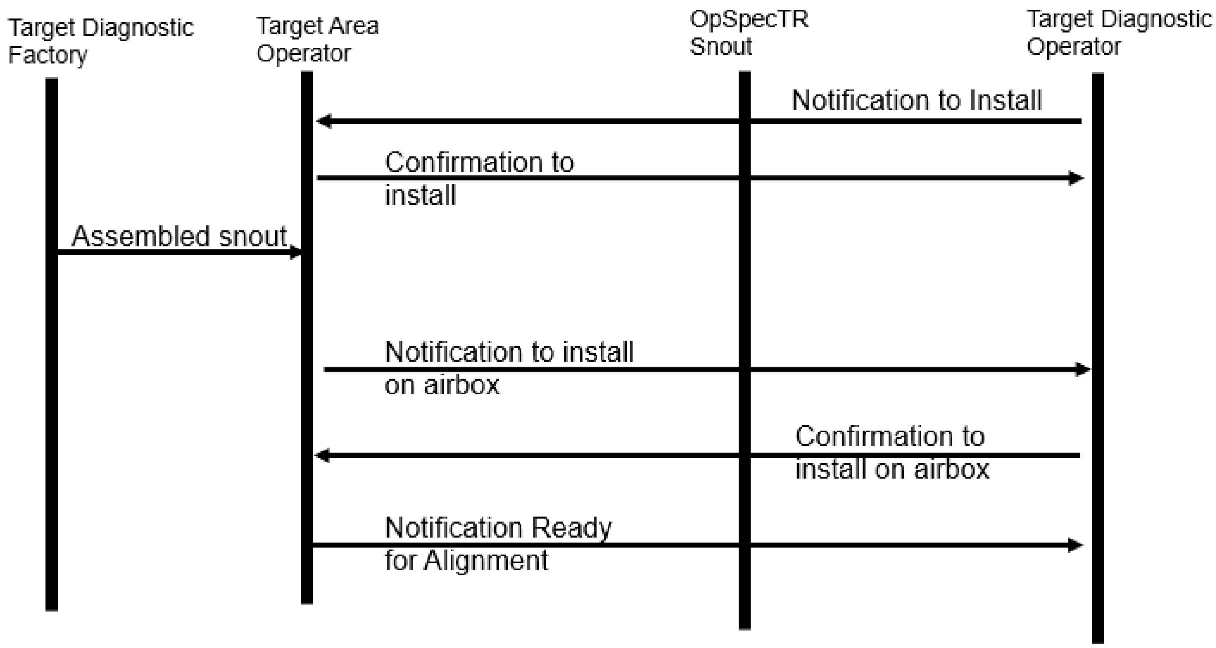

Figure 20. Sequence Diagram for Snout DIM Install Use Case

The sequence diagram above breaks down the sequences for the snout install into the DIM. The target diagnostic operator coordinates and communicates with the target area operator notifying to install the snout. A confirmation is sent back from the target area operator to the target diagnostic operator. The target diagnostic factory delivers the assembled snout to the target area operator. A final notification to install the snout is sent to the target diagnostic operator. A confirmation to install is sent to the target area operator and the snout is installed ready for the alignment sequence at TCC.

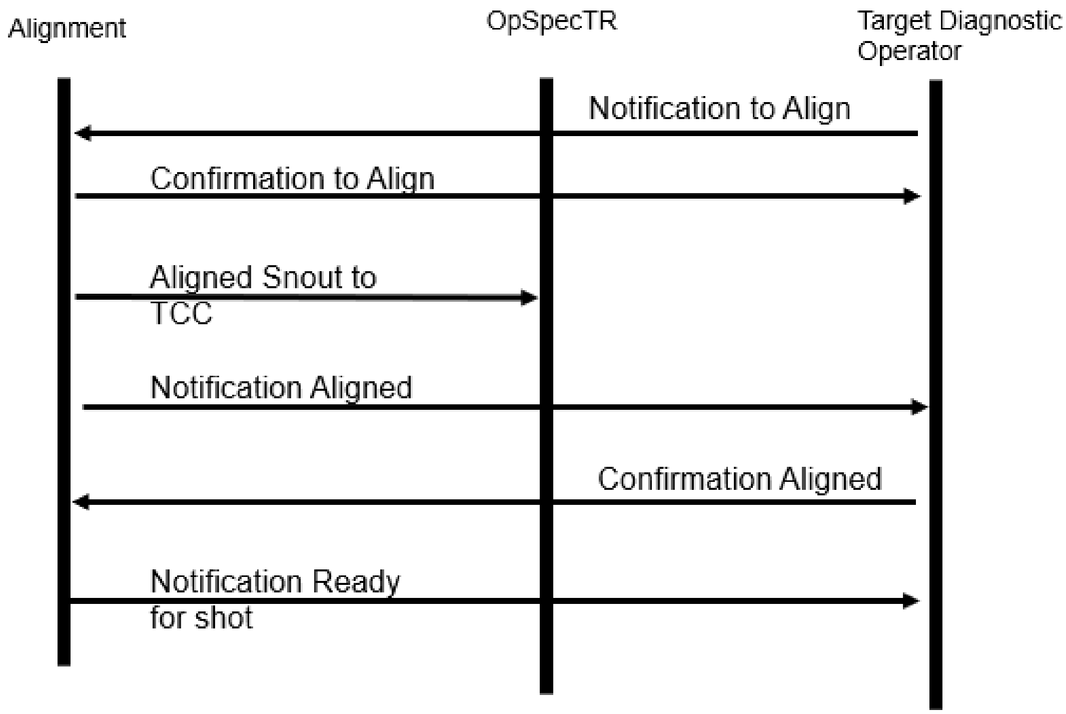

Figure 21. Sequence Diagram for Snout Alignment at TCC Use Case

The sequence diagram above breaks down the sequences for the snout alignment at TCC. The target diagnostic operator sends a notification to the alignment group to align the snout. A confirmation to align is sent back to the target diagnostic operator. The snout is then aligned to TCC via the ATLAS alignment system. A notification is sent to the target diagnostic operator that the snout is aligned. A confirmation of alignment is returned to the alignment group and the snout is ready for the shot sequence.

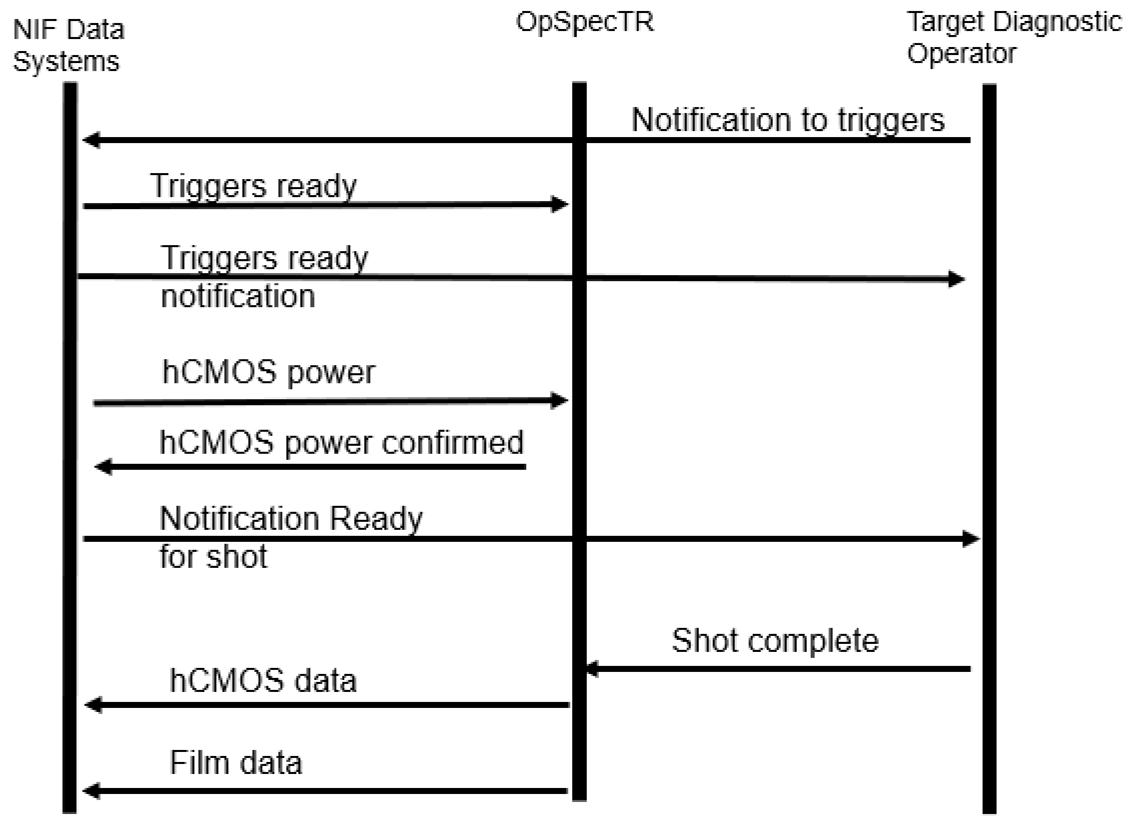

Figure 22. Sequence Diagram for Shot Use Case

The sequence diagram above breaks down the sequences for the shot sequence. The target diagnostic operator send a notification the NIF data systems to confirm triggers. The NIF data system readies the triggers in the OpSpecTR system. A notification is send to the target diagnostic operator that triggers are ready. The NIF data systems turn the hCMOS power on. The OpSpecTR confirms power activation. A notification is sent to the target diagnostic operator that the OpSpecTR system is ready for the shot. The shot is fired. The hCMOS and film data are extracted to the NIF data systems for storage.

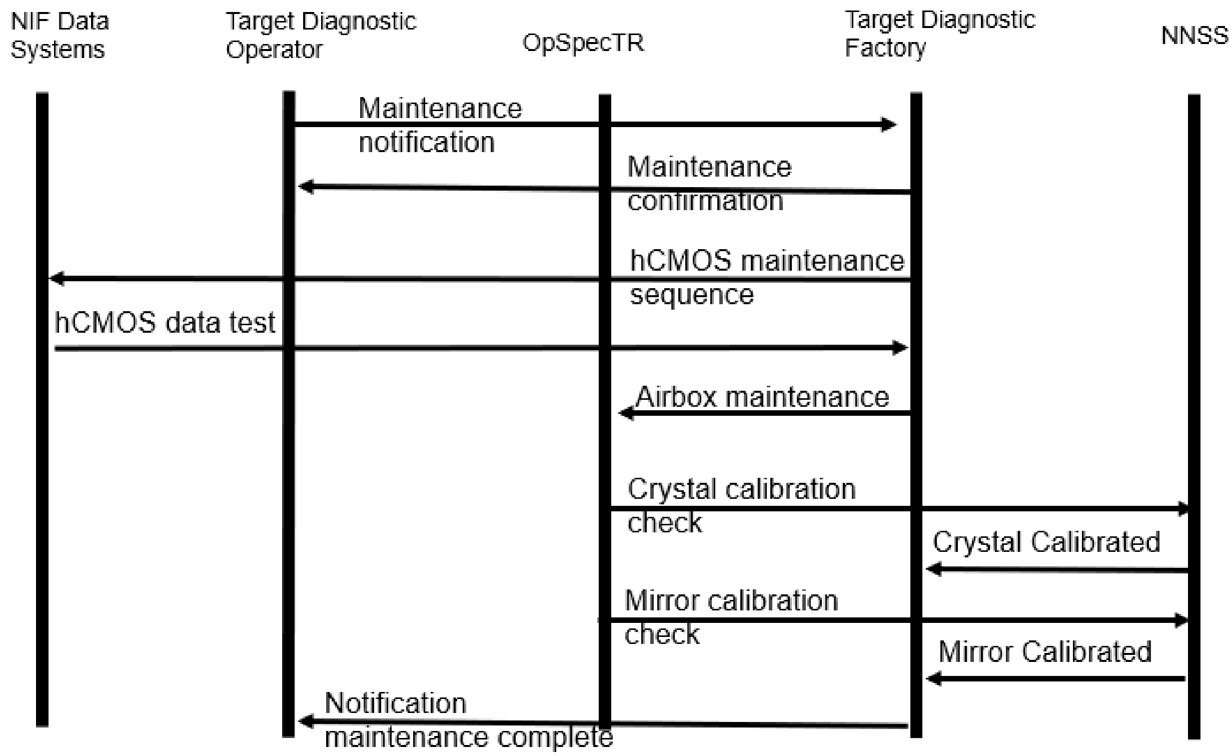

Figure 23. Sequence Diagram for Maintenance Use Case

The sequence diagram above breaks down the sequences for the maintenance sequence. The airbox electronics require confirmation of functional operation and timing confirmations. The snout will require optic exchanges following campaigns as well. These maintenance steps begin with the target diagnostic operator sending the target diagnostic factory a maintenance notification. The target diagnostic factory sends a confirmation of the request. The target diagnostic factory sends the NIF data systems the hCMOS maintenance sequence. The NIF data system send maintenance test data back to the target diagnostic factory. The target diagnostic factory performs maintenance as needed on the airbox. The OpSpecTR crystals and mirrors are sent to NNSS for calibration checking. The crystal and mirrors are returned from NNSS to target diagnostic factory. The target diagnostic factory finally sends a notification to the target diagnostic operator that the maintenance activities have been completed.

5 Quality Function Deployment

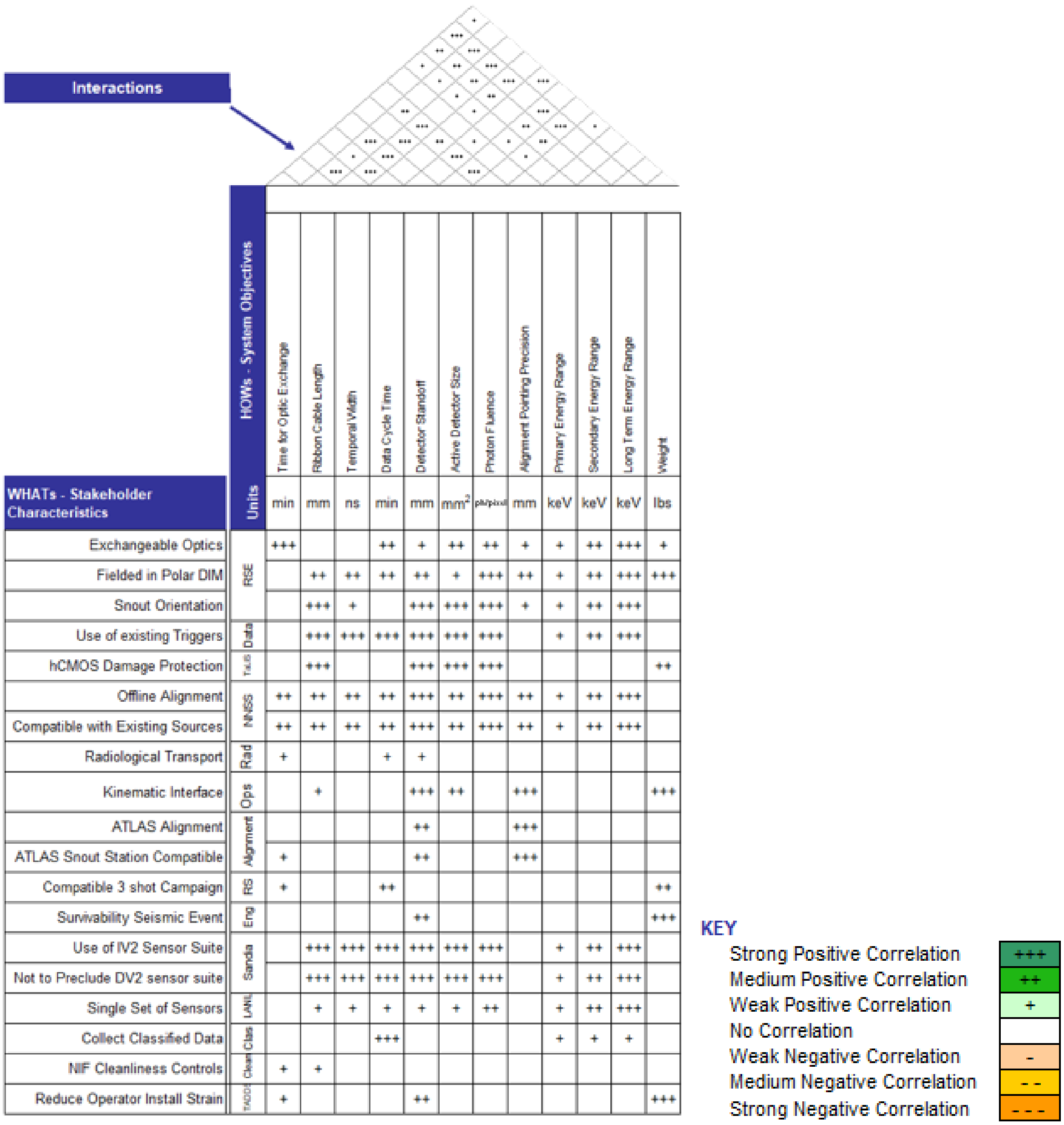

Figure 24. System QFD

A Quality Functional Deployment (QFD) analysis was used to translate the stakeholder characteristics in to system objectives and non-functional system requirements. The QFD is designed to understand the correlation between various characteristics and objectives and their interactions with each other.

Some key requirements became apparent in their correlation with each other specific to the sensor objectives. The length of the ribbon cable has clear interactions with the sensor performance such as temporal width and data cycle time. If the design attempts to protect the hCMOS from damage with a change in detector standoff distance from TCC the ribbon cable length, data cycle time, and photon fluence are strongly affected. It is clear that the performance of the sensor suite will be a key design aspect for OpSpecTR.

Another interesting set of interactions and correlations is from the survivability characteristic from a seismic event. NIF has standards for factors of safety on components and bolt loading in a seismic event and the weight of the system and location in the DIM interact to dictate what can be fielded without careful design to meet the factors of safety. The detector standoff distance also dictates the size of the snout by enveloping the location the x-rays must land on the sensor suite. This characteristic is closely coupled with the characteristic to reduce the strain on the polar DIM area operator during a snout install. The weight and detector standoff both correlate in determining whether the snout is awkward to install. A balance between detector standoff and photon fluence to meet the physics goals must be considered for safe seismic and ergonomic deployment at NIF.

6 System Requirements

The system requirements for OpSpecTR are captured below. The requirements for OpSpecTR are organized in sections with the top level requirements which flow from the key acceptance criteria. Section 2 are flow down requirements specific to the top level requirements. Similarly sections 3 and 4 flow down as well. The flow down characteristics are directly derived from the QFD analysis. The requirements all have verifications methods to confirm acceptance of each specific requirement. Each requirement also lists the owner of the requirement which NIF considers the main stakeholder in the specific requirement. Interested stakeholders specific to each requirement are also indicated.

The below requirements represent the culmination of the work in the previous discussions of this document however they are developed in an iterative process until all stakeholder expectations are accurately captured. Many of the requirements listed are standardized NIF requirements for any diagnostic fielded at NIF, however these requirements must also be confirmed due to the evolution of these standard requirements as NIF continues to evolve with new characteristics and capabilities.

Rqmt Level	Req #	Rqmt Category	Rqmt Title	Rqmt Text	Owner	Rqmt Verification Method	Related Rqmt(s)	Stakeholders
0	A	Top Level	Mission Statement	OpSpecTR system shall produce time-resolved data and will reduce background in OpSpec to allow opacity measurements at higher temperature to support program nDatads	RS	Demo	0	RS, RSE, Data, Ops, Fac, Align
1	B	Top Level	X-Ray Energy	The system shall have long term X-ray Energy Range 0.5-15 keV	RS	Demo	A	RS, RSE, Data, Ops, Fac, Align
1	C	Top Level	X-Ray Energy	The system shall have X-ray Energy Range Primary Goal 1.0-1.8 keV Secondary Goal 0.5-2 keV	RS	Demo	A	RS, RSE, Data, Ops, Fac, Align
1	D	Top Level	Timing	The system shall have Minimum of 1 temporal frame with full width half max temporal width of less than 2 ns, centered within 0.3 ns of requested time.	RS, Data	Test	A	RS, RSE, Data, Ops, Fac, Align
1	E	Top Level	Spatial Size	The system shall have image area sufficient to record 3 specific regions of interest, each ROI being 500x80 resolution elements, from opacity target X-ray emission entering Polar DIM. ROIs are separated by several mm. ROIs are separated by 10 mm per current target design.	Data,RSE	Insp	A	RS, RSE, Data, Ops, Fac, Align
1	F	Top Level	Environment	The system shall interface and operate in the existing NIF and experimental environment (it must fit, be triggered, and operate in NIF) (zero to low neutron yield shots <1e13, EMP)	RSE	Analysis	A	RS, RSE, Data, Ops, Fac, Align
1	G	Top Level	DIM Location	The system shall operate in an polar configuration	RSE	Analysis	A	RS, RSE, Data, Ctrl, Ops, Fac, Align
1	H	Top Level	Photon Fluence	The system shall design to constrain Photon fluence within operating range of hCMOS sensor. Design not to preclude future upgrade to larger-well sensors.	Data,RSE	Analysis	A	RS, RSE, Data, Ops, Fac
1	I	Top Level	Detector Compatibility	The system shall be compatible with CMOS detector and either IP, film, or a second CMOS adjacent in the width direction	RSE	Analysis	A	RS, RSE, Data, Ops, Fac, Align
1	J	Top Level	Classified Data Collection	The system shall collect classified data at SRD level	Data,RSE	Analysis/Insp	A	RS, RSE, Data, Ops, Fac
1	K	Top Level	Uncertainty	The system shall have relative uncertainty between sensors of 1% of signal averaged over 2 mm column of pixels (80 pixels) in the non-spectrally resolving direction, after background and sensitivity correction	RS	Demo/ Test	A	RS, RSE, Data, Ops, Fac, Align

Rqmt Level	Req #	Rqmt Category	Rqmt Title	Rqmt Text	Owner	Rqmt Verification Method	Related Rqmt(s)	Stakeholders
2	1	Alignment	Standoff Distance	The system shall nominally operate at a standoff distance from target to CMOS sensor of not less than 0.6m, and shall not preclude operation at longer distances.	NIF	Demo	H	RS, RSE, Ops, Fac, Align
2	2	Alignment	Alignment	The system shall be pointable in the DIM centering directions to obtain a view of the target and create a clear data path betwDatan the target and the hCMOS sensor through the apertures of the system with ±0.5mm pointing precision	NIF	Demo	H	RS, RSE, Ops, Fac, Align
2	3	Controls/Data Systems	Distributed Controls System Configuration	The system should use standard NIF control software	NIF	Insp	G	RS, Data, Ctrl, Ops, Fac
2	4	Controls/Data Systems	Classified Data Collection	The system shall support classified experiments	NIF	Insp	G	RS, Data, Ctrl, Ops, Fac
2	5	Controls/Data Systems	Software Development	The system should use standard NIF Controls for hCMOS sensors.	NIF	Insp	G	Data, Ctrl, Ops, Fac
2	6	Controls/Data Systems	Data Collection, Timing Verification	The system shalll allow data acquisition on a 5-minute cycle to allow for timing verification with the fiducial system	NIF	Demo	G	RS, Ctrl, Ops
2	7	Detector	Mounting	The system shall be installable in Polar DIM not to preclude any equatorial DIM or TANDM	NIF	Analysis	G; H	RSE, Fac
2	8	Detector	Physical Envelope	The system envelope shall fit within the TDF factory stands, DIM Space Envelope and, upon insertion, remain outside the TaLIS stay-out zones for either Polar or Equatorial DIMs and TANDM 90-124.	NIF	Analysis	G; H	RS, RSE, Ops, Align
2	9	Detector	Weight	The weight of the system shall not exceed the weight limit of either Polar or Equatorial DIMs. Snout weight limited to 25 lbs	NIF	Analysis	G; H	RSE, Ops, Fac, Align
2	10	Detector	Photoconductive Detector	The system shall not to preclude installation of a photoconductive detector (PCD) in the optics enclosure with a Line of Light (LoS) able to see the X-ray source - to provide a lower-resolution, long-record RSEasureRSEnt of the x-ray signal to aid with post-shot timing of the CMOS camera data	SANDIA	Demo	0	RS, RSE, Data, Ctrl
2	11	Detector	Ride-Along Data	The system shall be capable of taking data on "ride-along" shots to verify system performance	NIF	Demo	0	RS, Data, Ops
2	12	Detector	Field of View	The system shall have field-of-view of the instrument no less than 5mm diaRSEter centered at the requested aimpoint.	NIF	Analysis	H	RS, RSE, Ops, Align
2	13	Detector	Low Energy Time Integrated Signal Film	The system shall allow use of removable filters, film or image plate in front of the hCMOS sensor in situ.	NIF	Analysis	C	RS, RSE, Ops, Align
2	14	Detector	NIF ATLAS Alignment	The system shall incorporate fiducials to support alignment with ATLAS in polar DIM, and to not preclude ATLAS provisions for future EQ DIM locations. As well as fiducials for optical alignment at NIF and the snout station.	SANDIA	Demo	G; H	RS, RSE, Ops, Align
2	15	Detector	Maintainability	The system design shall allow for changing the X-ray diffracting crystals and filters and image plate or film detector (non-hCMOS components) betwDatan consecutive shots without disconnecting the hCMOS.	NIF	Demo	B; C; G	#REF!
2	16	Detector	Data Collection, Primary Shots	The system shall be designed to allow for data collection on 3 consecutive primary shots without a change in detector location	NIF	Demo	G; H	RS, RSE, Ops, Align
2	17	Detector	Detector Orientation	The system design shall support the same orientation (e.g. chamber phi relative to polar axis) as the current OpSpec snout.	NIF	Analysis	A	#REF!
2	16	Detector	Data Collection, Primary Shots	The system shall be designed to allow for data collection on 3 consecutive primary shots without a change in detector location	NIF	Demo	G; H	RS, RSE, Ops, Fac, Align
2	17	Detector	Detector Orientation	The system design shall support the same orientation (e.g. chamber phi relative to polar axis) as the current OpSpec snout.	NIF	Analysis	A	RS, RSE, Ops, Fac, Align
2	18	Detector	Install/Service	The system shall be able to install, dismount, and remount at radial and polar locations regularly with minimal impact to the facility	NIF	0	H	RSE, Ops, Fac, Align
2	19	Detector	Mechanical Loading	The system shall withstand rare earth events / seismic activity without causing catastrophic failure.	NIF	Analysis	G	RSE, Ops, Fac
2	20	Detector	Mounting	The system shall have Electrical cabling compatible with the DIM Airbox design (including possible rotation options) without interference or breakage.	NIF	Analysis	27	RSE, Data, Ops, Fac
2	21	Detector	Operating Vacuum	The system shall be capable of operation at pressures from NIF chamber pressure (~1E-7 Torr) up to atmospheric pressure (for offline calibration).	NIF	Test	B	RS, RSE, Data, Ops, Fac
2	22	Detector	Spatial Resolution Elements	The hCMOS sensor shall have at least 20 resolution elements, spanning at least 10 mm in the "short" direction of the sensor for spatial resolution and averaging of the data.	NIF	Test	E	RS, Data
2	23	Detector	Position and Angle	The hCMOS sensor shall be positioned and angled so as to capture X-rays diffracted off the crystal in the energy range of interest without an extreRSE incidence angle (>45 deg from normal).	NIF	Analysis	G	RS, RSE
2	24	Detector	CMOS Camera Calibration	There shall be a commissioning plan to verify timing after installation	NIF	Test	A	RS
2	25	Detector	CMOS Camera Calibration - Post Installation	The CMOS camera timing shall be verified with a timing shot after installation as detailed in approved commissioning plan	NIF	Test	0	RS, Data, Ops, Fac
2	26	Detector	Survivability	The system shall be design to not incur damage other than to the blast shields and crystals over the range of experiRSEntal conditions described in this requirements document	NIF	Analysis	G	RS, RSE, Data, Ops, Fac, Align

Rqmt Level	Req #	Rqmt Category	Rqmt Title	Rqmt Text	Owner	Rqmt Verification Method	Related Rqmt(s)	Stakeholders
2	27	Detector	Temporal Gating	The temporal gate shall be stable regardless of photon fluence into a given pixel.	NIF	0	F	RS, Data
2	28	Detector	Temporal Gating	The system shall include temporal gates of < 2 up to > 30 ns and shall be remotely switchable.	NIF	Test	D	RS, Data
2	29	Detector	Airbox Cooling	The electronics airbox shall be temperature controlled with active cooling as required.	NIF	Demo	G	Data, Fac
2	30	Detector	System Jitter	OpSpecTR shall not add more than ±50ps Peak-to-Peak jitter to the diagnostic timing	NIF	Test	D	RS, Data
2	31	Environment	Mechanical Loading	The system shall be designed to operate under the mechanical sesimic loading environment of the Polar and Eq DIM positioner at the intended locations of operation	NIF	Analysis	G	RS, RSE, Fac
2	32	Environment	Cable shielding	All cables sensitive to EMI betwDatan EMI enclosures shall be contained within EMI shielding conduit or shall have adequate EMI filtering	Fac	Insp	G	RS, Data, Fac
2	33	Environment	EMP/EMI	The system shall operate in the EMP/EMI environment of NIF at the intended locations of operation	NIF	Analysis	G	RS, Data, Fac
2	34	Environment	Neutron Flux	The system shall acquire usable data at 1E13 DT neutrons at TCC.	NIF	Analysis	G	RS, RSE, Fac
2	35	Environment	X-ray Flux	The system shall operate in the x-ray environment of NIF at the intended locations of operation	NIF	Analysis	G	RS, RSE, Fac
2	36	Environment	High Voltage	The detector shall be properly grounded to operate in the NIF DIM.	NIF	Analysis	G	RS, Data, Fac
2	37	Facility	Equipment Removal	All equipment, assemblies, and cabling shall be designed to be removable within standard NIF shot cycle.	NIF	Analysis	G	RSE, Data, Ops, Fac
2	38	Facility	Shot & Maintenance Operations	The system shall be designed to follow NIF facility shot operations and maintenance operations	NIF	0	G	RSE, Data, Ops, Fac, Align
2	39	Safety	Safety and Ergonomics	The system will be reviewed for and shall be safe, ergonomic, and in compliance with all regulations and institutional guidelines.	NIF	0	A	RS, RSE, Data, Ops, Fac, Align
2	40	Safety	EnginDataring Design Safety Standards	All work done at or by NIF shall comply with the LNLL EDSS	NIF	Analysis	A	RS, RSE, Data, Ops, Fac, Align
2	52	Detector	Camera Chiller	CMOS sensor shall be temperature regulated by vacuum campatible cooling methods	NIF	Demonstration	G	Data, Fac

Rqmt Level	Req #	Rqmt Category	Rqmt Title	Rqmt Text	Owner	Rqmt Verification Method	Related Rqmt(s)	Stakeholders
3	1	Detector	Weight	The system shall not weigh more than 400 lbs for Polar DLP limit	NIF	Demonstration	2.14	RSE, Ops, Fac, Align
3	2	Detector	Low Energy Time Integrated Signal Film	Filterpack assembly shall be light tight to allow for the use of film	NIF	Demonstration	2.18; 3.29	RS, RSE, Ops, Align
3	3	Detector	Removable Alignment Optics	Removable alignment optics shall mount with precision kinematic points to assure accuracy of alignment between dismounts of the assembly for each shot.	Sandia	Demonstration	2_23	RSE, Ops, Align
3	4	Detector	Camera Chiller	The chiller should have 3000W of cooling with 3 lpm maximum flow and produce at least 25 PSIG of pressure in the closed circuit cooling loop and have an internal reservoir of >1 liter with level sensor. Remote control via serial port. The water should be 14°C	NIF	Analysis	2.40	RSE,Ops, Fac
3	5	Detector	Trigger	The facility shall provide a trigger with less than ±100ps jitter peak to peak (or 30 ps RMS)	NIF	Demonstration	2.38	RS, Data,Ops, Fac
3	7	Detector		Trigger to Gate Time shall be consistent within +/-300 ps RMS for gate widths < 3 ns, or 10% of gate width for larger gate widths	NIF	Analysis	2.38	RS, Ops
3	8	Detector	Vacuum Gaps	The design of the enclosure shall maintain adequate vacuum gaps or dielectric insulation to ensure good high voltage standoff for the highest voltage as well as gaps to prevent damage to filters	NIF	Analysis		RSE,Data
3	9	Detector	Dry Run Timing	Timing facilities shall be available to provide dry run/pre-shot to check instrument timing	Sandia	Inspection	G	RS,Data, Ctrl, Fac
4	1	Facility	Install/Service	The detector mehcanical interface shall have alignment features to align the snout within the alignment tolerance	NIF	Analysis	2.28	RSE, Ops
4	2	Facility	Mounting	Location pins to ensure proper assembly	NIF	Analysis	2.28	RSE, Ops
4	3	Facility	Mounting	The instrument should have simple well labeled connections and a minimum number of connectors. Connectors shall be designed so that they cannot be interchanged.	NIF	Inspection		RSE, Data, Ops
4	4	Facility	Mounting	Work shall take place inside the DIM, in regards to snout transaction and CMOS connection	NIF	Inspection		RSE, Data, Ops
4	5	Facility	Mounting	Retroreflectors shall not be removed between snout transactions and need to have separate sets that are characterized in the facility	NIF	Inspection		RSE, Data, Ops

Table 6. System Requirements

7 System Functional Decomposition and System Functional Architecture

7.1 System Functional Decomposition

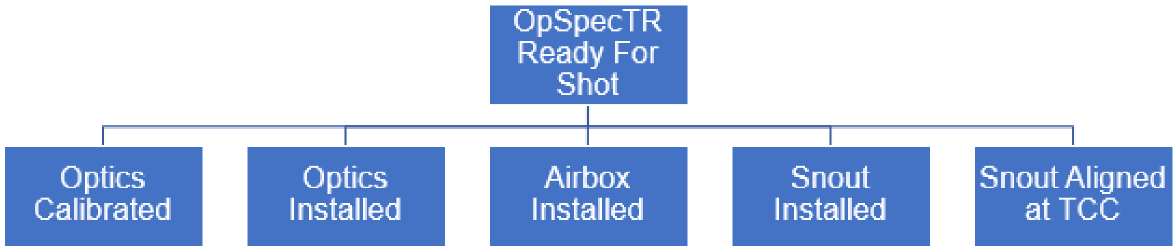

Figure 25. System Functional Decomposition

The figure above shows the first level decomposition for the OpSpecTR system. The goal of this decomposition is to have the OpSpecTR system level function ready for a shot. The system will require a number of steps and tasks to achieve the ready for shot status. This decomposition breaks those steps up into manageable tasks. The design effort will use this decomposition to aid in innovative and effective solutions to ensure the system achieves its requirements. The decomposition flows into the development of the functional architecture in the next section.

7.2 System Functional Architecture

The functional architecture translates the system requirements into a logical model that identifies the functions within the system that are required to translate the system inputs in to the desired outputs. Such an analysis would identify whether the set of functions identified in the functional architecture is necessary and sufficient.

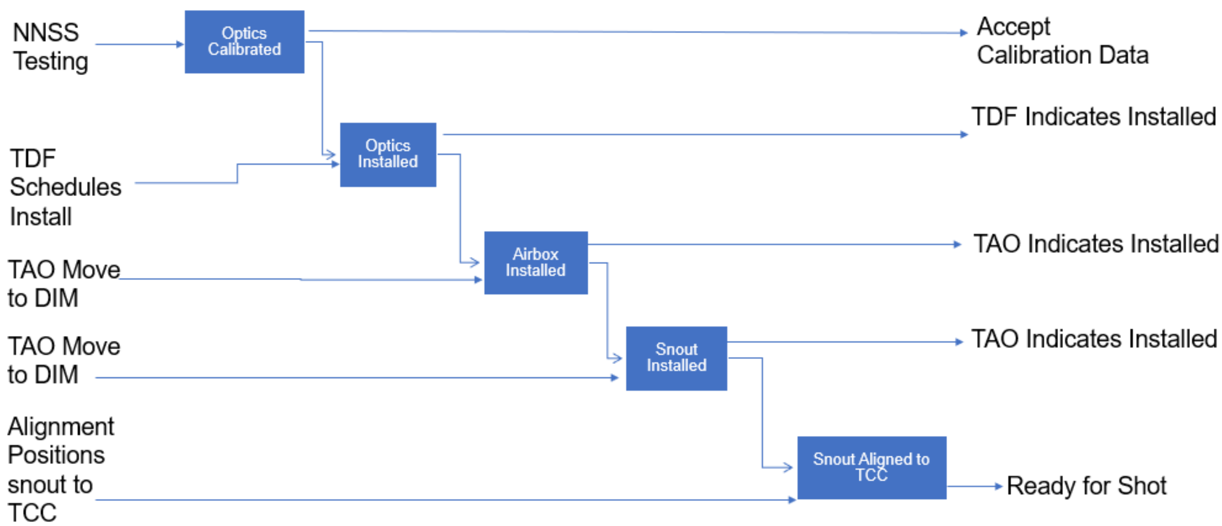

Figure 26. System Functional Architecture

The OpSpecTR functional architecture shown above has the system inputs on the left and the system outputs on the right. Each function is decomposed in a waterfall cascade style with each step in sequence with each other. The first step of the architecture begins with NNSS and optic calibration. This effort can begin early and well before any shot to confirm that optics are on hand and calibrated per the NNSS schedule. The optic installation at the target diagnostic factory begins the coordination effort within the NIF system. Careful discussion and coordination must occur from optics install until the NIF shot due to the complexity of the NIF shot schedule. The day prior to a shot the airbox will be installed by the target area operators. Following this effort hours before the shot the snout will be installed by the target area operators. The final OpSpecTR activity prior to the shot will be the snout alignment at TCC. Finally the system will be ready for the shot.

8 Risks Assessment

8.1 Technical Risks

The OpSpecTR active detectors with use of hCMOS sensors poses a technical risk to the system performance. This represents the key aspect of the OpSpecTR to achieve time resolved data collection for background signal reduction. The sensors are affected by many design features as indicated by the QFD and these features must be monitored frequently in the design to confirm acceptance against the system requirements. A key mitigation to this performance is early testing of optics to compare performance against the existing NIF inventory of IV2 sensors.

The concept selection process also indicated the need for a deviation from the standard snout install features and process. By employing a novel kinematic design, the implementation of this kinematic must be monitored frequently to confirm ergonomic and alignment requirements. A key mitigation will be to early prototype the design to gather operator feedback in order tom implement improvements early in the design phase.

8.2 Schedule Risks

The OpSpecTR system is a full DLP deployment at NIF. Because of this fact, the number of components required to manufacture is significant in comparison to a snout only diagnostic. The airbox mechanical components and x-ray cart are large parts which will requires significant manufacturing time. The schedule needs to reflect the time needed to design any new components. To mitigate this schedule, any NIF legacy parts that will remain unchanged need to be ordered early.

The hCMOS sensor suite using IV2 sensors poses a significant schedule risk in the manufacture and testing of the sensors at Sandia. The IV2 sensors are in the infancy in design and fielding at NIF and other national laboratories. It is known that the IV2 sensors are on the order of a 1 year lead time. To mitigate this NIF does have available stock on hand for testing and development however sensor testing must occur early to confirm performance. The hCMOS sensors should be procured and reflected in the schedule as inherent risks to meeting any milestone dates to further mitigate risk if existing on hand NIF inventory does not meet performance characteristics.

8.3 Funding Risks

The full DLP will require the purchase of 250k mechanical and electrical components independent of the hCMOS. It is expected that the manpower to design and implement the OpSpecTR system to be 500k. The hCMOS individual sensors are expected to cost 100k each. The 1.5M budget proposal for OpSpecTR represents a risk if initial estimates are exceeded.

8.4 Technical Performance Measures TPM's

The key technical performance measures will be monitored closely through the design effort. The hCMOS functional capabilities must be monitored at all stages of the manufacturing and testing stages to confirm requirements are met. The non-functional requirements related to hCMOS performance must be optimized for hCMOS performance coupled with optics performance at each stage of the design process specifically the photon fluence of the hCMOS.

In conjunction with the hCMOS performance the novel kinematic design must be carefully monitored against the hCMOS performance requirements. The novel kinematic design must also be frequently communicated to the target area operators to confirm requirements are met. It is recommended that the novel kinematic design is rapidly prototyped to ensure the target area operators can provide input from handling the new design. Weight of the system and ergonomics must be monitored.

9 Project Reflection

The OpSpecTR system is planning to field in FY24. I have worked on this project for over a year. I began the effort with a requirements review and the system is now beginning the procurement process following our final design review. This project would have benefited from this careful system requirement process in better documentation of system requirements. The hCMOS continue to pose risk for the system deployment but the novel kinematic design reflect an interesting aspect of this design that could have been captured sooner for OpSpecTR.

The novel kinematic design was not in fact initially selected as the concept to begin design. The target area operators and TADDS did voice concern for the polar DIM installation at the requirements review. However, this is often the case for any snout design with use of the polar DIM. It is a very challenging installation and needs to be improved, however at the requirements review this was deemed well beyond the scope of the OpSpecTR system. OpSpecTR could not possibly redesign the kinematic for all polar DIM snouts. Instead a movable mechanism for the hCMOS was selected for the concept.

The novel kinematic design became revisited when it was determined that the complexity required for the movable mechanism posed risks to making the design feasible. A mockup of the movable design was rapidly fabricated and deemed unacceptable. The OpSpecTR pivoted and revisited the concept to modify the kinematic interface. Due to the fact that OpSpecTR would have its own dedicated airbox the kinematic interface could be specific to the OpSpecTR snout, independent of any other snout field on the polar DIM. The off normal aspect of having a sensor suite parallel to the DIM axis and the challenging installation of snouts into the polar DIM provided the OpSpecTR team the opportunity to deviate from a known poor standard or operation. If this discussion had been iterated on with stakeholders earlier the project could have saved front end time and effort on developing a successful design selection.

When I began this project I realized that this system requirements and development could have reduced the schedule strain on the project in better listening to the stakeholders voice and then better weighing the concept options in the Pugh matrix. The OpSpecTR spent significant time developing and prototyping a concept that could have been eliminated for a simpler and improved design for DIM install. I will take this opportunity to improve my future system requirements and concept development to ensure that future concepts listen to all stakeholders and ultimately achieve the system requirements in the best achievable way possible.

Appendix A

Summary of Acronyms

ALARA – As low as reasonably achievable
ATLAS – Advanced Tracker Laser Alignment System
CIVS – Chamber Internal Viewing System
DIM – Diagnostic Instrument Manipulator
DOE – Department of Energy
ES&H – Environmental Safety and Health
HGXD – Hardened Gated x-ray Detector
ICF – Inertial Confinement Fusion
ICCS – Integrated Computer Control System
ICS – Industrial Controls System
IP – Image Plate
IPRB – Integrated Product Review Board
OpSpecTR – Opacity Spectrometer Time Resolved
LANL– Los Alamos National Laboratory
LEH – Laser Entrance Hole
LLNL – Lawrence Livermore National Laboratory
LoCoS – Location Component and State (tracking system)
LOS – Line of Sight
LRU – Line Replaceable Unit
NIF - National Ignition Facility
NIF & PS – NIF and Photon Science
NNSA – National Nuclear Security Administration
PDIM – Polar Diagnostic Instrument Manipulator
QFD – Quality Functional Deployment
RAM – Reliability Availability and Maintainability
RSE – Responsible Systems Engineer
SST – Shot Setup Tool
TAC – Target Area Coordinator
TaDA – Target and Diagnostic Alignment
TaDDS – Target and Diagnostic Deployment System
TaLIS – Target and Laser Interaction Sphere
TAO – Target Area Operator
TanDM – Target and Diagnostic Manipulator
TARPOS – Target Positioner
TASE – Target Area Science and Engineering
TD – Target Diagnostics
TDF – Target Diagnostic Factory
TDO – Target Diagnostic Operator
TEXOPS – Target and Experimental Operations
TC – Target Chamber
TCC – Target Chamber Center