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1. Purpose of this Document

The NGST project is concerned that low-level radiation induced transients will occur in the infrared arrays at a rate high enough to compromise the total noise of the near and mid-infrared IR detector systems. Transients of amplitude comparable to the system read noise cannot be reliably detected and removed in post-facto processing of the science data. These small transients may raise the system noise floor above the total noise requirement, regardless of how low the noise floor is when the spacecraft is not exposed to the natural space radiation environment. In order to understand how serious a threat low-level transients pose to the successful achievement of the NGST science goals, the project has initiated a study of the issue.

Because down-select of the prime contractor for the spacecraft has not been made, details that will affect the internal radiation environment of the arrays such as shield geometry, materials and mass thicknesses are not yet known with certainty. Furthermore, candidate ROIC and detector technologies are still in development. Given the stringent performance requirements for the NGST infrared arrays, significant challenges lie ahead as the project plans for future radiation testing of both ROICs and full hybrids. Even though the NGST program is still early in the design phase, definition of the radiation test plans for the ROICs and hybrids requires that the technical challenges be understood, and hopefully solved, well in advance of the actual tests.

Radiation transient testing of both ROICs and hybrids will provide data for the validation of array transient models. This document focuses only on the ROIC radiation transient testing element of the overall NGST array radiation test effort. Since a facility has not been chosen for the ROIC testing and the devices are still in development, a detailed test plan cannot be written as yet. In this ‘Test Plan White Paper’, we present our top-level concepts for the ROIC transient test. The intent is to both define specific requirements, again at top-level, and to identify technical issues of concern. When a facility is selected for the work, we will have a better understanding of the hardware and software capabilities at our disposal and what facility changes or upgrades may be required to meet the goals of the test. As final design details of the arrays become known, we will be able to determine the sub-array modes and frame rates that will actually be available during the test. We have attempted to incorporate into our top-level requirements sufficient flexibility to ensure that the facility is prepared to promptly proceed with testing when test devices become available. It is our anticipation that this ‘White Paper’ will eventually evolve into a formal test plan after selection of a facility and as we learn more about the flight ROIC design.

2. Introduction

The Next Generation Space Telescope (NGST) will be stationed at the L2 Lagrange point. At L2, NGST will be exposed to Galactic Cosmic Rays (GCRs) and Solar Particle Events (SPEs). Hydrogen (H^+) is the dominant constituent of the GCR and SPE environment, with a small (~5-15%) but non-negligible helium (He^{++}) component. The GCR and SPE spectra extend to energies high enough to penetrate any practical amount of shielding that will surround the NGST infrared arrays. NGST Document 570 defines the L2 radiation environment [1].

NGST will deploy an instrument complement comprised of four near-infrared (NIR) imaging cameras, one NIR multi-object spectrograph (MOS) and one mid-infrared (MIR) imaging camera. Final designs for the instruments have yet to be defined, but science-driven requirements for the IR arrays have been determined. The following table shows a subset of the infrared array technology development specifications (for imaging, unless otherwise noted):

Performance Parameter	NIR Channel	MIR Channel
Total Noise	10 e^- rms (3 e^- rms goal for spectroscopy)	20 e^- rms (3 e^- rms goal for spectroscopy)
Operating Temperature	30 K	6 K
Pixel Pitch	18 μm – 22 μm square	18 μm – 30 μm square
Pass Band	0.6 μm – 5 μm	5 μm – 27 μm
Radiation Immunity	‘causes minimal effect’	‘causes minimal effect’
Cosmic Ray Pixel Upsets	< 18%	< 18%
Maximum Exposure (On-Target Integration) Time	1000 seconds	1000 seconds
Frame Time	12 seconds	3 seconds

It is important to note that the total noise requirement applies at the system level rather than at the array level. NGST Document 641 contains the full set of array design requirements [2]. Footnote 1 of Document 641 indicates that the target number of Fowler samples necessary to achieve the read noise requirements (and goals) is 8. This is not a hard requirement, recognizing that the minimum number of Fowler samples required to meet the total noise specifications depends on the performance of the flight arrays and electronics. Dark current requirements have intentionally not been defined for the arrays. The intent is to allow design flexibility with a limited degree of latitude to trade dark current shot noise against other array (and system) noise sources (see Footnote 1 of Document 641).

The baseline read rate for both the NIR and MIR arrays is 12 μs/pixel. It is planned that the NIR arrays will utilize 1 analog output per Mpixel with all analog outputs to be read simultaneously leading to a frame time of 12 seconds. The MIR arrays will utilize 4 analog outputs per Mpixel leading to a frame time of 3 seconds.

Data will be acquired with up the ramp sampling, sacrificing S/N to obtain time resolved sampling of the pulse. Fowler sampling may be used to demonstrate compliance with the NGST total noise requirement, starting with the Document 641 target of 8 Fowler samples.

Two candidate ROIC technologies will be tested. For the NIR arrays, Rockwell is developing the Hawaii-1R and –2R ROICs (1024^2 and 2048^2 format, respectively) and Raytheon is developing the SB-290 (1024^2 format) ROIC. Raytheon is developing a MIR variant of the SB-290 suitable for operation at 6 K. Rockwell is not proposing a MIR array for NGST. Because the MIR variant of the SB-290 is in development, the format has not been finalized but it will either be 512x512 or 1kx1k. Reference pixels may be incorporated in the competing ROIC technologies to track array drift.

The goal of this test is to understand proton and heavy-ion induced charge contamination of the ROIC pixels. It is recognized that transient effects in the hybrid array will likely be dominated by ionization in the detectors. Testing of bare ROICs is required to isolate the transient behavior of the read out from that of the hybrid as a whole. Transient data will be obtained real time by clocking the ROICs while under irradiation. The transient time constant and decay behavior will be studied at the highest sampling rate consistent with the total noise requirements for the arrays. This data will be used to develop and validate models of the ROICs that will be used for the prediction of performance in the space radiation environment.

Persistence of charge contamination through reset will be studied by acquiring multiple full array images utilizing a flight-like science mode sample rate. The arrays will be irradiated at several particle energies and several angles of incidence. The goals here are to gain an understanding of the correlation between particle energy (or LET), pulse height, pulse duration and the spread of charge into neighboring unit cells.

We anticipate that transient testing of the ROICs will be the first phase of a larger test effort to characterize the radiation hardness of the NGST arrays. Subject to approval and funding by the program, we expect that testing of hybrids will be performed as a follow-up to the ROIC tests. Test requirements for the hybrid arrays have not yet been defined.

3. Accelerator Requirements

The spacecraft and instrument designs are not known with certainty at this point. Heavy amounts of shielding are often employed for imaging devices. For example, a systems engineering requirement of one inch of equivalent aluminum is typical for CCD imagers. Transients caused by secondary particles (or photons) generated in the shielding around the infrared arrays are a concern for

NGST. It may be necessary to tailor the shielding materials, overall mass, ordering of multiple layers or other shielding parameters to find a configuration that minimizes, or at least reduces, background transients due to secondaries. Until we gain a better understanding of the tradeoffs for various shielding configurations and the interactions that will affect both the primary and secondary particle environments, we will have a limited ability to define the low energy internal radiation environment. We will need to separately consider the background galactic cosmic ray environment and the solar proton environment. Particle transients in the NGST arrays will not be the same for these two environments, since the particle compositions, peak particle fluxes, interaction modes and time scales differ significantly.

Because of the practical limitations of the radiation facilities likely to be used for irradiation of the arrays, the following requirements should be viewed as best-effort goals. Deviations are allowable subject to review and approval by the GSFC NGST radiation effects team. The particle energy requirements refer to the energy at the ROIC *after* transport through any intervening shielding material, both intentional and incidental.

3.1 Protons

Energies: 10 MeV, 35 MeV, 300 MeV (TBR)
Angle of incidence (relative to the normal to the ROIC): 0°, 30°, 60°, 90° (TBR)

The proton energies were chosen to roughly coincide with the peaks of the transported differential SPE and GCR spectra. For thin shielding (50-100 mils aluminum), the worst-case SPE and GCR spectra peak at approximately 10 MeV and 300 MeV [1]. The SPE proton spectrum hardens for one inch of aluminum, peaking at ~35 MeV [4]. Additional shielding does not appreciably shift the peak of the transported GCR spectrum. Irradiation at three different angles of incidence is a crude attempt to simulate the omni-directional space radiation environment for the purpose of benchmarking our model calculations.

Particle fluxes depend on the width of the energy bin over which the differential spectra are integrated. Integration of the thin shielding worst-case SPE and GCR spectra yields 5.8×10^{3} p/cm^{2}/sec and 2.6×10^{-3} p/cm^{2}/sec, respectively, for a narrow 1 MeV bin. A wider 10 MeV bin gives fluxes of 5.5×10^{4} p/cm^{2}/sec and 0.026 p/cm^{2}/sec for SPE and GCR protons, respectively. Fluxes for the 1000 mil thick shielding SPE proton peak are 1.1×10^{2} p/cm^{2}/sec and 1.1×10^{3} p/cm^{2}/sec for 1 MeV and 10 MeV energy bins, respectively. It might be difficult, if not impossible, to simulate flight-like proton fluxes with a ground-based accelerator. Flight-like proton fluxes may not be necessary to achieve our goals.

3.2 Alphas

Energies: 25 MeV/nuc, 150 MeV/nuc (TBR)

Angle of incidence (relative to the normal to the ROIC): 0°, 30°, 60°, 90° (TBR)

For 100 mils of aluminum shielding, the exiting alpha spectrum exhibits a broad peak at ~150 MeV/nuc [4]. A second smaller (slightly lower flux) peak occurs at ~25 MeV/nuc. The ~25 MeV/nuc peak disappears for 1000 mils of aluminum shielding. Thicker shielding hardens the spectrum, but the upward shift in the 150 MeV/nuc peak is relatively minor and probably does not warrant a third test energy.

Alpha fluxes at the 2.5 MeV/nuc and 150 MeV/nuc peaks are 3.0×10^{-4} $\alpha/cm^2/sec$ and 3.7×10^{-4} $\alpha/cm^2/sec$, respectively, for a 1 MeV/nuc wide energy bin. The fluxes increase by a factor of 10 for a 10 MeV/nuc wide bin.

The need for heavy ion testing with one or more ions of Z>2 is under consideration. Requirements for Z>2 heavy ion testing will be defined should the decision to proceed be made.

4. High-Resolution Transient Test

Our goal is to collect transient data at a sampling rate fast enough to resolve the decay characteristic of the pulse. Study of the charge spread into the unit cells adjacent to the impacted unit cell necessitates the read out of a small sub-array. The high-resolution test will consist of acquiring small sub-array images centered at random positions in the full array. Each pixel will be sampled up the ramp with a uniform time step and at the highest sample rate possible without exceeding the NGST total noise requirement. It may not be possible to resolve the transient decay at a sample rate commensurate with the NGST read noise specification. Sampling at a higher rate might be permitted, subject to approval by the GSFC NGST radiation effects team.

At each sub-array position, 1000 (TBR) images sampled up the ramp will be taken. The individual images will be archived for post-facto processing and analysis. At the end of the integration, the array shift registers will be randomly set to another sub-array position, the sub-array will be reset and acquisition of another 1000 images will commence. The data acquisition/data storage/position reset/pixel reset/data acquisition sequence will be repeated as many times as necessary to collect a representative sample of transient pulses. Centered or off-center particle hits will occur at some positions. At other sub-array positions, no particle hits will be collected. To simplify analysis of the data, it is desirable that the beam current and number of up the ramp samples be adjusted to minimize the chance of multiple hits within a sub-array.

We cannot predict with certainty what the physical extent of the charge spread around the impacted pixel will be. To ensure that all of the neighboring pixels affected by charge spread are sampled, support for a variable sub-array size is required. The minimum sub-array size will be 3x3.

5. Transient Persistence Test

We seek to understand the transient behavior of the ROIC when it is read out in a manner that accurately simulates a normal science exposure. It might be advantageous to read the ROIC at a slower pixel read rate through multiple output ports simultaneously, if the ROIC architecture and read out electronics can support this mode. The bandwidth of the read out and video processing electronics can be reduced with a slower pixel read rate, possibly resulting in lower read noise in the noisy EMI environment at the accelerator.

Before beginning the transient persistence test, a 1000 second dark image will be taken with n=8 Fowler sampling and with the particle beam turned off. The read noise in electrons will be measured by computing sigma for the full frame (this assumes that the conversion gain has been measured or is known in advance). Transient data will be obtained by integrating on the beam with integration times of 120, 240, 480 and 960 seconds. For each integration time, repeat integrations will be performed to study the persistence of the transient pulses through reset. During integration, the full array will be sampled up the ramp at a rate equal to the NGST frame time requirement. The individual up the ramp images will be archived for post-facto analysis. Sampling up the ramp will result in lower S/N, but the images will provide information on the decay characteristic of the pulses under flight-like conditions.

6. Additional Requirements

Image display capability is required for real time inspection of the ROIC data as it is collected at the accelerator. A basic suite of statistical functions suitable for quick analysis of 2-dimensional images is needed. Streaming data capability for direct storage of the images to disk is desired but not required. In the absence of streaming data capability, sufficient computer memory must be available to buffer up to 80 full frames of up the ramp sampled raw images.

The images must be archived in Flexible Image Transport System (FITS) format for compatibility with image analysis packages run on other platforms. It is highly desirable to automatically record test specific information such as the number of Fowler (or up the ramp) samples, the integration time, the frame (or pixel read) time, the particle species, energy and angle of incidence, the ROIC temperature (or temperature sensor reading), and the ROIC biases in the FITS headers. Past experience shows that properly populated headers can provide invaluable diagnostic information for post-facto analysis and interpretation of the data.

Hardware and software support for measurement of the system conversion gain at the radiation test facility should be provided. Clock patterns for Fowler sampling and (equal interval) up the ramp sampling must be available. Provision should be made to vary the number of Fowler samples, the number of up the

ramp samples and the integration time. Full array and sub-array (with random dither of the sub-array position as an option) read modes must be supported. Hardware and software support must be provided to facilitate a rapid change in sub-array size.

The NIR and MIR ROICs will be tested at operating temperatures of 30 K and 6 K, respectively, in accordance with Document 641. Testing at other temperatures is not anticipated at this time. A transportable cryogenic dewar system, which can achieve and maintain a temperature of 6 K and that is compatible with the accelerator (or accelerators) selected for the test is required.

Entry ports in the dewar specifically designed for the particle beam and oriented at various angles relative to the focal plane are highly desirable. The entry port windows must be opaque to light. To allow for penetration of both protons and heavy ions with minimal energy loss, the windows must be as thin as possible. Low-Z window material is preferred to minimize the production of secondaries.

7. Open Issues

- Is heavy ion testing at Z>2 required (keeping in mind the ISOCAM LW array Ar test)?
- Should the ROICs be tested at different azimuth angles? What are the mechanical and thermal implications for the dewar design?
- How should the unit cell inputs be loaded to simulate the impedance of the detectors?
- What clock rails, biases and clock patterns are required to run the arrays?
- What are the physical and electrical (pin-out) requirements for the dewar/ROIC interface?
- How do we deal with transients caused by background radiation at the accelerator?
- How should the reference pixels be used to remove 1/f drift? Should the raw data be corrected on the fly during read out? Is it preferable to store the reference pixel data separately from the raw image data?
- How thin can the beam windows in the dewar be without compromising its mechanical integrity?
- Is a preliminary Co-60 test required? This will determine whether TID degradation is an issue and allow for a shake out of the data collection process.
- Is testing required (or desired) at temperatures other than the nominal NGST operating temperatures of 6 K and 30 K? What would the other temperature (or temperatures) be?

8. References

1. Barth, Janet L., Isaacs, John C. and Poivey, Christian, **The Radiation Environment for the Next Generation Space Telescope**, *NGST*

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3. McCreight, Craig, private communication.

4. Poivey, Christian, Undocumented.