R-GENTIC HANDBOOK/CHEAT SHEET

WHAT IS R-GENTIC?

R-GENTIC is a web-based tool that assists in providing guidance and an initial understanding of possible radiation risks that apply to a specific set of circumstances.

R-GENTIC does not replace the need for a radiation effects engineer or project specific environment modeling but provides a good starting place for understanding potential radiation-related risks.

GETTING STARTED

R-GENTIC can be found at https://vanguard.isde.vanderbilt.edu/RGentic/.

The front page, shown below, summarizes the process for using R-GENTIC. There are four steps in the process, each with its own page that will be discussed in more detail:

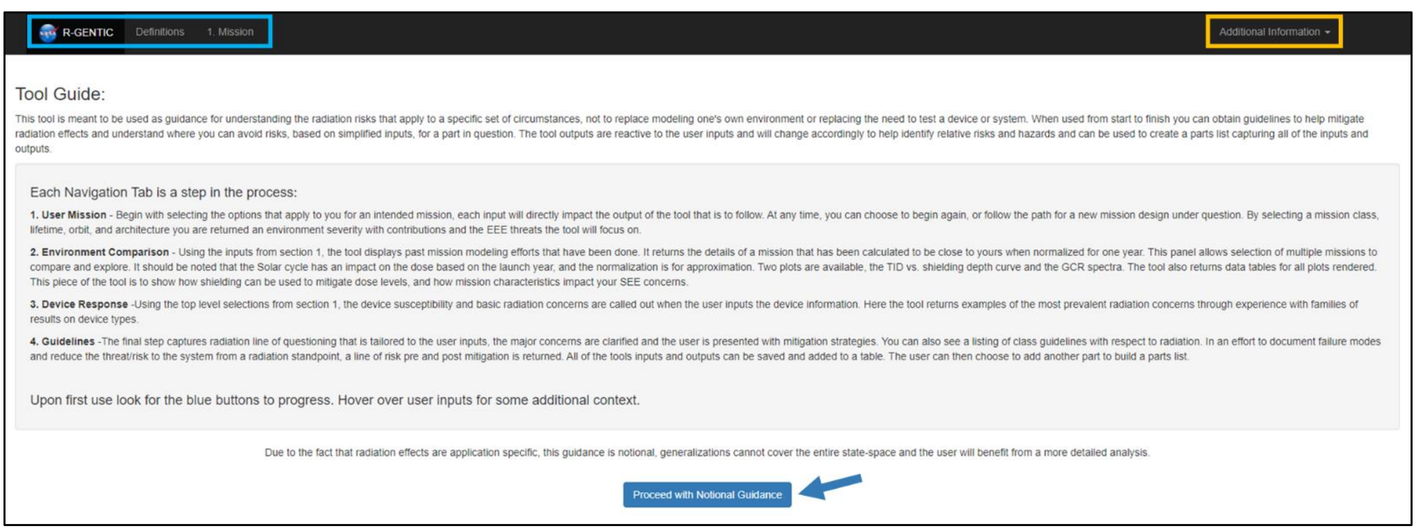
1. User Mission: Mission information, such as orbit, lifetime, and risk classification, are input.
2. Environment Comparison: Radiation environments similar to the user specified environment are provided as examples.
3. Device Response: Information about a generic EEE part type is input; generic radiation concerns are identified.
4. Guidelines: Guidelines and recommendations are provided based on previously input information. Parts can be saved to a summary sheet and downloaded for future reference

NAVIGATION

At the top left of each page is the navigation bar (blue box in figure). As you progress through R-GENTIC, you can go back to previous pages to update information.

At the top right of each page (yellow box in figure) are links to additional information, including a list of all the acronyms used and additional references/links. Use the navigation bar to return to your project.

At the bottom of every page is a blue box that allows you to proceed to the next step (blue arrow).



Definitions and Acronyms

After the front page, users are presented with a list of definitions and acronyms that are common to radiation effects analysis. These definitions are also available under *Additional Information*.

Energy Deposition:

Total Ionizing Dose (TID) - the mean energy imparted by ionizing radiation to a sensitive device region divided by the mass of the region. This is typically given in units of rad(Si), where 1 rad(Si) = 100 erg deposited per gram of silicon.

Non-Ionizing Energy Loss (NIEL) - is defined as the part of the incident particle energy consumed. Through Coulombic, nuclear elastic, and nuclear inelastic interactions that can occur between the incident particle and the lattice atoms, to produce vacancy-interstitial pairs (i.e., displacement damage)

Displacement Damage Dose (DDD) - the cumulative damage of the semiconductor lattice caused by ionizing radiation over the time of exposure. Displacement energy per unit mass, this is typically given in units of rad(Si), where 1 rad(Si) = 100 erg deposited per gram of silicon.

Linear Energy Transfer (LET) - a measure of the energy deposited per unit path length as an energetic particle travels through a material. The common LET unit is MeV-cm ^{2} /mg of material (Si for MOS devices, etc.).

Threshold LET (LET $_{th}$) - the maximum LET tested where no single event was recorded to a particle fluence of 1x10 ^{7} ions/cm ^{2}

Orbits:

Low Earth Orbit (LEO) - Earth Orbits ranging from 160 km to 2,000 km, 'polar' would be at an inclination near 90 degrees, 'equatorial' is of a lower inclination

Geosynchronous Earth Orbit (GEO) - an Earth orbit with a period of one sidereal day, geostationary is a special case given a circular orbit in the plane of the Earth's equator. These orbits share a semi-major axis, if circular the altitude is then 35,786 km.

Medium Earth Orbit (MEO) -Orbits ranging from an altitude of 2,000 km to that of GEO.

Single Event Effects:

Single Event Effect (SEE) - any measurable effect to a circuit due to a strike by a single ion. Such effects include (but are not limited to) SEUs, SHEs, SELs, SEBs and SEGRs.

Single Event Gate Rupture (SEGR) - a single ion induced condition in power MOSFETs that may result in the formation of a conducting path in the gate oxide.

Single Event Latchup (SEL) - a condition that causes loss of device functionality due to a single event induced high current state. An SEL may or may not cause permanent device damage, but requires power strobing of the device to resume normal device operations.

Single Event Functional Interrupt (SEFI) - a condition of repeated error states such that a reset is needed to clear the device.

Multiple Bit Upset (MBU) - an event induced by a single energetic particle such as a cosmic ray or proton that causes multiple upsets or transients during its path through a device or system.

Single Event Burnout (SEB) - a condition that can cause device destruction due to a high current state in a power transistor.

Single Event Upset (SEU) - a permanent or transient change of state induced by an energetic particle such as a cosmic ray or proton in a device. This may occur in digital, analog, and optical components. These are 'soft' errors in that a reset or rewriting of the device causes normal device behavior thereafter.

Single Event Transient (SET) - a transient change of state induced by an energetic particle such as a cosmic ray or proton in a device. This may occur in digital, analog, and optical components and may have effects in surrounding interface circuitry. These are 'soft' errors in that a reset or rewriting of the device causes normal device behavior thereafter.

Single Hard Error (SHE) - an SEU that causes a permanent change to the operation of a device. An example is a stuck bit in a memory device.

Galactic Cosmic Ray (GCR) -High energy radiation originating from outside of our Solar System.

Solar Particle Events (SPE) -High energy radiation events originating from our Sun during flares or coronal mass ejections.

Mission Description Page

The first step in the R-GENTIC process is the mission description page. Here, users input details about their mission under *Mission Description* and notional radiation risks are provided in *Overview*. The notional risks change as the user updates the mission description.

Users can specify the mission risk class, orbit, altitude, architecture, solar cycle, and lifetime. The default values for those categories are shown in the figure. Hovering over the titles provides information on how that user input is used in the analysis.

Users can choose from five mission classes using the dropdown list: *A*, *B*, *C*, *D*, and *Do No Harm*.

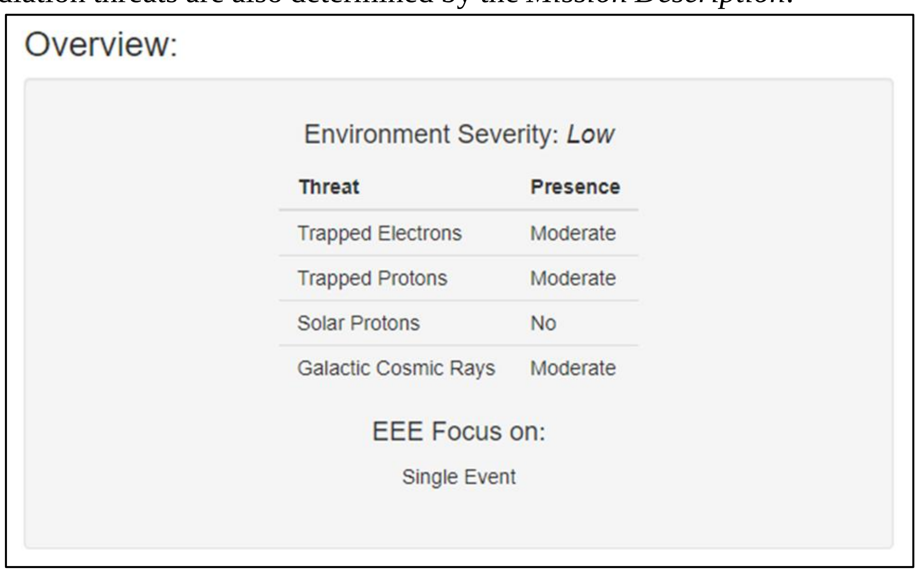
The *Orbit* dropdown list provides options for *LEO (Equatorial)*, *LEO (Polar)*, *Sun Synchronous*, *MEO*, *GEO*, *Lunar*, and *Interplanetary*.

Users type their desired *Altitude* into the provided box. Default values are provided for LEO, MEO, and GEO orbits, though the user can modify as necessary.

Architecture, *Solar Cycle*, and *Lifetime* can be chosen from the provided radio boxes.

As users change the *Mission Description*, the *Overview* containing the notional risks updates accordingly. The *Overview* provides an overall estimate of the *Environment Severity* as *Low*, *Medium*, or *High* based on the *Orbit*, *Lifetime*, and *Solar Cycle*.

The relative amounts of different radiation threats are also determined by the *Mission Description*. These threats include *Trapped Electrons*, *Trapped Protons*, *Solar Protons*, and *Galactic Cosmic Rays* and their presence changes between *No*, *Yes*, *Moderate*, and *Severe*.

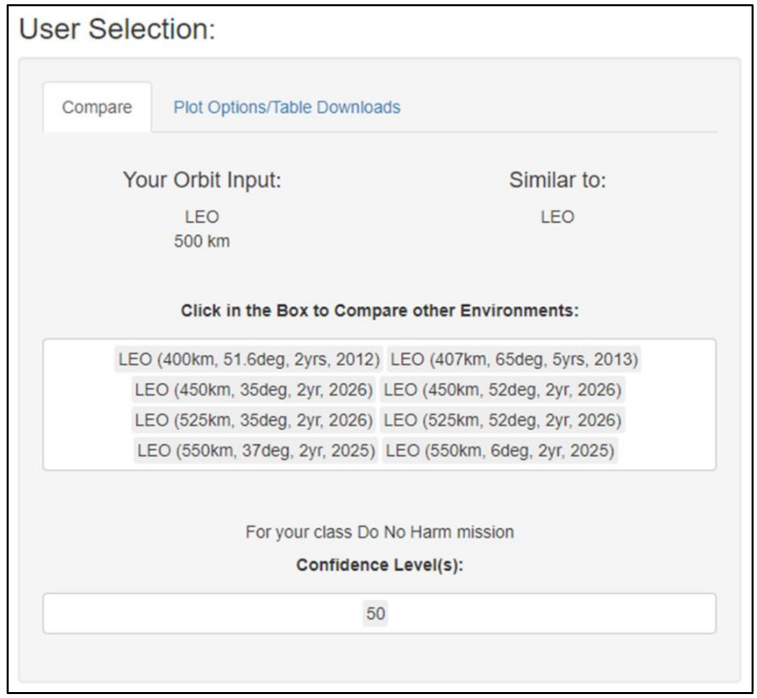


The *Overview* also provides basic advice on which radiation threat should be focused on for EEE parts. The *EEE Focus on* will displace *Single Event* and/or *Degradation* as appropriate for the given *Mission Description*.

Environment Comparison Page

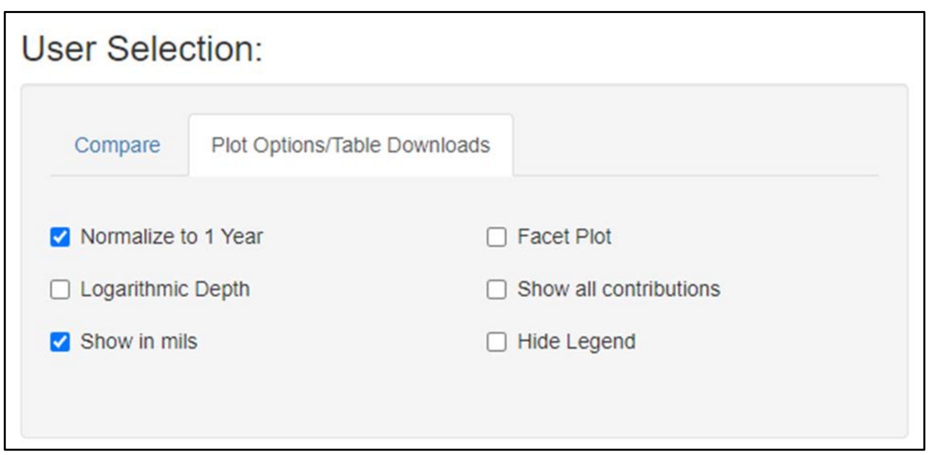
After the *Mission Description* has been defined, users can view radiation environments similar to their orbit. The similar environments come from previous NASA missions. Two radiation environment plots are provided: *Dose Depth Curve for TID* and *GCR Spectra Plot for SEE*. The plotted data is also available in tabular format under the appropriate tab.

There are several inputs the user can select to edit the graph displays under *User Selection*. From the *Compare* tab, users can see their orbit and which orbits are considered similar. Beneath that is a box which allows users to choose which other orbits to graph for comparison. It will prepopulate with all the similar orbits. Users can delete unwanted orbits by clicking on the desired orbit and hitting the delete key on their keyboard. Obits can be added by clicking in the white space of the box, prompting a dropdown box to appear with all the available orbits; clicking on an orbit will add it to the graphs.



The confidence level for the dose depth curves can also be selected under *Compare*. The default value is dependent on the mission class, selected in the *Mission Description*, but users can select any combination of confidence levels by clicking on the box and selecting the desired level.

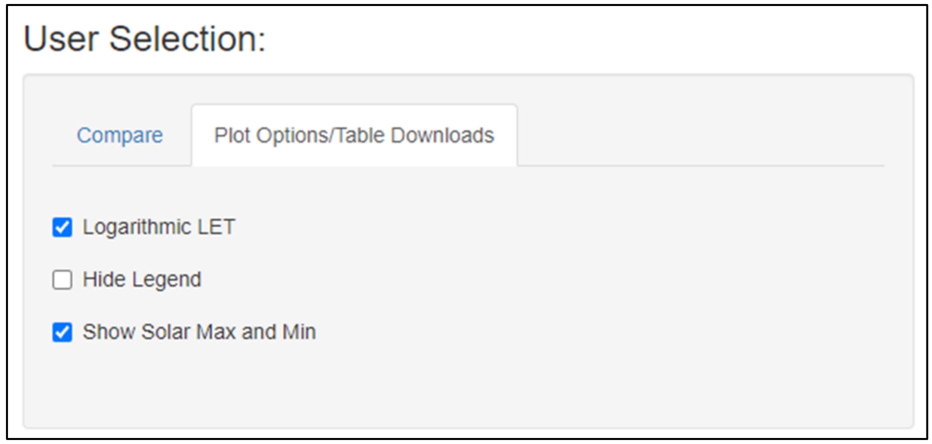
The *Plot Options/Table Downloads* changes depending on which of the environment graphs is currently selected. The figure to the left shows the available options when the dose depth curve is being displayed:



- Normalize to 1 Year
- Logarithmic Depth
- Show in mils
- Facet Plot
- Show all contributions
- Hide Legend

When the GCR spectra plot is selected, the *Plot Options/Table Downloads* displays the options in the figure to the right:

- Logarithmic LET
- Hide Legend
- Show Solar Max and Min



If either of the tables are selected, the *Plot/Table Options* provides the ability to download the selected table.

There are five outputs for the environment comparisons: *Dose Depth Curve for TID*, *GCR Spectra Plot for SEE*, *Dose Depth Table*, *Spectra Table*, and *Additional Considerations*. *Dose Depth Curve* and *GCR Spectra Plot* display the graphs for the selected orbits plus a sliding scale used to control the x-axis, while the *Tables* contain the corresponding data comprising the graphs.

Additional Considerations provides information that should also be considered for radiation effects but are out-of-scope for the analysis provided by R-GENTIC. These additional considerations include those for cumulative effects and SEEs during solar storms. The Additional Considerations have been reprinted below.

> **For Cumulative Effects** - While ionizing radiation is often referred to in part designations and ratings, non-ionizing radiation damage must also be considered. Displacement Damage Dose can be a driving failure mechanism depending on device process and function. It too will be a function of mission parameters, shielding, as well as non-ionizing energy loss of the incident particle:
>
> **For SEE** - While GCR flux are continuously present for a given orbit, our nearby environment is not in a steady state, the dynamicism of solar events must also be considered. Fluxes can be orders of magnitude higher for windows of time during and after these events:
>
> There is no substitute for modelling your own environment with accurate details like launch date, orbit, and duration. The aggregation of the tools used and resources available have made the state of the practice approachable after familiarization.
>
> There exist software for analysis of more complex geometries and transport through different materials, search for radiation ray-tracing for more details.

Links to radiation environment modeling tools are provided at the bottom of the page.

Device Response Page

After the environment comparisons, users can begin to develop a parts list with radiation information for different types of EEE devices. On the device page, user can choose from a selection of devices and they will receive information on types of expected radiation effects and typical responses for that device type.

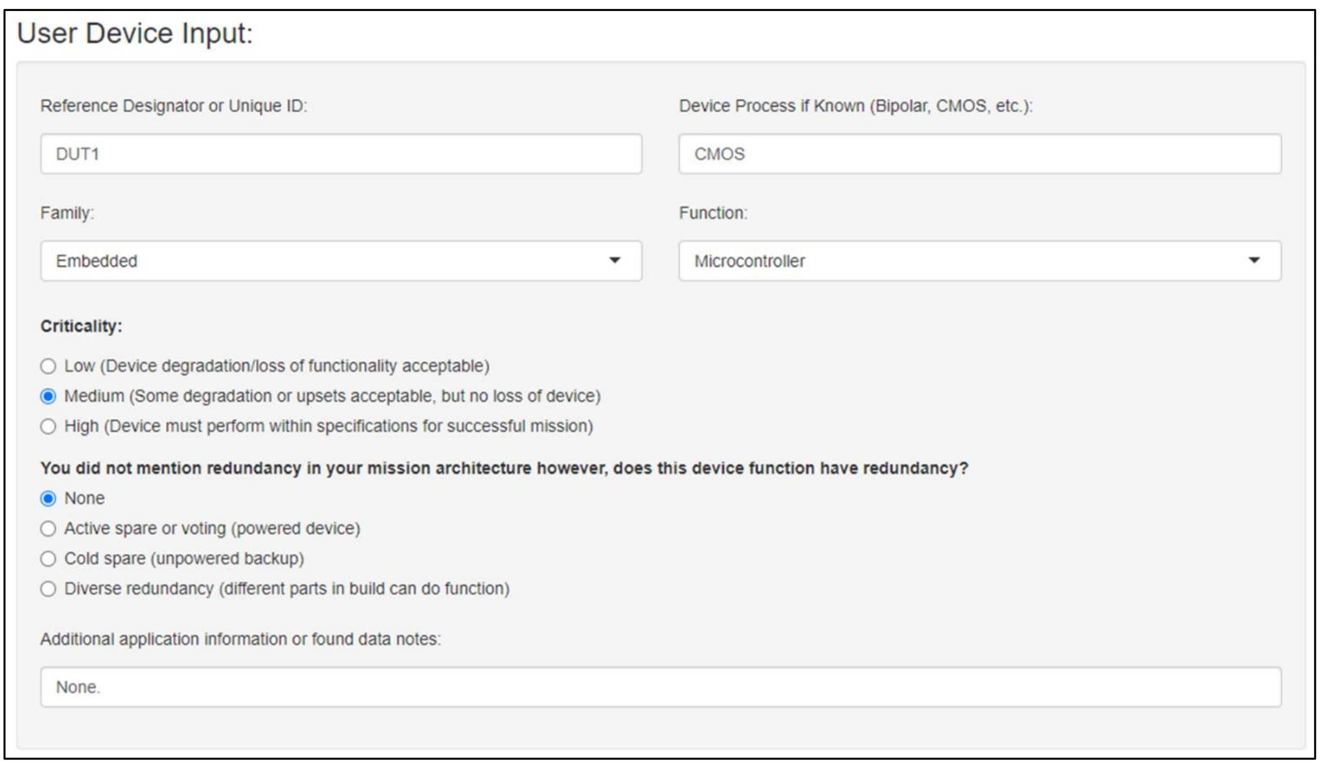
Users provide relevant device information in *User Device Input*.

Reference Designator and *Device Process* can be recorded by providing the information in the given boxes. This information is not used in the analysis but is saved to the *Summary Sheets* for future reference.

Users can select a EEE device from a preset selection, organized by *Family* and *Function*, using the provided dropdown boxes. There are 13 different families and 77 total functions, encompassing many of the standard devices used in spacecraft design, for users to choose from. Below is a list of the included families.

Clock/Timing	**Digital**	**Discrete Power**	**Discrete RF**
Discrete Signal	**Embedded**	**Imager**	**Linear**
Memory	**Mixed Signal**	**Opto-electronics**	**Power Hybrid**
Sensor			

The *Criticality* of the device is a measure of how important that device is to the overall design. Users can choose criticalities of *Low*, *Medium*, and *High* by using the provided radio buttons. *Criticality* is used in the next step to assign a level of risk to the device pre- and post-mitigation.

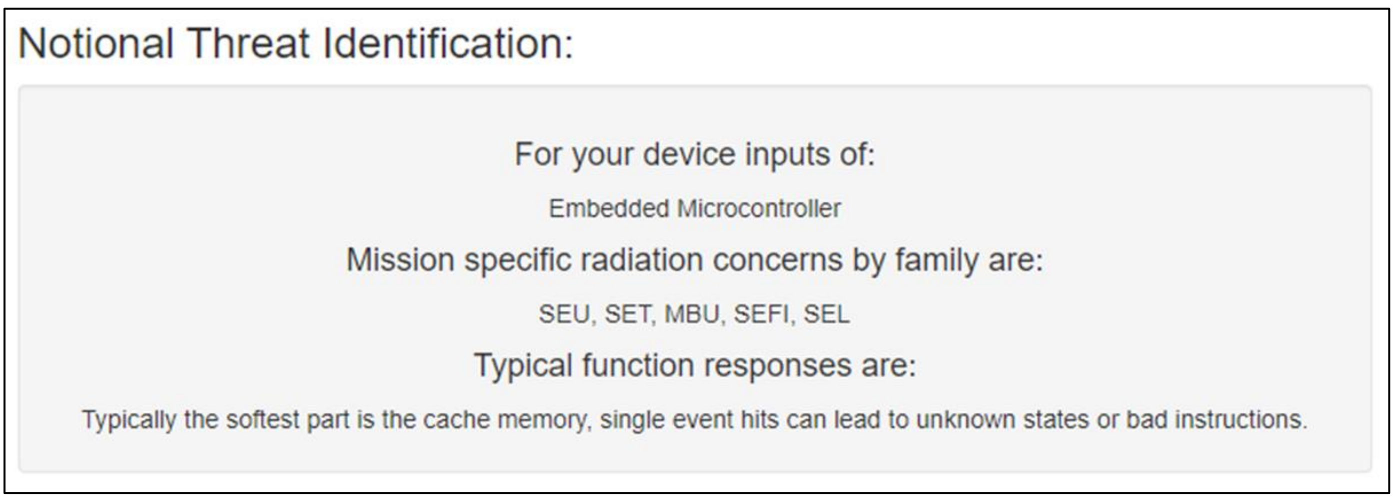


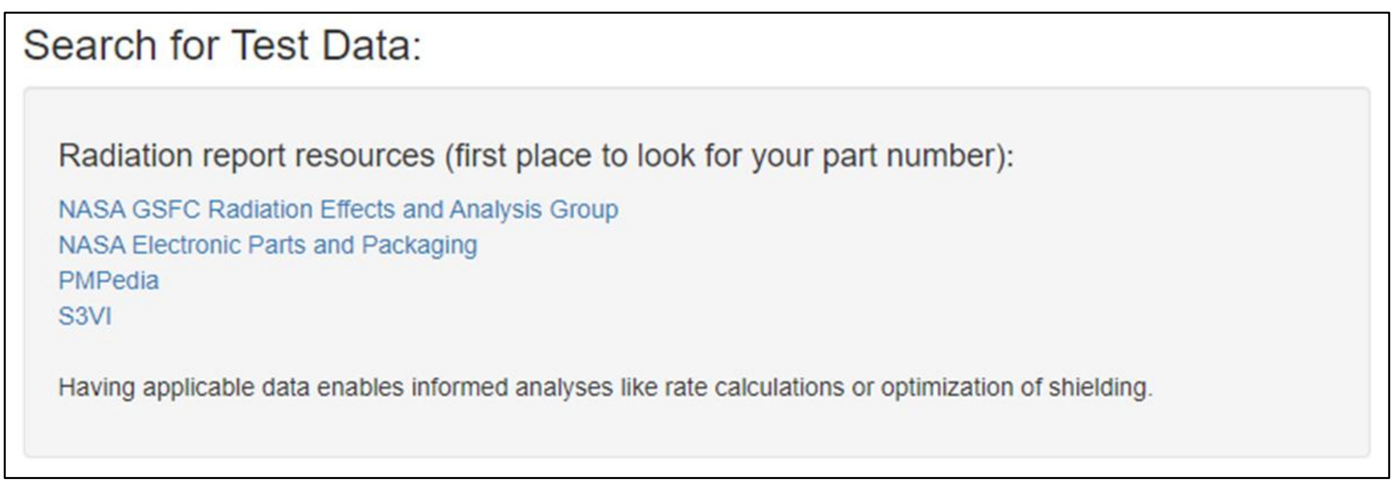
On the *Mission Description Page*, users specified if there was redundancy in the system. On the *User Device Input* page, users are asked if this particular part has redundancy. This can affect the part specific guidelines and is recorded for future use.

The last input for devices is a place for users to record any additional application information. This information is not used by R-GENTIC but is recorded for users in the *Summary Sheets*.

Under *Notional Threat Identification*, users are presented with mission specific radiation concerns and typical device responses to radiation based on the selected device. Radiation concerns are based on both the selected part family and mission environment; part specific radiation concerns are given on the next page. Typical responses are part specific and provide an example of what radiation effects look like in the selected part. It should be noted that R-GENTIC provides generic information that is common to different EEE part families and part types. It does not provide information for specific part numbers.

Beneath the radiation concerns, labeled *Search for Test Data*, users are provided links to various radiation report resources. Users can use these resources to find test data for their specific part numbers or for similar parts. Each site contains different parts and testing information, and users may not be able to find their specific part.





Guidelines Page

Guidelines is the final step in the R-GENTIC process. On this page, users are presented with guidance based on their mission parameters and selected devices. Users can also begin to build a summary sheet that contains relevant information for their selected mission and devices.

Programmatic Guidance provides users with top-level guidance based on the selected mission class. A link to the NASA procedural requirements this guidance comes from is provided, along with links to other relevant radiation hardness assurance resources. *COTS Specific Guidance* provides additional guidelines to follow when using COTS parts in the user defined radiation environment; additional resources are provided.

Programmatic Guidance:

Notional Class Do No Harm Guidelines:

Selective radiation effects evaluation shall be performed with emphasis on mission- and safety-critical components and assemblies. Flight lot radiation testing for mission- and safety-critical components and assemblies is suggested. Fault-tolerant designs for COTS parts are suggested. There will be known risks that cannot be quantified. Impacts include cost, schedule, and high technical risk acceptance.
- Paraphrased from GPR 8705.4, under NPR 8705.4

Radiation Hardness Assurance:

Mission Environment, Application, and Lifetime
Avionics Radiation Hardness Assurance Guidelines

COTS Specific Guidance:

Based on Criticality vs. Environment:

COTS upscreening/testing recommended; fault tolerance suggested
- Originally from the NEPP 3x3

Part Selection:

JPL COTS in Radiation Environments

Application Questions contains a detailed list of radiation-based questions that should be used with the selected part. The line of questioning is broken down by radiation effect, giving users an idea of things to be considered when choosing EEE parts for use in radiation environments.

Application Questions:

The typical line of radiation questioning for: Embedded CMOS Microcontroller with regard to TID, SEU, SET, MBU, SEFI, SEL

Device may exhibit SEL. Is there redundancy? Will you be able to power cycle? SETs can propagate and show up at system level depending on design. TID effects can occur depending on the process. Can the design tolerate timing degradation, increase power current? SEFI can occur. Can device be reset/power cycled? MBU can occur, some words will be corrupt. SEU can occur. Incorrect states in state machine. Design dependent. SBU can also occur.

Specific Recommendations gives a high-level overview of the radiation concerns for the selected part based on the user defined mission environment. This includes the radiation concerns by part family, greatest threats to the overall system, and a simplified estimate of the level of risk the part poses before and after mitigation techniques. The risk estimate is based on the criticality of the part and if it has redundancy in the system. This information is stored in the *Summary Sheet*. *Recommendations and Guidelines* provides some basic advice for mitigating radiation concerns in the selected part; the Post Rec Risk is based on the provided recommendations.

Specific Recommendations:

Considered for Low criticality component on a Single spacecraft, no redundancy ...

Your Part	Family Radiation Concerns	Greatest System Rad Concern	As-is Risk	Post Rec Risk
DUT1	TID, SEU, SET, MBU, SEFI, SEL	Degradation & Single Event	Low	Low

Recommendation and Guidelines:

Implement Watchdog If you can live with all SEE concerns, but need to know how frequent they may occur pursue rate calculations for your application, which requires test data and environment spectra. If you can live with degradation in parametric response but want to reduce dose, consider adding box wall thickness or spot shielding to your application. To tailor this would require test data and thorough environment modeling/transport.

At the bottom of the page, users can select *Save to Summary Sheet* and the current part will be added to a summary table. Selecting *Add my next part* will take users back to the *Device Response* page, allowing for as many parts to be added to the *Summary Sheet* as desired. As parts are added, the summary table at the bottom of the page will update accordingly. When users are done adding parts to the summary table, the entire summary sheet can be downloaded in .csv format by clicking on *Download Summary Sheet* or in .json format by clicking on *Download JSON fmt Sheet*.

The *Summary Sheet* contains the orbit, altitude, sun cycle, mission lifetime, mission architecture, part reference designators, device family, family radiation responses, process, part function, device criticality, greatest radiation threat, as-is and post mitigation risk levels, recommendations and guidelines, criticality vs environment, class guidelines, typical line of questioning, device redundancy, and application notes.

Your tailored table summary of saved runs has 3 Rows:

Undo delete

Show 10 entries

Search:

	delete	Orbit	Mission Architecture	Environment Severity	RefDes	Process	Function	Highest Threat	As-is Risk	Post mitigation risk
1		LEO	Single spacecraft, no redundancy	Medium	DUT1	CMOS	Microcontroller	Degradation & Single Event	Low	Low
2		LEO	Single spacecraft, no redundancy	Medium	DUT2	CMOS	Dual-Port Memory (SRAM)	Degradation & Single Event	Low	Low
3		LEO	Single spacecraft, no redundancy	Medium	DUT3	InGaAs	Photodiode	Degradation & Single Event	High	Medium

Showing 1 to 3 of 3 entries

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If users have any questions, they can send them to Michael Campola at michael.j.campola@nasa.gov.