INTEGRATION AND TEST OF S/C POWER SYSTEMS

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AGENDA

- Basic S/C Power Subsystem
- How you choose your power source?
- Discuss each element of the typical S/C power subsystem
- EGSE and MGSE we use to test the hardware on the S/C
- Specific testing we do with each element during S/C I&T
- A little bit about any safety issues that come along with integrating the hardware

Basic S/C Power System

1. Power Source
   - Solar Array, Battery, RTG
2. An Energy Converter
   - DC-DC or DC-AC
3. Energy Storage
   - Battery (s)
4. Energy Control System
   - Shunt regulators, etc…

Mission Dependent Architecture

Decisions for which type of power system are made at the mission design level and depend on many parameters:

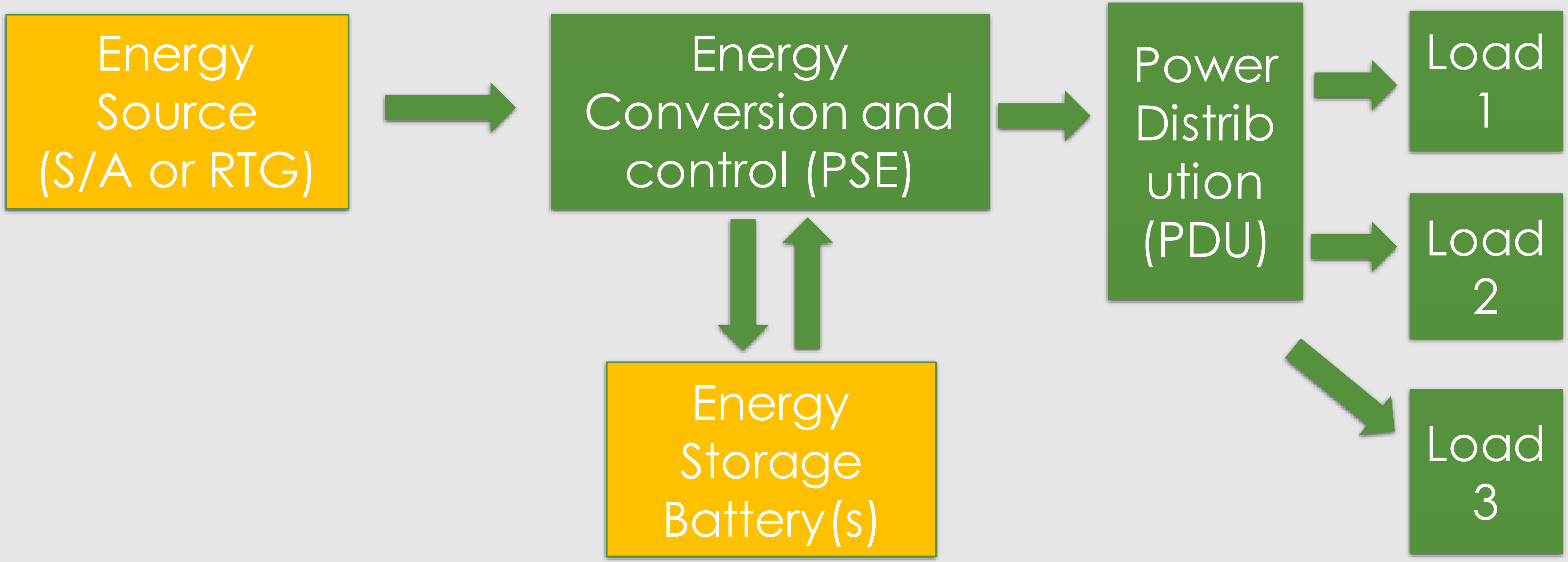
- Where is the Mission Going?
  - Past Jupiter will like require and RTG (Nuclear Option) due to less sunlight
  - Landing on a planet or moon can also require an RTG as rotation of the planet will cause long potential blackout periods
  - Solar Arrays are the most used energy source for S/C, but there can be trades on the type of arrays as well

Other Things That Come into Play

- Expected Temperatures
- Number and Length of Eclipses
- Attitude and Inclination
- Size/Weight of the Payload, mass constraints

Power System Electronics (PSE)

- Often times the Energy conversion and Energy Control functionality are combined into one box, the PSE



Integration Needs

- PSE, whether 1 box or a few, follows the basic integration test procedure model, safe to mate steps followed by some functional and performance testing
- EGSE is needed early on to complete this testing
  - Solar Array Simulator
  - Battery Simulator
- No real safety issues at this stage
- Test duration of 3-5 days is typical

Testing

- Functional testing at this stage of thing is best done without the flight power source or the battery
- Verify charge and discharge functionality
- Verify power conversion functionality
- Verify and Autonomous actions your system will take based on the health of the system
  - Low Battery State of Charge thresholds
  - Load shedding macros
  - High/low voltage testing

GSE Needs

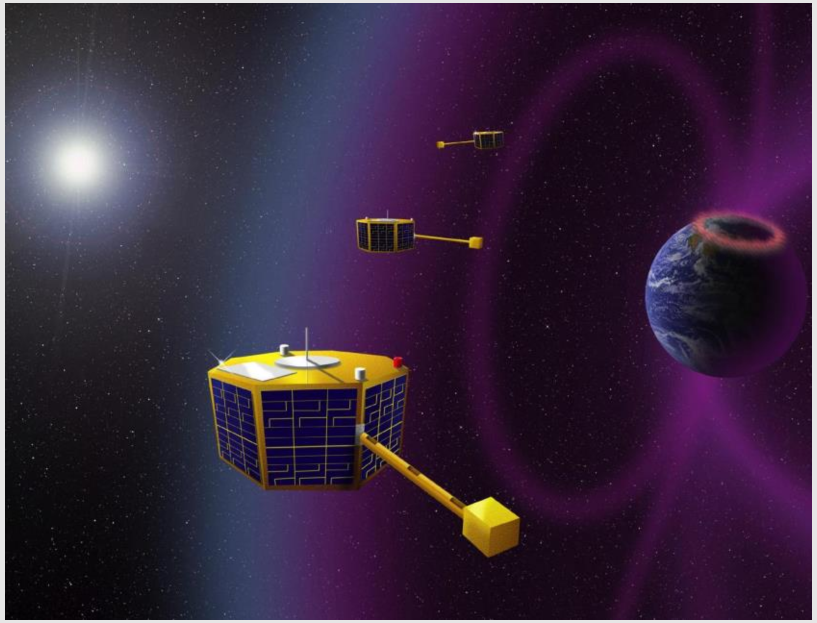
- **Battery Simulator-**
  - provides the ability to dial the voltage down to trigger a low battery state of charge event, allowing you to verify that autonomous functionality without putting where and tear on a battery and using valuable S/C schedule
  - allows you to have the S/C up and running at both its minimum and maximum voltages easily to verify all S/C components survive at either extreme

More EGSE

- **Solar Array Simulator**
- **RTG Simulator**
  - Allow the PSE to take in realistic source power and handle it as it will in flight
  - Functionality tested when you have a test battery in place

Solar Array (S/A) Types

- Body mounted
- Deployable rigid arrays
- Deployable semi-rigid
- Deployable flexible
- Water-cooled Arrays



ST5 Satellites with body mounted arrays, NASA Goddard 2006

Deployable Rigid Solar Arrays

Deployable Semi-rigid Arrays

Space-X Dragon capsule

Remote Roll out Flexible Solar Arrays

International Space Station

Water-cooled Solar Array

Artists rendering of Parker Solar Probe,
proximity to the sun
demanded new technology
development of water-cooled solar array

Electrical GSE needed for S/A Testing

- Solar Array Simulator (SAS)- This is a rack or two of high voltage power supplies that can be used during most of the I&T campaign when having the Array on the S/C would be problematic for most ground testing and also dangerous for the array
  - The cabling from these supplies would connect to the same connectors the S/A would, thus taking their place as the Energy Source
  - Also need an alternate SAS capability, this is a means of supplying enough energy to the S/C so that you can test, even while the Solar array are physically mounted on the Spacecraft
- High wattage lighting (to mimic the sun) for end-to-end testing

Mechanical GSE

- Covers- to protect the fragile solar cells
- Fixtures – to support the arrays during installation or removal
- Support Stands- to Support the arrays for subsystem level testing as well as inspection, cleaning and possible repair work during I&T
- G-negation apparatus- for use with deployment testing of the deployable arrays
- Rotation fixture- For use when S/C orientation needs to be changed for S/A flash testing

Special Testing for Solar Arrays

- Flash end-to-end test- Normally there is a desire for an end-to-end test that flashes the arrays with hi powered lighting in an effort to stimulate the cells and provide a current that we can detect in S/C telemetry
- Not trying to power the whole S/C, just attempting to detect S/C current flow
- Lighting could be theater lights, sun simulators or laser power, may require MGSE fixture for light source
- Test duration between 4 hours and 2 days depending on number of arrays

Solar Array Flash Testing

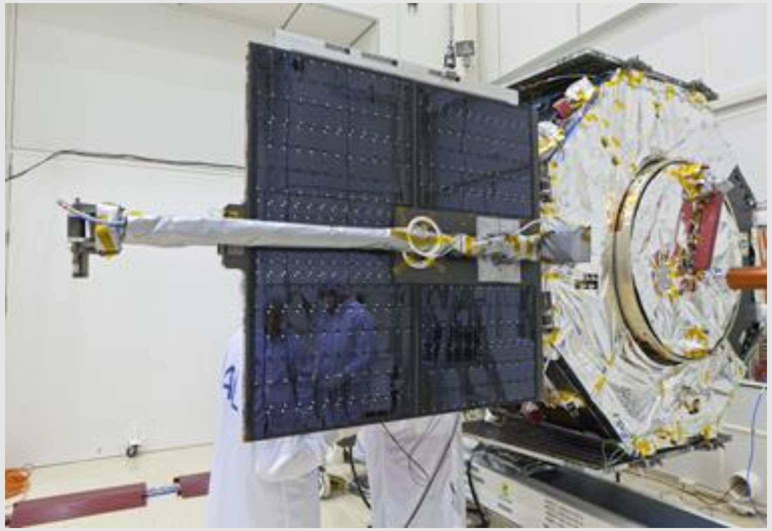
Solar Array deployments

- Solar Arrays that are going to be deployed in flight will be secured with either pyro connectors or frangibolts or pin pullers.
- All of these fasteners are activated by a pulsed voltage from the PDU to either explode, heat up a wax element or pull a pin that can then be reset.
- These circuits are generally "safed" by having a special plug (safe plug) installed on the outside of the S/C.
- Safe Plugs or test cables should be installed for most of I&T unless you are doing a deployment test.
- Prior to a real deployment test, an arm plug would be installed in its place.
- Arm Plugs would be install for flight prior to launch.

Solar Array G-negated Deployment

Van Allen Probes on a turnover fixture with one wing stowed on top and another deployed.

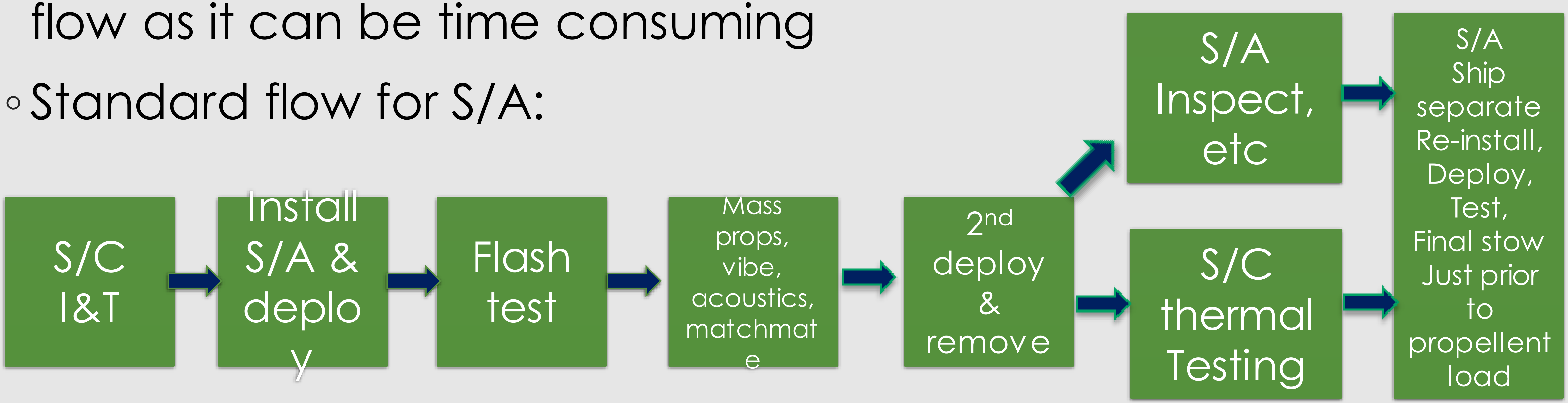
Wing partially deployed



Wing fully deployed

Other Notes on Solar Array Testing

- Anytime the arrays are installed/removed time should be put in the schedule for inspection, cleaning and potential repair
- Its good to schedule that as a parallel activity to the main Bus I&T flow as it can be time consuming
- Standard flow for S/A:



Safety Concerns and Solar Arrays

- Main Safety issue around the solar arrays themselves is mainly about the safety of the solar cells which can be fragile
  - Red Tag Covers can protect them when they are not being tested
- Safety around deployments involves assuring safety that the arrays will not deploy any time other than during the deployment tests and after launch and separation
  - Safe/Arm plugs and deployment circuitry testing and monitoring combine to mitigate and gain confidence

Other safety concerns

- Any time the S/A are lifted and installed or removed from the S/C there is a risk of damage to the arrays and these lifts are considered safety critical
- The light source required for End-to-End testing (Flash) needs to be substantial and there are often safety requirements and precautions taken and may require safety personnel in attendance

Impacts to Procedures, plans, schedule

- Plans, procedures or work orders involving any of these activities need to be marked in some way as being hazardous
- Requires extra verbiage and flagging around the safety critical steps
- Requires safety engineer to review and sign off on the documents
- All of this can sometimes add time and complexity to the schedule if not factored into the overall plan

Batteries Standard for Energy Storage

- Batteries are the main Energy Storage device
- Lithium ion batteries are the preferred batteries for spacecraft applications as they are lighter than the old Ni-Cd or Ni-H2
- Battery size is determined by voltage requirements as well as mission characteristics
  - For a mission using S/A, durations and numbers of eclipses affect battery size
  - Sometimes the launch case is the driving factor
  - If the launch case is particularly onerous, a second battery that can sustain the S/C through separation and light on the arrays, and then not used again
  - Low earth orbit Satellites generally have more eclipses to deal with than missions farther out
  - Missions farther out often have longer eclipse cases

EGSE for Batteries

- Battery Charge/Discharge/Monitor rack
- Air conditioning or cooling cart
- Test Battery for use during I&T that is form fit and function identical to flight

MGSE for Batteries

- Lifting fixture if battery is over 50 lbs or integration angle is difficult to get to
- Battery integration fixture to aid in holding the battery in place while being mechanically installed
- Air conditioning tubing and plenum to direct air flow over the surface of the battery or battery panel during use

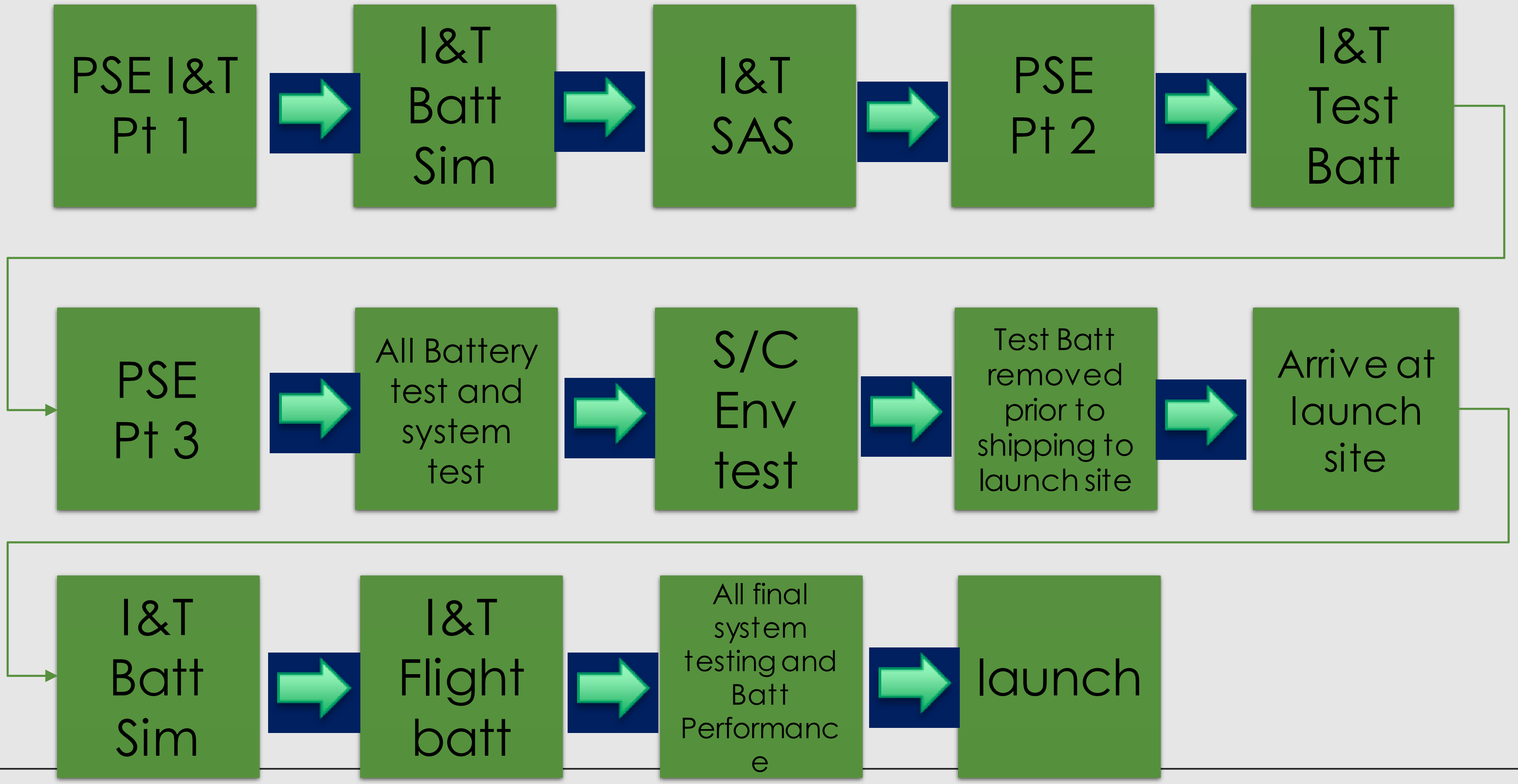
Battery Testing in I&T

- Low Battery State of Charge Test (LBSOC)
- Eclipse testing
- High rate charge/ low rate charge
- Depth of Discharge testing
- Launch scenario testing
- Generally always want the battery available for system level test, in particular for reaction wheel testing and deployment tests

Battery Relays

- Batteries are basically always on, unless shorted, so once they are integrated to the S/C, the S/C will also be always on (not ideal for I&T)
- For most S/C missions the batteries can be taken "offline" by switching relays in the system
- The battery would be switched online with flight relays and switched offline with GSE relays in a test rack
- This allows the S/C to be powered down at the end of the day
- In flight, you do not ever want to take the battery offline, which is why the only mechanism for doing so is in the GSE
- In the event there are no relays in the system (for mass or volume reasons) other means of powering off need to be employed

Test Battery/ Flight Battery Flow



Charge/ Discharge Durations

- Charging and discharging the battery can take many hours
  - Always plan up front to have that time available when possible, no amount of wishing or hoping can make the process happen faster
  - Verifiy with the Battery Engineer how long it takes to charge at high rate/ low rate and also how long it takes to discharge
    - Discharge in can take long, try to do it with the rack and not the S/C in parallel with other activities
    - If it has to happen on the S/C, investigate how many loads can be turned on to speed up the process

Eclipse Testing and LBSOC

- Eclipse testing is often a part of scenario testing and would take the time of the maximum expected eclipse for the mission
- Low Battery State of charge has two flavors
  - Hardware trip- this test discharges the battery until a hard wired trip point
    - This test is best done with the Battery Simulator so that you can dial down the SOC at will
  - Software trip- this test discharges until a software commanded trip point
    - This test is best done using the FSW to set that trip point reasonably high so it doesn't take so long to reach

Battery Safety Concerns

- Battery Safety is both for the battery and for personnel handling or near the article
  - Battery is always on unless shorted, so while you are connecting the battery physically to the S/C harness, there is risk to personnel of shock
  - Battery is also volatile and therefore, parameters such as temp and pressure, as well as individual cell voltages need to be strictly monitored for exceedances so the battery does not combust
  - In particular when the battery is discharging, the battery can get hot to the touch and personnel in close contact must beware

Safety Precautions in plans and procedures

- Connecting or disconnecting the battery to/from the S/C harness is a safety critical activity and requires hazardous notation on work orders and procedures, safety must review and sign off, depending on the size of the battery, safety may or may not be needed in attendance
- Lifting the battery is a hazardous activity
- The Battery Engineer/Power Subsystem Lead should provide the I&T team with a Battery Handling Plan which is reviewed by safety, and that spells out all of the limits on the critical parameters
- The Battery Rack should have alarms on all critical parameters
- I&T scripts and telemetry should also have alarms on these points

Umbilical features for battery operation and safety

- The Umbilical Rack (UGSE) should also have battery monitoring capability and in some cases, automatic shut down capability
- The UGSE should have charging capability for use when the S/C is on the launch vehicle on the pad, which should be tested prior to use
- Because in space you do not ever want the battery to be disconnected, you do not want a battery disconnect command or capability within the S/C, because you do need this capability during I&T, there needs to be a battery disconnect capability somewhere in the EGSE suite
  - For emergency use at the pad if needed, it is a good idea to have this capability built into the UGSE

Radio-Isotope Thermo-Nuclear Generator

- The current state of the art Nuclear Power Supply is referred to as an MMRTG
- As discussed earlier, this article is an energy source used on S/C that are flying either beyond Jupiter in the Solar System, or are landing on a planet or moon or where the rotation of the body will cause the S/C to be out of the sun's light for extensive periods of time

Logistics of the MMRTG

- MMRTG is fabricated and tested under the watchful eyes of the DOE
- There will be scheduled a dry run integration of the MMRTG 1 year to 18 months prior to launch
- The flight article will be fueled and delivered to the launch site 4 months prior to launch
- The flight MMRTG will be integrated on the launch pad just before fairing closeout for launch

MMRTG EGSE

- DOE will provide the mission with 2 simulators for use during test
  - A Thermal Simulator
  - A Mass Simulator
- An Electrical Simulator is generally developed by the mission and is a rack mounted piece of EGSE
- MMRTG will be delivered with a shorting plug installed to the launch site

MMRTG MGSE

- DOE will provide a shipping Cask that monitors both the environment and the MMRTG
- DOE also provides a transportation cage, nick-named the Gorilla, for transport to the launch pad
- The mission is responsible for building an integration fixture to support the MMRTG during the final integration process

Safety Concerns with an MMRTG

- Any interaction with the MMRTG at all is a safety critical activity and must be reviewed by the appropriate safety personnel
- Safety representatives must be on hand
- Critical parameters to monitor are temperature and pressure
- Once the shorting device is removed from the MMRTG, much like a battery, it is always on, for this reason, the connection of the MMRTG to the S/C harness is a hazardous activity

MMRTG Plans and Procedures

- All flight MMRTG plans and procedures are the responsibility of the DOE
- The integration of the MMRTG to the S/C is done by a hazardous procedure authored by the integration engineer on the Mission side
- There is a test referred to as the “Hot Fit Check” that is done in a hazardous processing facility towards the end of the I&T Campaign where the team can electrically integrate and de-integrate the real article
- Final flight integration is done at the last possible moment before fairing closeout and launch