The 2014 NASA Nuclear Power Assessment Study: Assembly, Test and Launch Operations Comparisons between a Notional 1 kWe Fission Power System and a Conventional Radioisotope Power System

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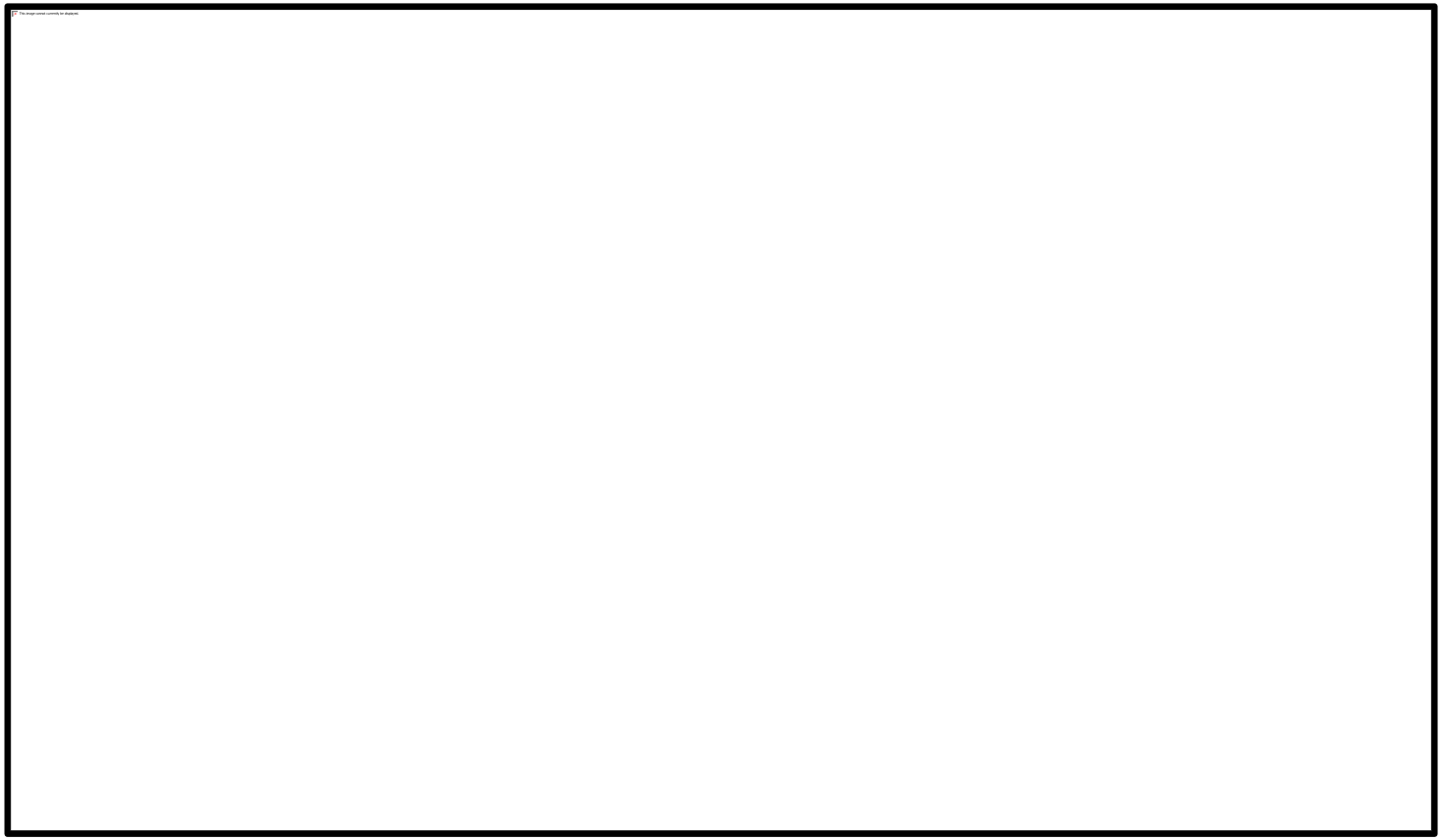
Outline

- ATLO Assessment Objectives and Process
- Notional FPS-based Configuration
- Notional ATLO timeline
- FPS Integration Options considered
- Discriminators for ATLO Options
- ATLO Discussion
- Security Considerations
- RPS System Assumptions for ATLO Assessment
- Off-normal Scenarios
- Future work and General Considerations

KSC ATLO Assessment Objectives

- Identify assumptions and ground rules that could apply to ATLO assessment
- Identify “ATLO” constraints that could have impacts or influences on Systems Team’s nuclear power system designs to minimize their local optimizations
  - Transportation, nuclear safety and security, ground processing and facility related constraints or limitations
- Identify system operability and affordability (~ilities) requirements that could impact “ATLO”
  - Minimize integration complexity at KSC if possible
- Identify any new FPS deliverables that need to be developed, considering the current set of RPS deliverables
- Develop a high level notional Assembly, Integration and Test Flow
  - Identify flight system functional testing needs at KSC
    - What type of system level tests will be performed in what sequences?
    - What type of facilities and procedures will be required to support those tests?
  - Identify launch site operations needs
- Identify nuclear safety and security needs
- Identify areas requiring future investigation

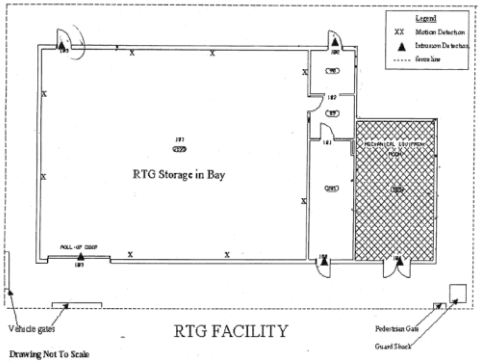
ATLO Assessment Development Process



RTGF

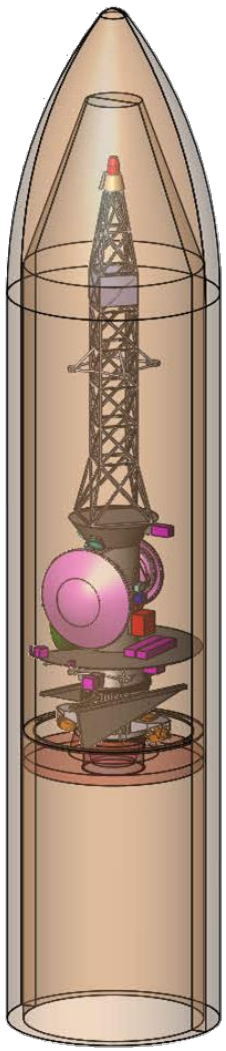
KSC Ground Operations Assessment Approach

- Utilized the existing well established integration pathway from the RPS enabled-missions
- Explored all options considering the following components and assembly operations
  - Fission power system (FPS)
  - Reactor Highly Enriched Uranium (HEU) core
  - Fairing
  - Atlas V rocket
  - Integration facility characteristics

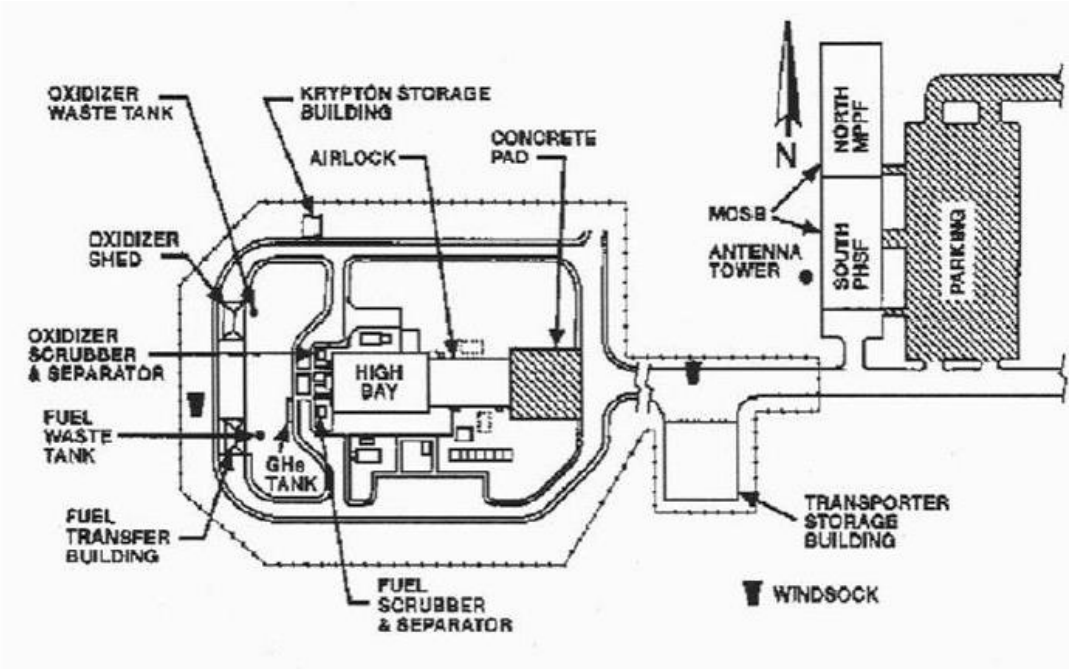


- Considered a total of six options
- Obtained the criteria for the down selection of options
  - Walk downs of existing facilities
  - Consultations with experienced individuals from past nuclear missions
- Down selected 2 of 6 options using logistics of operations

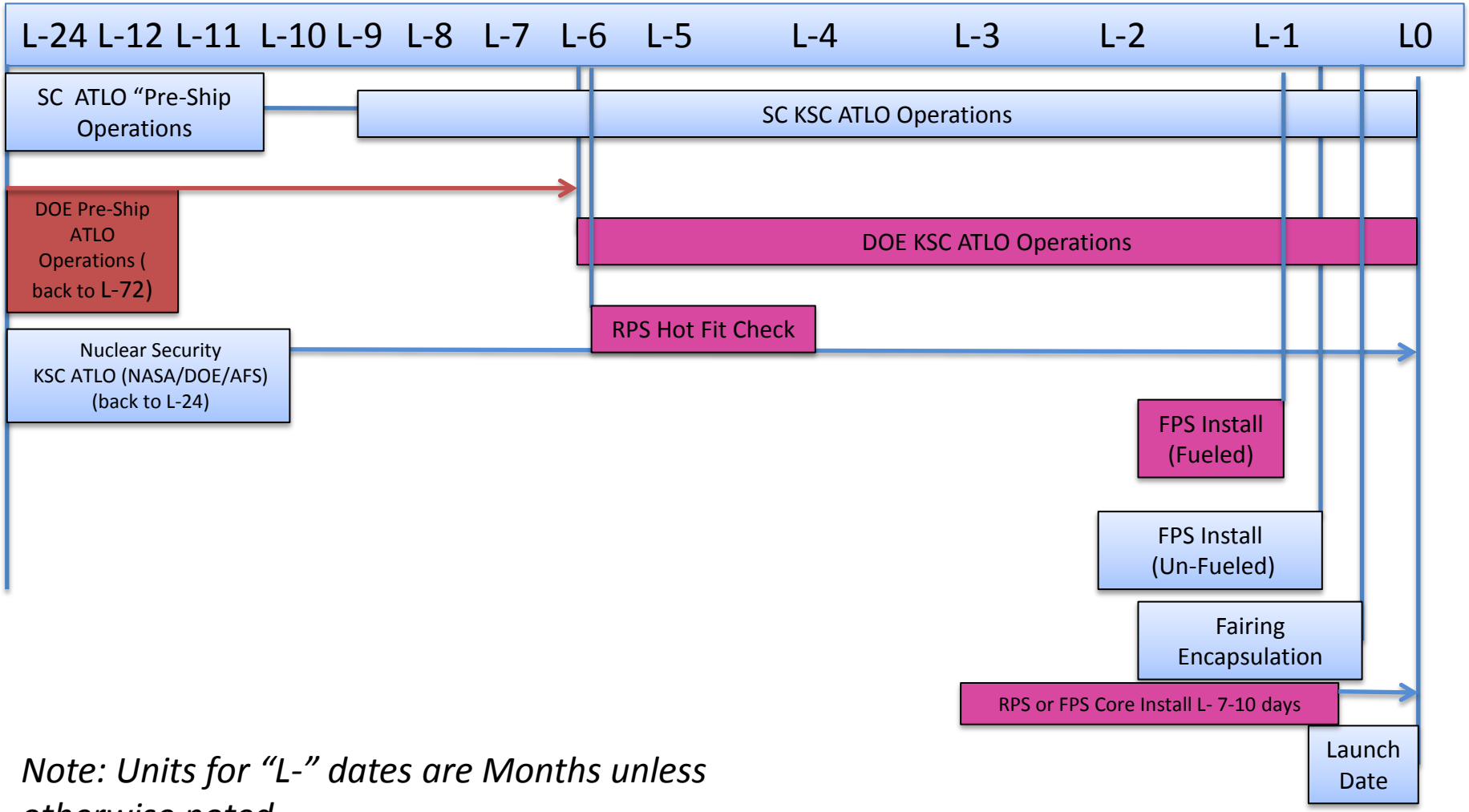
Notional FPS-based TSSM Launch Configuration (Atlas V, 5 meter diameter, Long Fairing)



Payload Hazardous Servicing Facility (PHSF)

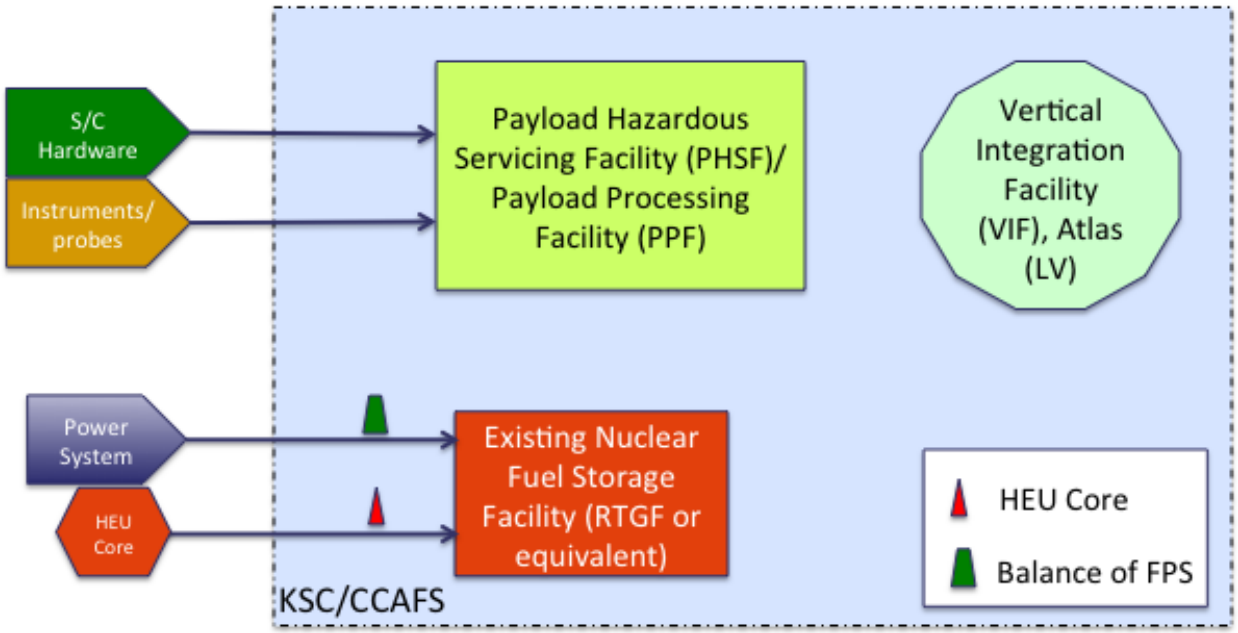


Notional TSSM ATLO Timelines



Note: Units for "L-" dates are Months unless otherwise noted

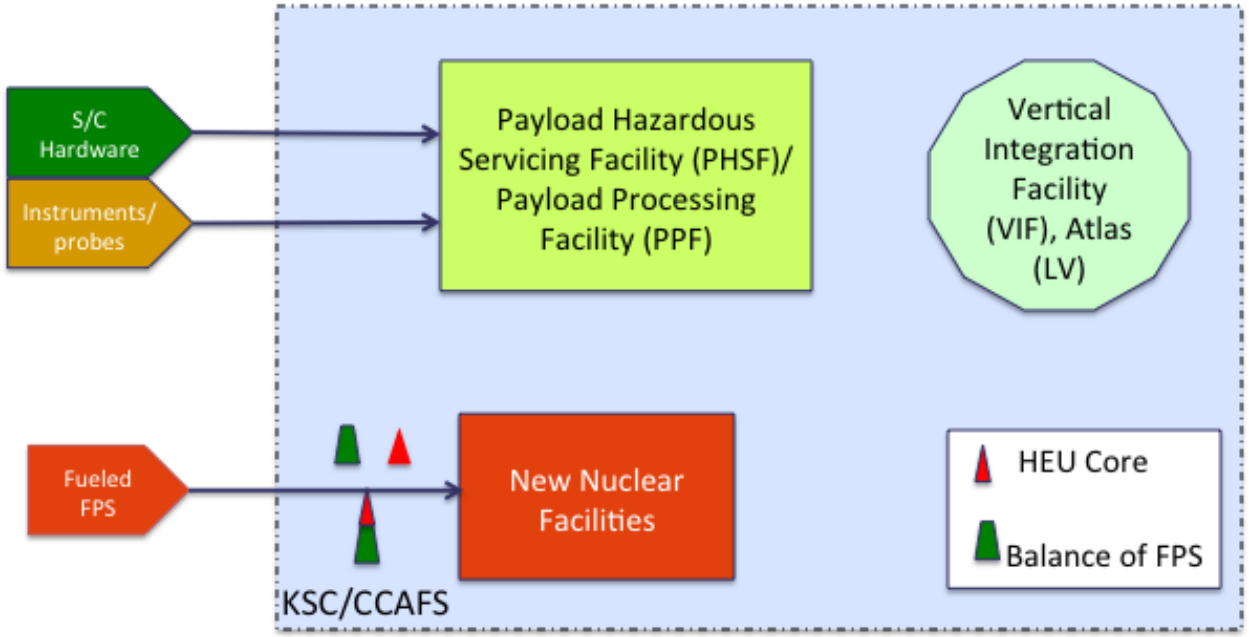
FPS Integration Options Considered: Scenario A



CCAFS: Cape Canaveral Air Force Station
RTGF: Radioisotope Thermoelectric Generator Facility

- Using the **Existing** Facilities at KSC
  - Option 1 – Core and FPS shipped to existing facilities and integrated then ship fueled FPS to PHSF and placed into S/C.
  - Option 2 – Unfueled FPS delivered to existing facilities and placed into S/C at PHSF with core inserted at Vertical Integration Facility (VIF).
  - Option 3 – Fueled FPS delivered to existing facilities and placed into S/C at VIF.
  - Option 4- Core and FPS shipped separately to existing facilities and then integrated and placed into S/C at VIF.

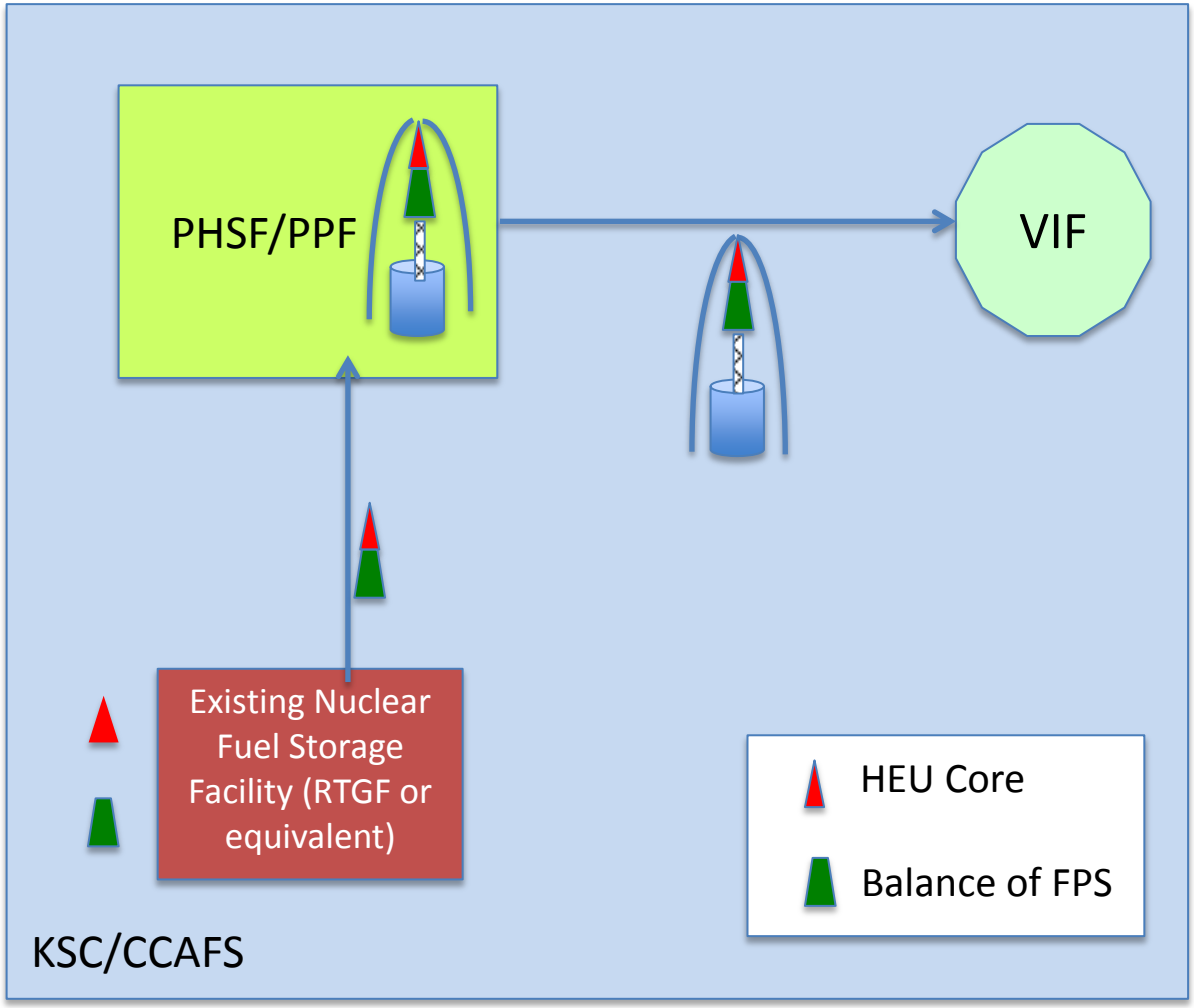
FPS Integration Options Considered: Scenario B



CCAFS: Cape Canaveral Air Force Station
RTGF: Radioisotope Thermoelectric Generator Facility

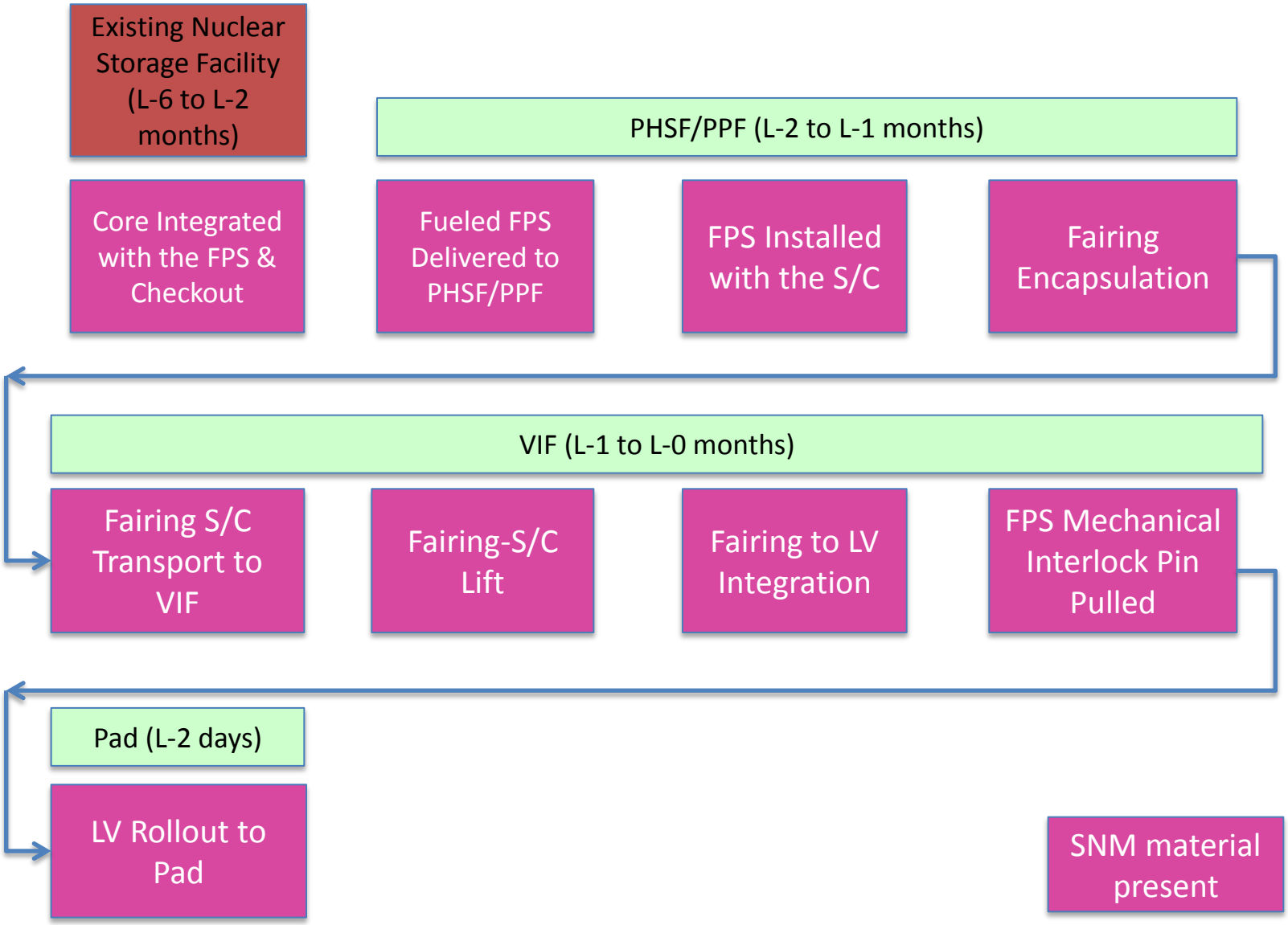
- Using possible **New** Nuclear Facilities at KSC
  - Option 5 – Core and FPS shipped separately to new nuclear facility and then unfueled FPS placed into S/C at PHSF and core inserted at VIF
  - Option 6 – Core and FPS shipped to new nuclear facility and then placed into S/C in same facility

Scenario A: Option 1



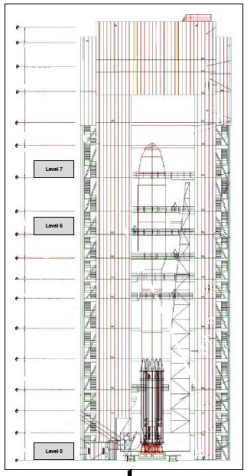
- Core and FPS shipped separately and received at existing fuel/FPS storage facility
- HEU Core integrated with power system assembly at existing fuel/FPS storage facility
- Zero power test performed at RTGF
- S/C payload stack/FPS encapsulated in fairing at PHSF
- Fairing S/C stack transported to VIF
- Lift to top of VIF and assemble onto the LV

Scenario A: FPS ATLO Nominal Flow Option 1



Discriminators for Considered ATLO Options

VIF



- Significant VIF Building Modifications (include adding new floors, new levels, etc.): Significant multiple millions $$ cost is anticipated
  - Requires significant Launch Vehicle Provider engineering studies
  - Requires schedule for facility modification dependent upon a favorable manifest opening
  - Unable to determine if, the anticipated VIF modifications are possible, etc.
- Significant Launch Vehicle Modifications
  - Modifying the existing fairing structural design
  - Modifying the fairing assembly procedures, tooling or assembly processes, etc.
  - Anything identified as likely to require the re-certification of an existing “certified” vehicle or, impact the launch vehicle data book development schedule, etc.
- Significant FPS System Integration Design Constraint
  - Any proposed operation to integrate a power source inside a fairing must be a relatively “simple” (a “plug and play”) design constraint imposed on a FPS system
  - If the system cannot clearly commit to this requirement, the discriminator is thus defined as “ significant”.
- If a new building is involved with no other redeeming virtue that option was less attractive.

KSC ATLO Recommendation: Scenario A, Option #1

- Assessed the option #1's (PHSF Encapsulation of FPS) impacts
  - Launch vehicle processing, screening of staff, additional security measures
  - Transportation/hoist and mate operations
    - Launch Vehicle Structural Design, Fairing encapsulation processes and the VIF Facility are generally, undisturbed from a technical perspective
  - Overall Least Risky Option
    - Eliminates risky, confined space/inside the fairing integration operations
  - Identified mitigations to the impacts are generally limited to adding staff, adding SC and LV schedule margin to accommodate added security layers applied to the RTGF, PHSF and VIF, adding security costs (more staff assigned) etc.
    - Also may require some modifications to launch vehicle fairing transportation equipment to add redundancy
  - FPS system can be fully assembled to SC, tested, verified as required at the PHSF
    - Again, elimination of the acrobat/circus acts required inside the fairing
- Option #1 is thought to be the lowest cost, lowest risk solution with the fewest number of unknowns at this time

Other ATLO Options: Option #2, #3, #4, #5 and #6

- Option #2 and #5: Not Recommended
  - VIF core installation with FPS installed in fairing prior to VIF
  - Anticipated (too many critical unknowns) to be a risky core installation operation at the VIF vs a MMRTG/RTG
  - Unknown post installation testing/verification requirements
  - Unexplored “unusual” fairing door location and TBD size located in the fairing nosecone
  - Significant VIF facility modifications anticipated (adding decks, et.) to access door in the conical section of the fairing (above level 7)
  - #5 involves use of a new nuclear facility due to security considerations
- Option #3 and #4: Not Recommended
  - VIF FPS with core in place installation
  - A complete fairing re-design for a single mission required to accommodate an opening large enough to install the FPS at VIF
  - Launch vehicle re-certification anticipated due to new fairing design
  - Verification of readiness to launch post installation unknown/unexplored
- Option #6: Not Recommended
  - New nuclear facility used for FPS and core mate up and subsequent encapsulation in fairing
  - Similar to option #1 but with new building
  - Not supported as necessary via security gap analysis performed to date

Summary of Security Considerations: Special Nuclear Material (SNM) for FPS would be Category I Attractiveness B

- Based on both the length of time Category I SNM would be physically present at the RTGF and the size, portability, configuration, and weight of SNM, it was recognized that the lowest risk option would be the construction of a new combined RPSF and FPS Facility, or RPSF/FPSF, including a new protected area that would meet DOE Order material access area (MAA) and protected area (PA) protection requirements.

- This approach meets DOE requirements and provides significantly more protective system effectiveness in comparison to other options evaluated.

- There are three other locations that would be utilized by the FPS campaign as Category I SNM is moved: the Payload Hazardous Storage Facility (PHSF), Vertical Integration Facility (VIF), and launch pad. The movement of Category I SNM as the project is relocated from one location to another would also be included in this category of protection.

- Unlike the protection methodology and approach used for the RTGF, these three project locations (and related movements between these locations) would incorporate manpower-intensive measures with a performance-based approach and a few selected security upgrades, as opposed to spending millions of dollars to meet DOE PA and MAA protection requirements at each.

- This protection approach is based on the shorter project duration phase at each of these facilities (usually lasting ~1 month or less), and the fact that the size, weight, portability, configuration, and accessibility of Category I SNM has inherent built-in security (for example, the Category I SNM would be located as high as ~150 feet above ground in the fairing of the Atlas V rocket, contained in a non-portable reactor).

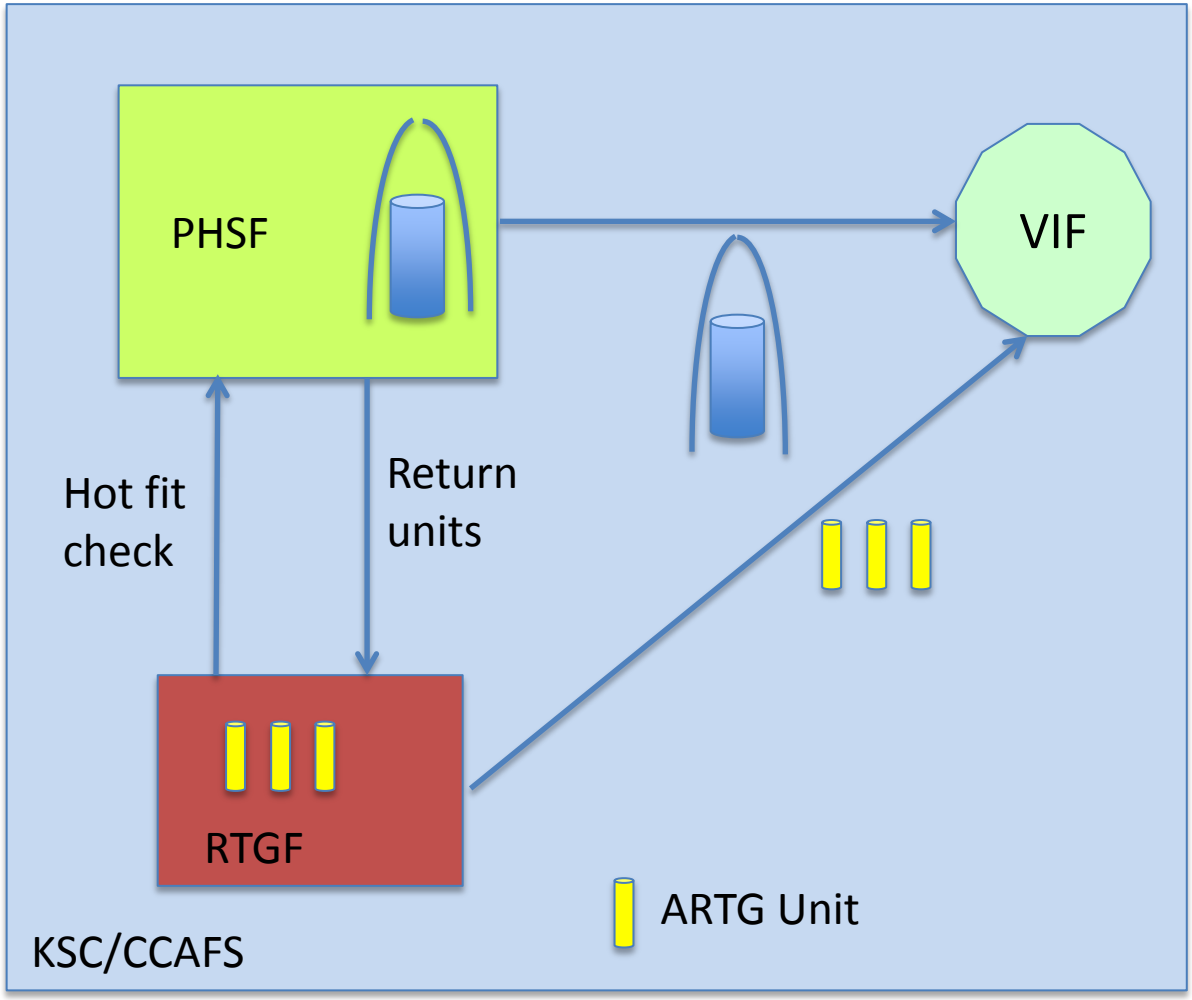
SNM is defined by quantity of U-235, chemical form and purity for security purposes.

Take away- Less than 1 month at a location- Lots of guys with guns.
More than 1 month at a location the use of engineered systems is desired and guys with guns.

New RPS System Assumptions for KSC ATLO Assessment

- The Systems Team developed both Stirling and TE (ARTG) RPS concepts for providing the TSSM S/C a total of 1,000 W_e at end of mission (EOM).
- SRG
  - TSSM Team X selected four (3+1 redundant) SRGs
  - Each SRG uses 6-GPHS modules (1,500 W_{th}) (~320 W_e ground ops)
  - Dimensions: 65 cm long, 33 cm diameter, active controller
- ARTG
  - TSSM Team X selected three ARTGs
  - Each ARTG uses 16-GPHS modules (4,000 W_{th}) (~430 W_e ground ops)
  - Dimensions: 107 cm long, 54 cm diameter, no active control
- Since both the SRG and ARTG units sizes are smaller than the GPHS RTG, it is assumed the current DOE fueling and assembly facilities, the Type B 9904 shipping containers and transportation system can be utilized.

Notional 16-GPHS module ARTG Case or 6-GPHS module SRG Case



- 3 ARTGs are delivered to KSC with current DOE shipping casks and transporter system
- RPS stored at RTGF
- Intra KSC transport to PHSF for "hot fit check" and then return to RTGF for storage
- Intra KSC transport to VIF
- Lift units and perform typical installation via fairing access doors

New RPS Integration Options Summary

- The **safety** and **security** classification of the RTGF, PHSF and VIF is likely to be **Hazard Category 2** and **Security Category II or III, respectfully,** when the Special Nuclear Materials (SNM) is present for the case involving the 3 ARTGs due to more material being present than for either Pluto Horizons (PNH) or Mars Science Laboratory (MSL)- more involved than the current RPS path.

- Existing DOE facilities should be usable for fueling, testing, transportation and storage although the design of the SRG will need to be better developed before this can be said for certain. Methods for installation of the GPHS modules and application of pre-load will deserve further attention for the SRG.

- No attempt was made to include installation either the 6-GPHS module SRG or 16-GPHS module ARTG at the PHSF at this time.

Off-Nominal Scenario(s)

This section is meant to address non-dramatic changes such as launch scrubs due to equipment, facility or weather issues not launch accident/recovery scenarios.

- These happen infrequently but they do occur
  - Early 1986- Challenger accident
    - RTGs already present for Galileo launch
    - RTGs were removed back to Mound, OH using same shipping method as delivery to KSC

- **A key fact: RPS systems remain the exactly the same from a handling/shipping point of view but FPS systems may undergo a change if they are operated at KSC**

- What would be different if FPS used?

  - If no non-reversible difference in physical configuration has occurred a simple repackaging and shipping operation would suffice
    - Type B shipping container(s) would be employed for nuclear payload (qualified transportation tech., leak checkers, Heavy Equipment Operators, Office of Secure transportation, etc.

  - If the system has been operated at some nominal level, then an evaluation would have to be performed to examine to key aspects:
    - Has there been the creation of atomic species that would complicate the shipping situation such that a different Type B container would be required? Comparison of isotopic inventory versus certificate of compliance of the container.
    - Is the radioactive inventory of the SNM such that personnel exposure would drive you to using a engineered construct to minimize exposure? Portable hot cell or shielded glovebox

Off-Nominal Scenario(s)(cont.)

- If portable shielding is required
  - An evaluation of where to stage it would be necessary as some of it would require an appropriate floor loading evaluation as it can be heavy.
  - This activity would have to be considered as part of the documented safety analysis (DSA) and analyzed 2-3 years in advance of launch.
  - Lead procurement time for some engineered systems would be 2-3 years (shielded glove-boxes and portable shielded “hot” cells)
  - These activities are not show stoppers but they need to be evaluated and planned for 3-5 years prior to launch!

Future ATLO Work for FPS

- Prepare more detailed con-ops defining the FPS ATLO/SC processes for Option 1.
  - Detail processes occurring during each process step per facility (RTGF, PHSF, VIF, new fac.)
    - E.g., FPS launch site assembly/operations (zero power, Heat pipe/core brazing ops, etc.)
  - Security
  - Safety (health physics)
  - Schedule

- Assess the impact of FPS design changes to ATLO processes by performing the needed FPS system design trade studies
  - E.g., impact of deployable boom vs fixed boom in an end-to-end mission perspective

General Considerations as an Outcome from ATLO analysis

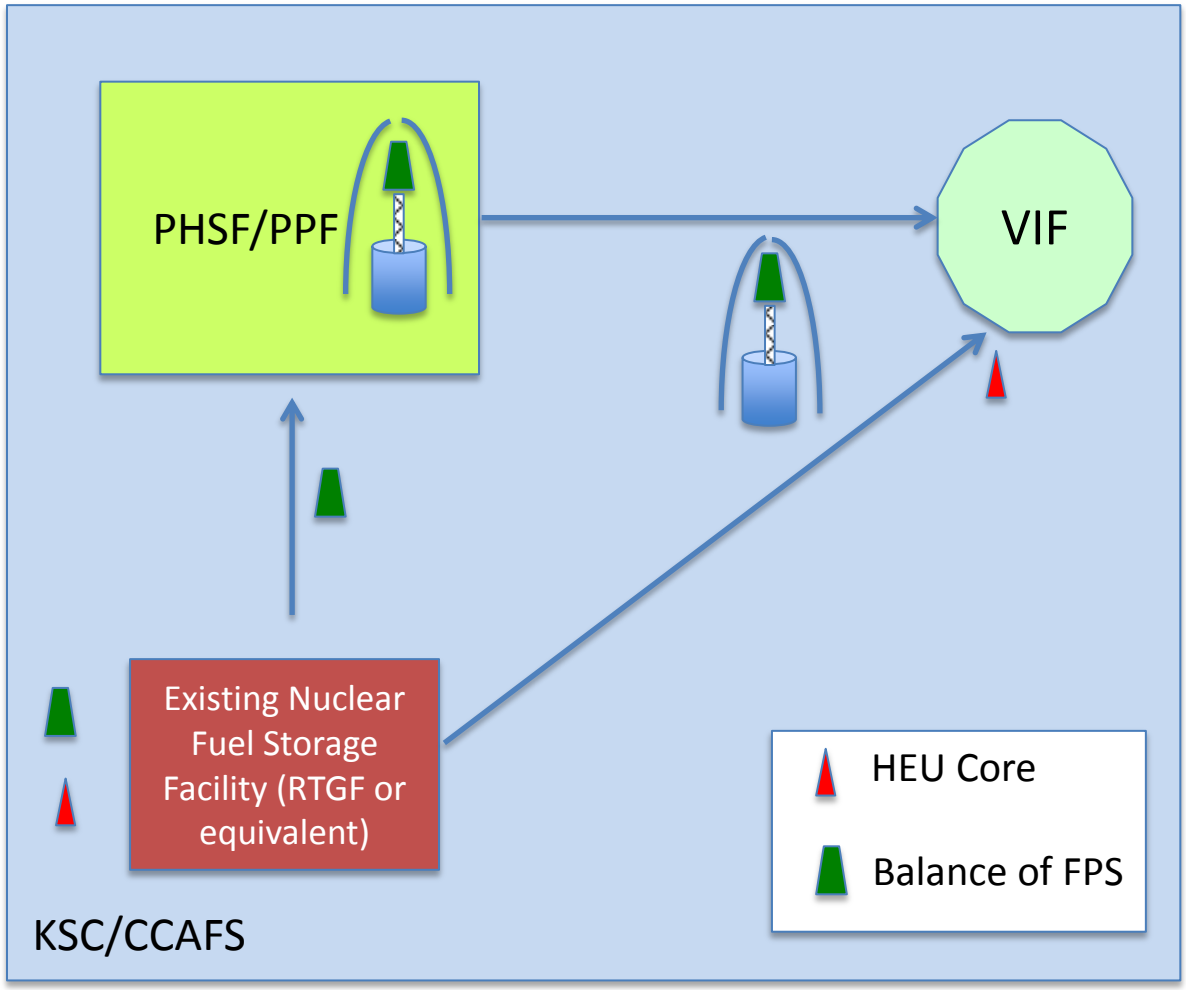
- Identify any differences between the 1 kW_e (25 kg HEU) and 10 kW_e (44 kg HEU) FPS options in the light of KSC processing infrastructure impacts

- Identify the needed LAE modifications for FPS
  - NEPA process starts at FPS System PDR

- Identify process location deltas for other LV's (Delta IV-H, Falcon Heavy, or SLS)
  - LV's Infrastructure and processing requirements

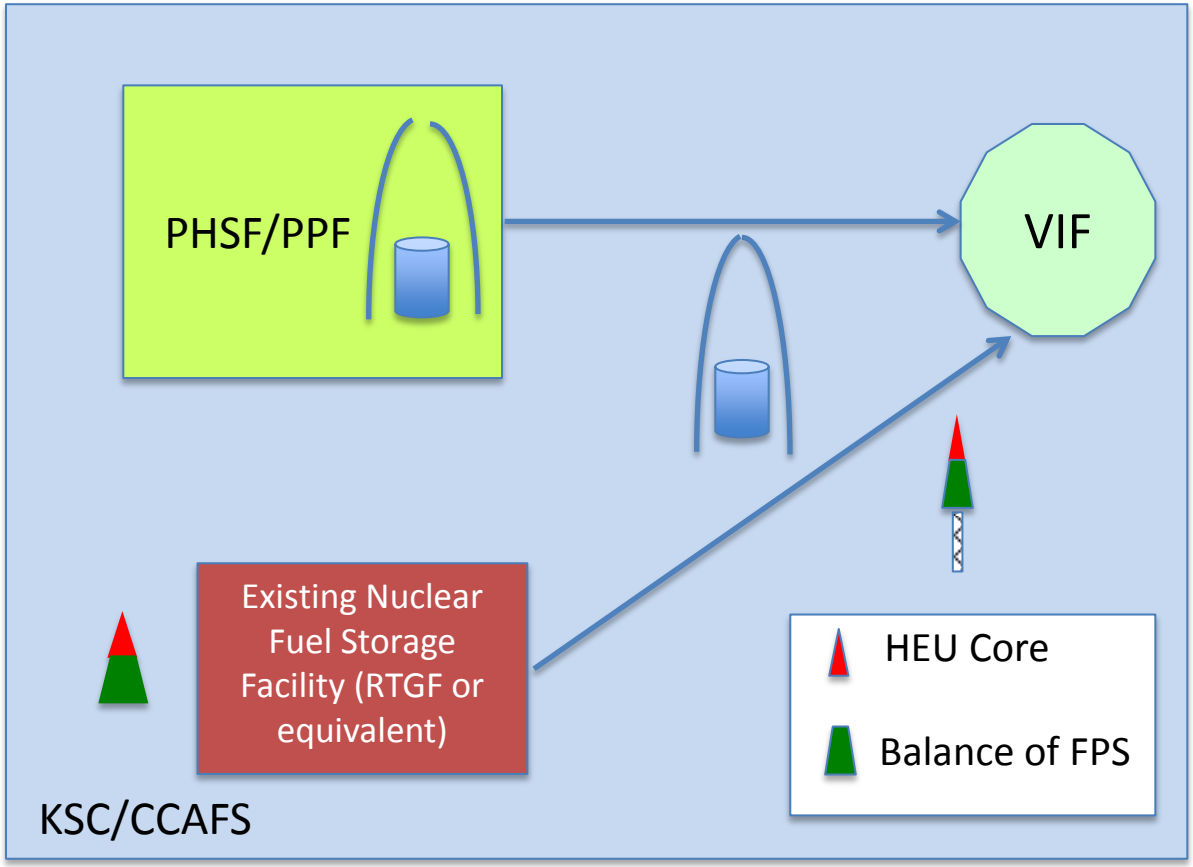
Back up slides

Scenario A: Option 2



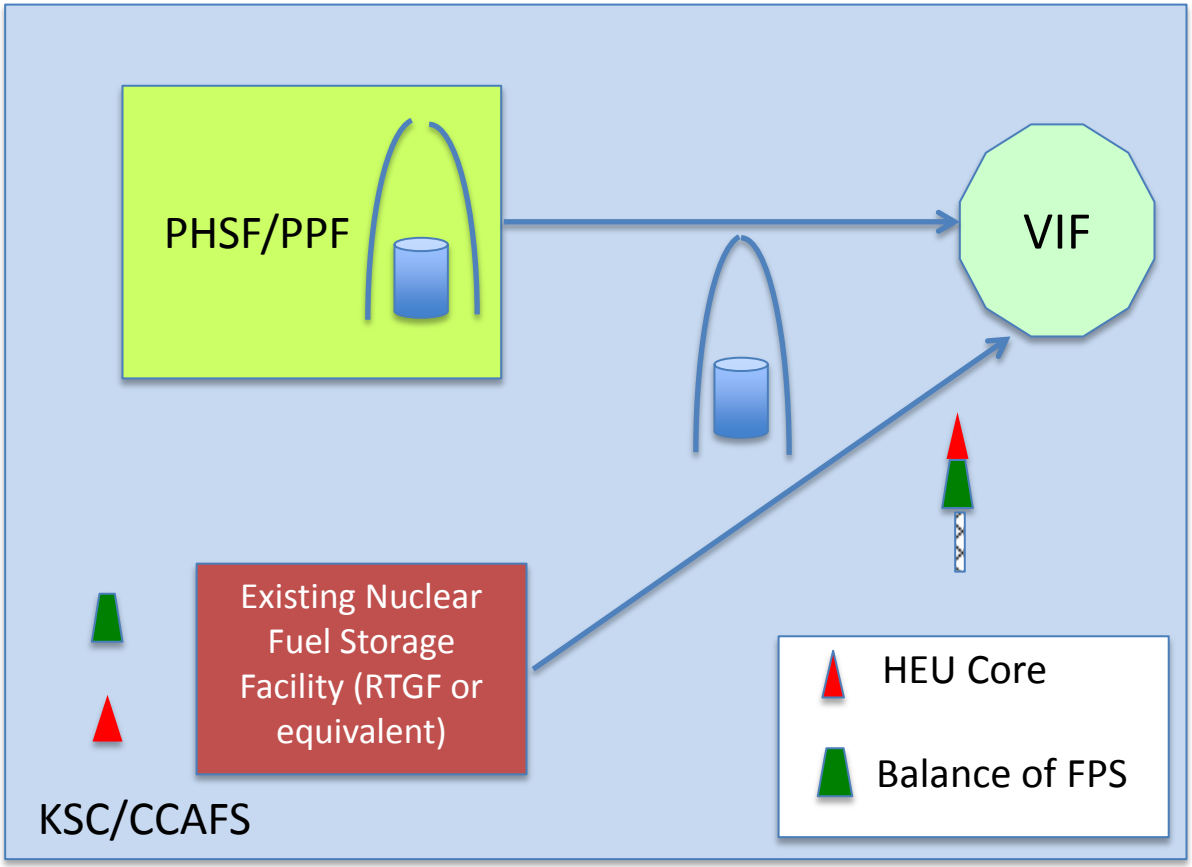
- Fission power system integrated with S/C at PHSF
- HEU core transported to VIF for final integration
- Core integrated with power system assembly via fairing access door
- Zero power test performed at VIF

Scenario A: Option 3



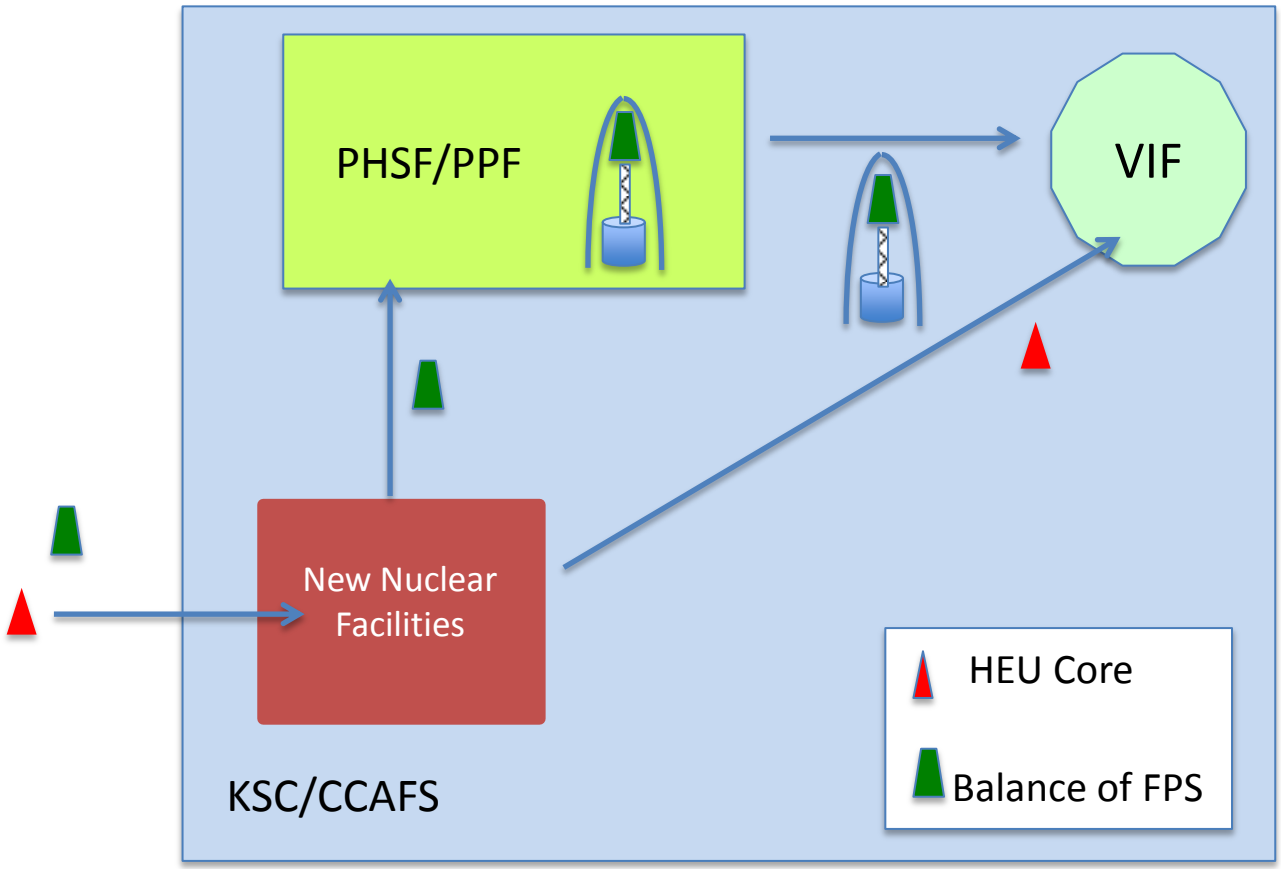
- HEU Core integrated with power system assembly delivered to existing fuel/FPS storage facility
- Zero power test performed at RTGF
- S/C payload stack encapsulated in fairing
- Fairing S/C stack transported to VIF
- FPS Installed onto S/C via **new fairing design**

Scenario A: Option 4



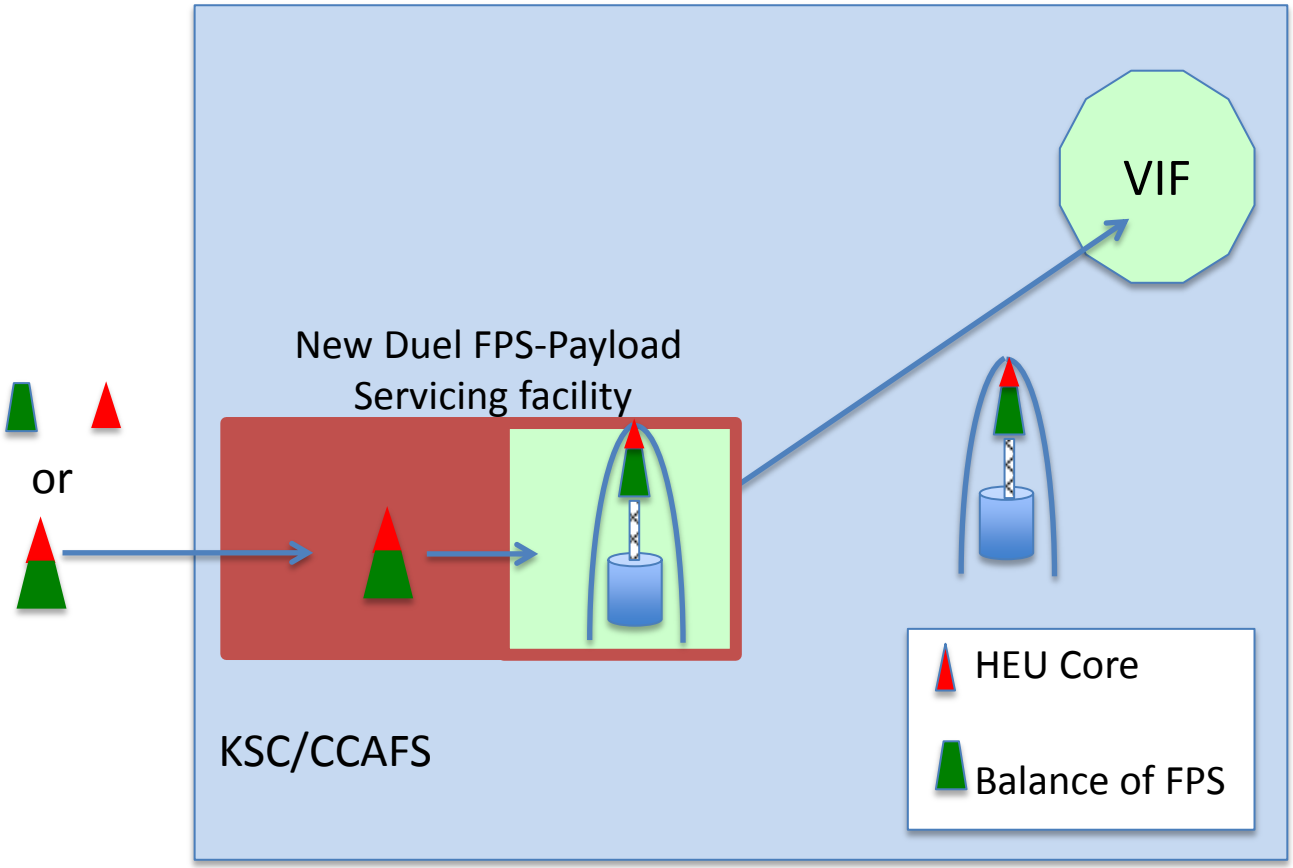
- HEU Core and FPS delivered separately to existing fuel/FPS storage facility and integrated there
- Zero power test performed at RTGF
- S/C payload stack encapsulated in fairing
- Fairing S/C stack transported to VIF
- FPS Installed onto S/C via new fairing design

Scenario B: Option 5



- HEU Core and FPS delivered/stored at new nuclear facilities
- FPS and S/C payload stack integrated at PHSF/PPF and encapsulated in fairing
- HEU core transported to VIF for final integration
- Zero power test at the VIF
- Core integrated with FPS power system assembly via fairing access door

Scenario B: Option 6



- Fueled or unfueled FPS received at new combined facility
- Core inserted into FPS if necessary
- Zero power check performed at New nuclear facility
- FPS and S/C payload stack integrated and encapsulated in fairing
- FPS and S/C stack transported to VIF and integrated on the LV