



NASA 40 kW Fission Surface Power I&C Technology Development Path

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National Aeronautics and
Space Administration



NASA Fission Surface Power – Technology Maturation Webinar

August 26, 2025

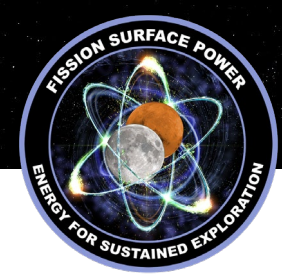
Hosted by Department of Energy –
Idaho National Laboratory

Clarification

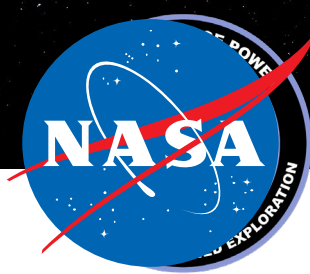
The following presentations are **solely** based on the 40-kW Fission Surface Power Project of the NASA Space Technology Mission Directorate.

The presentations are **ONLY** for public reporting and archiving purposes of the 40 kW NASA Fission Surface Power Technology Maturation activities.

The presentations do not imply, suggest, infer, advocate to represent or promote the recent NASA Directive to procure a 100 kW FSP system.



Fission Surface Power Technology Maturation Webinar



AGENDA: Aug 26, 2025 from 12:00pm - 2:00pm (ET)

START TIME	TOPIC	PRESENTER
12:00pm (ET)	WELCOME	Mr. Evan Nef DOE – Idaho National Lab
12:05pm (ET)	NASA Fission Instrumentation & Controls for Space (FICS) <u>2024 FICS Workshop Outcomes</u> • Live FICS Database • FICS Working Group • ‘Draft’ NASA I&C Technology Development Path for Fission Surface Power System	Dr. Robert Okojie NASA Glenn Research Center
12:15pm (ET)	Instrumentation & Controls: Evaluation of Unshielded SiC Pressure/Temperature Sensors	Dr. Robert Okojie NASA Glenn Research Center
1:00pm (ET)	Risk Reduction Activities for Stirling Controllers and Stirling Power System Development	Dr. Christopher Barth NASA Glenn Research Center
1:20pm (ET)	Power Management and Distribution	Mr. David Pike NASA Glenn Research Center
1:40pm (ET)	Testing the Effects of Lunar Dust on FSP Radiators at Glenn Research Center	Mr. Ronald Leibach NASA Glenn Research Center
2:00pm (ET)	END OF WEBINAR -- <u>Thank You</u> for your participation and time!	



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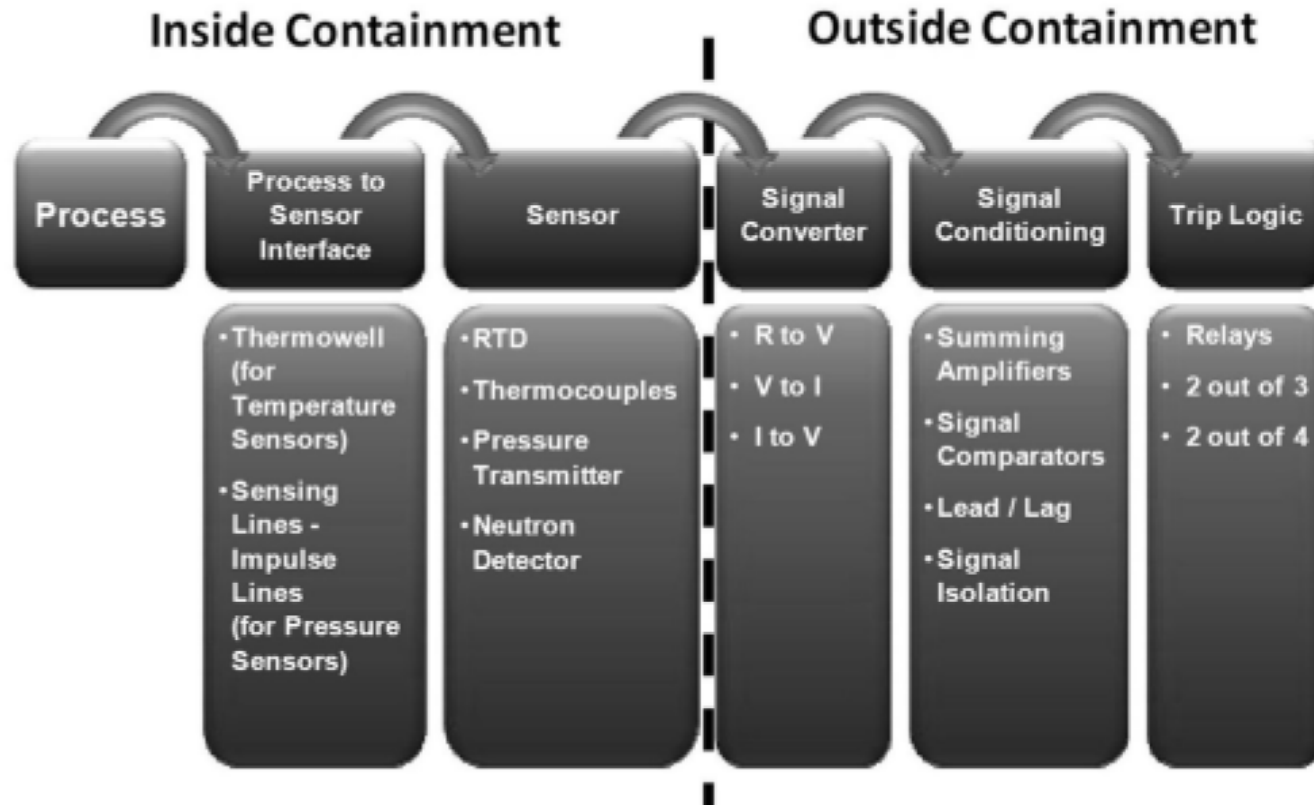
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Perspective: Leveraging Heritage Knowledge



Instrumentation requirements of terrestrial NPPs and FSP are largely the same.

Fundamental differences exist due to the operational environment of the FSP reactor.

However, leveraging decades of heritage knowledge from NPP and lessons from previous space-based reactor instrumentation (SNAP-10A and others) are crucial for accelerating FSP instrumentation development.

Typical Instrumentation Channel in Nuclear Power Plant (R = resistance; V = voltage; I = current).

Nuclear Power - Control, Reliability and Human Factors, Edited by Dr. Pavel Tsvetkov, ISBN 978-953-307-599-0, pg 52, 2011

NASA 40 kW Lunar Fission Surface Power

Attributes	Challenges on Instrumentation and Controls
Compact	Instruments must have small form factor and multifunctional to fit.
Autonomous	Agile to preemptive response to faults and deploy corrective action.
10-year Operational Life	Maintenance and replacement of faulty parts not possible
Reliability	Protocol to validate 10-yr robustness and reliability must be instituted.

Key Take Away

- No luxury of replacing faulty parts!
- Instrumentation with reduced form factor.
- Instrumentation will reside in-core and ex-core.
- **De-risk I&C by layered redundancies to ensure zero failure margin.**
- Invest in emerging innovative I&C systems to address FSP unique instrumentation requirements.

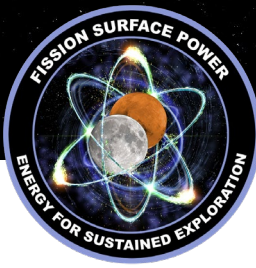


2024 NASA Fission Instrumentation & Controls for Space (FICS) Workshop

Fission Surface Power and Space Nuclear Propulsion Projects:

- Key Pointers - Why these are being developed
- 2024 Workshop Outcomes - *Over 130 Attendees*
 - FICS Centralized Database (CINDI)
 - FICS Working Groups
 - 'Draft' NASA I&C Technology Development Plan for FSP System

FSP-CINDI (Controls and Instrumentation Database Interface)



Problem Statement:

- FSP is going to require many I&C devices that can support extra-terrestrial harsh environment nuclear reactors (i.e. Moon and Mars)
- I&C technologies for this mission currently does not exists due to:
 - System compactness, 10-year no maintenance, and reliability challenges

Objectives:

- Develop a strategy as to where to start
- What are the technology gaps
- How do we catalog these gaps and share information?

Results:

- Conducted extensive literature research (i.e. journals, reports, articles)
- Developed Database (DB) to hold all relevant I&C information
 - Made an easy to use lookup page to search for devices
 - Can filter between categories, sort temperature and radiation from highest to lowest
 - Display the source information for each device (can lead to finding potential partners to work with)

FSP-CINDI								
Purpose Search ☐ Select all ☐ (Blank) ☐ Actuator ☐ Electronic ☐ Sensor			Sub-Purpose Search ☐ Select all ☐ (Blank) ☐ Accelerometer ☐ Acoustic Emission ☐ Amplification			Mechanism Search ☐ Select all ☐ (Blank) ☐ Acoustic ☐ Capacitive ☐ Capacitive / resistive gauge		
Part	Purpose	Sub-Purpose	Mechanism	Thermal Limits	Max Temp	Radiation Limits	Fluence	Fl ¹⁰
"Cambridge" Type N	Sensor	Temperature	Thermocouple	1250C	1250	3x10 ⁻²¹ n/cm ²	3.00E+021	
Fiber Optic Temperature Sensor	Sensor	Temperature	Fiber Optic	Max 700 C (850 C)	700	Fluence: 10 ⁻²¹ n/cm ²	1.00E+021	
Ultrasonic Thermometer	Sensor	Temperature	Multi-section Temperature	Room temperature to 2500 C demonstrated, potentially greater than 3000 C possible.	2500	8.8x10 ⁻²⁰ n/cm ²	8.80E+020	
Piezoelectric Ultrasonic Transducers - Aluminum	Sensor	Ultrasonic	Piezoelectric	Likely below 327C (reading mentioned melting wires ranged from 327°C to	327	fluence: 8.68x10 ⁻²⁰ n/cm ² gamma: 7.23x10 ⁻²¹ Gy/cm ²	8.68E+020	
Title	Year	Company	Journal	Name	Entity	Contact	URL	
UV Absorption Hygrometer for Fast-Response Airborne Water Vapor Measurements	2012		Journal of Atmospheric and Oceanic Technology				https://journal	
Ultrasonic Level Transmitter Model LU30		FlowLine					https://www.fli	
Ultrasonic High-Temperature Sensors: Past Experiments and Prospects for Future Use	2010		International Journal of Thermophysics	Mathias Laurie	European Commission	mathias.laurie@ec.europa.eu	https://nes.ene	

FSP-CINDI - Example



Step 1: Search for your device of interest

FSP-CINDI

Purpose

Search

Select all

☒ Sensor

Sub-Purpose

Search

☐ Pressure

☐ Radiation

☐ Reactor Power

☐ Resistance

☐ Strain

Mechanism

Search

☐ (Blank)

☐ Acoustic

☐ Differential Pressure

☐ Fiber Optic

☐ Linear Variable Differential Transformer (LVDT)

Part	Purpose	Sub-Purpose	Mechanism	Thermal Limits	Max Temp	Radiation Limits	Fluence	Flu
Transmitter								
Series 1900 Compact Low Differential Pressure Switch	Sensor	Pressure	Single-pole double-throw	from -34 to 82C	82			
Type 551 Pressure Transmitter	Sensor	Pressure	Transmitter	Process: 121C, Ambient: 85C	121			
IFE Halden LVDT Pressure	Sensor	Pressure	Linear Variable Differential Transformer (LVDT)	Max 700 C	700	Demonstrated performance in nuclear applications.		
Integrated SiC Pressure/Temperature Sensors	Sensor	Pressure	Piezoresistance	7/9/25 - 500C 24hrs 800 C reported. 1200 C, theoretically.	800	7/9/25 - tested at MIT at 10 ¹³ n/cm ² -s flux, 10 ¹⁸ n/cm ² fluence. 10 ¹⁵ n/cm ² has been reported. Theoretically, can go higher.	1.00E+018	1.0

Optional: Use the numeric columns to sort devices from highest to lowest

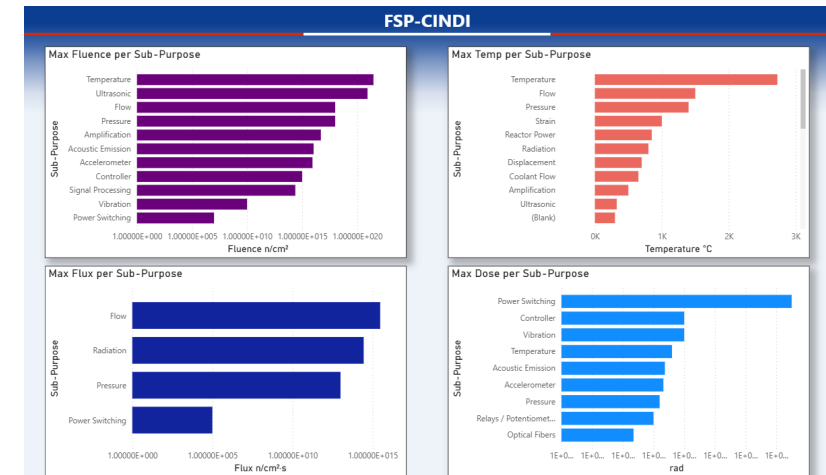
Max Temp	Radiation Limits	Fluence	Flux	Dose
800	7/9/25 - tested at MIT at 10 ¹³ n/cm ² -s flux, 10 ¹⁸ n/cm ² fluence. 10 ¹⁵ n/cm ² has been reported. Theoretically, can go higher.	1.00E+018	1.00E+013	
	fluence: 3.4x10 ¹⁵ n/cm ² gamma: 18 kGy (1.8x10 ⁶ rad)	3.40E+015		1.80E+006
	fluence: 6.1x10 ¹⁴ n/cm ² gamma: 1.7 kGy (1.7x10 ⁵ rad)	6.10E+014		1.70E+005
	fluence: 5x10 ¹⁴ n/cm ² gamma: 25 kGy (2.5x10 ⁶ rad)	5.00E+014		2.50E+006
51				

Step 2: Select device to automatically display source information at bottom table

Part	Purpose	Sub-Purpose	Mechanism	Thermal Limits	Max Temp	Radiation Limits
Transmitter						
IFE Halden LVDT Pressure	Sensor	Pressure	Linear Variable Differential Transformer (LVDT)	Max 700 C	700	Demonstrated performance in nuclear applications.
Integrated SiC Pressure/Temperature Sensors	Sensor	Pressure	Piezoresistance	7/9/25 - 500C 24hrs 800 C reported. 1200 C, theoretically.	800	7/9/25 - tested at MIT at 10 ¹³ n/cm ² -s flux, 10 ¹⁸ n/cm ² fluence. 10 ¹⁵ n/cm ² has been reported. Theoretically, can go higher.
Kulite XCE-062	Sensor	Pressure	Piezoresistance			fluence: 3.4x10 ¹⁵ n/cm ² gamma: 18 kGy (1.8x10 ⁶ rad)
Extrinsic Fizeau Cavity	Sensor	Pressure		800C	800	Demonstrated in ex-

Title	Year	Company	Journal	Name	Entity	Contact
Excel File: "FSP-SNP landC Maturity and Gap Analysis"				Dr. Robert Okojie	Government	robert.s.okojie

Visuals also highlight best performing devices



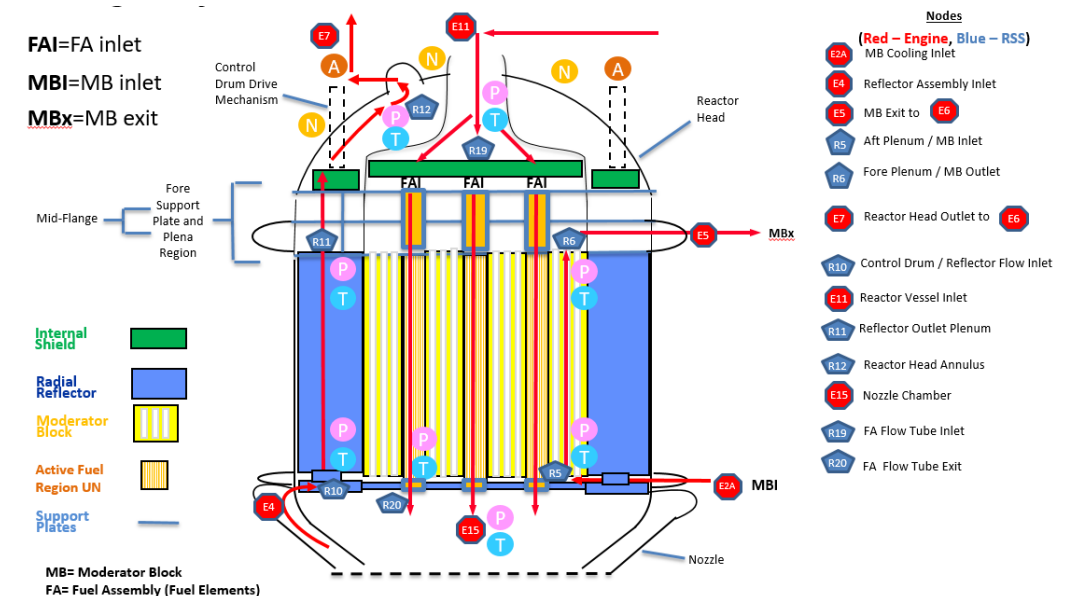
FICS Working Group (Sensor Pod)

OBJECTIVES

- Develop an understanding of sensor challenges related to Space Nuclear Propulsion (SNP) and Fission Surface Power (FSP), while harnessing expertise across multiple Gov't and industry organizations
 - Determine the sensors system needs for SNP and FSP
 - Foster development of complete sensor systems for NASA missions
 - Facilitate collaboration to develop Instrumentation and Controls (I&C) systems suitable for the harsh space environment enabling SNP and FSP operations.

ACTIVITIES

- Define Reference Systems for Instrumentation
- Identify High Level Sensor Requirements
- Identify Relevant Sensor Technologies including Database
- Determine Relevant State of the Art (SOA)
- Compare SOA to Requirements
- Formulate Gaps, Technical Barriers, and Risks
- Create a Roadmap to Meet Those Requirements



Test Case: Sensor Needs for Nuclear thermal propulsion (NTP) Reactor System. Courtesy of L3Harris

Drivers of I&C Maturity and Gap Analysis (40 kW FSP, 10-yr Life)

Survivability

Neutron fluence (10^{12} - 10^{21} n.cm⁻²), Gamma [30 krad – 8×10^{10} krad (Si)], Temperature (350-1250 K), Operability (10-year operation)

Reliability

Measurement integrity-What are the operating margins.

Performance characteristics compatible with FSP performance specifications.

Quantifying probability of failure-what standards to adopt/introduce.

High accelerated testing or reliability physics models, or both?

Compactness:

Small size and low weight. Technology with an intrinsically small size and weight should be prioritized, when possible, to avoid competing for payload allocation.

Technologies with miniaturization and multi-sensing potential should be prioritized as part of development activities.

Autonomous Operation

Self-diagnosis and fault detection capability.

Instruments with capability for built-in intelligence and communication should be prioritized.

Sensor technologies that can provide sufficient data for system fault detection should be deployed.

Control Automation.

Modern control system and diagnostic software should be integrated with smart sensors and fault detection systems to allow automated response in off-normal conditions.

40 kW FSP System I&C Sensors and Notional Functional Locations

(Red=Highest Priority, Orange=Medium Priority, Green=Low Priority)

Elements	Notional Ranges of Environmental Conditions (From PMAD to In-Core)	*Performance Characteristics	Reactor		Power Converter		Radiator	Transmission Line
			Process	Controls (i.e., drums)	Brayton	Stirling		
Radiation Detector (in- and ex-core)	Neutron $\sim 1 \times 10^{12}$ - 10^{21} n.cm ⁻² , Gamma ~ 30 k- 8×10^{10} rad (Si), ~ 1200 K							
Pre-Amplification	Neutron $\sim 1 \times 10^{12}$ - 10^{21} n.cm ⁻² , Gamma ~ 30 k-80 Mrad (Si) 300-1200 K							
Temperature Sensor (in- and ex-core)	Neutron $\sim 1 \times 10^{12}$ - 10^{21} n.cm ⁻² , Gamma ~ 30 k-32 Mrad (Si) 325-1200 K							
Pressure Sensor	Neutron $\sim 1 \times 10^{16}$ - 10^{21} n.cm ⁻² , Gamma ~ 30 k- 8×10^{10} rad (Si) 900-1500 kPa, 900-1200 K							
Flow Sensor	Neutron $\sim 1 \times 10^{12}$ - 10^{21} n.cm ⁻² , Gamma ~ 30 k- 8×10^{10} rad (Si) 0.05-0.5 kg/s and no flow intrusion, <1200 K							
Strain Sensor (in- or ex-core)	Neutron $\sim 1 \times 10^{14}$ - 10^{21} n.cm ⁻² , Gamma ~ 30 k- 8×10^{10} rad (Si) 900-1200 K							
Speed Sensor on motor	Neutron $\sim 1 \times 10^{12}$ - 10^{21} n.cm ⁻² , Gamma ~ 30 k-80 Mrad (Si), <1200 K							
Position Sensor (ex-core)	Neutron $\sim 1 \times 10^{12}$ - 10^{21} n.cm ⁻² , Gamma ~ 30 k-80 Mrad (Si), <1200 K							
Vibration Sensor	Neutron $\sim 1 \times 10^{12}$ - 10^{16} n.cm ⁻² , Gamma ~ 30 k-80 Mrad (Si), <1200 K							
Tilt Sensors	Neutron $\sim 1 \times 10^{12}$ - 10^{14} n.cm ⁻² , Gamma ~ 30 k-32 Mrad (Si), <1200 K							
Potentiometer	Neutron $\sim 1 \times 10^{12}$ - 10^{21} n.cm ⁻² , Gamma ~ 30 k-80 Mrad (Si), <1200 K							
Hydrogen sensors	Neutron $\sim 1 \times 10^{16}$ - 10^{21} n.cm ⁻² , Gamma ~ 30 k- 8×10^{10} rad (Si), ~ 1200 K							
E-Magnetic Sensors	Neutron $\sim 1 \times 10^{12}$ - 10^{16} n.cm ⁻² , Gamma ~ 30 k-80 Mrad (Si), <1200 K							

***Performance Characteristics yet to be completed**

40 kW, 10-yr Life I&C Technology Development Path for a Lunar Fission Surface Power System (DRAFT)

***Notional Subsystem Environmental Conditions (Based on a 40 kW System)**

PMAD* Temperature: 325-500 K Neutron flux: $10^8 \text{ n-cm}^{-2}\text{s}^{-1}$ Neutron fluence: $10^{12} \text{ n-cm}^{-2}$ Gamma dose: 300 krad	Cold-side Heat Exchanger* Temperature: 350-500 K Neutron flux: $10^8 \text{ n-cm}^{-2}\text{s}^{-1}$ Neutron fluence: $10^{14} \text{ n-cm}^{-2}$ Gamma dose: 10 Mrad	Radiator* Temperature: 350-550 K Neutron flux: $10^8 \text{ n-cm}^{-2}\text{s}^{-1}$ Neutron fluence: $10^{14} \text{ n-cm}^{-2}$ Gamma dose: 10 Mrad	Turbine/Compressor* Temperature: 390-1100 K Neutron flux: $10^8 \text{ n-cm}^{-2}\text{s}^{-1}$ Neutron fluence: $10^{14} \text{ n-cm}^{-2}$ Gamma dose: 10 Mrad	Hot-side Heat Exchanger* Temperature: 300-1100 K Neutron flux: $10^8 \text{ n-cm}^{-2}\text{s}^{-1}$ Neutron fluence: $10^{14} \text{ n-cm}^{-2}$ Gamma dose: 10 Mrad	Control Drums* These values are Design Specific	In-Core* Temperature: > 1200 K Neutron flux: $10^{12} \text{ n-cm}^{-2}\text{s}^{-1}$ Neutron fluence: $10^{21} \text{ n-cm}^{-2}$ Gamma dose: 8E10 krad
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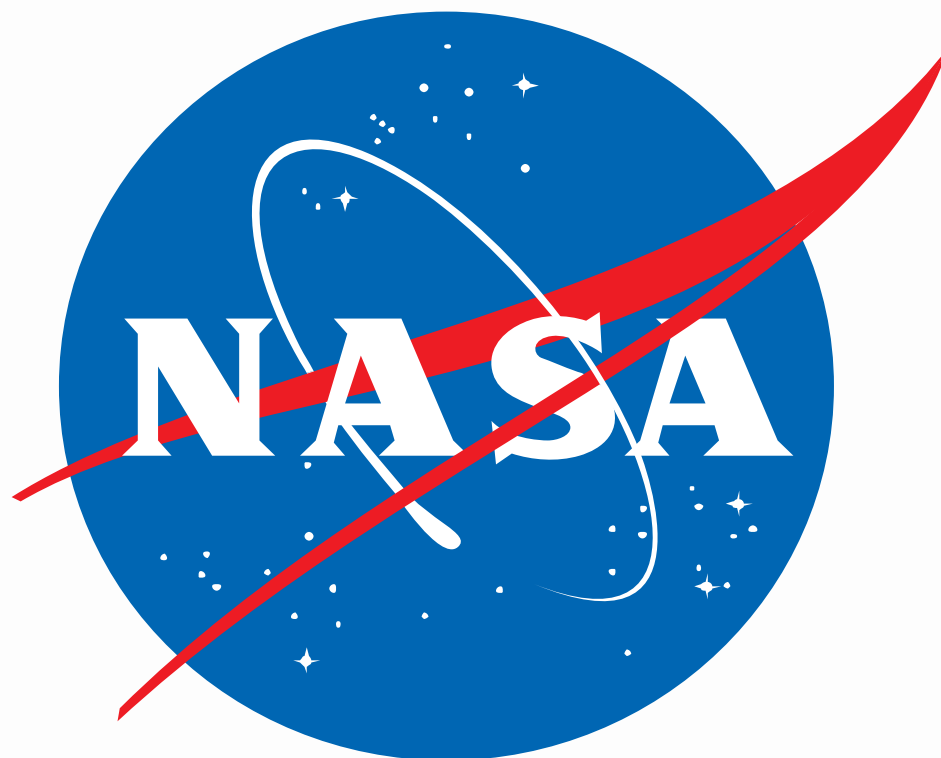
Sensors	Level of Difficulty and Complexity									
Radiation Detector (in- and ex-core)-RD Temperature Sensor-TS Pressure Sensors-PS Flow Sensors-FS Strain Sensors-SS Speed Sensors on motors-SPDS Position Sensors on Drums-PoS Vibration Sensor-VS Tilt Sensors-TLT Potentiometer-Pot Hydrogen Sensors-(H2) Electromagnetic-(Emags)	PMAD								Flight System Integration – Ready for Launch	
	Cold-side Heat Exchanger									
	Radiator									
	Turbine/Compressor									
	Hot-side Heat Exchanger									
	Control Drums									
	In-Core									
	Reliability Testing and Validation during Technology Development Years		Temperature, Radiation, Vibration, Vacuum, Temp. Coefficients of Sensitivity and Offset, Response Times, Linearity, Hysteresis, Offset Stability, etc.							

***Disclaimer: Values presented here are notional and do not represent any specific system requirement**

Recognition

NASA FICS Executive Committee		
Terri Benko	NASA FSP Project Integration Lead	teresa.m.benko@nasa.gov
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Appreciation to the FSP Project management and NASA GRC summer intern, Angel Martinez-Sanchez for developing FSP-CINDI



THANK YOU!



QUESTIONS & ANSWERS

LOOK AHEAD →

FSP Technology Maturation Webinar - September 2025

- Materials (NASA)
- Radiation Tolerance and Effects (NASA)
- Any significant Instrumentation & Controls updates (NASA)
- Moderator developments (DOE)