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ENGINEERING CRITICAL COMPONENT SPECIFICATION

**PERFORMANCE/DESIGN AND
PRODUCT CONFIRMATION REQUIREMENTS**

FOR

**ELECTRONIC, POWER, INSTRUMENTATION
& CONTROL**

**FORMING A PART OF
CEI NUMBER 090290A**

MASTER

PRELIMINARY PROPOSAL ISSUE

DATED 12-15-69

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AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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CODE IDENT. NO. 05824

Data Item Identification
No. C002-EC090155-F1

Engineering Critical
Component Specification No. EC-90155

Part I of Two Parts
Page - 1 of 36

PERFORMANCE/DESIGN AND QUALIFICATION REQUIREMENTS

for

ELECTRONIC, POWER, INSTRUMENTATION & CONTROL

Replace page(s) with the latest revised page(s) noted below. Revised paragraph(s) are identified with the latest revision letter (or number) in the margin.

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Specification No. EC-90155

1. SCOPE

1.1 Scope. - This specification establishes the performance design, test and qualification requirements for equipment identified as Engine Electronic, Power, Instrumentation and Control (EPIC), hereinafter referred to as the EPIC. The EPIC provides an aggregate of modular electrical/electronic assemblies to be used for engine control, signal processing and electrical supply distribution.

2. APPLICABLE DOCUMENTS

2.1 Aerojet-General Corporation Documents. - The following documents, of the exact issue shown, form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and other detail content Sections 3, 4, 5 and 10, the detail requirements of Sections 3, 4, 5 and 10 shall be considered a superseding requirement.

SPECIFICATIONS

CP-90290	NERVA Engine CEI Specification
EC-90214	Instrumentation and Controls Subsystem
EC-90177	Engine Instrumentation
EC-90179	Wiring Harness
EC-90216	Electrical Power Source
EC *	Nuclear Subsystem Instrumentation

* Number to be assigned by WANL.

DRAWINGS

1136653	EPIC Functional Block Diagram
1136874	Logic Diagram Malfunction Detection
1136876	NERVA Engine EPIC Physical Interface Control

PUBLICATIONS

(Copies of above documents required by suppliers in connection with specific procurement functions should be obtained from the procuring activity.)

3. REQUIREMENTS

3.1 Performance.- Except as otherwise specified herein, performance requirements for the EPIC shall be in accordance EC-90214 of which the EPIC is a part.

3.1.1 Functional Characteristics.-

3.1.1.1 Performance Characteristics.- The EPIC shall reliably operate with the rest of the nuclear rocket engine, the nuclear stage, and the complete mission vehicle; and shall be capable of monitoring and controlling the engine throughout the range of operations; conditioning and processing data and signals; and converting and regulating power as required to perform these functions.

The EPIC shall be capable of diagnostic and control activity which shall enable checkout operations and which shall maintain engine performance within design parameters required for completion of mission objectives and/or which shall report malfunction and perform contingency plans for emergency situations under malfunction conditions.

The EPIC shall also be capable of providing engine output data to: the Instrumentation Unit (IU) and stage systems; the Vehicle Emergency Detection System (VEDS); to the Spacecraft system and displays. The EPIC shall also be capable of providing inputs to the engine in response to: Spacecraft commands; I-U system commands; VEDS commands, range safety decoder; checkout commands through normal input channels.

3.1.1.1.1 Engine Control. - The EPIC shall, in conjunction with engine mounted control elements, meet the requirements for engine ground preparatory phases, boost phases, coast phases, engine startup, steady state operation, throttling, shutdown, cooldown, engine safety, disposal operations and restart in earth sub-orbit and orbital environments and during planetary exploration missions as follows:

(a) Startup Operations - Accomplish startup to steady state operation in minimum time. From receipt of the engine start signal, the startup to initiation of bootstrap shall be achieved in 23 seconds or less with a chill-down time not to exceed 23 seconds from initiation of propellant flow into the engine based upon a mean ambient engine temperature of 560°R or less. The startup from initiation of bootstrap to steady state full power operation shall be accomplished in 29 seconds or less at pressure and temperature rates of change of 50 psi/sec and 150°R/sec nominal respectively. Provide for alternate thrust buildup modes for a maximum engine specific impulse mode and a maximum thrust mode.

(b) Steady State Operation. - Maintain engine steady state conditions by controlling on thrust chamber gas temperature and pressure. During steady state operation, control thrust chamber gas temperature at 4250°R nominal and thrust chamber pressure at 450 psia nominal with the capability of throttling in the range of 450 psia to 270 psia chamber pressure at a rate of 50 psi/sec nominal; maintaining thrust chamber gas temperature at 4250°R nominal.

Specification No. EC-90155

(c) Shutdown Operation - Accomplish engine shutdown such that total impulse delivered is minimized while integrated shutdown specific impulse is maximized. The shutdown operation will begin upon receipt of the shutdown signal at the EPIC and shall be completed at the time the reactor control drums are positioned for maximum negative reactivity, the turbine power control valves are closed, and the tank propellant and pressurization conditions shall support engine cooldown requirements.

(d) Cooldown Operations. - The EPIC shall be capable of support structure continuous cooldown and pulse cooldown control during the time interval from completion of the shutdown operation until the engine does not require coolant fluid flow to remain at temperature below engine structural high temperature limits. When one or more engine components reach upper limit temperatures, initiate flow until temperature reaches the lower temperature limit, then interrupt flow. Repeat this sequence during the time interval from shutdown complete until the end of the engine cooldown operation.

During the cooldown period, maintain proper temperature distribution and efficient use of impulse propellant by heating the cooldown fluid to the highest possible gas temperature to maximize specific impulse.

(e) Restart Operations. - Accomplish engine restart if required by specific mission profiles at any time after the engine shutdown operation is complete. Dependent upon engine temperature conditions during or after cooldown operations specified in 3.1.1.1.1(d); restart the engine in either of the two modes specified in 3.1.1.1.1(a), at the pressure and temperature rates reflected by mission specified demand signal conditions at the EPIC interface. Response to an engine restart signal shall be in the same manner as the initial engine start signal; however, varied in real time as a function of engine temperature conditions at the time of receipt of the restart signal. In no case, compromise planned mission objectives as a function of time from receipt of

the restart signal to achievement of the demanded steady state engine operating condition.

(f) Thrust Vector Operation - Accomplish engine thrust vector control by responding to vehicle guidance commands to position the engine pitch and yaw actuators to alter the thrust vector around the vehicle longitudinal axis during powered operation. Provide for receipt of flight crew manually initiated position demand inputs as an alternate control mode.

(g) Disposal Mode - Provide engine control during the nuclear stage disposal operation.

3.1.1.1.2 Engine Signal Processing - The EPIC shall be capable of conditioning, amplifying and otherwise processing engine mounted transducer and sensor output signals to meet engine control, diagnostic, trend data and malfunction detection requirements during all phases of engine operation including ground checkout. The EPIC shall encode engine signals into a form compatible with the nuclear stage and/or mission vehicle astrionics system(s) and/or crew command module monitoring system.

3.1.1.1.3 Electrical Power Source Conditioning and Distribution - The EPIC shall regulate the electrical power source power to suitable levels and characteristics for the needs of the engine system. The electronics shall transmit the required signals and power within the EPIC and to the individual engine elements served that connect to the EPIC physical electrical interfaces for all phases of engine operation.

3.1.1.2 Engine Control.- The EPIC shall consist of elements that satisfy the following functions. The relationships of these functional elements shall be as shown on Drawing 1136653. Control of engine binary and analog functions; locking mechanisms; servo loops; demand level changes; and other time or parametrically related events shall be exercised as required:

3.1.1.2.1 Prestart Conditioning.- Engine control prestart functions to ready the engine for startup shall occur from receipt of the prestart signal at the EPIC interface until receipt of the engine start signal at the interface. These functions and related requirements are:

(a) Electrical Power Control.- The EPIC shall, upon receipt of the prestart signal, sequence the activation of electrical power supplies that satisfy engine operation power demands. The EPIC power control logic shall be capable of switching engine run power demand functions to the off state during engine cooldown and coast operations. During engine cooldown, engine operating power shall be switched off. After cooldown operations are complete, the EPIC power control logic shall terminate cooldown power and ensure that the coast phase power mode is in effect.

(b) Time to Start Calculation.- The EPIC shall monitor selected engine parameters, and from these, provide a signal proportional to the calculated time that will be required for engine startup to the vehicle guidance system and/or crew stations. The signal shall reflect the calculated time increment that will occur between receipt of the engine start signal at the EPIC interface and when the engine is ready for programming to a set thrust level. Accuracy of the calculation shall be within ± 10 seconds of the actual time required before the programming function can commence.

(c) Reset.- The EPIC shall be capable of providing for circuit operations and activation of power after receipt of the prestart command by removing reset. The reset removal command shall be received from crew/guidance at times other than during the prestart sequence. The command shall be issued for purposes of system checkout, ground preparatory phases or for an engine warmup cycle.

(d) Self-Check.- The EPIC logic shall perform a checkout of all elements of the engine I&C subsystem after reset removal. The checkout mechanism shall be capable of performing, self-check during earth preparatory phases as well as during earth sub-orbit, orbit and/or planetary maneuvers. Status of self-check shall be transmitted in the form of signals to the crew/guidance electronics. The self check shall initiate signals to appropriate selector logic to select backup functions for failed elements if primary; or exclusion if alternate. Self-check-completion signals shall be routed to the EPIC crew/guidance interface.

(e) Binary Valve Setup.- The engine binary valves shall be set by the EPIC in the required position for the engine prestart functions.

(f) Vector Alignment.- The EPIC shall incorporate circuitry to accept engine pitch and yaw commands from guidance/crew during the prestart sequence. The commands shall be translated into engine pitch and yaw actuator demands. Under stage/vehicle guidance computer/control computer direction, the EPIC circuitry shall drive the actuators in a mode which is proportional to the navigation signals received at the EPIC interface. Under crew direction (manual), the EPIC shall receive rate signals from the crew at the EPIC interface; and process these into vector actuator demand signals. Circuitry shall also be provided for the crew to select the manual mode of engine vector alignment. The EPIC portion of vector alignment control shall

not contribute errors that cause adjustment of pitch or yaw vectors exceeding the following system limits:

- (1) Angle, degrees, $\pm 3^\circ$ nominal ($\pm 4^\circ$ Maximum)
- (2) Minimum angular velocity, $0.75^\circ/\text{sec}$
- (3) Minimum angular acceleration, $0.5^\circ/\text{sec}^2$

(g) Warmup Cycle.- The EPIC shall incorporate features to effect adjustment of engine bulk temperature to the condition where average latent heat is sufficient for bootstrap operation as measured by a distributed material temperature average equal to or above 200°R . In the case where the average latent heat is equal to or above 200°R , the warmup cycle control shall not be active in the prestart sequence. Initiation of the warmup cycle in the engine prestart phase shall inhibit engine startup until sensible average latent heat has been detected by the engine electronic and instrument system. Operation of the engine system during the warmup cycle shall consist of the following:

- (1) Initiate control drum demand
- (2) Monitor system temperature
- (3) When average system temperature rises to 560°R , signal drums to sub-critical position.
- (4) After temperature rises to 560°R or above, control distribution of propellant flow with engine cooldown circuitry to maintain system temperature within established limits and to effect a necessary temperature distribution throughout the engine system.

In the event that a warmup cycle is required prior to engine startup, EPIC electronics shall produce a signal to the guidance/crew interface indicating this requirement. The warmup cycle time shall be included in the time to start function specified in 3.1.1.2.1(b). After the warmup cycle is complete,

Specification No. EC-90155

the time to start calculation shall be updated to transmit real time to start signals to the interface. The warmup cycle shall also be initiated by the EPIC upon command from guidance/crew independent of the prestart conditioning sequence to prevent occurrence of engine overcooling.

(h) Program Selection.- Prior to engine startup, the EPIC shall receive signals initiated by guidance/crew demands to setup the engine start program. The EPIC shall include provisions for two startup profiles for crew/guidance selection. These profiles shall be:

(1) High engine specific impulse startup

The EPIC control logic shall also include provisions to accept rate selection commands from crew/guidance for the two startup profiles. These rate selections shall be constrained to normal startup rates of 150°R/sec nominal and 50 psi/sec nominal; or less than the foregoing rates based upon given mission flight plans and/or crew operational decisions.

(i) Operating Point Thrust.- During the prestart sequence, the EPIC shall respond to guidance/crew command indicating the desired thrust level for the engine steady state run. The setting commanded shall reflect the end point for the programmed start sequence. The EPIC controls shall also be capable of responding to the operating point thrust setting for adjustment and trim for engine throttling functions during engine operation.

3.1.1.2.2 Startup.- Engine startup functions shall commence following the prestart conditioning phase specified in 3.1.1.2.1; upon receipt of an engine start command signal at the EPIC interface initiated by guidance/crew. The EPIC controls shall respond to the signal to advance the engine from fully shutdown and no flow conditions to the lower end of the engine operating

map. The startup function shall be considered complete when power, temperature and pressure conditions are such that a steady state hold could be effected and normal control loops are closed. The functions and related requirements are:

(a) Binary Valve Sequencing.- The EPIC shall issue signals to set engine binary valve positions for the startup function and provide monitoring of the set command reactions as follows:

- (1) Open Bypass Block Valve(s) #1 and #2 (BBV #1, BBV #2).
- (2) Provide signals to other engine binary valves as required.

3.1.1.2.3 Engine Autostart.- The EPIC shall provide control and monitor functions to advance the engine from initial conditions through bootstrap to the point where commanded pressure and temperature profiles are capable of being accomplished by the engine system. The engine autostart function and related requirements are:

(a) Startup Adjustment.- The EPIC shall monitor engine system temperatures and calculated after-heat (in the case of required restart); and adjust startup programming accordingly.

(b) Critical Position.- The EPIC shall incorporate logic to calculate critical position of the reactivity control devices for display and use in adjusting the autostart program.

(c) Time to Start.- The time to start calculation specified in 3.1.1.2.1.(b) shall be updated based upon program changes.

(d) Control Functions.- The EPIC shall, after initiation of the autostart sequence, signal the control drums to move into the position of positive reactivity contribution. At approximately this time,

Specification No. 90155

signal the tank propellant shutoff valve (PSOV) open. Timing of control drum and PSOV opening signals shall be partially based upon constraints imposed by the actions specified in 3.1.1.2.3.(a).

(e) Sensible Heat. - The EPIC shall monitor chamber gas temperature transducer signals for progress of the chilldown function and for an indication of sensible system heat. Sensible heat, as defined here, is when reactor power is of sufficient level to cause a 100°R increase in measured thrust chamber temperature.

(f) Condition Check. - The EPIC shall monitor engine thrust chamber nozzle coolant tube outlet temperature signals to interrogate status of the engine chilldown function. If the monitoring function indicates that chilldown is progressing ahead of pre-established schedules prior to detection of sensible heat in the system, then commands shall be initiated to the reactor control drum and/or the reactor structural component flow system to increase the rise to sensible heating.

(g) Thrust Chamber Temperature Control. - The EPIC shall monitor the measured engine thrust chamber temperature signal for an indication of sensible heating. When sensible heat has been detected, thrust chamber temperature control shall be initiated. Thrust chamber temperature control shall consist of temperature demand compared to temperature measured, required compensation of the comparison result, and resultant drum position demand.

(h) Support Structure Coolant Valve - SSCV. - The EPIC autostart controls shall issue a signal to position the SSCV during the chilldown/power-rise to sensible heating and succeeding phases.

(i) Temperature Demand.- The EPIC shall, when sensible heating has been detected and the temperature control has been initiated as specified in 3.1.1.2.3.(g), program thrust chamber temperature demand toward the level required to start the programmed rise to the preset thrust level in the range of the nominal operating ramp rate.

(j) Thrust Chamber Pressure.- The EPIC shall initiate engine bootstrap by activation of the turbopump turbine flow circuit after chilldown and achievement of sensible heat level are complete. The activation of the flow circuit shall be accomplished by initiating thrust chamber pressure control of either of the two engine bypass control valves (BCV #1 or BCV #2) and opening of the appropriate Turbine Blocking Valve (TBV #1 and/or TBV #2). Thrust chamber pressure control of the selected or both BCV's shall consist of chamber pressure demand compared to chamber pressure measured, required compensation of the comparison result, and transmission of the BCV position demand to BCV controls. The BCV position command shall be compared to BCV position measured for driving the BCV until measured position is equal to demanded position.

(k) Temperature Demand.- During the operations specified in 3.1.1.2.3.(h), (i) and (j), the EPIC shall program the thrust chamber gas temperature demand up. When demanded chamber pressure and present chamber gas temperature level are reached, the temperature and pressure demand programs to the preset thrust level specified in 3.1.1.2.1.(j) are initiated.

3.1.1.2.4 Engine Operation.- The EPIC shall perform the functions that are required for the various missions following startup and preceding shutdown. During the engine operation phase, the EPIC controls shall ensure that system limits are not exceeded that are under control for any conditions other than those associated with system malfunctions

shown on Drawing 1136874. The primary requirements during the operation phase are to provide thrust control and I_{sp} control over the increase and decrease extremes of the high I_{sp} and high thrust profiles. The EPIC shall incorporate provisions for programming, self-test and control option selection. These provisions shall consist of a time-base program of pressure and temperature demands, a self-test operation to ensure readiness of backup and alternate controls, and conditioning of backup/alternate controls to preclude undesirable transients if selection of these occur. The engine operation functions and related requirements are:

(a) Transfer to Run Controls.- The EPIC shall incorporate provisions in the startup function to transfer to the point where closed loop chamber pressure and temperature control shall be exercised by crew/guidance.

(1) Thrust Chamber Temperature.- Thrust chamber gas temperature control shall be exercised through positioning of the drum system or SSCV and drum systems.

(2) Chamber Pressure.- Chamber pressure control shall be exercised through positioning of the selected or both BCV's.

(b) Ramps to Thrust Setting. The EPIC shall, for high specific impulse startups where temperature reaches maximum before pressure ensure that the pressure rate after reaching maximum temperature shall be a function of the set temperature rate. For high thrust startups, where pressure reaches maximum before temperature, the EPIC controls shall ensure that the temperature ramp shall continue at the set rate to operating design point unless a temperature cutback function occurs.

(c) Thrust Hold/Adjust.- The EPIC temperature and pressure loop controls shall be capable of holding the engine at the preset thrust level

when the thrust level is reached. During this phase, SSCV shall be used for temperature control as required. Provisions for guidance/crew input shall be incorporated to trim or adjust the thrust level by changing the thrust set-point signal.

(d) I_{sp} Trim.- The EPIC shall be capable of correcting for engine system temperature measurement inaccuracies upon receipt of guidance crew initiated continuous engine I_{sp} trim command as a function of vehicle dynamics at the EPIC interface.

(e) Thrust Vector Operation.- The EPIC shall process vector adjustment signals continuously demanded by guidance/crew. The thrust vector operation shall be the same as the thrust vector alignment function of paragraph 3.1.1.2.1.(g).

(f) Malfunction Protection.- The EPIC shall incorporate means for engine system malfunction detection. Malfunction detection capability shall include provisions for sensing and transmitting to the EPIC guidance/crew interface, internal EPIC and engine mounted equipment malfunctions. Malfunction protection for anomalies occurring within the EPIC shall be provided by replacement of functional blocks of circuitry by identical backup functions and/or by alternate controls. For malfunctions occurring in engine mounted equipment, the EPIC shall provide protection circuits for corrective action where possible. All malfunction protection action shall result in appropriate signals transmitted to the EPIC guidance/crew interface. Circuitry shall also be incorporated for crew/guidance selection for alternate

or backup controls. The EPIC malfunction protection circuitry shall provide for the following in the order of precedence listed:

(1) Maintain engine operation at demanded operating conditions with capability for normal type shutdown.

(2) Provide for engine operation at a reduced operating level with capability of a safe shutdown.

(3) If either of the two preceding cannot be met, provide a safe shutdown.

(g) Cutback - Maximum Dependability Mode.- The EPIC shall incorporate circuitry to provide for engine cutback as required to prevent engine damage from occurring. The cutback functions shall be initiated automatically upon detection of deviation of selected engine parameters for normal conditions. The EPIC shall also accept crew/guidance initiated cutback demand as a function of determinations made based upon other engine operating indications that reflect deteriorating conditions in the engine system. The cutback function shall act to reduce engine operating temperature supplemented by a reduction in pressure.

3.1.1.2.5 Status Indication.- The EPIC shall provide circuits to transmit engine system operational status indications to crew/guidance/telemetry interfaces. These signals shall include:

- (a) Malfunction detection signals
- (b) Malfunction corrective action signals
- (c) Indication of function removal and replacement
- (d) Indication of cutback in effect
- (e) Self-check status

- (f) Mode of control in use
- (g) Engine parameters reflecting system status as required for positive control action.
- (h) Critical command inputs

3.1.1.2.6 Manual Mode Options.- The EPIC shall incorporate provisions to accept crew/guidance originated signals for manual mode control of the engine system control elements. Manual mode control options shall include vehicle system originated commands to operate:

- (a) All engine binary components
- (b) Engine proportional controls by receipt of rate commands
- (c) Selection of operation modes
- (d) Override control of EPIC automatic functions

3.1.1.2.7 Pre-shutdown.- The EPIC shall provide means for execution of engine shutdown preparatory functions. The function action shall ensure that efficient and controlled shutdown actions are obtainable. These preparatory functions shall include:

(a) Shutdown/Cooldown Impulse Remaining.- The EPIC shall be capable of performing calculations of engine thermal power. From this calculation and other engine measurements, the EPIC circuitry shall be capable of deriving an electronic calculation of decay impulse. The decay impulse calculation shall include the impulse obtained from engine system after heat plus the impulse that is obtained during engine shutdown. The impulse remaining signal shall be transmitted to the crew/guidance interface(s).

(b) Throttling for Shutdown.- The EPIC shall incorporate circuitry to effect throttling to a reduced thrust prior to shutdown action. Duration of the reduced thrust shall be at the option of guidance/crew commands.

3.1.1.2.8 Shutdown.- The EPIC shall include features to bring engine operating conditions from design point temperature and pressure to a level where engine cooldown control can supply the means for engine after-heat removal. The shutdown program shall consist of the following:

(a) Command Response.- The EPIC shall include circuitry to receive shutdown commands from guidance/crew stations. The circuitry shall provide means for reduction of engine temperature and pressure demands to the point where engine turbopump tailoff control is initiated.

(b) Pump Tailoff.- The EPIC shall provide for engine turbopump tailoff control by signaling the reactor control drums to the full negative reactivity position while controlling engine heat removal by control of propellant flow rate. This control mode shall be initiated when conditions exist where component limits shall not be exceeded and pump stall shall not occur while adjusting propellant flow rate to meet the desired shutdown temperature profile. During the pump tailoff control mode, the following shall occur:

(1) The drums shall be positioned to the maximum negative reactivity position.

(2) The selected or both BCV's shall be positioned to control propellant flow such that measured chamber temperature equals demanded temperature.

(3) The SSCV demand shall be adjusted to prevent overheating of the reactor support structure and to prevent occurrence of reactivity contributions outside of desired limits.

(c) Transfer to Cooldown.- The EPIC shall include automatic transfer provisions when engine heat has decreased such that the nominal cooldown temperature cannot

Specification No. EC-90155

be maintained without decreasing propellant flow below a level indicated by 50 psia chamber pressure. When this condition is reached, chamber temperature shall be reduced to 1600°R and a transfer to cooldown control effected. The transfer to cooldown control shall consist of:

- (1) Activation of cooldown mode controls
- (2) Close off turbine fluid circuit
- (3) Reset portions of EPIC circuits not involved in the cooldown operation.

3.1.1.2.9 Cooldown.- The EPIC shall be capable of performing the control functions that are required to remove engine system after-heat while providing impulse and system temperature distribution control. These functional requirements shall include:

(a) Flow Rates.- Provision of flow rates from the propellant tank system consistent with the requirements specified in 3.1.1.1.1(d).

(b) Control Modes.- Provision of control modes such that coolant flow is proportioned through the engine nozzle and reactor support structure as required to satisfy system cooling demands.

(c) Impulse Remaining.- The EPIC circuitry shall ensure that the impulse remaining calculation described in paragraph 3.1.1.2.7.(a) will be continuously revised during shutdown/cooldown operations, and the results transmitted to the crew/guidance interface.

(d) Impulse Trim.- The EPIC shall be capable of raising or lowering the thrust chamber temperature during cooldown as required for achievement of high engine I_{sp} versus low total impulse, or low engine I_{sp} versus high total impulse.

(e) End Cooldown.- The EPIC shall ensure that the engine cooldown control function shall terminate when no further cooling is required to prevent overheating of any engine component and/or an engine restart is required.

3.1.1.2.10 Restart.- The EPIC shall incorporate control circuits for engine restart. The required functions to be performed shall be:

(a) Time to Start Calculation.- The time to start calculation requirement specified in 3.1.1.2.1.(b) with the following additional factors taken into account in the calculation:

(1) Cooldown Status.- Variation in restart timing due to system temperature distribution if cooldown operation is still in effect and the requirement to initiate/terminate coolant flow during the time of restart power increase and the chilldown function.

(2) Estimated Power.- Time to reach sensible heating for restart shall vary such that the after heat calculation specified in 3.1.1.2.7.(a) shall be used as a determining factor in the time to start function for restarts.

(3) Temperature Conditions.- Engine system temperatures shall be monitored and the time required to reach the necessary temperature distribution shall be included in the time to start calculation.

(b) Restart Conditioning.- The EPIC shall provide the means for control of engine restart temperature conditioning. The required conditioning function shall include:

(1) Chilldown.- Means shall be incorporated to ensure that engine chilldown is achieved in such a manner that sufficient energy is available for turbine drive gas to enable engine bootstrap during restart.

(2) Low Temperature.- The EPIC shall ensure that sufficient energy is available for the initial portion of restart bootstrap to preclude highly sensitive timing requirements for bootstrap and power rise requirements.

(3) Other Restart Functions.- The EPIC shall perform other required restart functions in the same manner as described for prestart and startup specified in 3.1.1.2.1 and 3.1.1.2.2.

3.1.1.2.11 Nuclear Stage Disposal Mode.- The EPIC shall be capable of performing required engine system control operations for the nuclear stage disposal mode. The EPIC system circuitry shall provide for minimum electrical power consumption during the disposal mode operation.

3.1.1.3 Engine Signal Processing - The EPIC shall be capable of processing engine signals required for engine control, diagnostic purposes, trend data and malfunction detection.

3.1.1.3.1 Information Transfer.- The EPIC shall translate information from engine system transducers into a suitable electrical form for use by engine control circuitry and stage astrionics systems. The electronics shall be compatible with the requirements specified in EC-90216, EC- *____ (Nuclear Subsystem Instrumentation), EC-90177, and EC-90179.

3.1.1.3.2 Measurement Channel Output.- Each EPIC signal processing channel used for engine control shall incorporate isolated outputs. One output shall be conditioned to meet engine control electronic requirements while the other output(s) shall be conditioned for the vehicle/stage astrionics equipment. These signals shall be processed such that failure of one signal

*To be supplied by WANL.

receiving element shall not affect the other output signal(s). Electrical isolation between the conditioned outputs shall minimize interaction for all possible failure modes of any one output circuit.

(a) Engine Controls Output. - The conditioner outputs for engine controls use shall provide full scale output signal amplitudes of 10 volts. The amplitude response shall be flat $\pm 5\%$ from DC to 100 Hz and shall exhibit a -3 db rolloff point of greater than 200 Hz. The signal conditioning contribution to the uncertainty of measurement shall be $\pm 0.05\%$ of full range voltage in the engine system operational environment.

(b) Vehicle/Stage Astrionics System Output - The EPIC outputs for vehicle/stage systems shall be 0 to 5 volts nominal. The signal conditioner contribution to the uncertainty of measurement shall be $\pm .2\%$ of full range voltage in the system operational environment. Binary outputs shall be 0 + 1.1 volts off state and +28 ± 2.0 volts.

3.1.1.3.3 Telemetry - The EPIC shall provide to the vehicle/stage telemetry transmitter input, all engine data in the form of a digital (NRZ) pulse train containing frame SYNC information. The bit rate will be synchronized to the vehicle/stage system rate.

3.1.1.3.4 Power Input.- The EPIC shall operate on electrical power received from the internal EPIC power conditioning equipment.

3.1.1.3.5 Performance.- The EPIC signal processing equipment shall meet the following performance requirements:

(a) Channel Assignment - Measurement channels shall be assigned to separate categories of checkout, engine operation, engine cooldown, and coast phase operation to enable selective power input control for these mission phases.

(b) Warmup. - The warmup period required to reach specified conditioner performance after electrical power on shall not exceed 0.5 seconds.

(c) Noise. - The signal processing elements shall not produce noise components that shall degrade the signal being conditioned and/or amplified to a point where other subsystem element requirements cannot be met.

3.1.1.4 Engine Electric Power. - The EPIC shall provide elements that satisfy the following functions: (a) The relationship of the EPIC power supplies to other elements of the engine system is as shown on drawing 1136653. (b) EPIC power conditioning shall consist of equipment necessary to convert and invert the EPS supplied 24 to 32 volt DC power into voltages required by the electrical/electronic elements of the NERVA engine system.

3.1.1.4.1 Power Conditioning Types. - The EPIC, deriving power from the EPS 28 VDC supply, shall be divided into three functional types of power: coast essential, cooldown essential and operate. Separate conditioning shall be provided for primary and backup controls.

3.1.1.4.2 Power Input. - The EPIC shall be capable of accepting an initial surge of 32 volts from the primary supply diminishing to rated supply voltage in 500 milliseconds. It shall also be able to accommodate periodic changes in supply voltages from +24 to 32 volts DC.

3.1.1.4.3 Power Consumption.- The instantaneous electrical power consumed by engine system equipment during engine operational phases shall not exceed 10,000 watts at 28 VDC nominal.

3.1.1.4.4 Power Supply Ratings.- The EPIC power source shall meet voltage and current output requirements under all specified conditions of EPS output.

3.1.1.4.5 Power Distribution Control.- The EPIC shall incorporate provisions for switching to "power consumption down" modes during the engine operational phases of cooldown and coast.

3.1.1.4.6 Performance.- The EPIC power conditioning equipment shall meet the following performance requirements:

(a) Warmup.- The warmup period required to reach performance level after "power on" shall not exceed 0.5 seconds.

(b) Voltage Surge.- The voltage surge from each output under all specified input conditions shall not exceed one volt and shall be limited to a period no longer than 500 milliseconds.

(c) Isolation.- Excluding the nominal 28 VDC voltage, all conditioned voltages shall be electrically isolated from ground and each other.

3.1.2 Operability.-

3.1.2.1 Reliability.- The EPIC shall be capable of 600 minutes of rated operation of 60 cycles with a minimum reliability of .999184.

3.1.2.2 Maintainability.- The EPIC shall be designed to incorporate maintainability features necessary to comply with the quantitative mean time to repair (MTTR) and mean active maintenance time apportionments assigned and defined in CP-90290.

(a) Mean Time to Repair (MTTR).- The total EPIC apportionment for launch and flight significant performance of corrective maintenance tasks that contribute to system downtime shall be 4.0 manhours.

(b) Mean Active Maintenance Time.- The EPIC apportionment for mean active maintenance time shall be 0.5 manhours.

(c) Maintainability Design.- The EPIC shall be designed to meet the following maintainability objectives.

(1) Equipment components shall be accessible for circuit tests, adjustments, unscheduled maintenance and repair.

(2) Component mounting shall be such that removal and replacement can be effected easily when no hazard exist to maintenance personnel and without sacrificing the basic integrity of the system.

(3) Equipment components shall be interchangeable and standardized consistent with the design requirements to ensure minimum spares loading and maximum return from system down status to operational readiness.

(4) The requirement for the use of special tools for maintenance shall be held to a minimum.

(5) Necessary maintenance shall be accomplished with minimum disturbance to interfacing equipment.

(6) Required maintenance shall be performed by qualified technicians.

(7) Components shall be designed to afford a minimum of maintenance and recalibration.

3.1.2.2.1 Maintenance and Repair Cycles.- The EPIC shall not require scheduled maintenance under the storage conditions specified in 3.3.11. The EPIC design shall incorporate features for performance of unscheduled maintenance activities.

3.1.2.2.2 Service and Access.- The EPIC shall be designed and constructed for ease of servicing and access and shall be capable of indicating the readiness of the engine system for operations.

3.1.2.2.2.1 Prelaunch Operations.- The EPIC shall incorporate provisions to accept signals initiated by the vehicle airborne and/or ground support systems for purposes of engine prelaunch operations (excluding checkout functions) shall consist of purging the engine system. The EPIC, upon receipt of suitable signals, while being supplied with power from the vehicle system busses, shall generate commands to the necessary engine mounted control components for the purging and fill operations. The EPIC circuitry shall monitor these operations and provide suitable signals reflecting status to the vehicle/EPIC interface.

3.1.2.2.2.2 Checkout.- The EPIC shall incorporate circuitry to meet NERVA engine system checkout requirements.

(a) Functional Checks.- The EPIC shall be capable of accepting externally generated signals from the vehicle system for engine functional checkout. All engine mounted control components shall be accessible through EPIC circuitry on an individual basis upon receipt of appropriate command signals from the vehicle astrionic systems. The engine functional check capability shall be effective for prelaunch, boost and flight mission phases.

(b) Self Check.- The EPIC shall incorporate means for vehicle system initiated signal access to the EPIC self-check functions specified in 3.1.1.2.1.(d), for purposes of engine pre-operational checkout. The EPIC self-check function shall validate all EPIC control circuit elements prior to launch vehicle mission operations.

(c) Calibration.- The EPIC shall be designed to provide access to signal processing circuits for calibration purposes, upon receipt of suitable commands from the vehicle/stage system for preflight checkout and as required during engine operation.

3.1.2.2.2.3 Self Repair.- The EPIC shall include the capacity for functional self repair of operating controls through functional such a manner that critical components shall be maintained, replaced or substituted for, before, during, and after engine operations during applicable mission flight duration.

3.1.2.2.2.4 Manual Maintenance.- The EPIC shall be designed and constructed so that effective maintenance can be performed.

(a) Modular Construction.- The EPIC system shall be designed in accordance with a replaceable modular concept.

(b) In-Use Maintenance.- The EPIC design shall include features to allow rapid replacement of operational modules consistent with the maintainability goals specified in 3.1.2.2.

3.1.2.3 Useful Life.- The EPIC useful life shall be as specified in EC-90214.

3.1.2.4 Environmental.- The material and induced environments experienced by the EPIC shall be as specified in EC-90214 and in addition to the following:

(a) Nuclear Radiation

(1) Neutrons	0 n/cm^2
(2) Gammas	
Total Dose	1400 Rads
Maximum Dose Rate	140 Rads/hr

3.1.2.5 Transportability.- The EPIC shall be transportable within the limits specified in EC-90214.

3.1.2.6 Human Performance.- The EPIC human performance features shall be as specified in EC-90214.

3.1.2.7 Safety.- The EPIC design shall incorporate features that conform to the requirements specified in CP-90290.

3.1.2.7.1 Flight Safety.-

3.1.2.7.1.1 Engine Shutdown.- In the event that malfunction protection, redundancy, and crew action cannot prevent loss of engine operation, the EPIC shall provide for safe transition from operating conditions to a shutdown condition upon receipt of a shutdown signal. The criteria for shutdown action requirements shall be where flow integrity exists (TPA and tank operating and flow path intact), but loss of ability to control engine nuclear power below a set limit or when a loss, or impending loss, of flow or control of flow occurs, and/or when the vehicle emergency detection system initiates an emergency type shutdown signal. Conditions requiring these shutdowns and the EPIC action required are:

3.1.2.7.1.1.1 Flow Integrity Shutdown.- Shutdown shall be initiated by suitable EPIC circuits upon receipt of a shutdown signal to reduce the engine operating level such that subcritical operation is achieved. Circuits shall be provided for crew/guidance to bypass the detection circuits.

(a) Detection.- Conditions requiring flow integrity shutdown shall be of the following types:

(1) Detection of engine nuclear power signals that exceed a preset value.

(2) Detection of loss of critical electrical power to the control drum actuation system.

(3) Detection of a crew manually initiated shutdown signal.

(b) Action.- The shutdown action shall be of two types depending on the cause of shutdown and condition of the system. These types shall be as follows:

(1) If the detection circuitry indicates loss of ability to control power or upon receipt of manual command when the drums and/or SSCV are in position control, the action upon receipt of a shutdown signal shall be as follows:

a Control drums shall be placed in shutdown control and rotated in at maximum velocity.

b Shutdown control of BCV's and SSCV's shall occur.

(2) If the detection circuitry indicates either nuclear power excursion or receipt of manual command, and the drums and SSCV are not in manual control, the action shall be upon receipt of a shutdown signal as follows:

- a Controls shall remain in operate conditions.
- b A command from shutdown circuitry shall initiate the shutdown program.
- c The shutdown control shall be armed for shutdown.
- d Engine temperature and pressure shall be programmed down resulting in a reduction of nuclear power and achievement of a subcritical drum position.
- e When engine operating conditions have decreased sufficiently, the shutdown control shall transmit signals to roll the drums full in and effect control of the BCV in use and SSCV.
- f Signals reflecting shutdown action status shall be transmitted to the EPIC vehicle emergency detection system interface.

3.1.2.7.1.1.3 Vehicle Emergency Detection System Shutdown.- Engine shutdown shall be initiated by EPIC circuitry upon receipt of a shutdown signal from the vehicle emergency detection system.

3.1.2.7.1.2 Failure.- The EPIC shall incorporate circuitry to transmit appropriate signals to the vehicle emergency detection system if engine system malfunction protection, redundancy, crew action, and/or shutdown action fails

to correct an engine system anomaly. The signals shall reflect that a degraded engine condition exists and that control cannot be effectively exercised any longer.

3.1.2.7.2 Ground Safety.- The EPIC shall include the capability to preclude the inadvertent operation of engine subassembly components during pre-launch preparatory phases. During ground preoperational module tank LH₂ loading tests, the EPIC circuitry shall ensure that inadvertent signals initiated to open the engine PSOV's shall not occur. The EPIC shall also incorporate circuits to monitor PSOV positions during these tests and transmit the resultant status to the vehicle system electrical interface. The EPIC shall also incorporate circuitry to monitor conditions prerequisite to launch operations. Upon detection of conditions considered "no go" engine system condition to the overall launch vehicle monitoring system. In no case, shall the EPIC circuitry allow the inadvertent attainment of engine reactor super critical conditions during ground preflight preparatory functions.

3.1.2.7.3 Nuclear Safety.- The EPIC shall incorporate circuitry to comply with the nuclear safety requirements specified in CP-90290.

3.1.2.7.4 Personnel Safety.- The EPIC shall include circuitry designs that provide for maximum safety to personnel that are performing maintenance operations. Open power busses shall be clearly marked with caution notices. Circuits that exhibit precise adjustment requirements that in turn affect mission success shall be identified as potential safety significant functions.

3.1.2.7.5 Explosive and/or Ordnance Safety.- The EPIC shall include circuits and provisions for engine ordnance explosive and/or ordnance safety oriented functions.

3.2 CEI Definition.-

3.2.1 Interface Requirements.- The functional, physical, electrical, and environment interfaces between the EPIC and other equipment and facilities shall be as defined in the following paragraphs:

3.2.1.1 Schematic Arrangement.- The schematic arrangement of the interfaces which the EPIC has with other system equipment shall be as follows:

3.2.1.1.1 Interface #1 - EPIC/Module Structure.- The EPIC design shall incorporate structural support means for attachment to the nuclear module forward skirt area. The structural support design shall include considerations for heat flow path to maintain EPIC environmental conditions within operating limits.

3.2.1.1.2 Interface #2 - EPIC to Module/Vehicle Astrionics System(s).- The EPIC design shall include electrical circuit interface points for connection to the module/vehicle astrionics system(s) and module to engine subassembly cabling in the nuclear module forward skirt area. These interfaces shall be:

- (a) EPIC to Basic Electrical Power Network
- (b) EPIC to Telemetry System
- (c) EPIC to Guidance/Command System
- (d) EPIC to Engine Subassembly Raceway Cabling
- (e) EPIC to Vehicle Emergency Detection System
- (f) EPIC to $5.000 \pm .005$ VDC Reference Source

3.2.1.1.3 Interface #3 - EPIC to AGE.- The EPIC design shall incorporate features to interface with handling, shipping and checkout of Aerospace Ground Equipment (AGE). These interfaces shall insofar as practical be the same interfaces specified in 3.2.1.1.1 and 3.2.1.1.2.

3.2.1.2 Detailed Interface Definition.- The quantitative detailed interfaces of the EPIC to other equipment shall be as supplied on the following drawings:

	<u>AGC Drawing Number</u>
(a) NERVA Engine EPIC Physical Interface Control Drawing	1136876
(b) NERVA Engine EPIC Electrical Interface Control Drawing	1136876

3.2.2 Component Identification.-

3.2.2.1 Government Furnished Property List.- The EPIC shall incorporate no government furnished equipment or materials.

3.2.2.2 Engineering Critical Components List.- The EPIC shall incorporate no engineering critical components.

3.2.2.3 Logistics Critical Components List.- The EPIC shall include no logistic critical components:

3.3.3 Design and Construction.- The EPIC design shall comply with the applicable requirements specified in CP-90290 and EC-90214.

3.3.1 General Design Features.- The EPIC shall be designed and constructed to be compatible with the foregoing specifications and the flight module forward skirt area structure and electrical configuration. Additional design features shall be in accordance with the following:

3.3.1.1 Drawings and Data.- The EPIC shall be as described by the following drawings and reports:

Drawing and Report Numbers

(a) NERVA Engine EPIC Functional Diagram	1136653
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3.3.1.2 Mechanical Criteria.- The EPIC shall be designed insofar as practicable to incorporate modular features. The modules shall be rapidly replaceable and the number of different types of modules shall be minimized. The mechanical design shall provide features for low thermal resistance paths to the package mounting structure and for high nuclear radiation resistance. The EPIC target maximum weight shall be 600 pounds. The mechanical design shall satisfy all functional requirements specified for envelope, physical mounting, weight, cable interfaces, the operational environment and maintenance access.

3.3.1.3 Electrical Criteria.- The EPIC electrical design shall comply with the applicable requirements specified in EC-90214 as follows:

3.3.1.3.1 Electrical Signals.- The EPIC shall provide circuits that are consistent with signal transmission requirements.

3.3.1.3.2 Shielding.- The EPIC shall incorporate suitable circuit shielding to minimize the possibility of extraneous or spurious noise interference induction that is capable of causing engine operation outside of design limits.

3.3.1.3.3 Circuit Access. - The EPIC design shall provide circuit access such that all engine mounted control and monitoring components shall be operated and/or monitored by crew/guidance upon receipt of the appropriate command signal at the EPIC command/guidance interface.

3.3.1.3.4 Redundancy. - The EPIC design shall incorporate component and circuit redundancy and other techniques as necessary to meet the reliability requirements specified in 3.1.2.1.

3.3.1.3.5 Spare Circuits. - The EPIC shall incorporate connector provisions for spare circuit access.

3.3.1.3.6 Connectors. - The EPIC design shall provide means for rapid disconnection/connection from module cable termination.

3.3.1.3.7 Adjustment and Test. - The EPIC design shall incorporate means for minor circuit adjustments and for test equipment access.

3.3.1.4 Nuclear Design. - The EPIC shall be designed to withstand the nuclear radiation environment specified in 3.1.2.4 without degradation of performance.

3.3.1.5 Installation. - The EPIC shall be designed to be capable of being installed in the nuclear module forward skirt area before or after engine subassembly installation.

3.3.2 Selection of Specifications and Standards. - The selection of specifications and standards shall be as specified in EC-90214.

3.3.3 Materials, Parts and Processes. - The selection and application of materials, parts and processes shall be as specified in EC-90214.

3.3.5 Moisture and Fungus Resistance.- Control of moisture and fungus resistance shall be as specified in EC-90214.

3.3.6 Corrosion and Metal Parts.- Corrosion of metal parts shall be controlled as specified in EC-90214.

3.3.7 Interchangeability and Replaceability.- The criteria for interchangeability and replaceability shall conform to the requirements specified in EC-90214.

3.3.8 Workmanship.- Workmanship shall conform to the requirements specified in EC-90214.

3.3.9 Electromagnetic Interference.- Compatibility of electromagnetic interference shall conform to the requirements specified in EC-90214.

3.3.10 Identification and Marking.- Identification and marking shall conform to the requirements specified in EC-90214.

3.3.11 Storage.- The EPIC shall be capable of performing as specified herein subsequent to storage while protected from the ground environmental conditions specified in 3.1.2.4 for a period not exceeding the ground storage life specified in 3.1.2.3.