A.G. NUCLEAR DRIVE YARDS

NUCLEAR THERMAL PROPULSION SYSTEM OPERATOR'S HANDBOOK

EDITION I - 2223

A.G. Nuclear Drive Yards congratulates you on your purchase of a cutting-edge interplanetary-capable spaceship.

This document has been prepared to help the responsible flight engineers get acquainted with the instrumentation and the controls of the main propulsion systems of Rubycore-IV class nuclear modular spacecraft.

This document must be read to completion by at least two flight engineers aboard the vessel before the ship is switched to internal power for departure for the first time. The responsible flight engineers must write down their names and sign this page of document using a blue ball pen.

During flight, a copy of this handbook should be attached to the allocated space near the AFT LEFT cockpit panel.

It is also strongly advised for the commander to read this documentation completely before setting off for their first journey with their new spacecraft.

A.G. Nuclear Drive Yards wishes you nice journeys towards new frontiers – luxurious ports of Luna and Mars, the pretty views of Saturn, the distant colonies of Oberon, or places that were never visited in history (like the hypothetical Planet 11)!

This handbook has been prepared according to the Interplanetary Nuclear Power Utilization Treaty of 2182, the Universal Treaty for Free Space Travel, and the Renewed Nuclear Space Propulsion Agreement of 2175.

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ABBREVIATIONS*

NTR: Nuclear Thermal Rocket

NTP: Nuclear Thermal Propulsion

MPS: Main Propulsion System

TCS: Thermal Control System

CDR: Commander

PLT: Pilot

FLE: Flight Engineer

* Not all abbreviations might be used in the text. I have this habit of writing everything that might be necessary, just in case, you know.

NUCLEAR THERMAL PROPULSION

If you are reading this handbook, chances are, you already have a good idea about what nuclear thermal propulsion is, and how nuclear thermal propulsion works, and why nuclear thermal propulsion wouldn't work sometimes, and what happens when nuclear thermal propulsion doesn't work. But Mr. Bureaucracy states that we shall put this section in our operator's handbook, so we do it.

Nuclear thermal propulsion works using the same basic principles of classical (chemical) rocket propulsion. Some substance (hopefully a fluid) is accelerated to high velocities and expelled in a focused direction. The conservation of momentum shows us that a ship that expels propellant in one direction accelerates in the opposite direction.

In classical rocket propulsion, the energy to expel the propellant is provided by a chemical reaction, releasing the energy held in the chemical bonds of the reactant substances. This occurs in a "combustion chamber", where the obtained energy increases the pressure and temperature of the combustion products. The pressure and temperature are then converted into bulk kinetic energy by running it through a converging-diverging nozzle.

In nuclear thermal propulsion, instead of a chemical reaction, the energy is provided by nuclear interactions. The most popular method nowadays is to use a fission reactor to heat up an inert fluid before running it through a converging-diverging nozzle. Yes, the same kind used by old-school chemical engines. Hydrogen (H2) is the most popular propellant due to its small molecular weight, which allows it to be expelled faster than other propellants. Single protons (as opposed to hydrogen molecules) would be an even better option, but to isolate hydrogen atoms is not worth it. Trust me. I've been in this business for quite some decades now. (I hope Mr. Editor lets this paragraph into the final revision of the handbook.)

To get the highest efficiency from the same amount of propellant, a rocket must expel the propellant at the highest exhaust velocity possible. Increasing the exhaust velocity, and therefore the efficiency (called specific impulse or Isp (eye-es-pee) for short), usually involves increasing the pressure and temperature in the reactor chamber.

However, the chamber temperature and the pressure are limited by the endurance of the materials the engines are made of.

If the temperatures in the reactor chambers rise suddenly, the H2 Quench Thermal Stabilization System is automatically activated, provided it is enabled. This increases hydrogen flow into the chamber above nominal, to help cool the reactor at the expense of efficiency. Safety 1st.

Speaking of temperatures and controlling them, the Thermal Control System helps things remain cool aboard a spacecraft, such as the nuclear engines and the flight engineers responsible for them.

THERMAL CONTROL SYSTEM

Thermal engineering is one of the most cursed fields of mechanical engineering by far. When we mechanical engineers wake up, the first thing we do is to get in front of the shrine of The Great Unnamed Engineer (we all have a shrine for him in our homes) who is said to have lived on Earth in the past centuries and came up with the "Modified Finite Quasi-Particles Analysis". Sure, the name of the method is quite a mouthful, but if it wasn't for him, we could be stuck with the unbearable "Quantum Finite Element Method II" for centuries to come.

Well, anyway, using this new technology, our engineers have created the ultimate nuclear reactor and heat exchanger systems for use in our Main Propulsion System (MPS). Now, I can hear you say, "If the heat exchangers are so good, why do we still need radiators to carry away waste heat?" – well, not so fast buddy. Waste heat is one of the fundamentals of mechanical engineering, and although we can minimize its generation, we can never fully stop waste heat. And laws of thermodynamics state that we need to deal with it. So, we deal with it. With radiators. As always. (Turns out space is a near-perfect vacuum, and nature doesn't give us many choices there.)

So, the Thermal Control System (TCS) carries away the waste heat generated by the MPS. A heat exchanger on the MPS side deposits the waste heat into a water flow circuit, which then carries the waste heat to the radiators. A heat exchanger array then takes the waste heat from the water and deposits it onto the radiator material, which, by blackbody radiation, emits the excess energy into space as electromagnetic waves (mostly microwaves). This also makes your ship visible from the other end of the Solar System to all sorts of visible-spectrum observers.

RADIATION SHIELDING

We all get a little irritated by the security X-ray scanners at orbital ports, don't we? Well, imagine this: you are standing inside a running X-ray scanner continuously – one that's in a larger X-ray machine, that's in an even larger X-ray machine.

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To be honest, I don't know where I'm going with this analogy. I don't even know how much radiation modern X-ray scanners emit. But if there is something I know, it's that nuclear fission reactors emit lots of radiation. So, aboard a crewed spacecraft, there has to be some radiation shielding in between the nuclear reactors and the crew habitats.

Luckily for you, our engineers remembered to put some! Flying aboard a Rubycore-IV, you will be protected by **thick** lead plates located between the MPS and all the pressurised areas. The radiation shielding adds quite an extra mass to the ship's hull, but we can give away some gas mileage for passenger comfort, right? Who would like to get radiation sickness in the order of minutes? No one!

That being said, no radiation shielding is perfect, and that's especially true for spaceflight, where you regularly dive through ionization belts. We don't claim that the radiation shielding will protect you from cancer, we are merely trying to postpone its development as much as the law requires us to do so.

SAFE OPERATION LIMITS

The safe operation limits for the MPS and the TCS are given below:

MPS Tc (Chamber Temp.)	< 4200 K
MPS Pc (Chamber Press.)	None*
TCS Radiator Temp.	< 700 K
Crew Habitat Irradiation	4.0x10^-8 Sv/s **

* In all failure cases, catastrophic MPS failure due to burn-through is observed before the chamber yield strength is exceeded.***

** In case of any doubt, that's "four times ten to the power of minus eight sieverts per second". Sometimes the printouts aren't very nice.

*** Some of our engineers had concerns about design or quality assurance errors, but they ultimately went silent after a staff meeting in which I wasn't present. Two of them resigned, by the way.

INSTRUMENTATION & CONTROL PANEL

The control panel for the MPS is located on the AFT LEFT cockpit panel. It is to be used by a flight engineer or the commander.

Figure 1. MPS Control Panel

Both the MPS and the TCS are capable of operating completely automatically under nominal circumstances, but crew monitoring of the system is required at all times during operation for safety. Only when the control rods are fully inserted and the reactor power, the mass flow and the thrust force is zeroed can the crew leave the AFT LEFT panel unattended.

Automated mode is the recommended mode for operation, and is expected to be used for the majority of orbital maneuvers.

To switch the control mode between automatic and manual, the CTRL MOD switch has to be rotated.

Figure 2. Location of the CTRL MOD switch

At any time during operation, the H2 Quench Thermal Stabilization System should be in ENABLED position. The system can be activated manually at any time during operation by switching this control to the EMRGNCY ACTIVATE state.

Figure 3. Location of the H2 QUENCH THRML STABL switch

For manually controlling the power output of the reactors and therefore the thrust and efficiency of the three Main Propulsion Systems, the control rods can be manipulated using the control rod position command sliders.

Figure 4. Location of the control rod manual command sliders

The sensor output instrumentation is explained below.

Figure 5. Location of sensor output instruments

There are 5 outputs for each MPS.

- MPS X Tc displays MPS chamber temperature in Kelvins,
- MPS X Ft displays measured thrust force in Newtons,
- MPS 1 M' displays propellant mass flow in kilograms per second,
- TCS X TEMP displays TCS radiator temperature in Kelvins,
- MPS X CTROD displays control rod insertion percentage.

Above the sensor outputs is the Caution & Warning System.

Figure 6. Location of the Caution & Warning System

In case some operation conditions are off-nominal, the caution lights light up. A yellow light means that a reading is off-nominal, but is still within failure limits. A red light means that a reading is off-nominal and unless the situation is resolved immediately, it may lead to a catastrophic failure.

The CREW HAB RADTN LVL light may turn yellow if all three reactors are running at normal power outputs. This is normal behaviour – since the orbital maneuvers make up a small portion of the spaceflight, the extra radiation doses at that level for a short duration should not noticeably affect the crew's health. It is when the light turns red you should really start panicking.

We actually wanted to put a radiation gauge on this panel too, but the chief designer said there was one on the CDR panel and another on the FRONT RIGHT panel already, so we left it out.