72320 Roversystemtechnik
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INSPIRE

IN-situ Sampling and Primal Investigation Rover on Europa

Phase 0/A-Study of a Rover Mission on the Surface of the Jupiter moon Europa

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Symbols

Symbol	Definition	Unit
a	Constant for the Geometry of a Porous Media	nm
h_{Ice}	Ice Crust Surface Thickness on Europa	m
T_{Surface}	Surface Temperature on Europa	K
ϵ	Emissivity	-
ρ_{Ice}	Inner Encoder Ring Diameter	$\frac{\mathrm{kg}}{m^3}$

Abbreviations

PCDU	Power Control and Distribution Unit
BOL	Begin of Life
BOM	Begin of Mission
EOM	End of Mission
2D	Two Dimensional
3D	Three Dimensional
PCU	Power Control Unit
PDU	Power Distribution and Control Unit
EPS	Electrical Power System
IMU	Inertial Measurement Unit
IRS	Institute of space Systems at the University of Stuttgart
ESA	European Space Agency
NASA	National Aeronautics and Space Administration
SPENVIS	SPace ENVironment Information System
RTG	Radioisotope Thermoelectric Generator
eMMRTG	Enhanced Multi Mission Radioisotope Thermoelectric Generator
eSMMRTG	Enhanced and Scaled Multi Mission Radioisotope Thermoelectric Generator (3kg)
TID	Total Ionizing Dose
OBC	On-Board Computer

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The Mission

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1.3.4 RadHard Solar Arrays

As a secondary mission goal for INSPIRE a cooperation with the european project RadHard which is led by the german solar array manufacturer Azure Space is intended. They are currently developing a new generation of 4 Juniction solar cells with an efficiency of up to 35%. But the main feature of the new solar arrays is their radiation hardness which will be the highest radiation hardness ever designed with an efficiency of $> 3\%$ after $1E15\ cm^{-2}\ 1MeV$ electron irradiation. So the Jupiter environment with its extreme radiation would be the best suitable destination for a test and evaulation mission of this new technology. Therefore INSPIRE will be equipped with a limited amount of RadHard solar arrays for a technology demonstration.

Chapter 2

Operation

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2.1 Mission Phases

For the INSPIRE Mission Phase 0 study five basic mission phases have been defined. Furthermore a sixed optional mission phase after the nominal mission lifetime has been established which will be conducted if the rover is still operational after its nominal lifetime.

- **Phase 0:** Launch and Flight Phase
- **Phase 1:** Entry, Descent and Landing Phase
- **Phase 2:** Depolyment Phase
- **Phase 3:** Egress, Comissioning and Early Operation Phase
- **Phase 4:** Mission Operation Phase
- (**Phase 5:** Exceeding Mission Operation Phase)

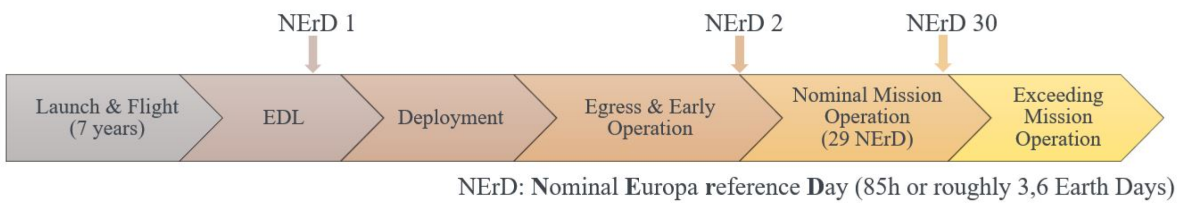

Figure 2.1: Preliminary Mission Timeline for INSPIRE.

Based on these missions phases some preliminary rover system modes as well as a basic mission timeline were concluded.

2.1.1 Rover System Modes

For this case study several rover system modes were defined. All ten modes are listed in Table 2.1. They are seperated into two groups. The design critical modes are displayed in white and are defined as system modes, which significantly influence the preliminary design of the rover subsystem like the thermal or power subsystem. None design critical modes (grey) also have a major influence on multiple subsystems of the rover but play a secondary role in the thermal and power budget of the rover for this Phase 0 study. These non design critical modes extend from the rover storage and launch until the finale deployment of the rover is completed. These modes and their design options depend heavily on the final design of the lander with which INSPIRE flies to Europe. Therefore, a clear definition of such modes is not possible at this time in the course of this phase 0 study. However, the respective considerations, preferences and options have been briefly described in the mode descriptions. It is important to note that INSPIRE's

goal is to provide a flexible rover design with as few hard requirements as possible for the parent lander. Therefore, many aspects of the rover, as well as the none design critical modes, will need to be further defined and elaborated in later phases of the project in close consultation with the customer.
For example, the exact interfaces between rover and lander should be defined in more detail. Depending on the subsequently chosen interfaces, many possibilities may arise in the corresponding rover system modes. With an appropriate interface, for example, the excess electrical and thermal energy of the RTG, which is already active during the flight, could be used to supply the lander system with heat and power. A corresponding interface could also enable the transmission of health checks from INSPIRE.
The deployment phase will strongly depend on the final design of the lander, INSPIRE's position within the lander and also the possibilities that the lander provides to INSPIRE. Possible deployment strategies would be as follows:

- **Option 1:** If INSPIRE on ground level: Release from storage box through spring mechanism or actuators. Rover storage configuration allows rolling and possible motorized actuation

- **Option 2:** If INSPIRE is above ground level: Similar as Option 1 but an additonal ramp and ramp deployment would be required.

- **Option 3:** INSPIRE will be deployed through the landers robotic arm if it is capable of lifting its mass.

Number	Rover System Modes	Abbrevation	Definition
0	Launch/Off Mode	OFF	From Launch until EDL Phase Rover System is OFF Exact mode description t.b.d. and can be adapted to meet the lander demands Health tests on Occasion during flight time are foreseen (PCDU could be active) Batteries on Storage Capacity at launch and may be recharged on occasion (like Rosetta Mission) Telemetry data shall be sent by the Lander (optional if possible) RTG on =>Electrical and Thermal Power may be used (for Lander Power and Thermal Systems) or is disposed of by shunts
1	Entry, Descent and Landing	EDL	From Entry until next morning after secure landing of Lander on Europa See Mode OFF PCDU ON after secure landing (Powered by RTG) Heaters ON (powered by remaining RTG Power) Battery charging if no Kill Switch is used
2	Deployment and Early Operation Mode	EOP	First Morning after EDL Exact mode description t.b.d. and can be customized to lander =>Dependant on final Lander Design Critical Deployments (Egress System) and leaving the lander Optional whether Kill Switch ejected =>Battery charging can start Rover System Activation possibilities: Kill Switch, Lander Interface, HPC from Earth PCDU ON OBC ON Heaters ON After sufficient Battery Capacity is reached (50%): Deployment of Rover Boogie and checkout/health check of all Rover Systems Afterward switching to Charging Mode
3	Idle/ Perception	ID	During Idle Operation Time Rover powered by RTG or Batteries (Excess Power charges Batteries) PCDU ON All Components in Standby or Power Saving Mode if possible Stereovision Camera ON for Orientation and Observation (Science Data) Hazcams and OBC ON for Orientation and Path Analysation COMM ON for larger time intervals (Listening Mode)
4	Safe Mode/ Hibernation (SAFE)	SAFE	Entered in case of emergency or contingency Rover Survival Mode =>Minimum Power PCDU ON COMM sends Emergency Signal then switches to COMM ON for small time intervals (Listening Mode) OBC OFF until Command received =>High Power Commands (HPC) Heaters ON Science data shall be stored without data loss Applicable during Day and Nighttime Exit after receiving the corresponding command (Optional: Timer ON and Restart of Rover System after time period has passed)
6	Communication	COMM	During Transmission of major Telemetry or Science Data Rover powered by RTG or Batteries (Excess Power charges Batteries) PCDU ON All Components in Standby or Power Saving Mode if possible OBC SB COMM ON (Transmission Mode)
7	Charging	BAT	For Battery charging Rover batteries charged by RTG PCDU ON All Components in Standby or Power Saving Mode if possible OBC SB Quit after sufficient charge is reached
8	Locomotion	LOC	For Rover Movement and Observation Locomotion and Navigation ON Hazcams and Traversing Path Analysis ON OBC ON PCDU ON COMM OFF Stereovision Camera ON for Orientation and Observation (Science Data) Only during Daytime
9	Payload Observation Mode	OBS	Payload Mode for Science Data Collection during Daytime OBC ON PCDU ON COMM OFF Stereovision Camera ON for Orientation and Observation (Science Data) RADAR ON for Ground Investigation =>Drill Location Only during Daytime
10	Payload: Ice Core Mode	ICE	Payload Mode for Science Data Collection during Daytime or Nighttime OBC ON PCDU ON COMM OFF Ice Core Drill ON during Ice Core Sample Collection Afterwards Sample will be analysed =>APXS ON

Table 2.1: Collection of Rover System Modes. [Kommt noch in Anhang]

Chapter 3

Subsystems

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3.1 Rover

...

3.2 Structure and Mechanics

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3.3 Communications and Command and Data-Handling

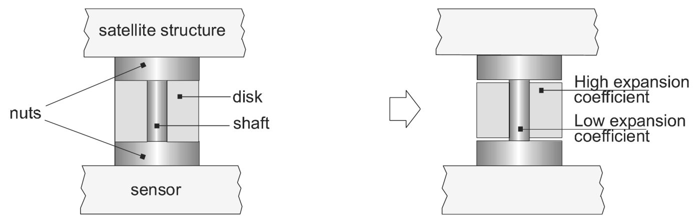
...

3.4 Payload

...

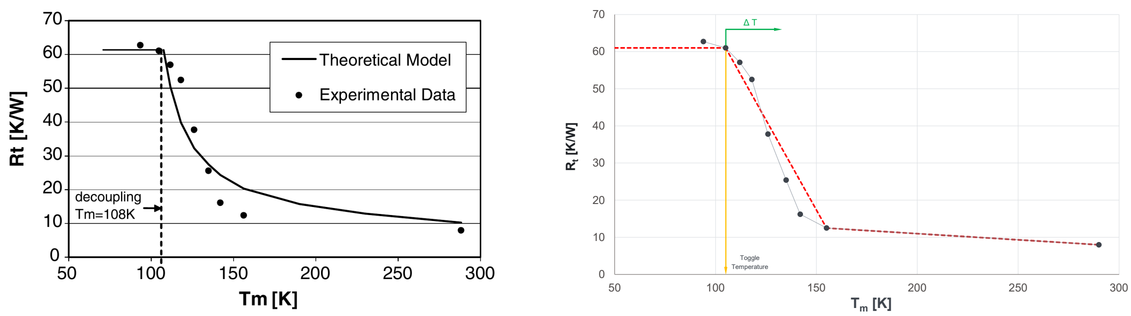
3.5 Thermal Control System

The main object of the Thermal Control System (TSC) is to keep the eletric components within their temperature limits, listed in Table A1. As a result of Europas low ground temperature, a small solar constant and the thin atmosphere the heat loss of the rover has to bin minimised. This shall be reached by a smart heat distribution as well as by an adequate insulation and surface finishing.
The main heat source of the rover is the waste heat of the RTG (see Section 3.6), which will be lead by thermal straps to the thermal critical components. The camera, exposed on a mast, will be heated by a seperat Radioisotope Heater Unit (RHU), citeRHU. For the insulation, the material *aerogel* will be applied, which has a very low heat conductivity (cite aerogel) and has also been used in space applications (citeaerogel). The overheating of the rover shall be prevented by heat switches (see Figure 3.1). These components change their heat conductivity beyond a certain temperatur due to the expansion of the disk (see Figure 3.2). It was assumed, that the toggle temperatur can be adapted by increasing the disk height. The influence of the changed disk stiffens on the contact pressure and the heat conductivity was neglected for this study. The measured heat conductivity characterisitc was divided in three linear sections (Figure 3.2b), to enable a simple modelling in the upcoming thermal calculation.



(a) Closed (b) Open

Figure 3.1: Heat switch.



(a) Original (b) Linearised

Figure 3.2: Change of the heat switch conductivity R_t over the mean temperature T_M.

A thermal analysis, which was performed to get

- the dimension of the isnulation and heat straps,
- the necessary amount of RHUs and heat switches,
- the required surface finishing.

For that, a thermal network with ten nodes was derived from the rover, shown in Figure 3.3. At the intersection of the steering and drive engien, two additional nodes were defined to calculate the heat flow.

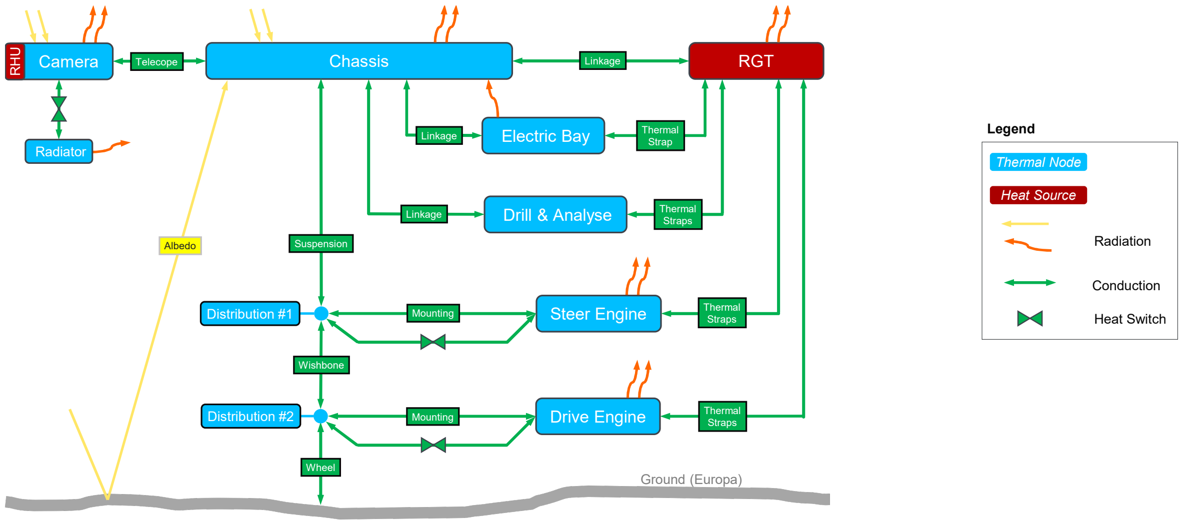


Figure 3.3: Thermal network of the rover.

On the basis of the thermal network, the heat energy equlibrium for each node was defined (see Section A). The calculation were considered as a quasi-static analysis, were the component temperatures stay constant, $\frac{\mathrm{d}T}{\mathrm{d}t} = 0$. Due to the early state of the rover, simplifications and asumptions were made.

- The convection was neglected due to the thin atmosphere.
- The whole electrical power of the components will be dissipated into heat.
- A variation of $\pm 20\%$ for the emisivity and absorpsivity values were considered, if applicable (seet Table A2).
- The heat as a result of retardation radiation inside the shielding was neglected.
- The E-Bay emitts heat energy only in one direction to the chassis.
- Only the chassis and the camera absorb sun radiation.
- The ice core drill and the APXS analyser were summerised as one single node.
- The thermal resistance between two surfaces was neglected because of the lack of necessary values. Therfore, the heat conductivity was reduced about 10%.
- There is no heat loss of the thermal straps.

The thermal analysis was perfomred as a Excel calculation, which can be found in the corresponding folder of Team 3. There were different load cases defined not only to cover the most important hot and cold cases but also some relevant operating cases.
The results of the temperatures for each node at each load case are listed in autoreftab:. The temperature margins for uncertainties, acceptance tests and qulification tests were considered with $5K$ each, $\pm 15K$ in total. The corresponding temperatures are listed in autoreftab:. All temperature lay betwenn their limits.
In a furher step, a more detailed analysis has to be carried out with the Finite-Element-Method to identify the correct heat and temperature distribution.

3.6 Electrical Power System

The EPS (Electrical Power System) is the subsystem responsible for the electrical power supply of INSPIRE. It consists of four funadmental parts, which are the energy source, the PCDU unit (Power Control and Distribution)and the Energy Storage as well as the rover subsystems as the consumers.

3.6.1 EPS Budget and Overview

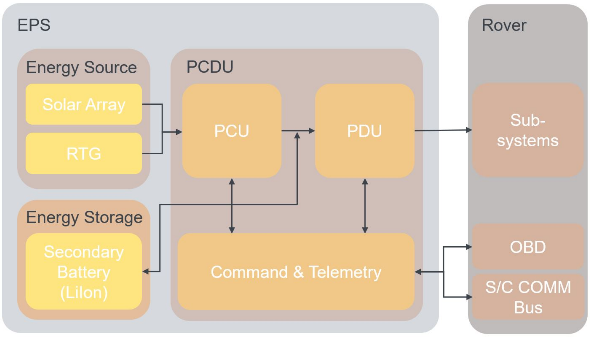


Figure 3.4: Functional Flow Chart Diagram for the EPS Subsystem.

3.6.2 Energy Source

For the energy generation of INSPIRE many possible sources were taken into consideration for a trade-off. The outcome of this trade-off is shown in Figure 3.5 for the most promising energy sources. As a conclusion of this trad-off the decision was made to utilize a Radioisotope Thermoelectric Generator (RTG) as the main energy source for INSPIRE.

As the research couldn't find an RTG with a mass suitable for INSPIRE, the solution was to scale down a bigger RTG as an approximation. As a baseline of the scaling the eMMRTG (Enhanced Multi Mission Radioisotope Thermoelectric Generator) was utilized, which is currently under development at NASA and is especially designed for deep space missions like Europa. For the scaling a goal RTG mass of $m_{\text{RTG}} = 3$ kg was defined and the eMMRTG was scaled down using the given data. In Table 3.1 the scaling results for the eSMMRTG (Enhanced and Scaled Multi Mission Radioisotope Thermoelectric Generator) are listed. The eSMMRTG has a mass of $m_{\text{RTG}} = 3$ kg and a BOL specific power of $\alpha_{\text{BOL}} = 4.0\ \frac{W_{el}}{kg}$ and provides an electrical power of $P_{el} = 12.08\ W_{el}$ during the mission duration.

criteria	mass	costs	TRL	reliability	energy generation	durability	safety risk	sum	weighting factor [%]
mass		+	+	0	-	-	-	2	10,5%
costs	-		-	0	-	+	-	1	5,3%
TRL	-	+		-	-	-	-	1	5,3%
reliability	0	0	+		-	+	-	2	10,5%
energy generation	+	+	+	+		+	-	5	26,3%
durability	+	-	+	-	-		-	2	10,5%
safety risk	+	+	+	+	+	+		6	31,6%
	Total number of "+"							19	
	weighting of one "+" [%]							5,3%	

criteria	weighting factor	EPS systems: RTG + secondary battery		primery battery		solar arrays + secondary battery	
mass	10,5%	2,00	0,21	1,00	0,11	1,00	0,11
costs	5,3%	0,00	0,00	2,00	0,11	2,00	0,11
TRL	5,3%	1,00	0,05	2,00	0,11	2,00	0,11
reliability	10,5%	2,00	0,21	1,00	0,11	0,00	0,00
energy generation	26,3%	2,00	0,53	0,00	0,00	1,00	0,26
durability	10,5%	2,00	0,21	0,00	0,00	1,00	0,11
safety risk	31,6%	1,00	0,32	1,00	0,32	2,00	0,63
max. percentage	100,0%	10,00	1,53	7,00	0,74	9,00	1,32
sum	max. 2,00	1,53		0,74		1,32	
rank		1		3		2	

Legende	
Pkt.	%
2	>80
1	>40
0	<40

Figure 3.5: Trade-Off Conclusion for the EPS Energy Source.

Scaled eSMMRTG Parameter	
System Mass m_{RTG} $[kg]$	**3.5**
BOL Specific Power α_{BOL} $\frac{W_{el}}{kg}$	4.0
BOL Power $P_{el,\mathrm{BOL}}$ W_{el}	14
Isotrop	Pu-238
Isotrop Half-Life $[a]$	87.7
Flight time and Storage (incl. Margins) $[a]$	7
Power Loss Degradation until BOM W_{el}	0.56
BOM Power $P_{el,\mathrm{BOM}}$ W_{el}	13.44
Europa Day Duration $[h]$	85
Mission Duration $[d]$	106.25
End of Mission Power $P_{el,\mathrm{EOM}}$ $[W_{el}]$	13.42
Final Power for Study P_{el} $[W_{el}]$ (incl. 10% scaling Margin)	**12.08**

Table 3.1: Parameters for the scaled eSMMRTG based on the eMMRTG.

Furthermore INSPIRE will also be equipped with some radiation hardend solar arrays as already explained in Subsection 1.3.4. Since these solar cells are primarily used for technology testing, the mission must also be able to operate completely without this generated energy. For this reason, and because the expected energy generated by the solar cells is minimal, only the energy generated by the RTG is considered for the Phase 0 Study. However, it should be noted that these solar cells will also generate a certain amount of energy, which will benefit the EPS.

3.6.3 Energy Storage

For the energy storage of INSPIRE many possible battery types were taken into consideration for a trade-off. As a conclusion of this trad-off the decision was made to utilize LiIon batteries as the secondary batteries of INSPIRE. This decision is primarily based on LiIon batteries high energy density, temperature range, robust performance and long operating and cycle life in extreme environemnts.
As the RTG only generates a small constant power the main energy source during the mission will be the accumulated energy of the batteries. The rover will charge the batteries at night, so the next exploration day can start with full capacity. Furthermore the batteries have to be charged during day time to maintain operations.

For the sizing of the batteries, the rover motion was chosen as the design driver, since this is the highest energy consuming state of the rover and additionally mission critical for INSPIRE. The rover motion consists of an interaction of the Locomotion and Perception mode as already mentioned in Chapter 2. Therefore it was defined that INSPIRE shall be able to drive 50 m (including alternating Locomotion and Perception Mode) with a fully charged Battery. The required Battery Capacity $C_{\mathrm{Batt,req}}$ can be caculated using Equation 3.1. The results are listed in Table 3.2.

$$C_{\mathrm{Batt}} = \frac{P_{\mathrm{el,req}} \cdot t_e}{DoD \cdot \eta_{\mathrm{LiIon}}} \tag{3.1}$$

Using these values a suitable battery cell and battery design configuration were conducted. Using these parameters the battery capacity C_{Batt} can be calcuated:

Power Consumption Mode:	**Locomotion**	**Perception**
Required Electrical Power $P_{\text{el,req}}$ $[W_{el}]$	283.43	14.01
Duration of the modet_e $[s]$	500	15000
DOD for Dimensioning [-]	0.90	0.90
Efficiency of LiIon Cells η_{LiIon} [-]	0.95	0.95
Required Battery Capacity per mode C_{mode} $[Wh]$	46.04	68.27
Total Required Battery Capacity $C_{\text{Batt,req}}$ $[Wh]$	**114.32**	

Table 3.2: Power consumption mode used as design case for the battery sizing.

$$C_{\text{Batt}} = C_{\text{cell}} \cdot V_{\text{cell}} \cdot N \cdot M. \tag{3.2}$$

According to the ECSS reliability restrictions 1 battery string must be substracted for dimensionsing. Furthermore a 30% margin on the energy content was applied. This leads to a final battery configuration with a capacity of C_{Batt} = 138,88 Wh and a mass of m = 1980 g. The final battery values are listed in Equation 3.2.

3.6.4 EPS Power Control and Distribution

In order to ensure the full functionality of the EPS, the last main component to be selected is a suitable PCDU. As described in Figure 3.4, the PCDU forms the heart of the EPS and is also an important interface to the OBC and COMM. Furthermore the PCDU shall be able to monitor and control the rover system if necessary through watchdogs, HPC (High Priority Commands) and direct connections to the OBC and COMM.

The PCDU has the challenging task not only to process the RTG as the main energy source, but also to process solar cells as secondary energy sources. Therefore, a PCDU was sought which has the required size, dimensions and range of functions. The research resulted in the Nova PCDU from Bradford DSI. In addition, margins were added to the PCDU to ensure feasibility.

SAFT 176065 xlr	
Configuration:	
Battery Configuration	$4s3p$
Cells in Sereis s N [-]	4
Cells in Parallel p M [-]	3
Cell Parameters:	
Typical Cell Capacity $[Ah]$	6.8
Nominal Cell Voltage $[V]$	3.65
Nominal Cell Capacity $[Wh]$	24.8
Typical Cell Mass $[kg]$	0.15
Energy Density $[Wh/kg]$	165.33
Actual Battery Configuration Parameters:	
Battery Voltage V_{Batt} [V]	14.6
Battery Nominal Capacity E_{Batt} $[Wh]$	297.6
Battery Mass $[kg]$	1.8
Battery Mass (incl. 10% Margin) $[kg]$	**1.98**
Configruation according to ECSS reliability restrictions and margins included:	
Battery Configuration	$4s2p$
Cells in Sereis s N [-]	4
Cells in Parallel p M [-]	2
Battery Voltage V_{Batt} $[V]$	14.6
Battery Nominal Capacity E_{Batt} $[Wh]$	198.4
30% Margin on Energy Content	0.3
Battery Nominal Capacity E_{Batt} incl. Margin $[Wh]$	**138.88**
Useable Energy Density $[Wh/kg]$	70.14

Table 3.3: INSPIRE battery parameters.

3.7 Radiation

Compared to the radiation environment near Earth the radiation environment near Jupiter is multiple times stronger. It has the highest radiation levels of any planet in our solar systems [**Platzhalter**]. In order to survive these harsh environmental conditions, special emphasis must be placed on the radiation protection. In Figure B1, the average trapped proton and electron fluxes on Europa's orbit around Jupiter are shown in comparison to the outer Van Allen radiation belt around Earth. However, in contrast to the Van Allen radiation belt, the duration within the radiation environment on Europa cannot be minimised and the rover has to be designed to withstand the entire mission duration of 30 days.

In oder to design and evaluate different radiation protection approaches, different calculations have to be performed. For this purpose the ESA SPace ENVironment Information System (SPENVIS) is used [**Platzhalter**]. All calculations and figures in Section 3.7 are performed with SPENVIS unless otherwise stated.

3.7.1 Radiation Protection

Various options are available to protect the rover against the radiation. A common approach is the use of aluminium or titanium as these materials can also act as structural elements. However, due to the mass constraints of 30 kg other materials or material compositions are taken in consideration which are more mass effective. In Table 3.4, an optimised shield structure is presented for different weight thresholds designed for the radiation environment around Jupiter. The difference between an aluminium or titanium shielding and an optimised structure listed in Table 3.4 for the total ionizing dose (TID) is shown in Figure B2.

Due to the mass savings of the optimised structure it will be used where the radiation protection of the aluminium structure is not sufficient. In order to reduce the mass further, a radiation vault is utilised that highly sensible components do not have to be shielded separately.

Table 3.4: Optimal shield structure for an Jupiter mission. [**Platzhalter**]

Areal Density / g/cm^2	0.5	1	2	3
Layer No. 1	Pb	Pb	W	Ta
/ mm	0.415	0.829	0.984	1.563
Layer No. 2	Fe	Mg	Mg	Al
/ mm	0.033	0.158	0.540	0.399
Layer No. 3	-	-	-	Mg
/ mm	-	-	-	0.150

3.7.2 Components

Every component on the rover has a different radiation tolerance and therefore have to be placed at different compartments within the rover. The radiation tolerances are listed in Table B3. None sensitive components like the electric motors and harness are only shielded by an aluminium structure where components like the metal within the wire are resistant against the radiation. However, isolators around the cables have to be selected to be resistant in order to prevent short circuits. Highly sensitive components like cameras have an additional protective layer in order to reduce the TID to under 30 krad. Components which are within the rover like the on-board computer (OBC) are placed within the radiation vault which reduces the TID to under 20 krad. For this purpose the optimised shield structure with a weight target of 0.5 g/cm^2 is used. Detailed TIDs for all components are shown in **??**.

3.7.3 Improvements

Even though the radiation protection is sufficient for the rover to survive at least the nominal mission of 30 days, further improvements can be performed in order to extend the secondary mission.

Local shielding can be applied on less resistant components in order to reduce the wall thickness of the whole radiation wall. If components with a radiation tolerance under 30 krad are individually shielded a mass saving of xx % can be achieved. Additionally, water ice extracted from the surface of Europa can be used to improve the radiation protection. With a layer of one centimetre of water, the TID within the radiation vault can be reduced by xx %.

Detailed calculations for local shielding and water improvements can be found in **??**.

3.7.4 Conclusion

In order to protect the rover against the high radiation levels at the surface of Europa, the rover has different compartments. High sensible components are placed within a radiation vault which has a mass optimised structure. Components which has to be outside the radiation vault but are highly sensible are shielded individually. Low sensible Components are protected by the Aluminium structure. Figure 3.6 illustrates the different compartments within the rover and the accorded TIDs.

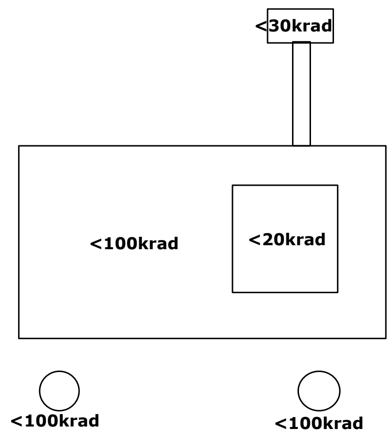


Figure 3.6: Overview of TIDs within different compartments within the rover.

3.8 Locomotion

3.9 Control and Autonomy

Chapter 4

Lander System

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4.1 Storage Configuration

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4.2 Depolyment Strategy

.... Test 123

Chapter 5

Trade-Offs

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Chapter 6

Risk and Technology Assessment

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6.1 Risk Assessment

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6.1.1 Risk Assessment Subsection

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6.2 Technology Assessment

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6.2.1 Acceleration segment

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Appendix

A Thermal Controls System

A.1 Heat energy eqilibrium

RTG:

$$\dot{Q} = 0$$

Electric Bay:

$$\dot{Q}_{B,intern} + CON1 \cdot (T_{RTG} - T_{Bay}) + CON3 \cdot (T_{Chassis} - T_{Bay}) - \epsilon_{alloy} \cdot \sigma_b \cdot S_{Bay} \cdot T_{Bay}^4 = 0$$

with:

$$\dot{Q}_{B,intern} = \dot{Q}_{C\&DH} + \dot{Q}_{Tranceiver} + \dot{Q}_{Receiver} + \dot{Q}_{PCDU}$$

Drill & Analyser:

$$\dot{Q} = 0$$

Camera:

$$\dot{Q} = 0$$

Radiator:

$$\dot{Q} = 0$$

Chassis:

$$\dot{Q} = 0$$

Steer Enine:

$$\dot{Q} = 0$$

Distribution Node 1:

$$\dot{Q} = 0$$

Drive Engine:

$$\dot{Q} = 0$$

Distribution Node 1:

$$\dot{Q} = 0$$

A.2 Heat conductance

A.3 Values

	Temperature limits in [$°C$]	
Component	min.	max.
Command & Data Handling		
Transmitter	-10	50
Receiver	-30	70
PCDU	-40	60
Battery	-35	60
Camera	-40	70
Objektive	-40	71
Steering Engine	-30	100
Steering Gear	-30	85
Drive Engine	-40	100
Drive Gear	-40	100

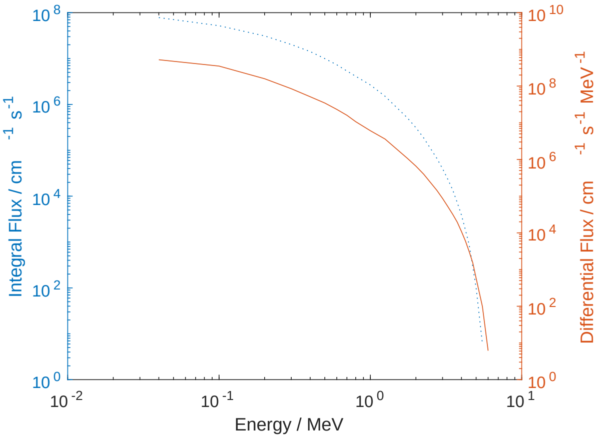
Table A1: Temperatur limits of the rover components.

	Emisivity [-]		Absorptivity [-]		Source
Surface finishing	min.	max.	min.	max.	
Sand blasted alloy					
White paint					

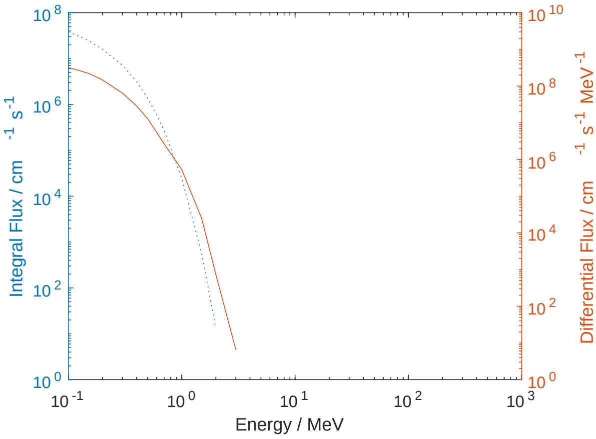
Table A2: Minimum and maximum of surface emisivity and absorptivity values.

B Radiation

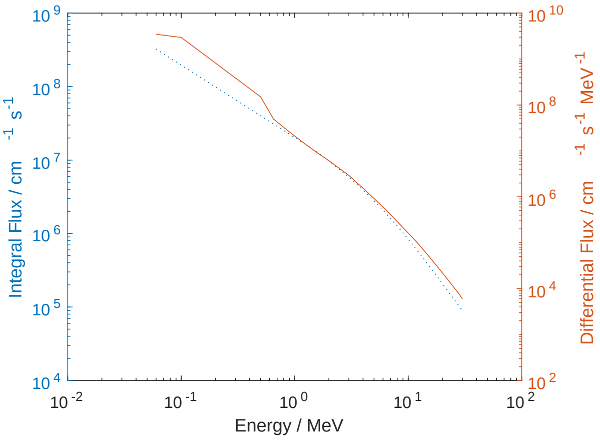
All calculations and figures in Section B are performed with SPENVIS unless otherwise stated.



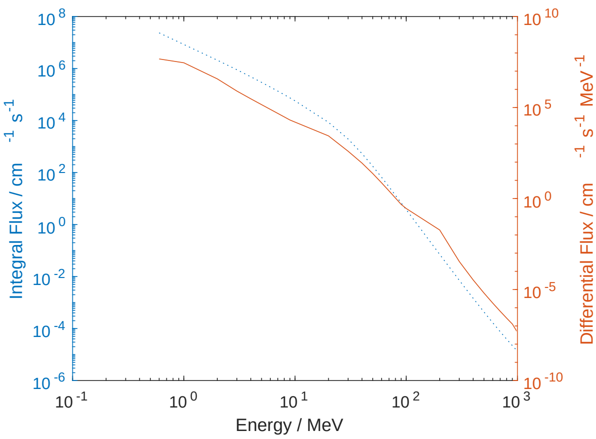
(a) Average spectra of trapped electrons around Earth



(b) Average spectra of trapped protons around Earth



(c) Average spectra of trapped electrons around Jupiter

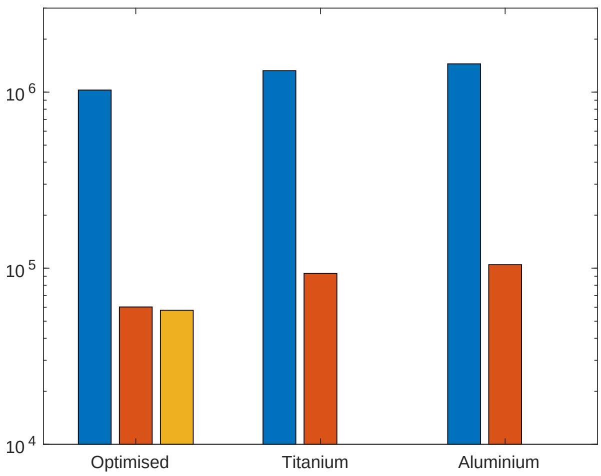


(d) Average spectra of trapped protons around Jupiter

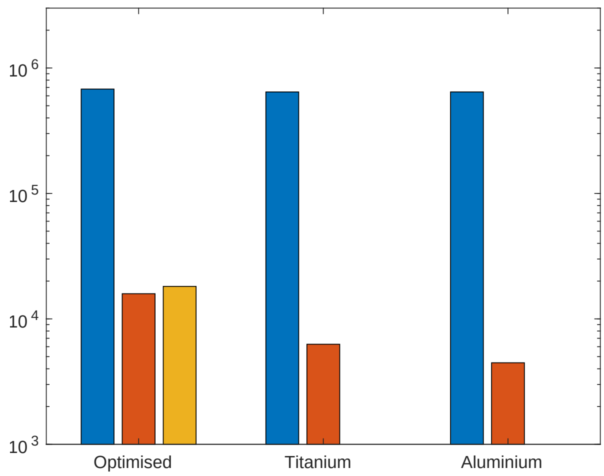
Figure B1: Average trapped proton and electron fluxes on an orbit around earth at 25,000 km, through the outer Van Allen radiation belt, and on Europa's orbit around Jupiter.

Table B3: Used components and the respective radiation tolerance and location

Components	Rated TID	Exposed TID	Location



(a) TID for Electrons as Source Particles



(b) TID for Proton as Source Particles

Figure B2: TID of aluminium, titanium, and the optimised radiation structure shown in Table 3.4 with an weight target of 0.5 g/cm^2 over 30 days of exposure on Europa

C Appendix 2

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