POLITECNICO DI TORINO

Master's Degree Course in

Aerospace Engineering

Master degree Thesis

A Concept for space mission to icy moon: Small probes for a subsurface ocean exploration mission to Europa

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Summary

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ABSTRACT

This thesis focuses on a concept of space mission on icy moon, based on small probes with large radiogenic heat source.

Icy moons could be the best candidates for the next space mission because there is possible to find liquid water and the conditions to host life. The attention of this paper is focused on Europa.

Europa is an icy moon of Jupiter with a subsurface ocean of liquid water. Since water is one of the fundamental ingredients for life, its study has gained a lot of interest within the science community. Recently, concepts for a probe, which could potentially melt though Europa's ice shell, have been discussed in the open literature. To date, these concepts have mainly focused on a single probe design that makes use of a relatively large radiogenic heat source based on plutonium-238. However, due to Europa's relatively low temperature (100 K), low atmospheric pressure (0.1 μPa) and low gravity (g=1.35 m/s2), smaller probe designs with higher thermal power densities are could play a significant role to help overcome the challenges associated with ice sublimation and refreezing. In this paper, new smaller melting probe designs are examined that make use of radiogenic heat sources with higher thermal power density. Specifically, designs that utilize curium-244 and uranium-232 are assessed. Probes with relatively small lengths (0.20-1.50 m) and small radii (0.06-0.12 m) are considered and compared with different melting velocities and radioisotopes. Different concepts are studied for the communication problem.

1.INTRODUCTION

One of the most important targets for the space exploration consists to find other bodies with the similar environment of the Earth. Humankind wants to explore new frontiers of space to expand the limit of knowledge and to find life outside our planet. Moon, Mars, these are the future target for the next phase of space missions.

Into our solar System there are different planets, small bodies, moons that could be possible future targets of space mission. However, there are bodies that could be the best candidates for the future: icy moons.

On this bodies there are the perfect conditions where is possible to find the fundamental ingredient for the life: water.

So, if we want to find the ask to the question "is there life outside the Earth?", it needs to move the space interest to this kind of bodies. For this reason, the future space mission could consist to send lander to study the surface, the ice and the water of these bodies to searching for life.

Europa and Enceladus are two icy moon that could be the best candidates for the next mission.

Europa surface is covered by a deep ice layer with a thickness from 5 to 30 Km. Above this surface layer, there is a deeper ocean where maybe there are the right condition for host life. Recent study of the geyser , with MISSION GALILEO [1], confirm the presence of the water ocean under the surface, so the main challenge consist to send a probe to melt the ice layer to reach the water and study it

Enceladus is another icy body of our solar system and a Saturn's moon. Its surface is covered by three different materials with ice on different zone of the planet. On this moon are observed high geysers that prove the presence of the water under the surface.

Our attention is focused on Europa and its deep ocean covered by thick ice layer. Europa and its environment represent a true challenge for a space mission on its surface. With a very low gravity, low pressure, low temperature it could be a very hard to send a probe to melt ice and reach the ocean to study the environment.
A mission based on to use small probes, with a high energy in small volume is the best solution to respond to the Europa environment challenges.

One of the biggest problems of a space mission in this environment is the heat and the power source needed to the spacecrafts. The best solution, with the technologies of these days, consists to use a radioisotope power.
In this paper, different solutions are analysed with different radioisotopes.
Plutonium is the radioisotope used for all space missions to Mars and into the deep space, so it could be a solution for the mission considered in this paper. However there are others materials that could be best candidates for this kind of mission: uranium and curium.
With an high thermal power it is possible to use a lower quantity of its and in this way you have an high energy and heat source in the small volume. However, there are different challenges about these materials.

The uranium is a material with a high thermal power, around 4,4 W/g [5]so with small mass is possible to produce enough quantity of energy for icy moon mission. There is need to study the production process and the decay of thorium.

Curium with its thermal power of 2,4 W/g [2,3,4]is a very good candidate for icy body environment mission. Another good property of this material consists to the production, because is possible to produce it by the waste of nuclear plant.

On this paper we study these different materials and we make a comparison between them.

The main challenge consists to design the main part of the mission that consist to melt ice to reach the target. The Europa's ice layer has thickness from 5 to 30 kilometres, so the probe needs to melt the ice to reach the ocean. [6]
The low surface temperature, the low pressure and the communication are the big problems of the mission. Using a different number of probes with antennas and different quantity of radioisotope is possible to melt 30 km down through the ice. In this paper, different architectures are analysed

The main solution consists to a mission architecture based on the use of 5 different small probes and one main probe. The small probes reach different ice depth targets and in this way with its communication subsystem is possible to link the main probe to the lander. Where the lander with a main communication subsystem, send information to the orbiter. Then, the information will be sent to the earth.

2.EUROPA

2.1 EUROPA environment

Europa is one of the most important Jupiter's Moon. It is the smallest of the four Galilean moons, and it is the sixth largest moon of the solar system. It orbits around the Jupiter with a circular orbit and a mean orbit radius of 670 000 km.[6] Its small size, its orbit and the other condition allowed to the presence of ice and the water on Europa.

Figure 1.Europa, Jupiter's Moon: https://www.hindustantimes.com/science/jupiter-s-moon-europa-may-host-life/story-EHX2G8lserWfrlCCB6fOYP.html

Recently study and collected data by different space mission, confirmed the presence of high water vapor plumes, so this is the proof of the water under the surface of the planet.

2.1.1 Thermal conditions of the moon

The Europa surface's temperature is very low, its values is around 100 K. It rises to 273,15 at the bottom of the ice. In this way there are the conditions to the presence of the liquid water. The heat situation of the planet is caused by the tidal of the ocean and the radioactive decay of the mantle. The tidal friction, flexing and radiation decay are the main heat source of the moon. [6]

2.1.2 Tidal friction

The Jupiter gravity effects and the resonance with other moons generate the tidal of the ocean of Europa. The energy of tidal is converted in heat by friction phenomenal. The waves that generate energy is called **Rossby waves** and could contain 7.3e18 J of kinetic energy. This energy could be the main heat source of the ocean. [6]

2.1.3 Tidal flexing

The core and the surface of Europa are pulled under the effect of the gravity of Jupiter. The kneads and the ice deformation produce a high quantity of heat and a hydrothermal activity similar to Earth undersea volcanoes.[6]

2.1.4 Radioactive decay

The rocky mantle contains the radioactive materials that produce heat that contribute to the other heart source of the planet. However, different study proved that the quantity of heat generated by this source, is very low and the tidal phenomenal are the lead heat source of the moon.[6]

2.2 EUROPA SURFACE

On the surface of Europa was observed a series of dark streaks on the entire globe, the **lines(linae).** There are different hypothesis about them, but the main consist to the lines were produced by eruptions of warm ice on the surface.

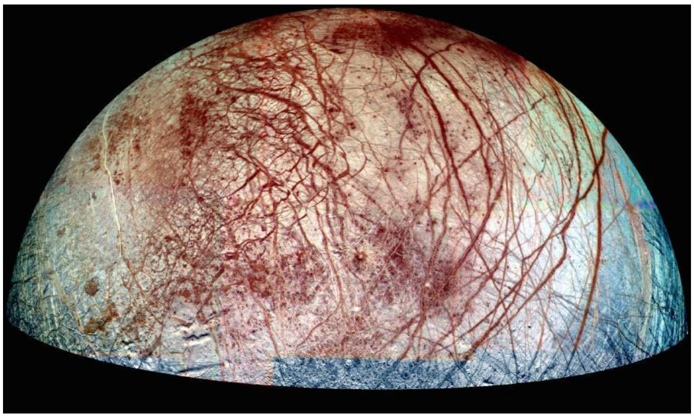

Figure 2.Europa's surface:https://www.britannica.com/place/Europa-satellite-of-Jupiter

The albedo surface is 0.64 and it is one of the highest into our solar system. That is the proof of a young and active surface.

The Europa Surface is made by silicate rock and in the main part by ice. The ice layer depth goes from 5 to 30 km and beneath there is a water ocean with a depth of 100 km. For these different properties, Europa it will be the best target for the next space mission for find the answer to the question of "Is there life in our universe".

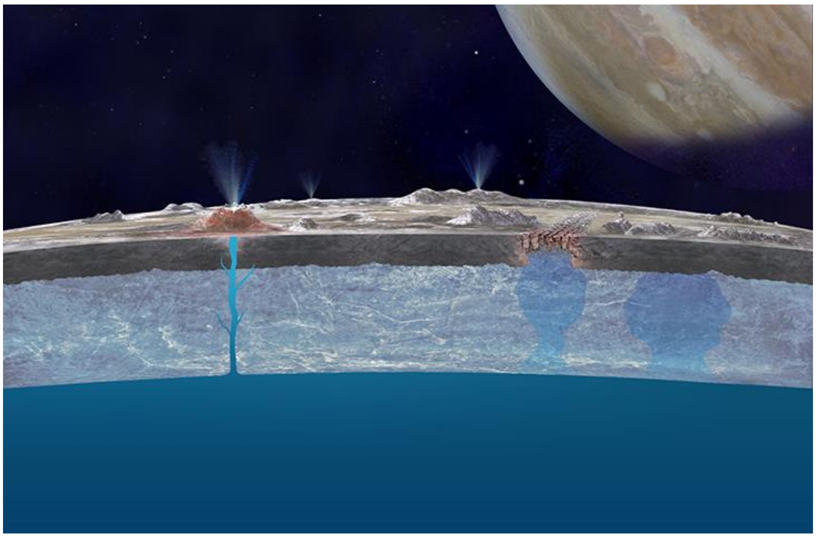

Figure 3. Europa ice layer and ocean: http://nautil.us/issue/71/flow/why-europa-is-the-place-to-go-for-alien-life

However, Europa environment is very challenging for a space mission on its surface; with low temperature, low gravity, low pressure, and the absence of the atmosphere is very difficult to landing on the ice surface.[7]

Europa environment	data
Surface pressure	0.1 μPa
Surface Temperature	Min: 50 K – Avg: 100 K – Max: 125 K
Gravity	1.314 $\frac{m}{s^2}$
Radiation	5400 mSv

Table 1.Europa surface data

In tab.1 are described the main properties of the Jupiter's moon. The temperature and the pressure are very low and for this reason one of the most challenge of the mission consists to avoid the sublimation when the probe with the thermal source touches and starts to melt ice.

Another big challenge of the Europa environment consists to the high value of the radiation. The iron-nickel core produces a very high quantity of radiation. 5400 mSv on the surface would cause severe illness or death human beings exposed for a single day. That radiation could be dangerous also for the electronic and communication subsystem of the lander. Regarding the probe into the ice.

2.2.1 ICE LAYER TEMPERATURE

The ice layer temperature follows a linear increase behaviour in function of the ice deep.

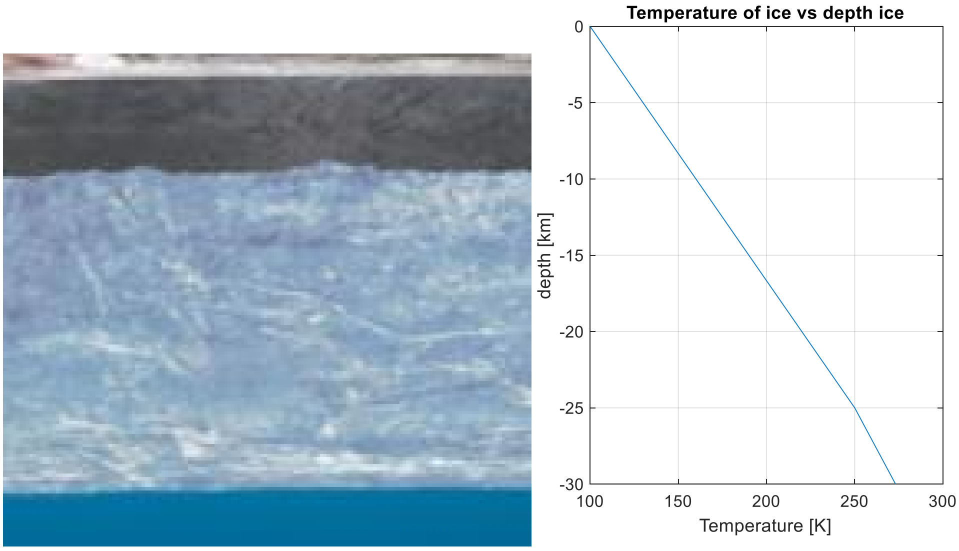

Figure 4.Temperature of ice behaviour: http://nautil.us/issue/71/flow/why-europa-is-the-place-to-go-for-alien-life (left image)

There is this behaviour of the temperature due the heat source of the inner of Europa.

For this phenomenal, there is need to study the concept mission considering different interval of environment temperature.

Depth [km]	Temperature [K]
0-5	100
5-10	145
10-15	175
15-20	205
20-25	235
25-30	265

Table 2. Main temperature values of different intervals depth of ice layer

3.THEORICAL STUDY

3.1 THERMODYNAMIC STUDY

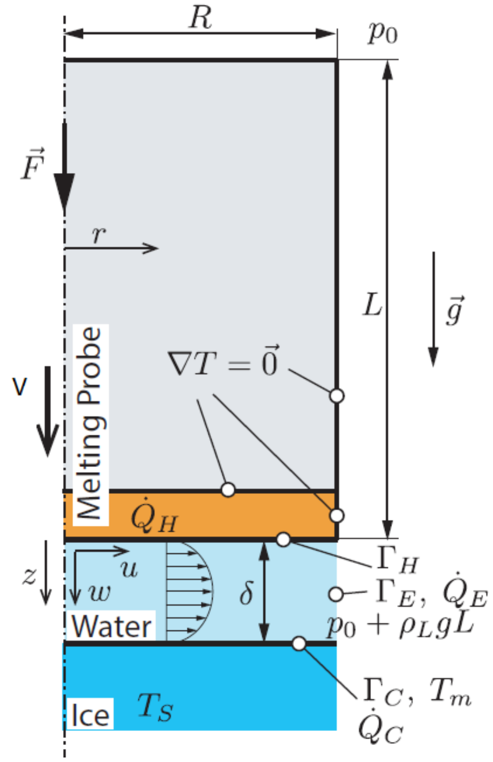

Figure 5. Concept of the thermal study[7]

Europa environment is very challenging, the surface low pressure and the low temperature are the big problem to avoid. There are different papers that study a probe on Europa. The main solution consists to use a probe with a small cross section and small volume. The Europa data used are in the tab.3:

Europa environment data		
$g[\frac{m}{s^2}]$	Gravity acceleration	1.3
$K_L[\frac{W}{mK}]$	Thermal cond. Liquid water	0.6
$\rho_L[\frac{Kg}{m^3}]$	Density of liquid water	1000
$c_{p,l}\ [\frac{J}{KgK}]$	Heat capacity liquid water	4200
$\mu[\frac{Ns}{m^2}]$	Dynamic viscosity	0.0013
$K_s[\frac{W}{mK}]$	Thermal cond. Solid water	3.5
$\rho_s[\frac{Kg}{m^3}]$	Density of ice	927.8
$c_{p,s}[\frac{J}{Kg}]$	Heat capacity ice	1476
$h_m[\frac{J}{Kg}]$	Reduced latent heat of melting	333700
$T_m\ [K]$	Melting Temp.	273
$T_s[K]$	Ice Temp.	100

Table 3. physical properties [ref.7]

The general study is based on a cylinder probe due it is easier to study than other shape and it is perfect for Europa environment. The main equation used to study the heat needed to melt ice with a probe with a determined values of cross section and melting velocity is (Ref.1)(file equation):

$$\dot{Q_{M\imath n}} = VA\rho_s[h_m + c_{p,s}(T_m - T_s)] \quad (1)$$

[7,8]Here, V is the melting velocity, A corresponds to the cross section of the probe and ρ_s *is the ice density*. Other data are:

h_m is the latent heat of melting, $c_{p,s}$ *is the ice heat capacity* and T_m, T_s are correspondingly melting and solid temperature of the ice.

From this equation, if the heat flux value is constant, is possible to study the variation of melting velocity with different size of the cross section:

$$\dot{Q} \propto VA \quad (2)$$

[7,8] The melting velocity, with a heat flux constant, increases when the size of cross section decreases. So, if we want to melt with a reasonable velocity, we need to use a probe with small section.
However, the main study that is made on this paper, consist to fix the cross section of the probe, and study the quantity of heat need to melt ice with different values of melting velocities.

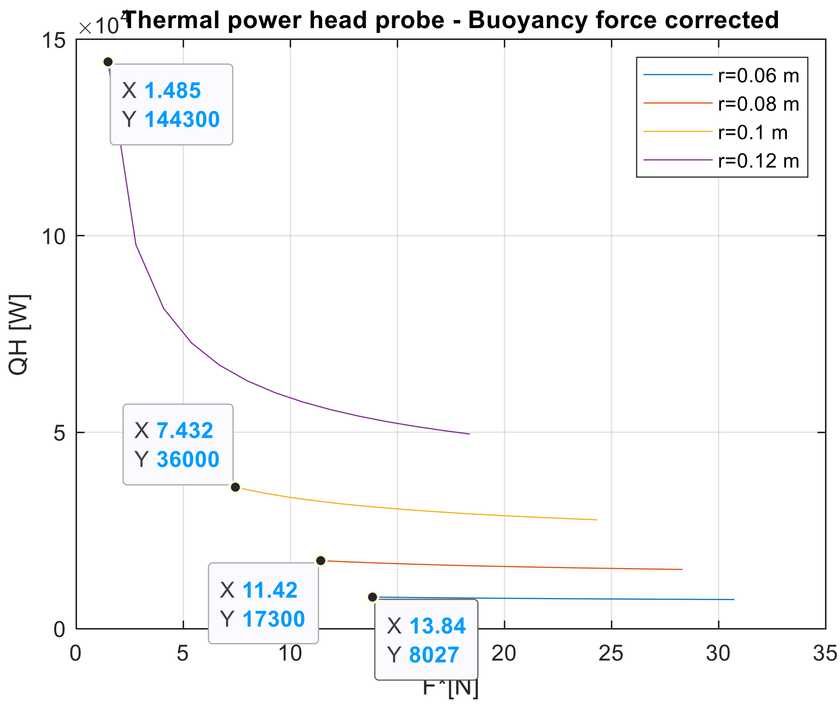

Figure 6.Effect of different radius with interval of probe's mass :[12:25] kg

In fig. 6 there is a general study need to show how to change the quantity of heat needed in function of the cross-section radius with a fixed melting velocity value.

Each value indicated into the fig.6 corresponds to probe mass of 12 kg and different radius. How it is possible to see, the power needed at the head of the probe is very high for a probe with a high crosse section. The length of the probe does not have much influence on the heat head needed.

In the fig. 23 the heat head probe is figure in function of the corrected force.

3.2 Buoyancy force

The buoyancy force is another phenomenal that we take in consideration for the mission. When the probe melt through the ice, there is a film of liquid water around the probe. For this reason, there is need to calculate the real force of the probe on the ice and the pressure needed to avoid the buoyancy,
The normal force of the probe on the ice correspond to:

$$\boldsymbol{F = mg} \quad \textbf{(3)}$$

Where m=mass of the probe and g= gravitational acceleration

Considering the buoyancy force, it is possible to calculate the corrected value of force, called Corrected force:

$$\boldsymbol{F^{*} = mg - \pi R^{2} \rho_{L} g L} \quad \textbf{(4)}$$

[7]Where R is the radius of the cross section of the probe, ρ_L is the water density and L is the length of the probe.

-mg is the force that pulls down the probe.

$-\pi R^2 \rho_L g L$ is the force that pushes up the probe.

There is need that the mg is more stronger than the other force
So if we want to avoid the stall of the probe into the liquid water, there is need a probe with a small cross section and short length .The concepts analysed in the literature based on small probes, considering this problem.

So, a probe with a high mass, small radius and small length is the best candidate for this kind of mission.

3.3 Film water thickness

When probe melts through the ice, is surrounded by a water film thickness. If we know the values of melting velocity is possible to calculate the film thickness:

$$\delta = \left(\frac{\frac{3}{2}\left(\pi R^4 \mu \frac{\rho_s}{\rho_L} W\right)}{F^*} \right) \quad (5)$$

With $\mu = dinamic\ viscosity\ of\ the\ water$ [7]

Studying different concept of mission with different melting velocities is possible to study the water layer around the probe, monitoring the quantity of water around the probe and eventually control the buoyancy stuck of the probe.

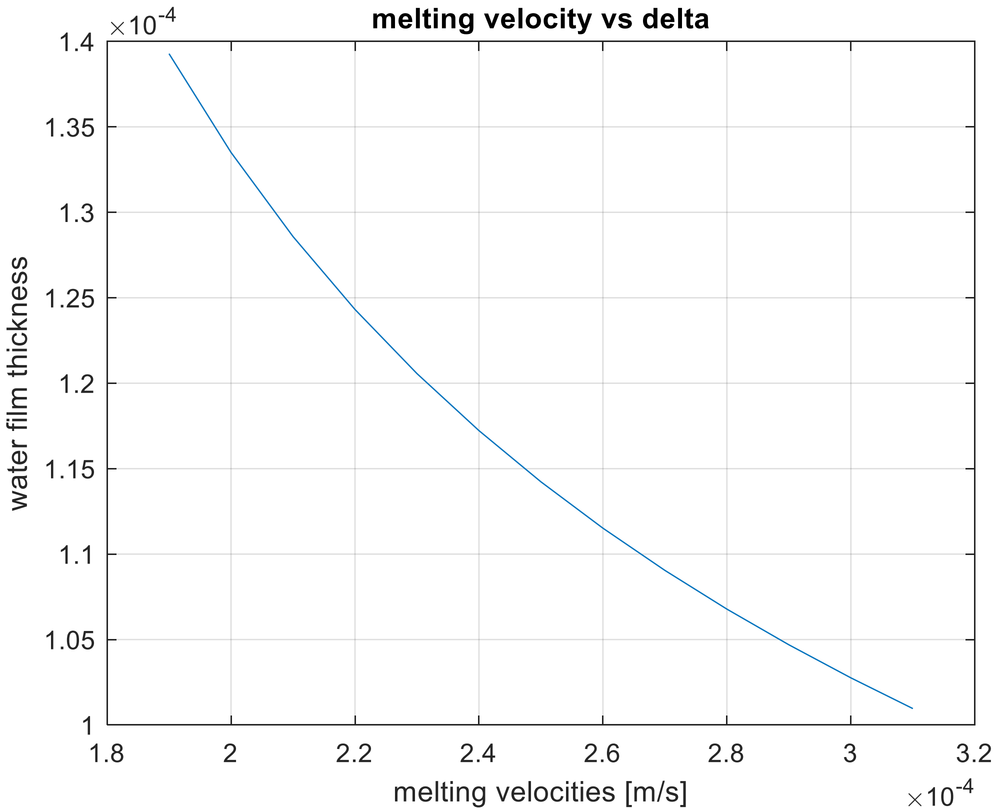

Figure 7. water film thickness considering different melting velocities and mass probe values.

In fig. 1 is described the water film thickness behaviour and it is considered different values of melting velocities (V) with [0.00019:0.00001:0.00031] m/s and different values of mass [12:24] kg

How it is possible to observe by the equation, the film thickness could increase with the increase of melting velocities values but in fig.2 it follows an opposite behaviour due the influence of the corrected force (F*). In that case, it is considered a growing interval of mass. Then, to avoid the stuck of the probe into liquid water, the probe with high mass are the perfect candidate for melt through the ice.

4.CHALLENGES

The environment of Europa previously descripted presents different challenges for a space mission.

4.1 Triple point

The low pressure on the surface of 0.1 μPa represents one of the big problems for a mission based on to use small probe with a high thermal source to melt through the ice and reach the target. This pressure is under the triple point water pressure, so when there is a heat source and the ice temperature rise, there is the sublimation phenomenal. So, this could be a big problem, because the water vapour hinders the pass of the probe into the ice. There is need to a system to avoid this phenomenal.[4]

4.2 Refreezing length

Refreezing length is the distance after the heat source of the probe, where the water refreezes. This is an important phenomenal to take care because if the probe has a not good thermal subsystem that produce the heat needed due the thermal losses, probes could be stuck into the ice.[7,8]

The temperature values of the first kilometres of the ice layers came from 100 to 150 K. At this temperature there is another important physical phenomenal that it is considered for the studio of the space mission on Europa: the refreezing. When the probe is melting through the ice, the water above the probe start to refreeze. This phenomenal start after a determined length that depends by the probe parameters. Different situations are studied in this paper.

$$\boldsymbol{L^*} = \left[\frac{\boldsymbol{Q_{Min}V^{d-1}R^{2(d-1)}}}{\boldsymbol{n(T_m - T_s)}}\left(\frac{\boldsymbol{(7\gamma+1)}}{\boldsymbol{1-3\gamma}} - \boldsymbol{1}\right)\right]^{\frac{1}{d}} \qquad \textbf{(6)}$$

where

$$\gamma = \frac{1}{20\alpha_1}\left(\frac{\left(\frac{\rho_S}{\rho_L}VR\right)^{\frac{4}{3}}\frac{3}{2}\pi\mu}{2F^*}\right)^{\frac{1}{3}} \quad and\ \alpha_1 = \frac{K_l}{\rho_l g}$$

and

$$n = 932\frac{Ws}{K/m^3} \text{ , d=0.726 and } K_l = 0{,}6\, W/mK$$

[7,8]]From the eq.6 is possible to see that the refreezing length increase with the increase of the flux heat and it is reasonable because if there is a high flux heat, the refreezing length is high. However, the refreezing length values is in function of the corrected force, than of the length and radius of the probe.

From a general study it is possible to observe the variation of the Refreezing Length in function of different mass, melting velocity and length of the probe.

The temperature of ice and the environment is fixed at 100 K and Radius (R) is 0.07 cm.

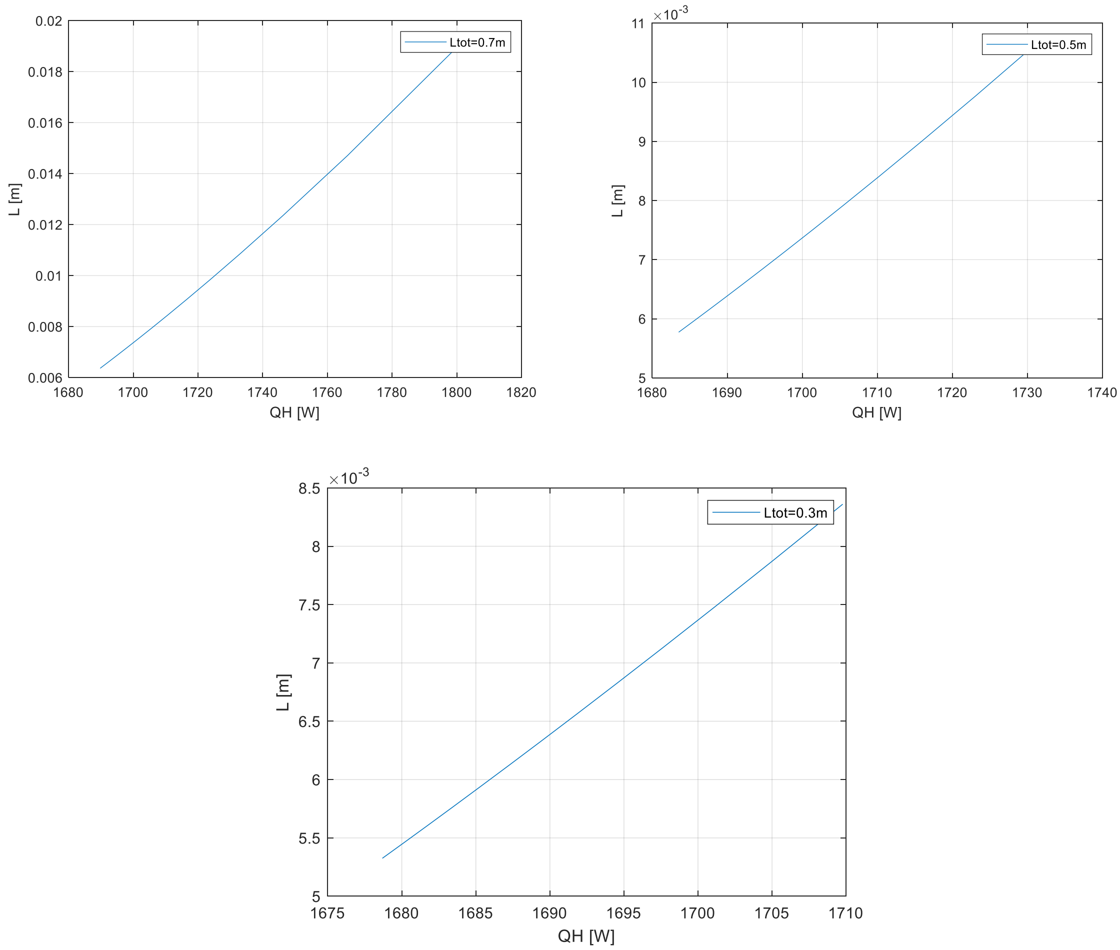

Figure 8.Refreezing length in function of the head heat flux

In the fig. there is figured how to change the refreezing length in function of the heat head probe and different length. The mass, radius and the melting velocity are fixed. How it is possible to read, the Refreezing Length (RL) increase with the length of the probe. However, the value of the RL are very small and there is need to a lateral heat to avoid the stuck of the probe into the ice.

How it is explained in the next paragraphers, if it has a probe with an high value of length, there is need to more weight to avoid the buoyancy phenomenal and a lot of lateral heat to avoid the stuck into the ice.

Considering a constant heat flow rate at the melting head, the RL increases if the corrected force decreases. Because, if the exerted force decreases the convective losses occur so there is a lot of heat that cause the increase behaviour of the refreezing length.

If the value of corrected force is fixed, the refreezing length increases with the increases of the flux heat head problem, so with the increase of the melting velocity.

This phenomenal is very important to study the environment around the probe and the dangerous that the probe could be stuck into the ice and not melting other ice. The ice that is created above the probe generates pressure over probe, so when the probe starts to melt the first meters of ice and there is the refreezing phenomenal above it, the ice the is created generates pressure, so there is not the sublimation of ice but only the transformation from ice to water.

5. THERMAL LOSSES

The refreezing length and the convective losses are two phenomenal that it takes care for the study of the mission concept. The main source of the thermal losses is the energy needed to avoid the refreezing phenomenal.

5.1 Convective losses

To consider the losses due the film thickness of water around the probe it is possible to calculate the quantity of energy there is need to take care of this energy losses

$$\boldsymbol{Q_E = (1 - \gamma) Q_H} \quad \mathbf{(7)}$$

[7]The quantity of heat needed to the convective losses is in function of the corrected force F^* , in particular if the corrected force increases, the quantity of the convective losses decreases because the layer of the liquid water around the probe is thinner.

However, the convective losses are lower than the lateral losses due the refreezing length.

5. 2 Lateral losses due the refreezing length

One of the big challenges of the mission concept analysed is the heat needed to the lateral walls of the probe to avoid the refreezing phenomenal and the stuck of the probe into the ice [7,8].

$$\dot{Q}_{rl} = (R^2V)^{1-d}nL^d \tag{8}$$

With n= $932\frac{Ws}{K/m^3}$ and d=0.726

From fig.9, with the value of the environment temperature and the length of the probe fixed, if the melting velocity chosen is high, the value of the heat needed for the lateral losses is high too. Due if we use a lot of energy to melt ice, the energy needed to the losses increases.

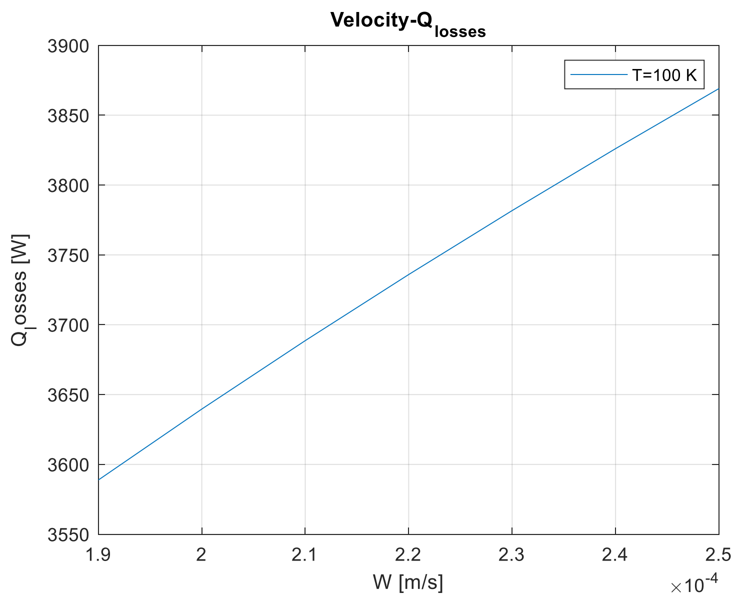

Figure 9. Heat needed to the losses in function of melting velocities (Temperature fixed)

If the radius of the probes is too large, the quantity of thermal energy needed to melt with a fixed velocity increases and increase also the lateral thermal energy needed to thermal losses due to the refreezing length phenomenal. From fig.9 is possible to read the behaviour of the thermal needed for the lateral losses in function of the radius of the cross section of the probe.

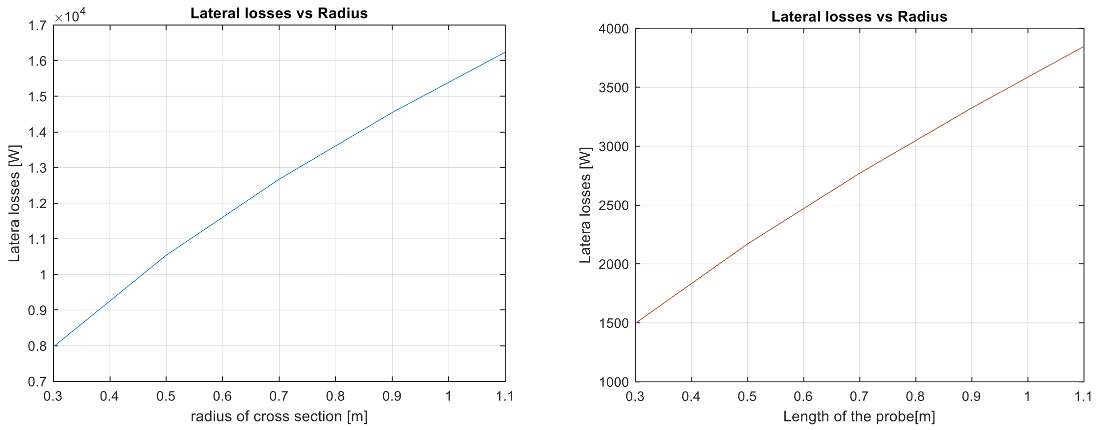

Figure 10. Lateral losses in function of the cross-section radius (right) and in function of the length of the probe (left)

In the fig.10 it is possible to see a comparison between the:

-Power needed for lateral losses in function of radius of cross section.

-Power needed for length of the probe.

How it is possible to see, the lateral losses increase a lot with the increase of the radius of the probe. The values go from the 8000 W to 17000W for a different radius of probe (0.3 to 1.1 m). For this reason, the small radius cross section is the best solution. In that way the heat needed to melt ice and the heat needed to the latera losses.

The lateral losses increase slower with the increase of the probe length with radius and melting velocities fixed.

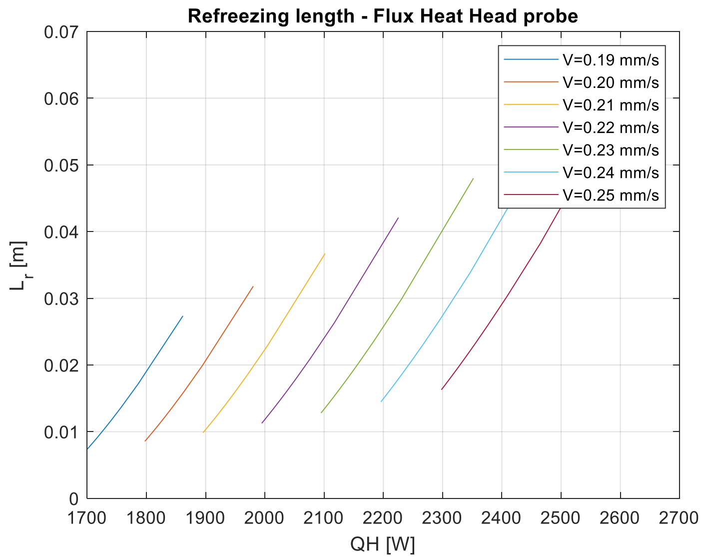

Figure 11.Refreezing length in function of masses, heat head probe and velocities.

In fig.11 is figured the refreezing length in function of the melting velocity, the head heat flux, and the weight of the probe.

If the weight of the probe increase, the refreezing length value decrease with the flux heat head needed to melt with a fixed value of the melting velocity. If the melting velocities increase the refreezing length increase only of small step.

For this reason, it is very important to use a probe with a high weight. In this way the total quantity of the energy needed is low and it is better for the quantity of radioisotope needed.

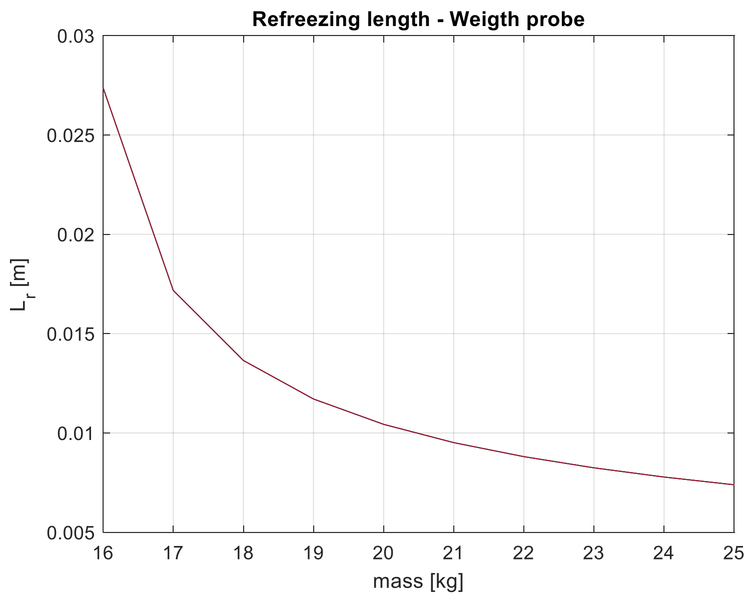

Figure 12.Refreezing length in function of mass

The link between the refreezing length and the mass of the probe is figured in fig. How it is possible to note, if the weight probe value is low, the refreezing length is high. Because at fixed velocities, the quantity of the flux heat head needed is higher, so if this value is high there is a high thermal energy heats up around the probe and the refreezing length increases.

For this reason there is the necessity to find a compromise between the perfect weight of the probe to reduce the quantity of the flux heat head needed and to reduce the quantity of heat needed to avoid the stuck into the ice and increase the value of the refreezing length.

If it considered the changing of the temperature when the depth increases, we have a different behaviour of the refreezing length and the thermal needed for the lateral losses.

In the end, the refreezing phenomenal is dangerous for the probe but it is very important due the layer above the end of probe.

The ice above the probe it is necessary to generate pressure and to avoid the sublimation problem in the deepest ice layer. However, due the presence of ice, there is a big problem for the communication between the probe and the lander because there is not possible to send radio wave for big distance through the ice. Into the paper, different solution is described to avoid this problem.

6.COMMUNICATION PROBLEM

The communication between the probe and the lander is a critical problem of the mission. If it decides to use the wavelength technology for the communication, there could be different problems. In Europa surface, where there is only water ice or liquid, the wavelengths are not very reliable. The attenuation of the radio wave into the water ice is 1000 times smaller than the water liquid. However, considering the mix between salt, liquid, ice water the attenuation is very high.

On Earth, to communicate with submarine through the liquid water is using a very low frequency [3-300 Hz] and it is a problem because to broadcast with these values there is need large antennas and it is not good for Europa environment. For this reason, is very hard to create a link communication. Considering the worst case with the ice thickness of 30 kilometres, the probe that reached the ocean, needs a high power to send information with its communication S/s through a large ice layer. Therefore, the wavelengths through the ice are not considered a reliable way. However, it is a solution that permit to use this kind of technology based on to use different small probe with only a communication subsystem to release at different ice depth. In this way the distance between the different comm s/s is low and the technology is reliable also in this environment. [7]

There is an alternative solution to the electromagnetic technology for the communication link: the use of a tether to link the probe to the lander. However there a lot of problem with this concept discussed in the literature.

7. ENERGY SOURCE

One of the best mission concept for Europa's environment based on to use a probe with a small cross section, because in this way it is possible to melt ice with a reasonable values of melting velocity with a low quantity of heat source.

7.1 Plutonium-238

Plutonium-238 is the radioisotope used until today for the space mission on other planet, like curiosity on Mars, and deep space mission. It is possible to produce it with different laboratory process, but the time needed to produce a large quantity of it are very large. Now is possible to produce 400 g for yea but for the next space mission there is need to a lot of quantity of it.[9]

Properties	
Density power [W/g]	0,57
Half-life [years]	88 ys

Table 4. Properties of Plutonium

From tab.3 is possible to read the density power of plutonium-232 is very low. This means that for produce a large quantity of energy, we need a lot of gram of plutonium. (E.c. with 400 g is possible to produce 204 Watts).
The best quality of this radioisotope consists to the half-life time: it is very large and it's a good quality for space mission with a long life activity and for mission with a long travel from the Earth to the target.

Concept mission to Europa needs a high heat and energy source because it needs to produce an order of energy of **5000 W.** Then, to produce the quantity of energy needed, a large quantity of gram of Plutonium are needed, around **8,77 Kg.** For Europa environment and the concept mission, this quantity is not recommended due the perfect concept mission based on to use a small probe. If we use 8 kilograms of Plutonium, it needs to build a big probe that means big quantity of energy needed and less space for other subsystems.

7.2 Uranium-232

Uranium -232 is a radioisotope with a high-density power value. It is a product of thorium (Th-238). It is an alpha emitter with a long half-life time. The products of its decay are all alpha emitters and the end of the decay chain is the Pb-208 . However, some products of the decay process have an high activities, so it needs a study to understand what kind of radiation they produce and how it could be dangerous during the clads fabrication.[3]

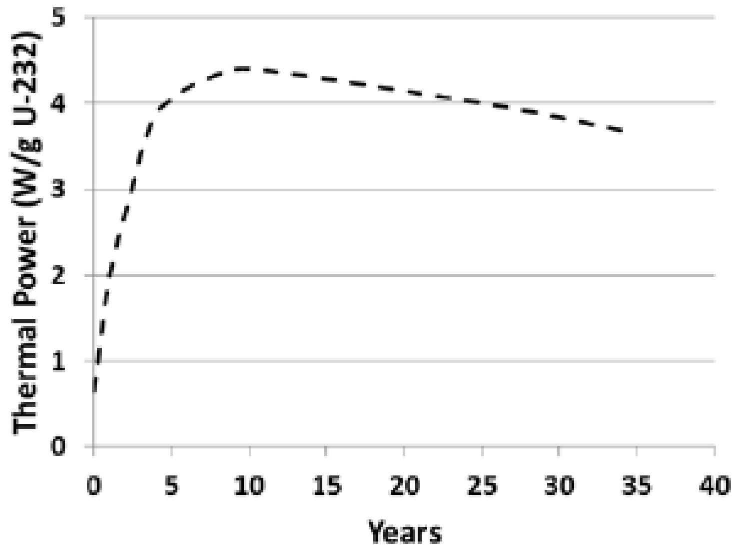

Figure 13.Uranium behaviour[5]

From fig.3 is possible to observe the behaviour of the Uranium-232. It is thermal output increases as a function of time. At the start of the decay process it produces ~0.7 W/g, its values increase also in function of the quantity of the uranium-232 products by the decay process. After ~6 years, the energy output reaches 4.4 W/g. After this point, the energy output decreases slowly until 35 ys.[5]

For these properties, it could be better for Europa mission, because the travel from earth to Europa lasts 6 years. So, If it considered the start of the mission with the start of the decay process of Th, it is possible to have a low quantity of heat produced during the travel, so there is no need to a big dissipation subsystem. Meanwhile, when the probe reaches the Europa Surface, Uranium produces high quantity of energy. In this way it is possible to reach the energy required with a very small quantity of the radioisotope.
The half-life time is not a problem because it is enough for the time mission considered.

With the uranium power is possible to produce 5000 W with only 1.136 kg.

Properties	
Density power [W/g]	0.6 (start) – 4.4 (after 6 years)
Half-life [years]	68.9 years

Table 5.Uranium properties[5]

7.3 Curium-244

Curium-244 is a radioisotope with a high density power that in these years it is studied to be used for the next space mission.

It is considered for the future mission for two reason: one is its power capacity and the other is the production process. It is possible to produce large quantity of curium by the waste of nuclear plant.

(Curium in the space) It is possible to produce curium by the waste of nuclear plant. From only the Swedish's plants it could be produce 6-12 kilograms for years.

This radioisotope could be one of the best candidates for space mission based on small probe and high energy required. Its density power is very high and with small quantity of it is possible to produce a lot of energy.

Properties	
Density power [W/g]	2.4
Half-life [years]	18.1 ys

Table 6.Curium properties[3]

From table 2 is possible to read the density power of curium. With this source is possible to respond to elevate value of energy required, in fact for produce **5000W** it needs only a **2,5 Kg.**

This value it is better than 8 kilo of plutonium and considering a probe of the same size, with curium there is more free space than the plutonium case.

The worst quality of the Curium is its half-life time. For this reason, curium -244 could be used only for mission with short time of activity. In this study, this value is considered for the calculation of the quantity needed. In particular, the study of the total quantity of curium needed is based on the half-life time, due the travel from Earth to Europa lasts 6 years. For this reason, the quantity of the radioisotope at the start of the mission is higher than the true quantity for the mission.[2,3,4]

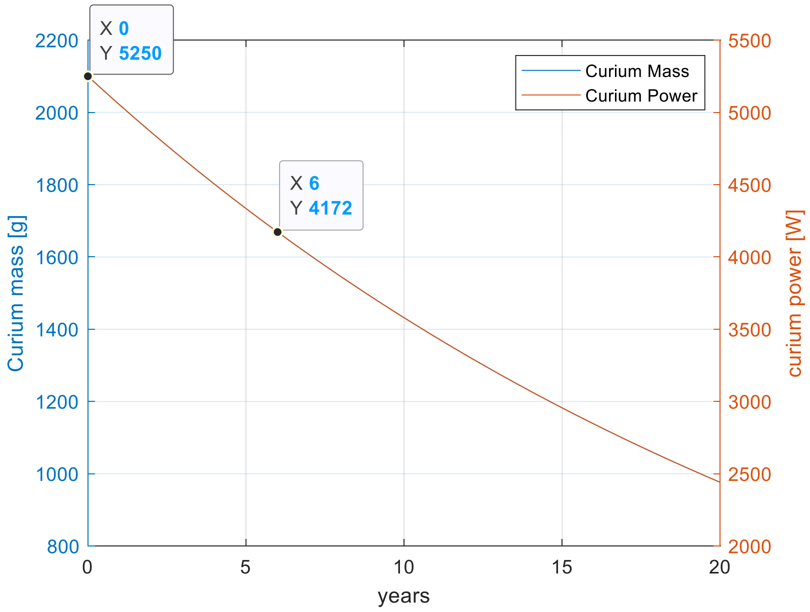

Figure 14.Decay of curium during the time.

In the fig.14 it is considered a concept that need 4100 W at the start of the mission on Europa surface. To produce the quantity requested it is needed 1738 gr of curium if it is not considered the decay of the curium power.
Taking care of the curium half-life, the quantity needed at the launch moment is higher than on Europa surface, 2100 gr. That is the right of curium needed to produce 4172 W after the time travel to the moon,6 ys.

Another problem due the lower half-life time consists to store the curium. For example, with plutonium is possible to produce the clads time before the launch. With Curium it needs to produce it near the time of start of the mission.

Now, there are not enough information to the decay radiation and how it is possible to manage it during the creation of clads for the probe or the satellite.

7.4 Comparison between radioisotopes

Plutonium-238, curium-244 and uranium-232 are the radioisotope considered for the concept studied in this literature.

Plutonium is the radioisotope used into the past and present space mission. It is not dangerous for the human body during the creation of the clads for the space mission and it has a large half-life time, so it is perfect for mission with long operational time. In fact, it used for the Voyager mission and for a long mission on Mars surface. However, its production processes are very long and it is possible to produce only small quantity of radioisotope for years (400 g). For Europa, this last property is not good because it needs a large quantity of radioisotope.

Curium-244 is a radioisotope considered for the future space missions. One of the most important properties is the high thermal power that it produces, in this way with a low quantity of grams is possible to produce enough energy for mission with high requirements.
It is very easy to produce, in fact from only the Waste of the Swedish nuclear plants is possible to produce from 6 to 12 kilograms for years.
It is an alpha emitter; however, the problem of this radioisotope is the half-life decay values, 18.1 ys. It is very low value, so the cm244 is perfect candidate for mission with short operational time. This property affects the study of the quantity of curium needed. Because it is considered the energy required for the operation part of the mission end the energy lost due to decay during the travel time (6 years).

Uranium232 with its behaviour and its energy output could be the best choice for a space mission. In fact, with it, it is possible to reach up the energy value required with the lower weight. This property is perfect for a space mission due low weight is better for cost and design of mission.

However, there is need to study its decay chain of uranium and the radiation product that could be dangerous for the human body.

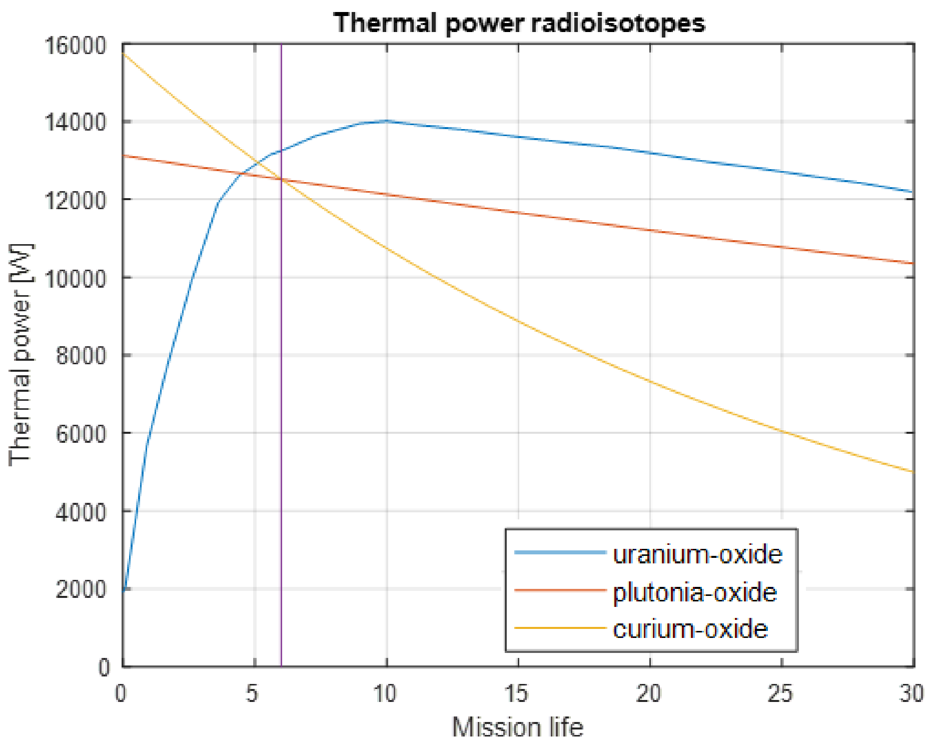

Figure 15.Radioisotopes comparison at 6 years before launch (time to arriving to Europa)

In the fig.5 are figured the thermal power behaviour of the three radioisotopes in function of the mission lifetime. The main point that we take in consideration is 6 years. This is duration of the travel from Earth to Europa. Currently, at the start of the operational life of the probe, there is need of 12500 W for the total time of the mission. Considering this, it is possible to observe the true values energy, so the quantity of the radioisotope needed at the time of the launch.

To produce 12500 W after the travel to Europa, there is need to a quantity of curium that produce 15500 W at launch time, so c.a. **6,2 Kg.** The cause of this values is the low decay-time, 18.1 ys.

Considering plutonium and its large decay time, at the start of mission the value of energy is the same that value required after the time travel. For this reason, it is perfect for space mission. However, there is need a large quantity of it the respond to the mission requirement.

Uranium, with its behaviour represent a best choice for this kind of concept. In fact, it is possible to have a high energy power constant for different years. However, there is need to a study the radiation behaviour during the creation of the clads.

8.MISSION CONCEPTS

8.1 FIRST CONCEPT

Europa and the icy body with its environment are the best target for future mission because there could be the possible that host life.

To study the water liquid layer under the ice, the best mission concept based on to use small probe with a powerful heat source to produce enough energy to melt through the ice and reach the water.

Different concepts are analysed in this literature.

The first concept studied is based on to use of one big probe with 1 meter of length and a small cross section with a radius of 0.06 m. In the previously paragraphers, it speaks about the link between the cross section of the probe and the heat energy required.

The best shape for a probe that works to melt ice is a cylinder with a flat head. Different practical experiment with different probe's shape. Then, the pyramid shape and oval shape are not good because to permit to the probe a reasonable melting velocity value, it needs a high quantity of heat. [10,11,13,14]

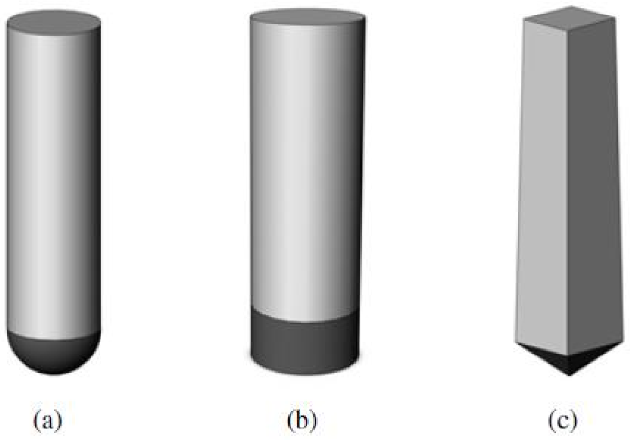

Figure 16. Different probe shapes.[14]

The best compromise between the pyramid and spherical probe is the flat head probe.
So, considering this shape, the heat needed is lower than other probe's concepts.

First concept	
n. probe	1
Mass [Kg]	[15:25]
Melting velocities [mm/s]	0.19

Table 7. First mission concept studied

Fixed the value of melting velocity and mass of the probe, is possible to calculate the quantity of flux heat head of the probe to melt whit these parameters. For this first study, the thermal losses are not considered.

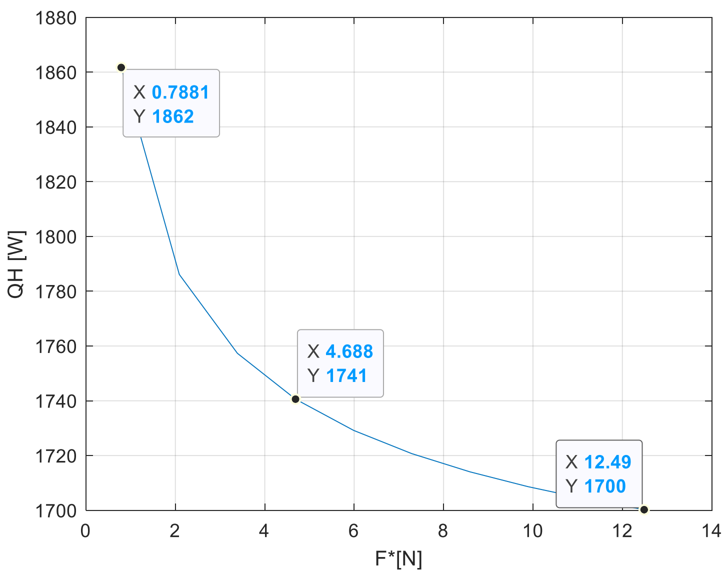

Figure 17. thermal power head probe vs corrected force

In the fig. 17 there is the head heat flux in function of the buoyancy force (that take in consideration the mass and the length of the probe).

How it is possible to observe. If the mass of the probe increases with fixed value of melting velocity target, the energy needed at the head of the probe to melt ice decrease. This happen because, if the exerted force by the probe is high, the losses due to the buoyancy force and the film water created around the probe are low.

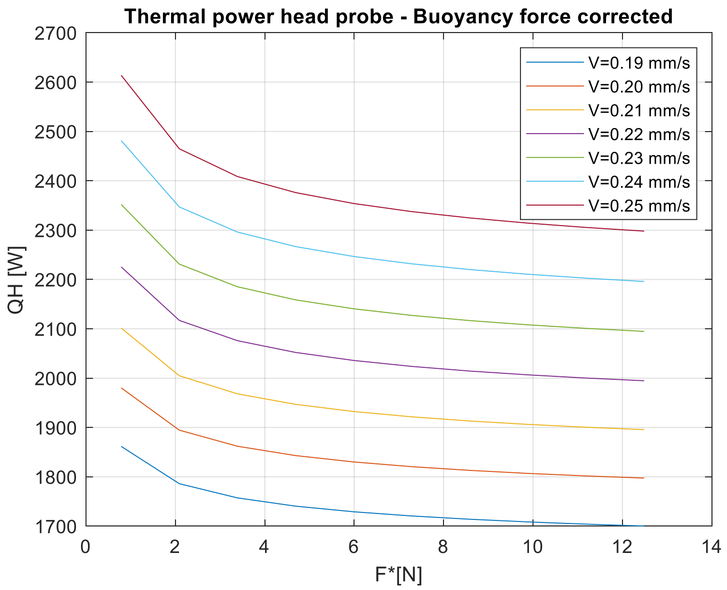

Figure 18. Power needed at the head probe vs Corrected force in function of different masses and melting velocities

In the fig.18 is figured the change of the quantity of heat needed in function of the melting velocity. If we consider a probes with fixed size but with different weight, the flux heat head decreases when the mass increase until there is a constant behaviour of the head flux needed.
If it change also the melting velocities value target, there an increase of the flux heat required, due to melt ice faster , there is need an higher quantity of heat.

This is a preliminary study with the environment temperature fixed at 100 K but it is useful to know the behaviour of the heat head flux needed with different kind of probe mass and different values of melting velocities that we know.

Values	Mass [kg]	Flux Heat head probe [W]
Min	15	1862
max	25	1700

Table 8.The heat head probe needed for min and max power analysed. Melting velocity fixed at 0.00019 m/s. (melt 30 km of ice in almost 4 ys)

8.1.1 Thermal losses

Considering the convective losses and the problem of the refreezing length there is need to add heat flux for the lateral walls of the probe. Considering the same conditions used to calculate the flux heat head probe, there is need to calculate the heat needed to the convective losses and the lateral losses.

If it considered environment temperature at 100 K and different melting velocities the thermal losses due the refreezing length, follow the behaviour figured in fig.19

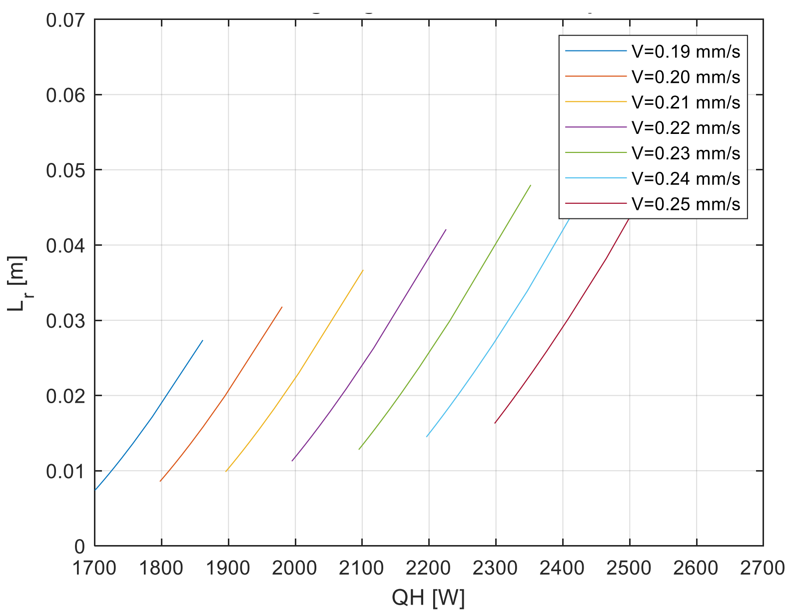

Figure 19. Refreezing length in function of the head power, melting velocities and masses)

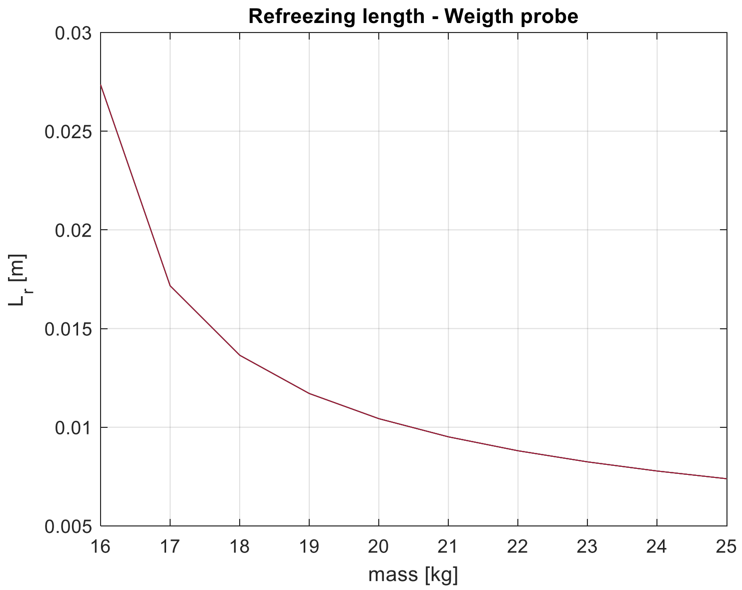

Figure 20 Refreezing length in function of the mass with fixed size of the main probe.(V=0.19 m/s)

For the reason of the previous there is need to a compromise to find a right mass of the probe.

Considering the first value of melting velocities fixed at 0.19 mm/s, the total ice deep of 30 kilometres and the temperature of 100 K. The time needed to the probe to reach the ocean under the ice is 5 years. This could be a lot of time to melt 30 kilometres of ice, however it could be a compromise between the right mission time and the head and lateral power needed.

Values	Mass [kg]	Heat for lateral losses [W]
Min	15	3588
max	25	3588

Table 9. Power needed for lateral losses/refreezing length phenomenal with min e max probe wheigth considere. (V=0.19mm/s)

How it is possible to see from the equation (12) and the fig.2 the power needed to the latera losses does not change with changing mass of the probe.

However, considering a time mission lower than the case with melting velocity of the probe of 0.00019, there is need to study the quantity of heat needed for lateral wall to avoid the stuck.

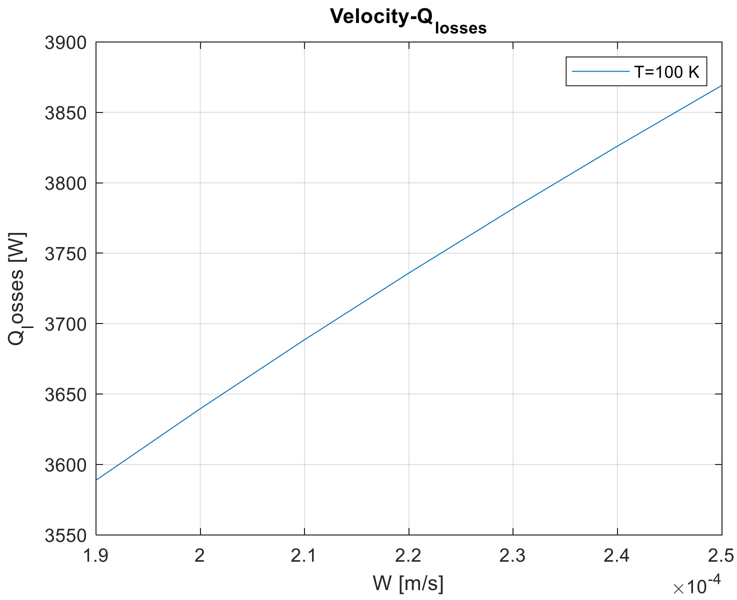

Figure 21. Power needed to losses in function of the melting velocities with size and mass probe fixed.

Values	Melting Velocities (mm/s)	Flux Heat head probe [W]
Min	0.19	1734
avg	0.22	2039
max	0.25	2353

Table 10. Power needed at the head of the probe considering three different values of melting velocity.

So, if we want that the time mission low, there is need to melt ice with a high value of velocity. However, this means that the quantity of total heat needed increases and there is need other quantity of radioisotopes grams.

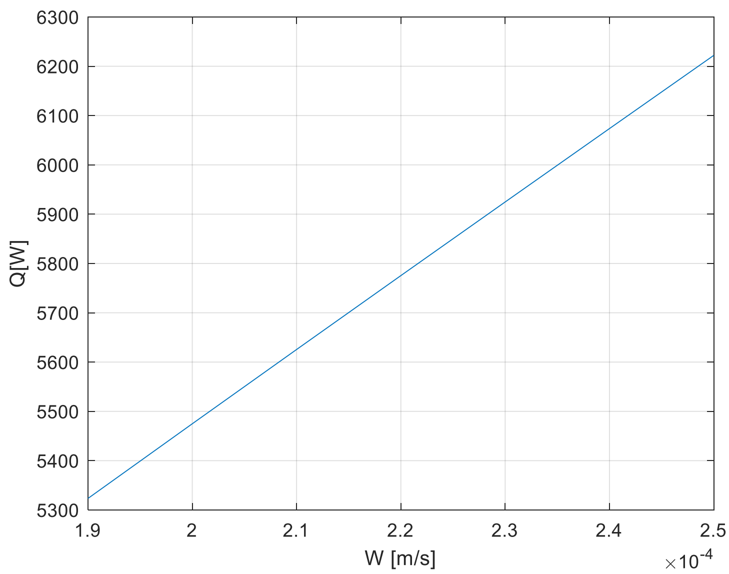

Figure 22. Total quantity of thermal power needed in function of melting velocity

8.2 STUDY CONSIDERING THE INCREASE OF THE ICE TEMPERATURE

Considering the melting velocities of the tab.7 and the max mass value of the main probe, with the behaviour of the ice temperature, the melting velocity of the probe changes with the increase of the depth.

It is considered an average temperature for each ice depth interval of 5 km (tab.2). And fixed a melting velocity

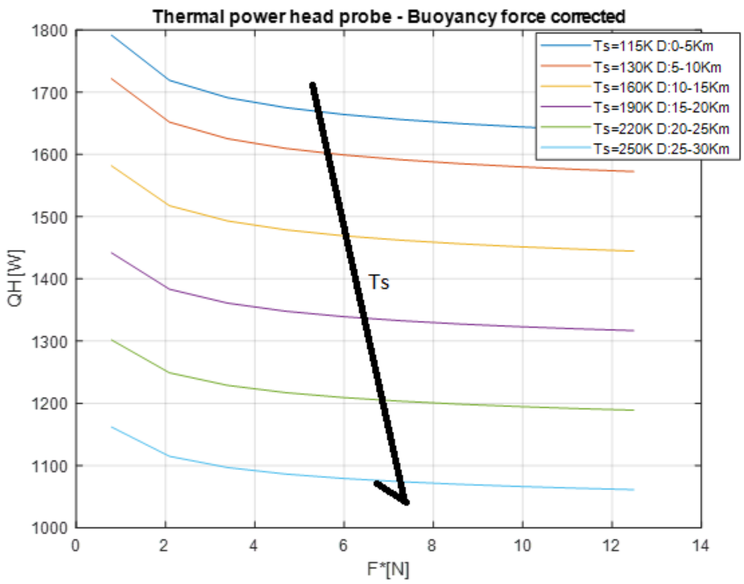

Figure 23. Thermal power needed at the head of probe vs the buoyancy force and different depth temperature.

In fig.23 it is considered the probe 1 with a melting fixed velocity of 0.19 mm/s , How it is possible to see, when the temperature of the ice increase, the flux head heat probe decreases.

8.2.1 STUDY OF MELTING VELOCITY

Considering the increase in temperature as a function of the increase in ice depth, a study was developed on how the speed varies having calculated the amount of heat needed using the ice temperature of 100 K. In that case, having the lowest temperature of ice at the start of the layer, the probe needs the higher quantity of energy to melt into the ice with the melting velocity pre-fixed.

In this way, the probe melts whit a fixed velocity but when the temperature starts to increase along the ice layer, the melt velocity increases, too. So, the probe has an acceleration with the increase of the environment.

Temperature	Melting velocities [mm/s]	years	Interval of depth [km]
115	0.19	0.83	0-5
145	0.21	0.75	5-10
175	0.22	0.72	10-15
205	0.235	0.65	15-20
235	0.26	0.60	20-25
265	0.28	0.55	25-30

Table 11. Melting velocity values with the fixed size probe and head thermal probe.(mass=15 kg)

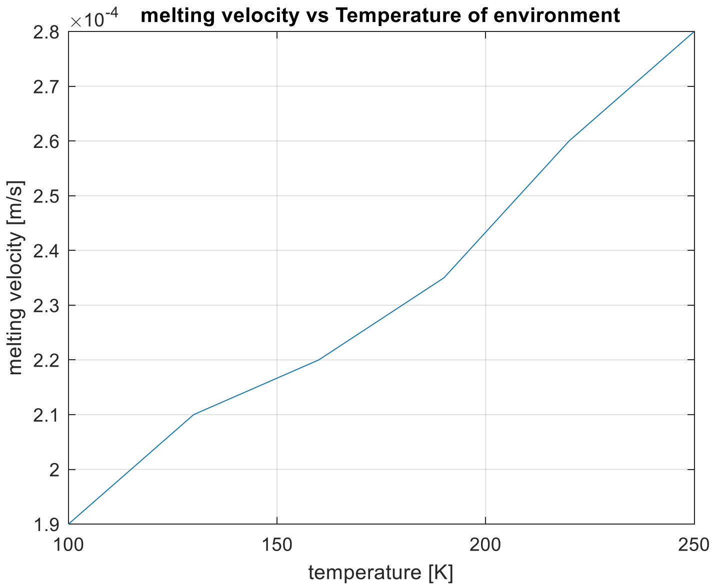

Figure 24.Melting velocity in function of the ice temperature.

So, the melting velocity increases with the temperature of the ice. In this way the time needed to melt the ice layer decrease and the time mission decreases.

8.3 PROBLEMATIC OF CONCEPT MISSION WITH ONE PROBE

8.3.1 Tethered probe: lander-probe linked by wire

The main problem of this concept based on to use a single probe is the communication link between the probe and the lander. There are different designs mission on internet that speak about a wire link between the two main body of the mission. The lander provides energy and a link communication by optic fibre solution, but this solution has different problem:

-the structural strength of the wire. At low temperature, the elastic properties of the wire materials could be worst, so there is the risk that it breaks with the loss of the link of the probe. There is needed to also consider the irregularity of the ice that could cut the wire.

-the refreezing length and the stuck problem into the ice: If the wire is not heated correctly, the water around it refreezes and it will be stuck into the ice and the probe could not continue melting the ice.

-the reliability of the optic fibre in an irregular environment and low temperatures.

-needed a wire long from 5 to 30 km: wire with a high reliability has a large structural strength and it could have a large weight. This feature in add to the length of the probe, represent a challenge to storage the wire into the probe. [15]

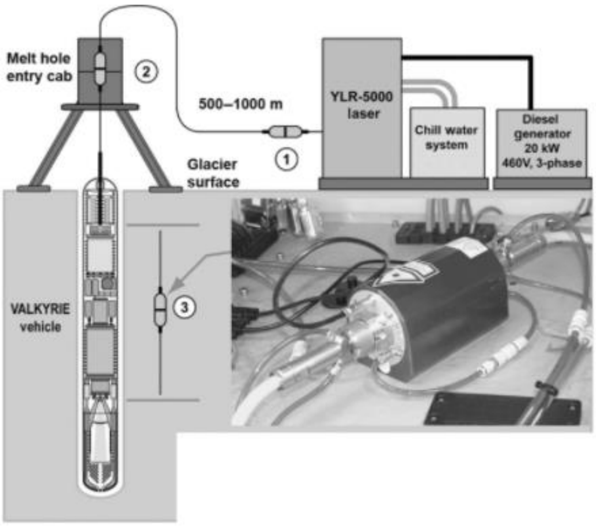

Figure 25. Concept with tether melting probe (Valkyrie)[15]

So, the concept based on to use a wire of melting probe has different critical point. Another problem is the storage of 30 km of wire too. It could be used now the ice layer thickness is around 5 kilometres.

This concept, for the problems previously analysed, is not studied in this paper.

8.3.2 Communication link by electromagnetic signal

A probe with an inner energy source and a communication subsystem could be the best solution for a mission through the Europa Ice. The energy source is represented by radioisotope. With the thermal energy products by the radioisotope is possible to melt ice and to produce electrical energy with the TEG configuration, for all subsystems.

The communication subsystem of the probe sends information to the comm S/s of the lander. The energy needed is very high due the presence of ice. However, is not possible to send information between large distance due the presence of the ice. The wavelength does not travel through the ice, so could be two different solution:

- To use larges antennas to send information with a very low frequency and to cover a large distance. However, this is not reliable and practicable into the Europa environment.
- To use different communication small probe to release at different ice depth into the ice, in this way the distance between the different communication subsystems released into the ice is low and it is possible to create a link between the main probe and the lander.

8.4 HIGH REQUEST OF ENERGY

The concept mission with only a big probe with a length of 1 metre and the radius of 0.07 m has different challenges and problem.

The large size of the probe requests a high quantity of energy. Considering the start velocity of 0.19 m/s to reach the ocean in almost 5 years.

	Heat head power (W)	Lateral losses (W)	Total power needed
Probe 1	1792	3277	5069

Figure 26.Power needed for a probe with Length=1m and R=0.07 m

So, the total energy is 5069 W and it considered only the thermal heat needed to melt ice and the losses.

To produce the energy required it is possible to make a comparison between the three radioisotopes considered.

Radioisotope	Quantity needed [g]
Plutonium	8.892
Curium	2.668
Uranium	1.152

Table 12. Quantity of radioisotopes needed

From table.12 is possible to see the great difference in terms of grams between the radioisotopes.

For the low mass and low volume filled with the radioactive spherical clad, uranium with its high thermal power, is the best candidate to use for the mission. However, curium with its easier production method, could be a good compromise. Using curium or uranium it is possible to have a large volume for all subsystems and the payload.

The other problem consists also into the communication. Considering only one probe, it is not possible to create a link between the probe and the lander when the target was reach. So, it is not reasonable to use only one probe concept.

9. CONCEPT WITH DIFFERENT SMALL PROBES

The main concept considered in this literature consists to use one main probe and different small probe to be positioned at different ice layer depth. The main probe is designed to reach the ocean with the payload. The other small probe contains only a small communication subsystem and they are fundamental to create a communication link between the main probe and the lander.

Different concepts of small probe are analysed. The main design consists to a cylinder probe with different length and

The first mission concept analysed with the small probe consists to use 5 small probe and one main probe. In that way, it is possible to have one probe each 5 kilometres needed to create a radio communication link between the main crafts of the mission.

The communication through the ice is very difficult, there is need to an available subsystem, however considering a pure ice composition, it is reasonable to think that 5 kilometres it is a good value for the communication range. [16]

The best communication range to consider with an impure ice is almost 3 kilometres considering the frequency interval from 3 to 30 kHz.[16]

Probe	Depth	Mass [kg]
1^{st} small probe	5 kilometres	10
2^{nd} small probe	10 kilometres	10
3^{rd} small probe	15 kilometres	10
4^{st} small probe	20 kilometres	10
5^{st} small probe	25 kilometres	10
Main probe	30 kilometres	25

Table 13. First concept with multiple probes analysed

The probe sizes are written into the tab.13:

	number	Sizes [m]
Small probe	5	0.06x0.20
Main probe	1	0.06x0.50

Table 14. Sizes of the probes

I start the study of this concept considering total time mission of **2.6 years**. Based on the time data, it is calculated the melting velocity needed to reach the target of each probe in 2.6 years. The velocity is different for each probe due it they have different target. In the tab.15 are figured the result for the concept.

Small probes:

Mass	Velocity (avg value)	Depth [m]	Head power [W]	Lateral power [W]	Total power[W]	Time [Ys]
10	0.000061 $\frac{m}{s}$	0-5000	394	757	1151	~2.6
10	0.000122$\frac{m}{s}$	5000-1000	803	916	1719	~2.6
10	0.000199$\frac{m}{s}$	10000-15000	1233	1024	2057	~2.6
10	0.000285$\frac{m}{s}$	15000-20000	1685	1108	2793	~2.6
10	0.00034 $\frac{m}{s}$	20000-25000	2085	1152	3237	~2.6

Table 15. Concept of mission considering time to melt ice of 2.6 years

Main probe:

Mass	Start velocity	Velocity (avg value)	Depth	Head power [W]	Lateral power [W]	Total power[W]	Time [Ys]
25	0.0003 $\frac{m}{s}$	0.000405 $\frac{m}{s}$	0-30000 m	1995	2260	4255	~2.6

Table 16.Main probe study

Quantity of the radioisotope:

Total energy needed [W]	Curium-244 [gr]	Uranium-232 [gr]
15212	7779	2200

Table 17. Total quantity of curium and uranium needed

The melting velocity indicated into the tab.17 are average values of the different probe velocities. Because the melting velocity increases with the increase of the temperature through the ice layer.

For the first and the second probes, the melting velocity is almost constant for the total distance melted and it needs a low quantity of energy to melt ice. The main quantity of heat requested is for the lateral losses.
The melting velocities of the other probes increase due they are melting a longer distance than the first probe at the same time. In that case, the quantity of the lateral heat needed decrease due the increase of the velocities.

The energy calculated with the equation (1) is based on the ice temperature of 100 K, due it is the environment condition of the start and the worst case, so every calculation uses the values of the worst case. Because the ice temperature has a strange behaviour, due it increases with the increase of the depth.

For this reason, there is need to take care about the energy that is not necessary at the high value of depth. Due where the temperature environment is high, the heat necessary for the melt and for the losses is low, so this energy could be used by the different subsystems.

10.STUDY FOR DIFFERENT SIZES OF THE MAIN PROBE

1)**L=0.12 m and r=0.06 m** [Main probe]

Mass [Kg]	T[K]	Velocity $\left[\frac{m}{s}\right]$	Depth [m]	Time [Ys]	Head power [W]	Lateral Power [W]	Total energy [W]	Refr. Length [m]
25	100	0.0003	0-5000	0.52	1985	106	2091	0.005
	145	0.00032	5000-1000	0.49				
	175	0.00035	10000-15000	0.45				
	205	0.00038	15000-20000	0.42				
	235	0.00041	20000-25000	0.39				
	265	0.00046	25000-30000	0.34				
				2.6				

Table 18.Main probe study with L=0.12 m and r=0.06 m

Total energy needed [W]	Cm-244 [gr]	U-232 [gr]	Pl-238 [gr]
2091	1060	648	3668

Table 19. Quantity of radioisotopes needed

2) **L=0.16 and r=0.08** m [Main probe]

Mass [Kg]	T[K]	Velocity $\left[\frac{m}{s}\right]$	Depth [m]	Time [Ys]	Head power [W]	Lateral Power [W]	Total energy [W]	Refr. Length [m]
25	100	0.0003	0-5000 m	0.52	3652	1157	4809	0.015
	145	0.00032	5000-1000	0.49				
	175	0.00035	10000-15000	0.45				
	205	0.00038	15000-20000	0.42				
	235	0.00041	20000-25000	0.39				
	265	0.00046	25000-30000	0.34				
				2.6				

Table 20.Main probe study with L=0.16 m and r=0.08 m

Total energy needed [W]	Cm-244 [gr]	U-232 [gr]	Pl-238
4809	2003	1092	8436

Table 21. Quantity of radioisotopes needed

3) **L=0.20 and r=0.10m** [Main probe]

Mass [Kg]	T[K]	Velocity $\left[\frac{m}{s}\right]$	Depth [m]	Time [Ys]	Head power [W]	Lateral Power [W]	Total energy [W]	Refr. Length [m]
25	100	0.0003	0-5000 m	0.52	5948	1537	7485	0.035
	145	0.00032	5000-1000	0.49				
	175	0.00035	10000-15000	0.45				
	205	0.00037	15000-20000	0.43				
	235	0.00040	20000-25000	0.39				
	265	0.00042	25000-30000	0.37				
				~ 2.6				

Table 22.Main probe study with L=0.20 m and r=0.10 m

Total energy needed [W]	Cm-244 [gr]	U-232 [gr]	Pl-238[gr]
7485	3269	1701	13131

Table 23. Quantity of radioisotopes

4) L=0.30 and r =0.15 m

Mass [Kg]	Velocity $\left[\frac{m}{s}\right]$	Depth [m]	Time [Ys]	Head power [W]	Lateral Power [W]	Total energy [W]	Quantity of Cm [g]	Quantity of U [g]
35	0.0003	0-5000 m	0.52	15150	2577	17727	>7091	4123

Table 24. Main probe study with L=0.30 m and r=0.15 m

Total energy needed [W]	Cm-244 [gr]	U-232 [gr]	Pl-238[gr]
7485	>7091	4123	>30000

Table 25.Quantity of radioisotopes

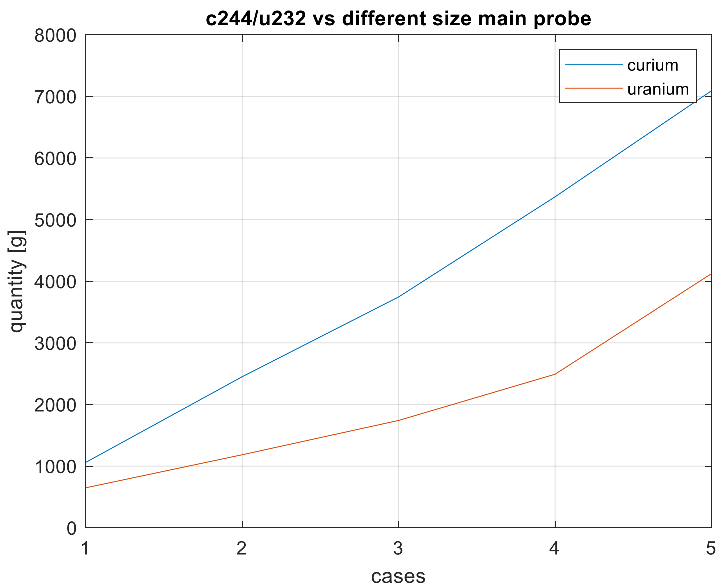

Figure 27. Quantity of curium and uranium in function of the cases analysed

Cases	
1	R=0.06/L=0.12
2	R=0.07/L=0.14
3	R=0.08/L=0.16
4	R=0.10/L=0.20
5	R=0.15/L=0.30

Table 26. Concepts of probe considered

How it is possible to observe by the figure, the total quantities of curium and uranium increase with the increases of the probe's sizes. The uranium is the best choice in terms of grams needed.

With the last concept considered

The right compromise between size and the thermal energy needed is the probe 3 of the tab.26 with the radius of the cross section: R=0.08 m and L=0.16 m.

11. CONCEPT WITH A LONGER TIME MISSION

Considering the probe 3 of the tab.26 like main probe, it is studied a concept mission with different time needed to reach the ocean.

I considered the same small probes studied in the previously paragrapher (R=0.06 and L=0.20) and I compared the same concept with different mission time of **2.6 and 3.7 years**

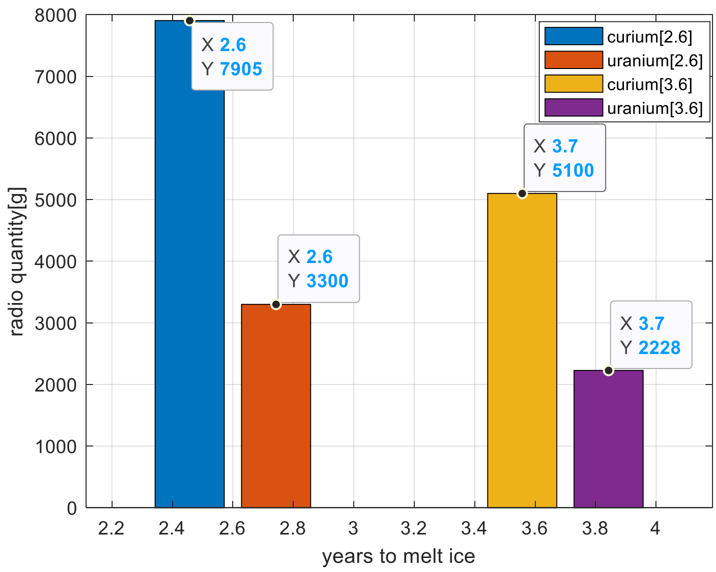

Figure 28.Quantity of curium and uranium considered the same probe but time to melt 30 km of ice different (2.6 vs 3.6 years)

From figure it is possible to observe that the total quantity of energy needed to melt ice decreases with the increase of the time. It is considered a greater time interval due in this way, the melting velocities is lower than previous concept, so the heat flux head requested decreases.

PROBE WITH L=0.16 m and R=0.08

Weight [Kg]	T (°K)	Avr Melting Velocity[m/s]	Ther. Power [W]	Refr. Length[m]	Power losses (RL) [W]
10	100	0.00019	2267	0.01	1021
	145	0.00021	~2267	0.016	776
	175	0.00023	~2267	0.027	609
	205	0.00025	~2267	0.05	432
	235	0.00027	~2267	0.12	246
	265	0.00030	~2267	1.18	53.5

Table 27. Main probe with L=0.16 m and R=0.08 and time to melt 30 km of ice in 4 years

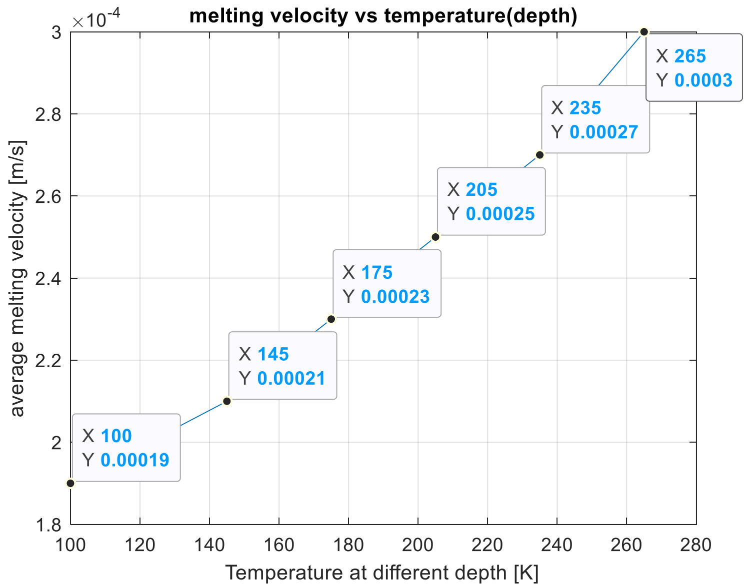

Figure 29. Average melting velocity in function of temperature ice at different depth

Considering the probe 3 I calculate how to change the melting velocities in function of the increase of the temperature through the ice. I considered for the study the probe 3 of the table 3 and a time mission of 4 years. The melting velocity increase a lot every 5 kilometres and this is an important data used to study the final concept mission considered.

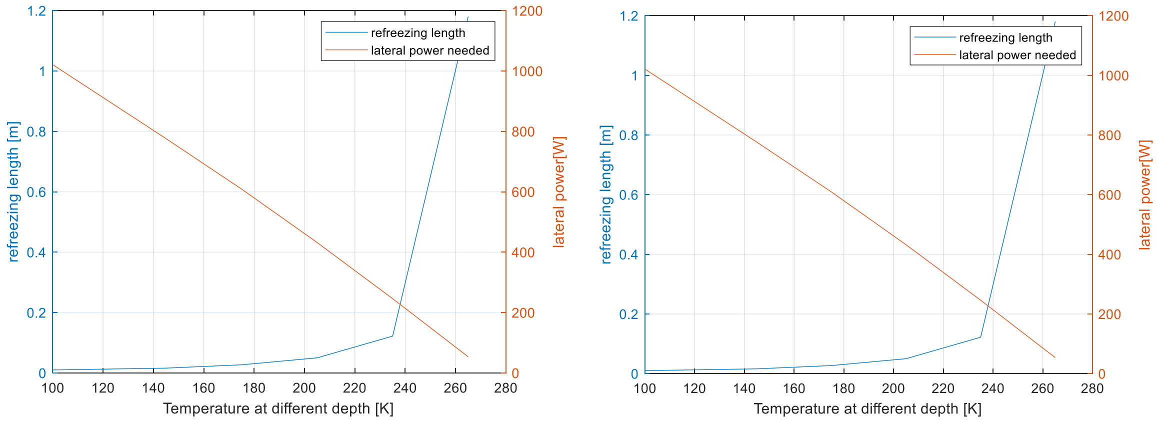

Figure 30. comparison between first probe r=0.08/L=0.16 m and second probe r=0.07/L=0.30

11.1 SPHERICAL PROBE CONCEPT

I considered the small probe sphere concept. I previously explained I studied the probe with the same diameter and the same length. In this way it is possible to approximate the probe shape to a probe.

I considered the quantity of energy calculated in the tab.27 The BOL indicates the Beginning of Life mission (the launch time). The total quantity of grams needed for a probe with the velocities indicated in the tab.28

11.1.1 Concept based on Curium-oxide

Curium

BOL	Head heat flux power [W]	Lateral heat [W]
	2267	1021
Weight	[gr]	[gr]
	1193	537
	Total Curium	**1730 g**

Table 28. Curium quantity for main probe with R=0.08 and L=0.16 m for 4 years to melt 30 km of ice

In the tab.29 it is designed the radioisotope configuration into a spherical probe.
To responds at the thermal energy required by the probe, it is designed a concept of four small curium sphere. In the second figure of fig.333 it is possible to see the configuration. The centre line indicates one centimetre dedicate to the protected the other subsystem by radiations.
With this concept, the volume filled by curium consist only the 9,5 % of the total volume. This is a plausible configuration for the mission probe.

r.sph [m]	Vol 1 sph $[m^3]$	P_sph [W]	n.sphe	T.sphe [K]	Vol.tot calotte[m^3]	Vol. restante [m^3]
0.02	3.35e-05	963	4	1027	5.655e-4	8.713e-4

Table 29. Configuration of curium clads sphere

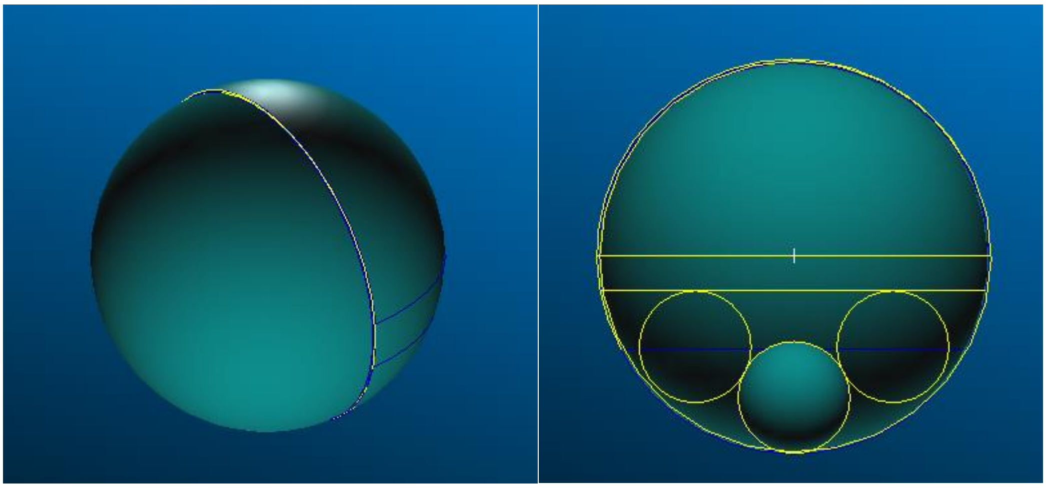

Figure 31. Concept of sphere probe with curium

Vol. filled by Cu-244	**9.5% of total volume**

11.1.2 Concept based on Uranium-oxide

In that case the radioisotope considered is the uranium. With its high thermal power, there is need to a lower quantity than the curium case. The sizes of the radioisotope spheres are the same of the curium case. In the fig.32 is figured the design with uranium and how it is possible to observe, the volume filled is very low. It is around 4,6 % (the half of volume filled by the curium) of the total volume of the sphere. The uranium is the best choice if you want to have the max value available for the other subsystem.

Uranium

BOL	Head heat flux power [W]	Lateral heat [W]
	2267	1021
Weight	[gr]	[gr]
	527	237
	Total Curium	764 g

Figure 32.Quantity uranium needed

r.sph [m]	Vol 1 sph	P_sph	n.sphe	T.sphe [K]	Vol.tot calotte[m^3]	Vol. restante [m^3]
0.02	3.35e-05	1730	2	1184	3.5e-4	0.0011

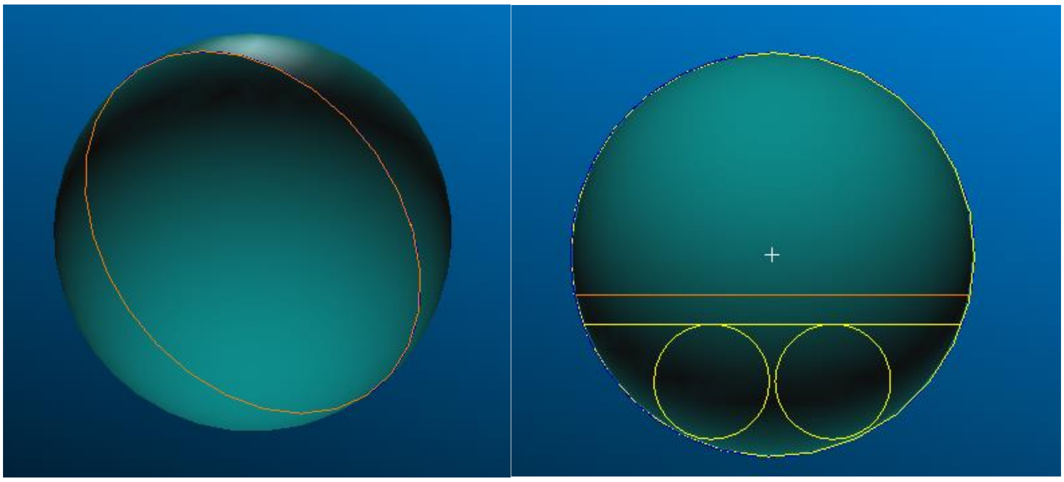

Figure 33. Concept with uranium clads sphere

Vol. filled by U-232	**4.8 %**

12.OTHER CONCEPT MISSION ANALYSED

To decrease the quantity of power needed to the mission, so the risk and the cost of it, another concept is analysed. In that case the small probe is lighter and smaller than the previous concept

Small probe	Radius [m]	Length [m]
	0.06	0.12

mass	Start Vel.	Velocity (avg value)	Depth [m]	Head power[W]	Lateral power [W]	Total power[W]	Time [Ys]	After 1 yr
5		0.000045 $\frac{m}{s}$	0-5000	281	477	758	~3.7	+1 km
5	0.00008	0.000085 $\frac{m}{s}$	5000-10000	510	552	1062	~3.7	+3 km
5	0.00012	0.00013 $\frac{m}{s}$	10000-15000	770	623	1393	~3.7	+5 km

5	0.000 15	0.00017 $\frac{m}{s}$	15000-20000	975	663	1638	~3.7	+9 km
5	0.000 18	0.00021 $\frac{m}{s}$	20000-25000	1187	697	1884	~3.7	+10 km

Table 30. Concept with a small probes with R=0.06 m and L=0.12 m and the melt ice during 1 year of payload mission

In the table.31 there are the values of the power needed to each small probe to reach their target in 3.7 years.

N. probe	**1**	**2**	**3**	**4**	**5**
Quantity of U	172	241	316	372	428
Quantity of cm	303	425	557	655	754

Table 31. Quantity of radioisotope needed to each small probe

Total energy needed for small probes

Total quantity of Cm [gr]	**Total quantity of U [gr]**
2694	1529

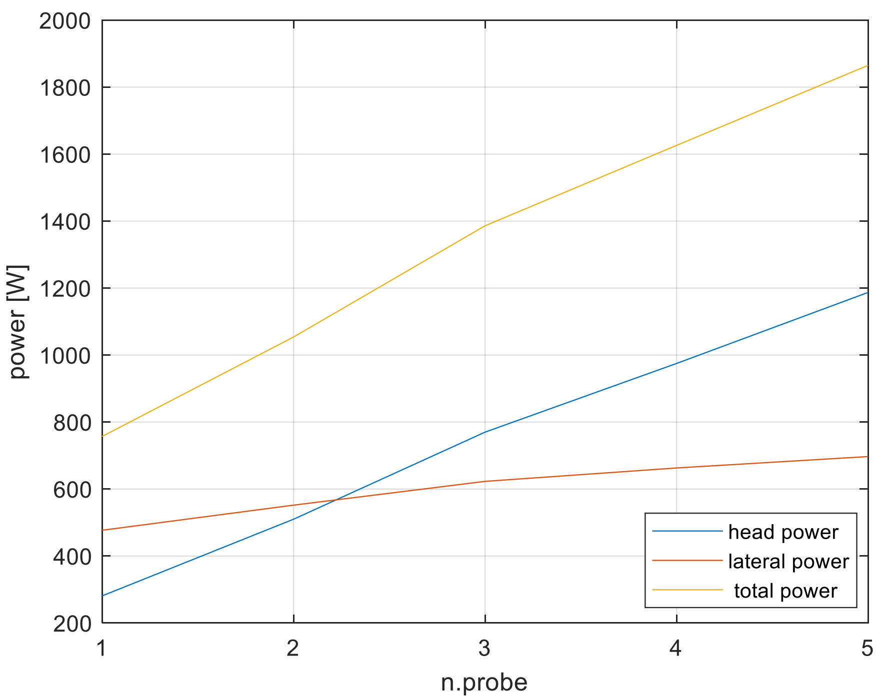

Table 32.Power in function the number probes considered

In that figure, is figure the behaviour of the total power needed in function of the number of probes considered. In this way it is possible to indicate approximately the quantity of power needed for the concept decided.

12.1 Main probe of the concept mission based on small probes

A cylinder probe is studied in that case. In that way there is more space available for the other subsystem. The probe sizes are written in the tab.33

Main probe	
R=0.07 [m]	L=0.30 [m]

Table 33. Sizes of the main probe (Small probes)

It is studied a probe with the main probe with 10 kilograms of weight. The study is focused on the changes of the melting velocity and the refreezing length in function of the temperature. How it is possible to see, the melting velocities increases with the same quantity of energy needed and the refreezing length increase also with the temperature. At the lowest point of the ice layer, the refreezing length is higher than the length of the probe due the high temperature of the environment.

The thermal powers indicated in the table are constants due the condition of the first layer of ice are considered, so the power needed by the mission is the highest value. To change it, it occurs to work on different probe concepts.

Weight [Kg]	T (°K)	Avr Melting Velocity [m/s]	Ther. Power [W]	Refr. Length[m]	Power (RL) [W]
10	100	0.00019	1722	0.01	1492
	145	0.00021	~1722	0.012	1139
	175	0.00023	~1722	0.024	893
	205	0.00025	~1722	0.051	635
	235	0.00028	~1722	0.14	365
	265	0.00031	~1722	1.18	78

Table 34.main probe concept

Time mission: 4 years

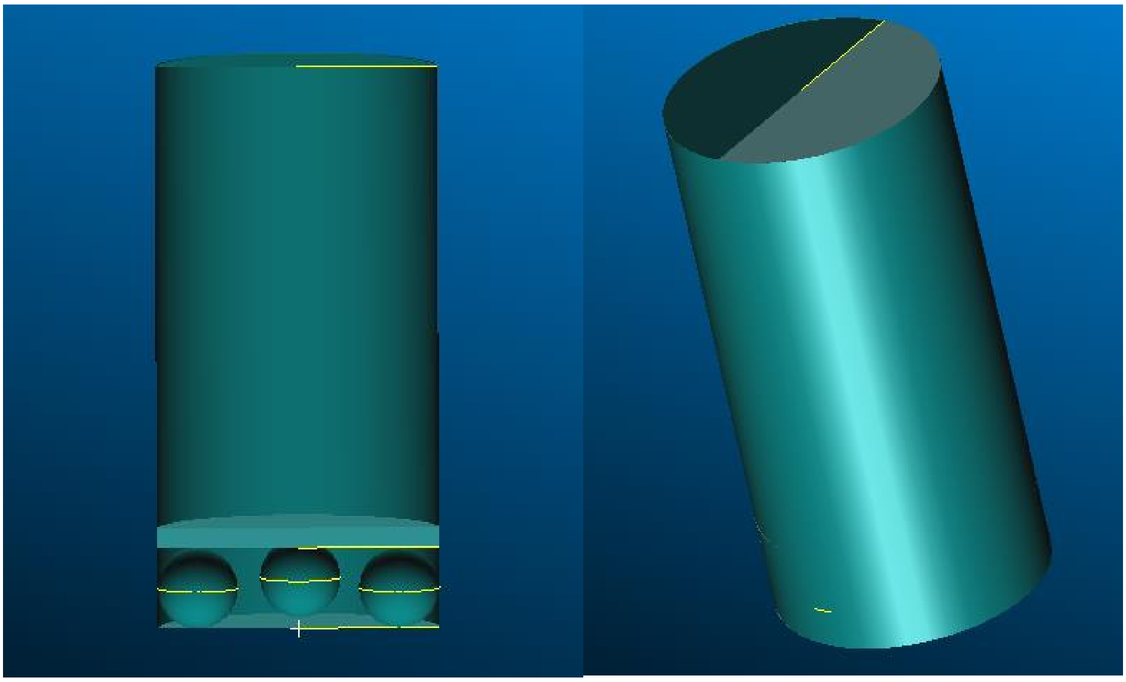

Fig.33 design of main melting probe

12.1.1 QUANTITY OF RADIOISOTOPES

Curium

(after 6 ys of travel)	1722	1492
g of Curium	870	750
	Total Curium	1620 g

Uranium

BOL	1722	1492
g of Uranium	400	347
	Total Curium	747 g

Table 35. Quantities of radioisotopes needed for main probe

TOTAL QUANTITY OF RADIOISOTOPE NEEDED

CURIUM	Head power	Lateral Power
BOL	2138	3012
g of Curium	1959	1585
	Total Curium	3544g (BOL)
	Main probe+small probes	**5164g**

URANIUM	Head power	Lateral Power
BOL	2138	3012
g of Uranium	866	700
	Total Uranium	1566 g
	Main probe+small probes	**2313g**

Table 36. Total quantity of radioisotopes needed for the concept with R=0.07 m and L=0.30 m

12.1.2 DIFFERENT ICE THICKNESS

For the previously study, it takes in consideration the thickness of ice of 30 kilometres. It is the worst case. However, now there are not enough studies o confirm the data of 30 km. So, different concepts are studied considering different ice depth

The first case that it is considered is the ice thickness of 5 kilometres. In that case the concept based on to use only the main probe due it is supposed the communication range of 5 km.
For every case it is fixed the start melting velocities at 0.19 mm/s, so I considered the time that the main probe needs to reach the depth of the concept analysed.

It is chosen the value of 0.00019 due with this melting velocities at the start permits to reach the bottom of ice (in the worst case) in 4 years and it is a good compromise between time mission and the radioisotope needed.

1) Case with ice thickness of ***5 km***
   MAIN PROBE
   R=0.08, L=0.16

Weight [Kg]	T (°K)	Avr Melting Velocity [m/s]	Ther. Power [W]	Refr. Length[m]	Power (RL) [W]	Time to melt ice layer (ys)
10	100	0.00019	2267	0.01	1021	0.83

CURIUM	Head power	Lateral Power
BOL	2267	1021
g of Curium	1193	537.4
	Total Curium	1730.4 g

URANIUM		
BOL	2267	1021
g of Uranium	527	237.5
	Total Uranium	764.5 g

Table 37. Quantity of curium and uranium needed to case 1 - ice thickness of 5 km

2) Case with ice thickness of ***10 km***:

MAIN PROBE

R=0.08, L=0.16

Weight [Kg]	T (°K)	Avr Melting Velocity [m/s]	Ther. Power [W]	Refr. Length[m]	Powe r (RL) [W]	True Melting Velocity	Time for 10 km
10	100	0.00019	2267	0.01	1021	0.00019	~1.5

SMALL PROBE

R=0.06, L=0.12

mass	Velocity (avg value)	Depth [m]	Head power[W]	Lat. power [W]	Total power[W]	Tim e [Ys]
5	0.000105	0-5000	670	601.4	1271.4	~1.5

CURIUM	Head power	Lateral Power
BOL	2937	1622.4
g of Curium	1545.8	853.9
	Total Curium [g]	2399.7
URANIUM		
BOL	2937	1622.4
g of Uranium	683	377.3
	Total Uranium [g]	1060.3

Table 38.Data for concept with ice thickness of 10 km

3) Case with ice thickness of **15 km**:

MAIN PROBE

R=0.08, L=0.16

Weight [Kg]	T (°K)	Avr Melting Velocity [m/s]	Ther. Power [W]	Refr. Length[m]	Power (RL) [W]	True Melting Velocity	Time for 15 km [ys]
10	100	0.00019	2267	0.01	1021	0.00019	~2.1

SMALL PROBE

R=0.06, L=0.12

Mass [kg]	Velocity (avg value) m/s	Depth [m]	Head power[W]	Lat. power [W]	Tot. power[W]	Time [Ys]
5	0.00007	0-5000	473.1	548.5	1271.4	~2.1
5	0.00015	0-5000	975.4	663.2	1638.6	~2.1

CURIUM	Head power	Lateral Power
BOL	3715.5	2233
g of Curium	1955	1175.3
	Total Curium	3130.3
URANIUM		
BOL	3715.5	2233
g of Uranium	864	519.3
	Total Uranium	1383.3

Table 39.Data for concept with ice thickness of 15 km

4) Case with ice thickness of ***20 km***:

MAIN PROBE

R=0.08, L=0.16

Weight [Kg]	T (°K)	Avr Melting Velocity [m/s]	Ther. Power [W]	Refr. Length[m]	Power (RL) [W]	True Melting Velocity	Time for 20 km
10	100	0.00019	2267	0.01	1021	0.00019	~2.63

SMALL PROBE

R=0.06, L=0.12

mass	Velocity (avg value)	Depth [m]	Head power[W]	Lateral power [W]	Total power[W]	Time [Ys]
5	0.00006	0-5000	376.5	516	892.5	~2.63
5	0.00012	0-5000	770	623.8	1393.8	~2.63
5	0.00018	0-5000	1187	697.1	1884.1	~2.63

CURIUM	Head power	Lateral Power
BOL	4600.5	2857.9
g of Curium	2421	1504.2
	Total Curium [gr]	3925.2
URANIUM		
BOL	4600.5	2857.9
g of Uranium	1070	664.63
	Total Uranium [gr]	1734.63

Table 40.Data for concept with ice thickness of 20 km

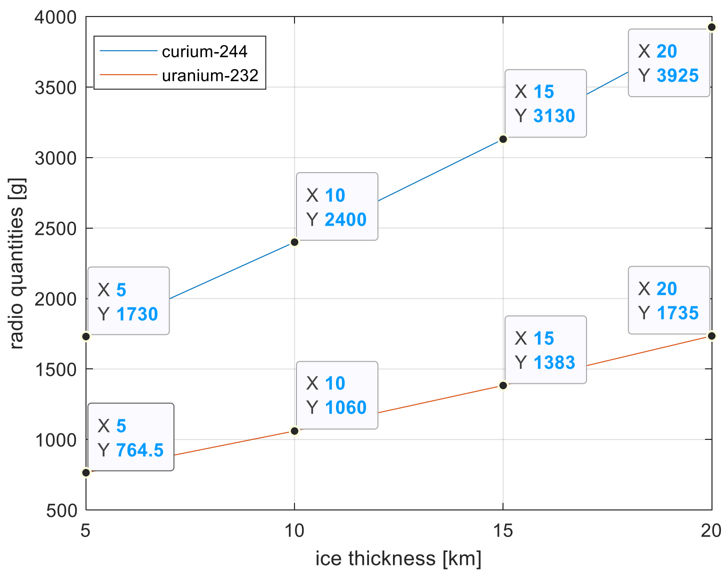

Figure 34. different mission concept with different ice thickness values. The radioisotopes quantities are for the total architecture (main + small probe)

In the fig.34 are summarized the different quantity of curium or uranium from every different concept analysed.

12.2 OTHER CONCEPTS FOR MAIN PROBE

R	**L**	**Mass [kg]**
0.12	0.24	11

Weight [Kg]	T (°K)	Avr Melting Velocity [m/s]	Ther. Power [W]	Refr. Length[m]	Power (RL) [W]	Time[ys]
11	100	0.00019	7601	0.49	1711	0.83
	145	0.000205	~7601	0.70	1301	0.75
	175	0.000215	~7601	1.05	1009	0.70
	205	0.00023	~7601	>2 m	708	0.65
	235	0.00024	~7601	>2 m	400	0.60
	265	0.00026	~7601	>2 m	86	0.55
						~4.08

For this case with a r=0.12 m and L=0.24 m it needs minimum mass of 11 kilograms.

And if we want to use this mass o low value of mass, it needs a lot of quantity of energy.

Then, considering the case with low melting velocities (probe melt 30 km in ~3.6 ys) we have:

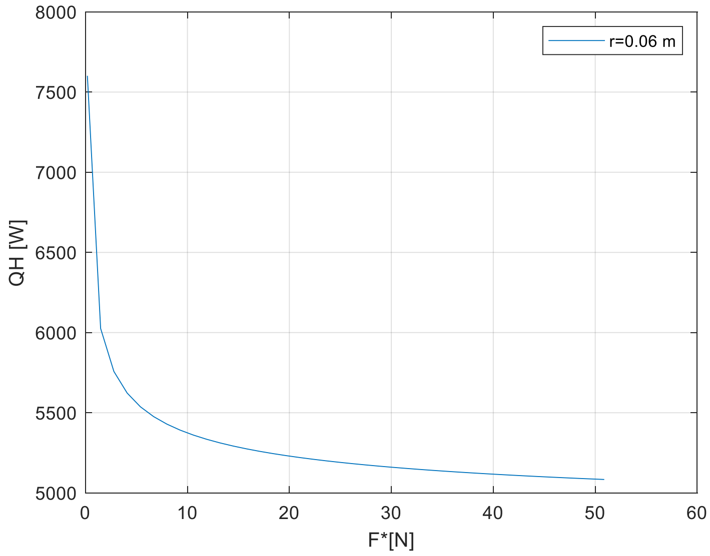

Figure 35. Melting Velocity: 0.19 mm/s-T:100 K

From fig.35 is possible to observe that if we want to use low quantity of thermal power, we need a high mass (>26 kg).

However, considering also the heat needed for the lateral power we have:

Mass=11 kg	Head	
Power [W]	7601	
Mass of Cu-244 [g]	4000	Tot:**4000**
Mass of U-232 [g]	1768	Tot:**1768**

Mass=26 kg	Head	Lateral losses	
Power [W]	5233	1711	
Mass of Cu-244 [g]	2754	900	Tot:**3654**
Mass of U-232 [g]	1217	400	Tot:**1617**

Table 41. Power probe needs for min e max mass of probe

These results are only for main probe, so probe needs of this quantity of energy (not considering the small probes)

Considering also small probes:

Mass=11 kg	Small probes	Main probes	Total
Curium	3544	4000	**7544**
Uranium	1566	1768	**3334**

Mass=26 kg	Small probes	Main probes	Total
Curium	3544	3654	**7198**
Uranium	1566	1617	**3183**

Table 42. Total power needed with probe of R=0.12 L=0.24

12.3 STUDY ON THE BUOYANCY FORCE VALUES

CASE 1

Different situations are analysed with different melting velocity values. In this study, the attention is focused on the corrected force (F*) buoyancy force and the thermal energy needed for the values studied. Each probe analysed as the same diameter and length value.

CASE 1	
Melting velocity [m/s]	0.0002
Weight [Kg]	[5:25]

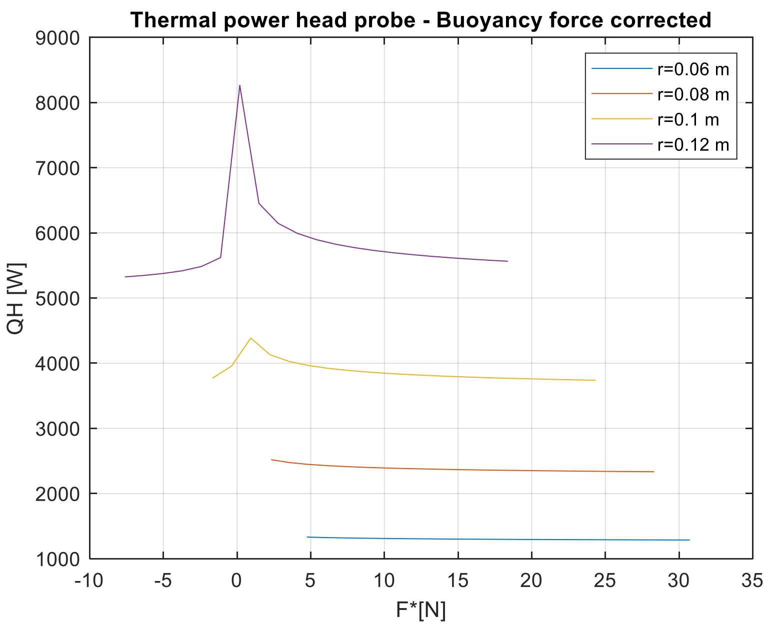

Figure 36.Head thermal power in function of corrected buoyancy force. Each line represents a probe with different radius.

This is the quantity of thermal power that I need at the head of the probe with a melting velocity of [0.2 mm/s] and mass included in [5:25 kg].

How is possible to observe from fig.1 the buoyancy corrected force for the cases with r=0.1 and r=0.12 represents a problem for small mass . To avoid the buoyancy problem the probe with r=0.1 needs 7 kg of minimum mass and the case with r=0.12 needs 11 kg.

Radius [m]	Mass needed to avoid the buoyancy [kg]
0.10	8 kg
0.12	11 kg

However, considering correct values the quantity of thermal energy needed increase with the radius. So, small radius is better than big.

CASE 2

CASE 2	
Melting velocity [m/s]	0.0005
Weight [Kg]	[5:25]

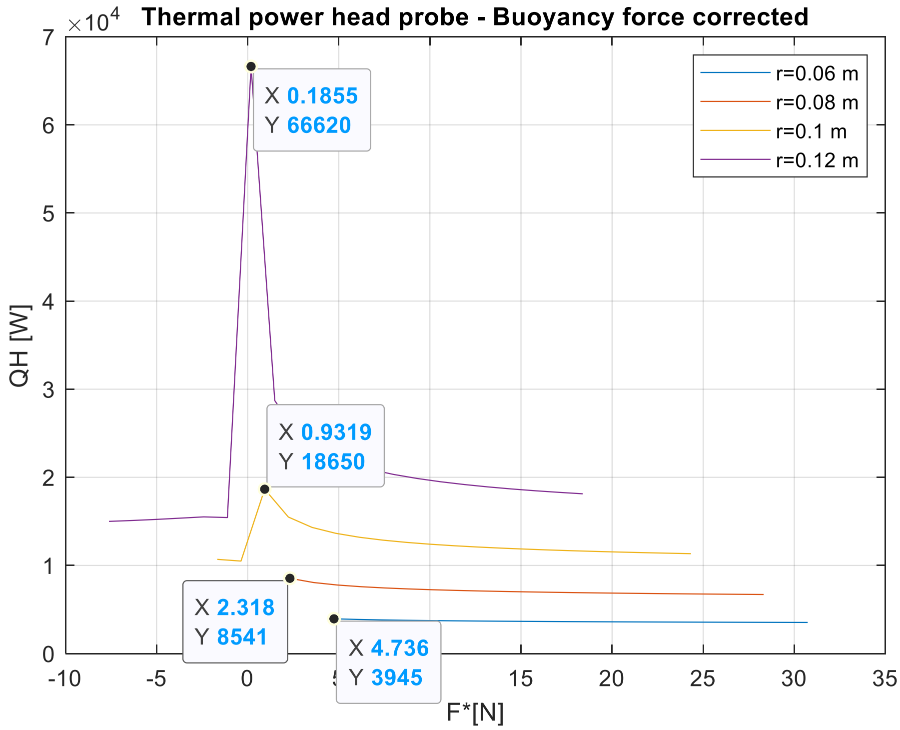

Figure 37. The min mass and the min buoyancy force for probes with different radius of cross section

The selected points represent the minimum value of right corrected force (the minimum mass to avoid buoyancy). How is possible to read, for a medium value of melting velocity the quantity of thermal watt needed increases. Considering the minimum mass for each case, the power needed for a probe (r=0.12) is **16 time the quantity needed for the smallest probe considered**.

Radius [m]	Mass needed to avoid the buoyancy [kg]
0.1	6 kg
0.12	11 kg

CASE 3

CASE 3	
Melting velocity [m/s]	0.0009
Weight [Kg]	[12:25]

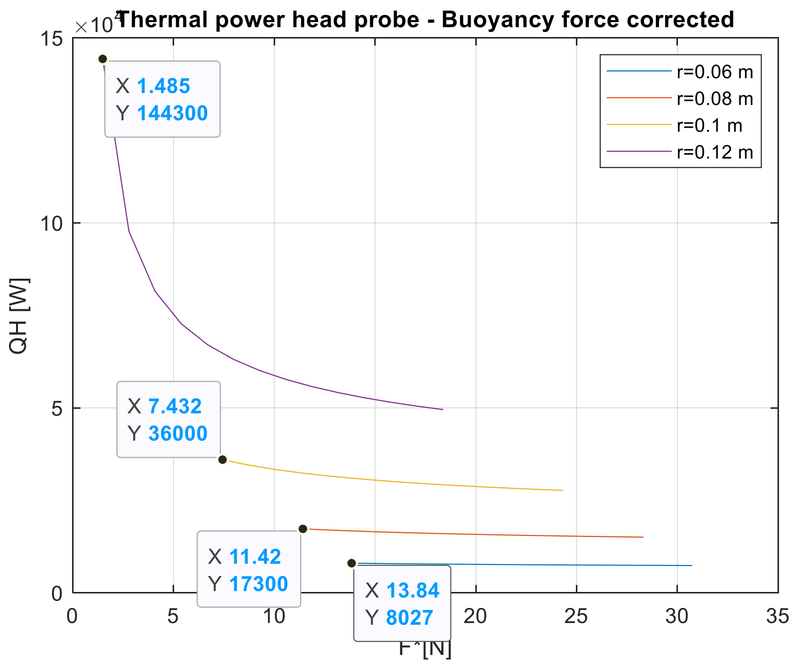

Figure 38. Thermal head power needed in function of the lowest buoyancy force possible

In this last case I considered a different interval of masses, starting by the minimum mass for the last case. Fig.38 tell us that to melt with high value of melting velocity probe with large radius requires a lot of quantity of energy ($10^4 - 10^5\ W$). So, if we want to melt ice with high velocity, it needs a very small radius, to spend the lower quantity of energy possible.

In all three cases, considering the maximum radius value (r=0.12 m), the perfect solution that guarantees the lowest energy required.

12.4 STUDY WITH DIFFERENT LENGTH VALUES

12.4.1 STUDY WITH LENGTH VARIATION with melting velocity of 0.9 mm/s

In this paragrapher I studied the probe with a fixed radius and fixed weight value, and it is figured how to change the quantity of heat head power needed in function of the length of the probe. In that case it is considered cylinder probe.

Considering the CASE 3, with r=0.06 m, it is possible to change length of the probe to study the effects on head thermal power and power needed for latera losses (Refreezing length). The **melting velocity** considered is **0.9 mm/s**

Length [m]	Head thermal power for 12 kg [W]
0.12	8027
0.16	8068
0.20	8112
0.24	8158
0.30	8234
0.40	8382
0.50	8566
0.60	8805
0.70	9133
0.80	9630
0.90	10530
1	13210

Table 43. Study with fixed mass and radius of the probe and different length(V=0.9 mm/s)

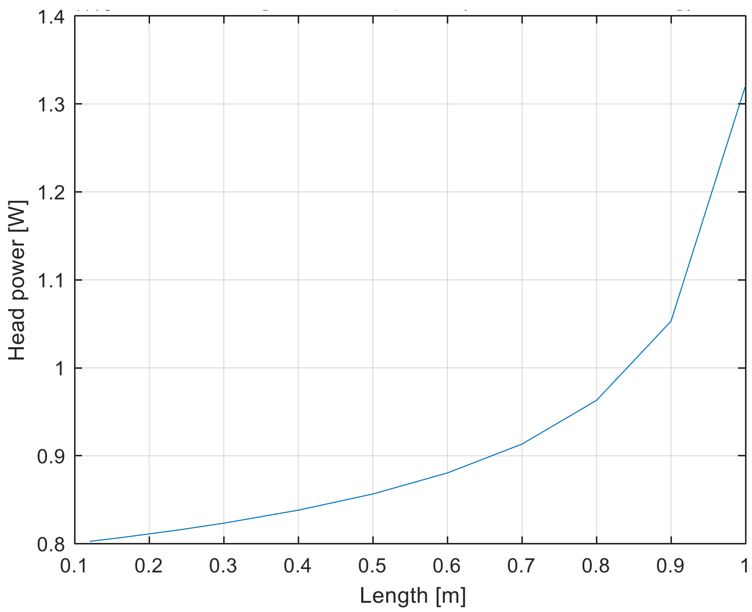

Figure 39. Head power in function of the length of the probe with mass and radius fixed

From fig.39 is possible to see how change the thermal power required at the head of the probe changing length with constant radius.

12.4.2.Length vs refreezing length (and lateral losses)

Length [m]	Refr. Length [m]	Thermal power for 12 kg [W] (lateral losses)	F* [N]
0.12	0.37	1082	13.84
0.16	0.38	1334	13.25
0.20	0.39	1569	12.66
0.24	0.40	1791	12.07
0.30	0.415	2106	11.19
0.40	0.45	2595	9.71
0.50	0.49	3052	8.6
0.60	0.54	3485	6.8
0.70	0.62	3898	5.3
0.80	0.74	4295	3.8
0.90	0.97	4679	2.4
1	1.77	5050	0.9

Table 44. Refreezing length, thermal power for lateral losses and buoyancy force in function of the length of the probe

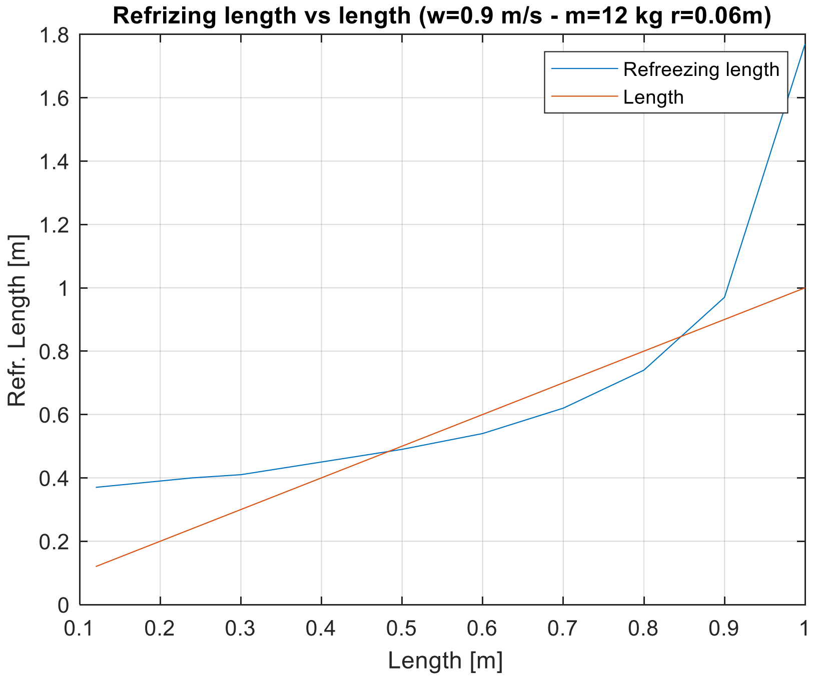

Figure 40.Refreezing length vs length of the probe with melting velocity, mass and radius constants.

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From fig.40 is possible to observe that the points of the red line above the blue curve represent the length values of the probe above the refreezing length values (in this case probe does not need by lateral thermal power). We have the same situation at the end of the plot. The cases that need lateral power are in the centre of figure (from 0.5 to ~0.85 m).

However, for this case we are considered an high melting velocity, so the probe needs a lot of quantity of thermal head (is not good for the previous calculation) and we have very low values of buoyancy corrected force with high length of the probe and 12 kg of mass and it is not good due there is risk of buoyancy. (F*<<10)

These calculations are for very low value of corrected buoyancy force, in this case is possible to see that the probe in the most cases has refreezing length bigger than length, so this is not a true problem. however, it needs quantity of heat power for lateral wall for the convective losses. If we want to consider a right value of corrected force to avoid surly the buoyancy(F*>10) for the lasts cases, we need to change the mass in function of the different length values:

Length [m]	Refr. Length [m]	Thermal power for 12 kg [W] (convective losses)	F* [N]	Mass [Kg]
0.12	0.37	1082	13.84	12
0.16	0.38	1334	13.25	12
0.20	0.39	1569	12.66	12
0.24	0.40	1791	12.07	12
0.30	0.41	2106	11.19	12
0.40	0.45	2595	10	12
0.50	0.42	3053	10.85	14
0.60	0.43	3485	10.68	15
0.70	0.43	3898	10.51	16
0.80	0.43	4295	10.34	17
0.90	0.43	4679	10.17	18
1	0.44	5050	10	19

Table 45. Study with different length and the corrected forces needed to spend less power

The values of mass change with the length considered due it is considered a reasonable value of the corrected force (F*>10) to avoid the buoyancy force.

12.4.3 STUDY FOR VARIATION LENGTH with melting velocity of 0.3 mm/s

Considering the CASE 3, with r=0.06 m and low velocity, is possible to change length of the probe to study the effects on head thermal power and power needed for latera losses (Refreezing length)

Length [m]	Head thermal power for 12 kg [W]
0.12	2027
0.16	2029
0.20	2032
0.24	2035
0.30	2040
0.40	2049
0.50	2060
0.60	2074
0.70	2094
0.80	2122
0.90	2172
1	2302

Table 46. Refreezing length, thermal power for lateral losses and buoyancy force in function of the length of the probe

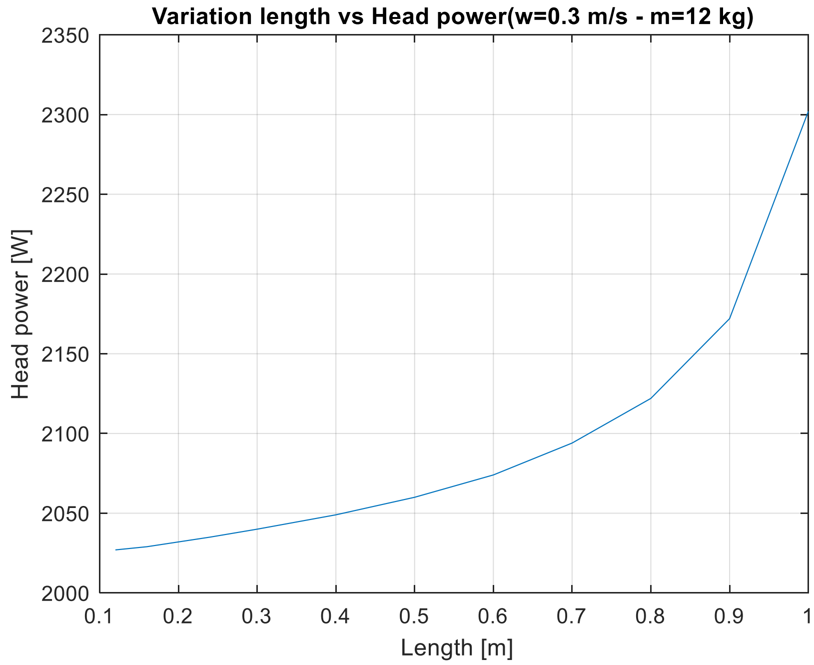

Figure 41.Head power needed in function of the length of the probe with mass and radius fixed(V=0.3mm/s)

In the tab.47 It is considered the values of mass to have a F*>10 N due it could be a reasonable solution

Length [m]	Refr. Length [m]	Thermal power for 12 kg [W]	F* [N]	Mass [Kg]

		(convective losses)		
0.12	0.0144	801	13.84	12
0.16	0.0147	988	13.25	12
0.20	0.015	1162	12.66	12
0.24	0.0154	1326	12.07	12
0.30	0.016	1560	11.19	12
0.40	0.017	1922	10	12
0.50	0.017	2260	10.85	14
0.60	0.0163	2580	10.68	15
0.70	0.0164	2885	10.51	16
0.80	0.0165	3179	10.34	17
0.90	0.017	3463	10.17	18
1	0.017	3738	10	19

Table 47.Refreezing length, thermal power for lateral losses and buoyancy force in function of the length of the probe (F>10)*

<u>The study started from 12 kilograms of mass because it is the minimum mass for probe configuration with r=0.06 m and L=1 m.</u>

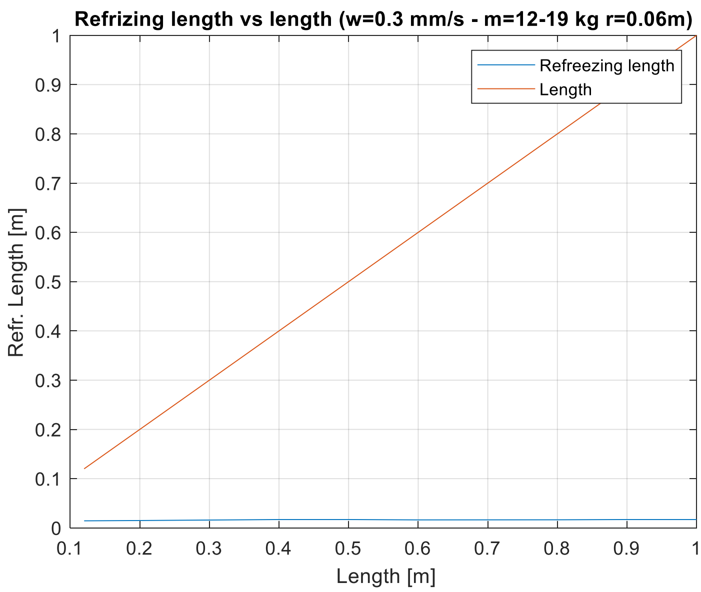

Figure 42.Refreezing length vs length of the probe

In this last case is possible to see how the melting probe has a length greater than refreezing length, so it needs a lateral heat to avoid the stall. However, with this solution we are using less quantity of thermal power, so radioisotope. (but we melt ice with a very small melting velocity)

For the refreezing length we know that with a constant flux heat at the head of the probe, increases if the buoyancy force decreases. This depend by the melting velocity, the melt film thickness increases, and higher convective losses occur.

By tab.47 is possible to see how for the first and last probes, refreezing length is bigger than length of the probe. We have this situation because we are considering high melting velocity, so we have a lot of power at the head of the probe with a constant value of buoyancy force.
However the best solution for the radioisotope consists to use small probes, with small melting velocity and "low mass".

13. TRADE OFF to find a solution with refreezing length greater than the probe's length

R=0.08 L=0.16 m	Melting Velocity [m/s]	Heat head power[W] [for 10 kg]	Cu244 [g]	U232 [g]	Min and max mass [kg]	Min and max Refr. Length [m]	Lateral power [W]	Probe needs lateral power? [10 kg]	Probe needs lateral power? [26 kg]
	0.0003	3829	2015	890	10 – 26	0.05-0.03	1157	Yes	Yes
	0.0004	5462	2875	1270	10 – 26	0.12-0.07	1252	Yes	Yes
	0.0005	7336	3861	1706	10 – 26	0.25-0.14	1331	No	Yes
	0.0006	9491	4995	2207	10 – 26	0.44-0.24	1399	No	No
	0.0007	11970	6300	2784	10 – 26	0.71-0.37	1459	No	No
	0.0008	14830	7805	3449	10 – 26	1.1-0.56	1514	No	No

Table 48. Compromise between min e max weigth, the refreezing length and the lateral power. (R=0.08,L=0.16m)

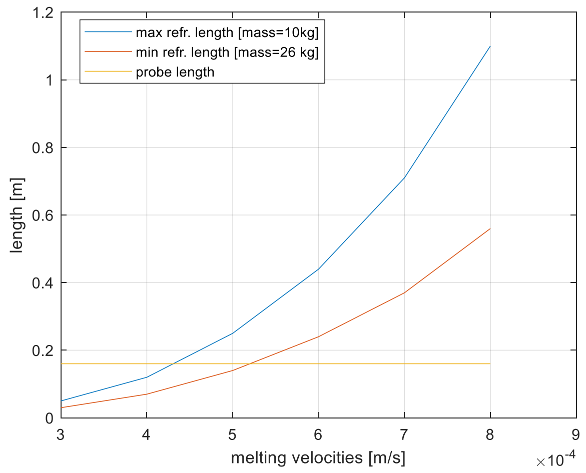

Figure 43. Refreezing length vs length of the probe

For the last 3 cases of the tab.49 is possible to increase the length of the probe, in this way the head power increases also, then the lateral length. So, there are not problems about the refreezing length. However, probes need a lot of quantity of energy to the head probe, due the high melting velocity considered. So, they are not good solution for concept mission.

R=0.06 L=0.16 m	Melting Velocities [m/s]	Heat head power[W] [for 10 kg]	Cu244 [g]	U232 [g]	Min and max mass [kg]	Min and max Refr. Length [m]	Lateral power [W]	Probe needs lateral power? [10 kg]	Probe needs lateral power? [26 kg]
	0.0003	2043	1075	475	10 – 26	0.01-0.02	988	Yes	Yes
	0.0004	2846	1498	662	10 – 26	0.02-0.04	1069	Yes	Yes
	0.0005	3730	1963	867	10 – 26	0.04-0.07	1137	Yes	Yes
	0.0006	4705	2476	1094	10 – 26	0.07-0.12	1195	Yes	Yes
	0.0007	5780	3042	1344	10 – 26	0.11-0.20	1246	Yes	No
	0.0008	6970	3668	1621	10 – 26	0.17-0.30	1293	No	No

Table 49. Compromise between min e max weigth, the refreezing length and the lateral power. (R=0.06,L=0.16m).

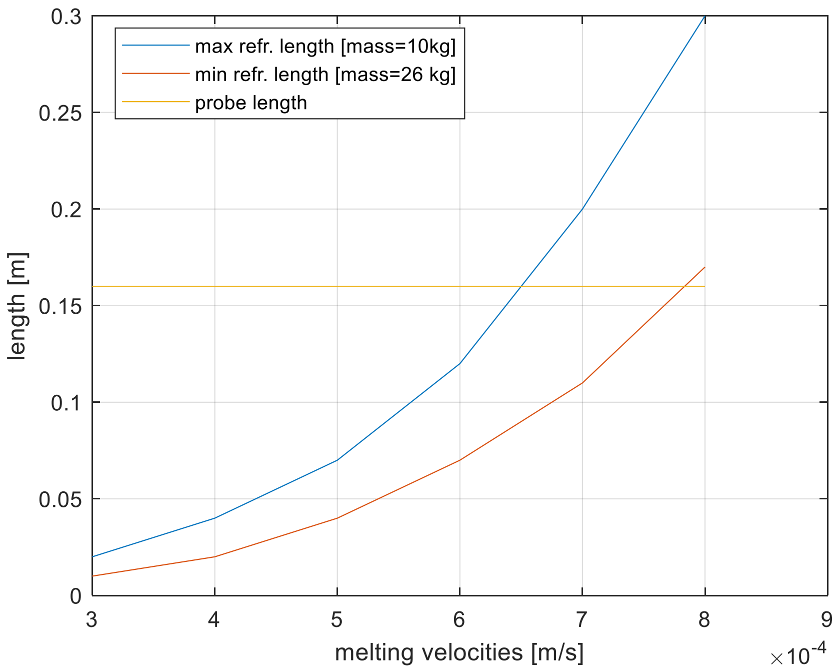

Fig 44. Refreezing length vs length of the probe

Also, in that case, considering high melting velocity, so high head heat probe, the refreezing length is higher than the length of the probe, however the quantity of energy needed is very high and it is not recommended.

The best solution consists to consider small probe with small melting velocity values. In that way, the energy needed is very low.

14. FINAL CONCEPT OF THE MISSION TO EUROPA

14.1 PROBES CONCEPT

The final concept of the space mission to Europa, after the different studies, consists to use 5 small probes with a communication subsystem only and one main probe with the payload.

The concept of the small probes consists to a sphere probe with the size indicated in tab.50

Small probe	Radius [m]	Weight [kg]	Total number
	0.06	5	5

Table 50. Small probe of final concept

The main probe has a cylinder shape(tab.51)

Main probe	Radius [m]	Length	Weight [kg]	Total number
	0.07	0.30	10	1

Table 51. Main probe of final concept

The mission design consists to release the probes into different halls and each probe must reach its prefixed target. Every probe is designed to reach different depths, in that way it is possible to create a communication link between the main probe and the small probes.

Into the main probe there is the payload and the communication subsystem.

The total time to need to melt 30 kilometres of ice is almost 4 years. It is decided this value due it good compromise between the time mission and the thermal energy required.

TOTAL QUANTITY OF RADIOISOTOPE NEEDED

CURIUM	Head power	Lateral Power
BOL	4600.5	2857.9
g of Curium	2421	1504.2
	Total Curium	3925.2

Main probe + small probes	**4451g**

Table 52.Total quantity of curium needed for the final concept

URANIUM	Head power	Lateral power
BOL	4600.5	2857.9
g of Uranium	1070	664.63
	Total Uranium	1734.63

Main probe + small probes	**1922g**

Table 53. Total quantity of uranium needed for the final concept

14.2 SPACE MISSION CONCEPT

For each probe it was made a study to calculate the right quantity of the thermal energy to melt ice with different melting velocities.

For the first probe it is calculate the melting velocity needed to melt 5 kilometres of ice in 4 years. Fixed the velocity, it is calculated the thermal energy for the head probe and for the lateral losses necessary.

The small probe

Mass [Kg]	Start Vel.	Velocity (avg value) m/s	Depth [m]	Head power[W]	Lateral power [W]	Total power[W]	Quantity of U [W]	Time [Ys]
5		0.000045	0-5000	281	477	758	176 g	~3.7
5	0.00008	0.000085	0-5000-10000	510	552	1062	245g	~3.7
5	0.00012	0.00013	0-10000-15000	770	623	1393	322g	~3.7
5	0.00015	0.00017	0-15000-20000	975	663	1638	303g	~3.7
5	0.00018	0.00021	0-20000-25000	1187	697	1884	434g	~3.7

Table 54. Small probes studies for final concept

n. probe	1	2	3	4	5
1 years of payload mission	+1.5 km	+3 km	+5 km	+9 km	+10 km
1 month of payload mission	+0.125	+0.25	+0.42	+0.75	+0.833

Table 55. Ice depth melted during the scientific payload mission (1 ys vs 1 month)

In the tab.54 it is considered that the probe, when reaches its prefixed target depths, it continues to melt ice and goes down through the ice. So, different time for the payload mission are analysed. If the time payload mission is 1 year, the small communication probes, after their target depth, melts ice for different kilometres. This is not good, due the probe for the 25 kilometres melt for other 10 kilometres after 1 years. So, the communication probe reaches he ocean and is not covered the distance of 5 kilometres between probe, necessary to the communication link.

Considering a low time of payload mission, 1 month, there is no problem, due in this time the communication probes melt only few meters.

The concept with 1 month of payload mission is the best choice.

For the main probe it is considered to use an anchor system to fix the probe into the ice and avoid that it goes down into the ocean.

15 ANCHOR SYSTEM

To lock the main probe into the ice and to avoid that It goes down at the bottom of the ocean it is possible to use a mechanical system to anchor the probe. One possible solution consists to use a mechanical spring that it could be activated when the main probe reaches the target.

The system that could be possible to use and to install to the probe is based on the concept figure in fig.43. This system works with springs that push against the ice wall to create grip and lock the probe. This mechanism could be linked a small computer that active the spring and the lock system. [12]

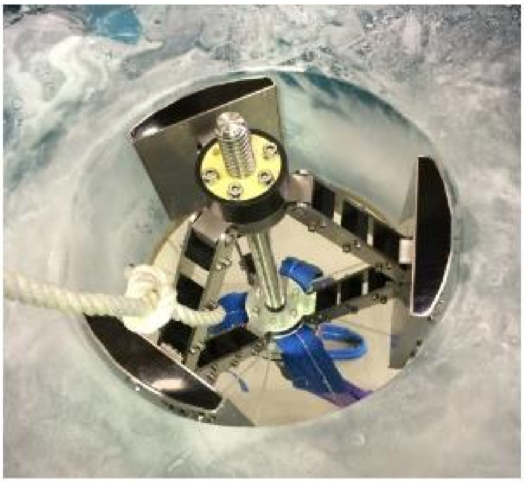

Figure 44. Anchor system of the project (Iceshuttle-Teledo)[12]

Another solution could be a joint for the top cover of the probe and a scissor self-deployable structure. When the probe arrives to the target, the computer actives the explosives micro charge and the self-deployable system take out the up cover and release anchor system. (but is the self-deployable system enough strong?

For the moment I have three different solution:

1)Use the same mechanism of the previous project, I do not know if Is possible to install this outside of the probe (refreezing problem). In the previous project it is installed outside near the heat source, so there is no problem about it.

3.1) first solution consists to take in this mechanism to avoid the corrosion problem or other water problems. It is possible to lock the bar into mechanism with soluble material.

3.2) Second solution consists to take the mechanism outside the probe using anticorrosion material and using a mechanical system to lock the bar into spring and a mechanical deploy system to release the bar to create grip and friction with ice.

16.CONFIGURATION OF THE MAIN PROBE:

For the main probe it is studied an inner configuration to design the space dedicated to the payload:

Main probe (cylinder)	Length [m]	Radius of cross-section[m]
	0.30	0.07

	Thickness dedicated [m]
Wall	0.006
Space for radioisotopes	0.05
Shield for radiation	0.01
TEG	0.005
Communication s/s	0.02
Payload	0.16

Figure 45. Inner space organization of the main probe

These data are approximate but are based on information from the various similar project analysed. [13]

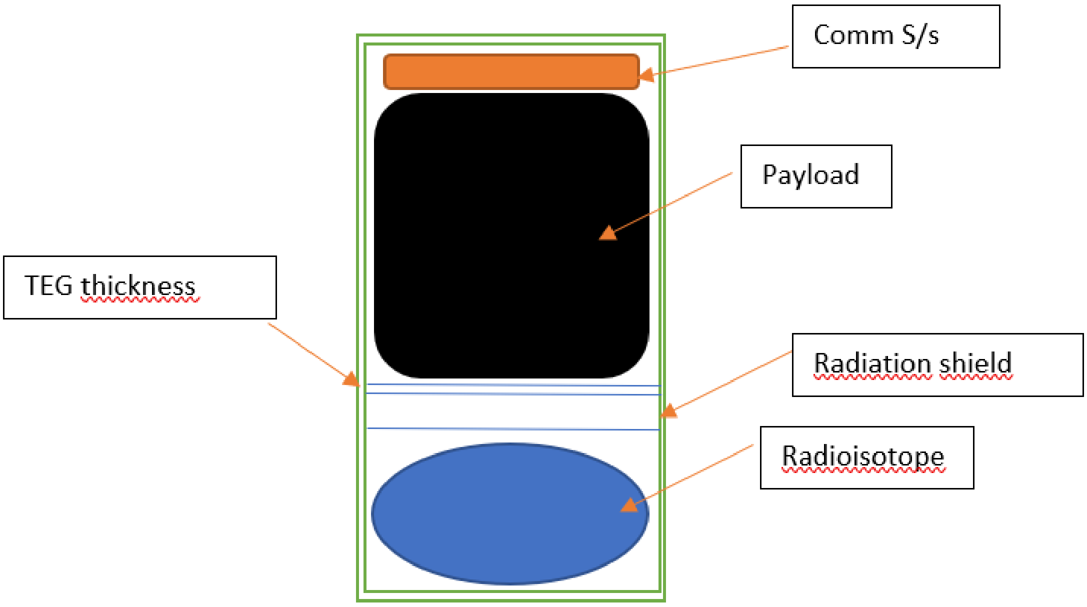

Figure 46. Design of the main probe

Volume dedicated to the payload: **0.0018** $\boldsymbol{m^3}$

CONCLUSIONS

The next space mission generation could be new targets. Icy body could be the best candidates due with them environment, them could be the cradle of the extra-terrestrial life. In the solar system there are different icy body: the icy moons are the best space bodies that could be the next space missions target. Europa, Enceladus, the polar of Mars has the similar environment: on this body it is possible to find water and ice, the two fundamental ingredients for the life.
This paper is focused on Europa, a Jupiter's moon with an ice layer on the surface and a deep subsurface ocean of 100 km. The thickness of layer ice goes from 5 to 30 km.

The environment conditions are very hard: low surface pressure, low gravity acceleration and low temperature are the main challenges for space mission concept to Europa. Another big problem that it take in consideration, is the communication link between the lander and the melting probe due the presence of the water and ice that hinder the electromagnetic waves transmission.
The target of the mission consists to melt through the ice to reach the ocean and study it with a scientific payload.

The perfect concept mission for this kind of environment consists to use different small probes to melt through the ice with a radioisotope with a high thermal power. In this way, in small volume is possible to have the energy source and the other subsystem.

The small probe with a small cross-section radius and small length is needed due the hard Europa conditions. Using this kind of probe, the quantity of thermal power needed to melt ice and reach the target is the lowest possible.

The heat quantity needed, and the lateral losses are in function of the sizes of the probe and the melting velocities values.

Different concepts are analysed, and the final choice consist to use:

-5 small probe with only a communication subsystem and power source.

-1 main probe with the scientific payload, communication subsystem and heat source.

The thermal power needed to the probes is very high, how it is possible in table.33, the best candidates are the radioisotope. The materials studied are the Curium-244 and the Uranium-232, compared with the plutonium-238.

The cm-244 and u-232 with their density thermal power of 2.4 and 4.4 W/g could be the best candidates for a concept mission to Europa.

Curium with its easier production process from waste plants could be the right choice for the mission, however uranium's thermal power is higher than curium and in this way it is possible to produce the same quantity of energy required with smaller quantity of grams. However, there is need an advanced study to the chain decay of the U and the particles product.

The total time of the mission is almost 10 years. The time travel from the Earth to Europa is 6 years and the time to melt 30 kilometres of the ice, for the concept designed is almost 4 years, considering also the time dedicated to the scientific mission.

Different studies are necessary to design a perfect TEG (thermoelectric generator) for the mission, to implement the communication subsystem and the science payload of the mission to insert in this small volume. Another challenge to need to study is how to avoid the sublimation problem at the surface of Europa. A solution could be a mechanical system that push down the probe against the pressure of water vapour created.

However, this kind of concept it could be the best solution for the next space mission on icy body or polar zones of the planets with ice and water, like Mars.

A paper for the NETS (Nuclear and Emerging Technologies for Space) meeting it was written considering the study on the radioisotope studied in this paper.

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N P Bannister

17)SMALL PROBES FOR A SUBSURFACE OCEAN EXPLORATION MISSION TO EUROPA

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