An Astrobiology Payload Complement for a Europa Penetrator

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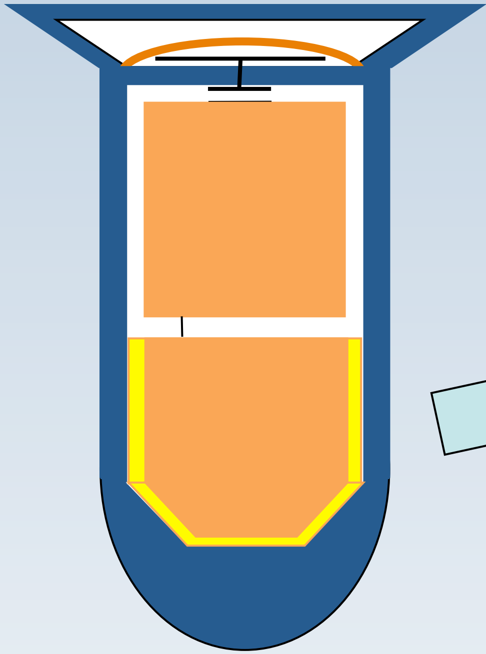
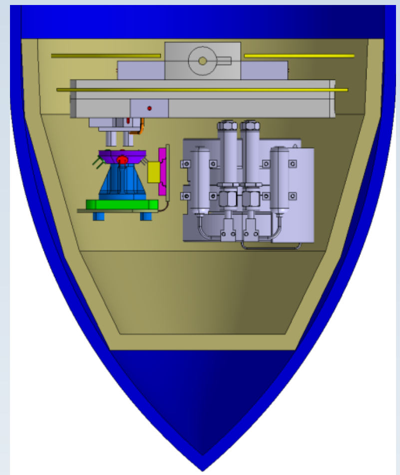
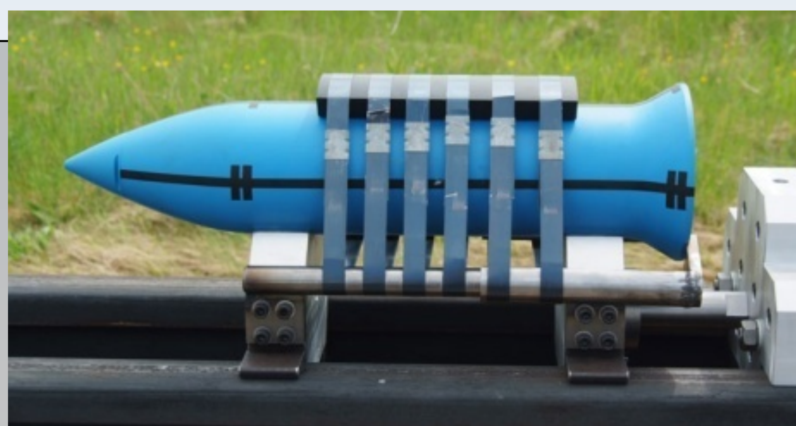
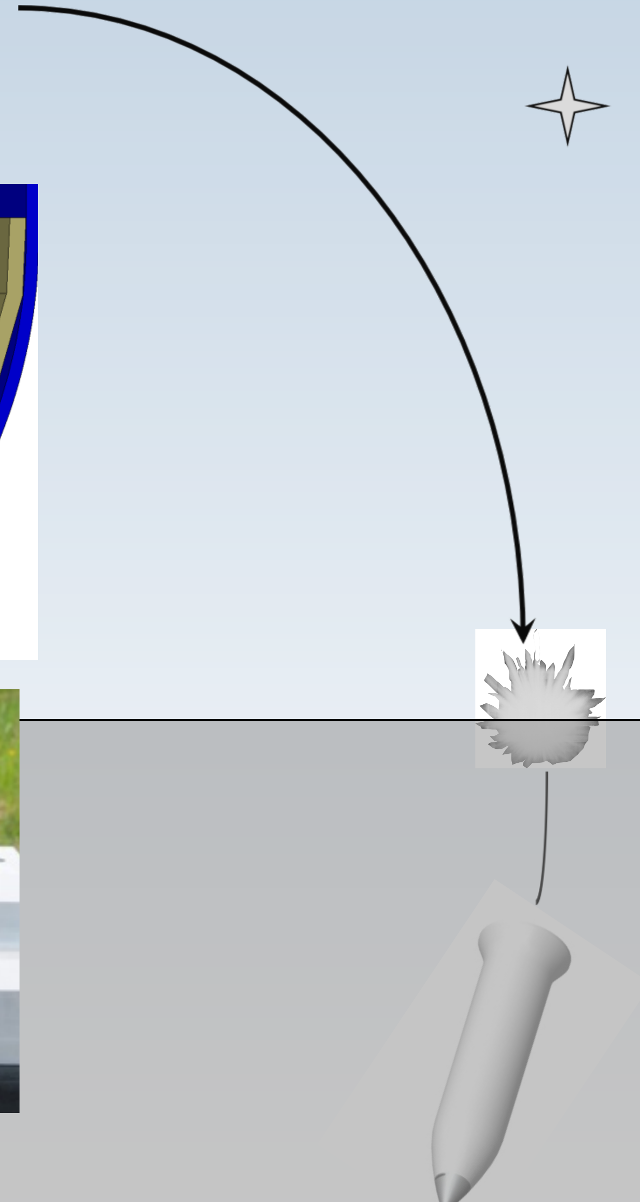
- E-PAC Design

Penetrator Consortium









Background to Current Study

2 ESA studies, special provision to UK Astrium prime, MSSL/UCL, QinetiQ, and now Rapid SpaceTechnologies

Penetrators to Jovian Moons, and Mars

Climbing the TRL ladder

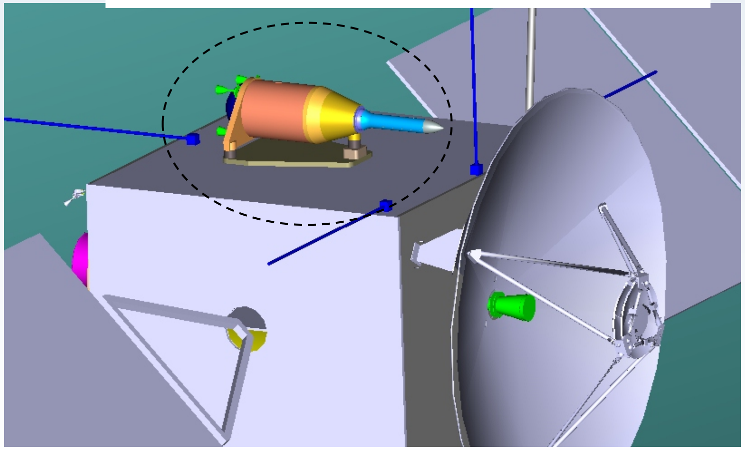
2010 Penetrator Phase-I Study

- Delivery system and penetrator

2012 Penetrator Phase-II Study

- Astrobiology Payload Complement
- Updates to penetrator and delivery system
- Small and full scale impact testing

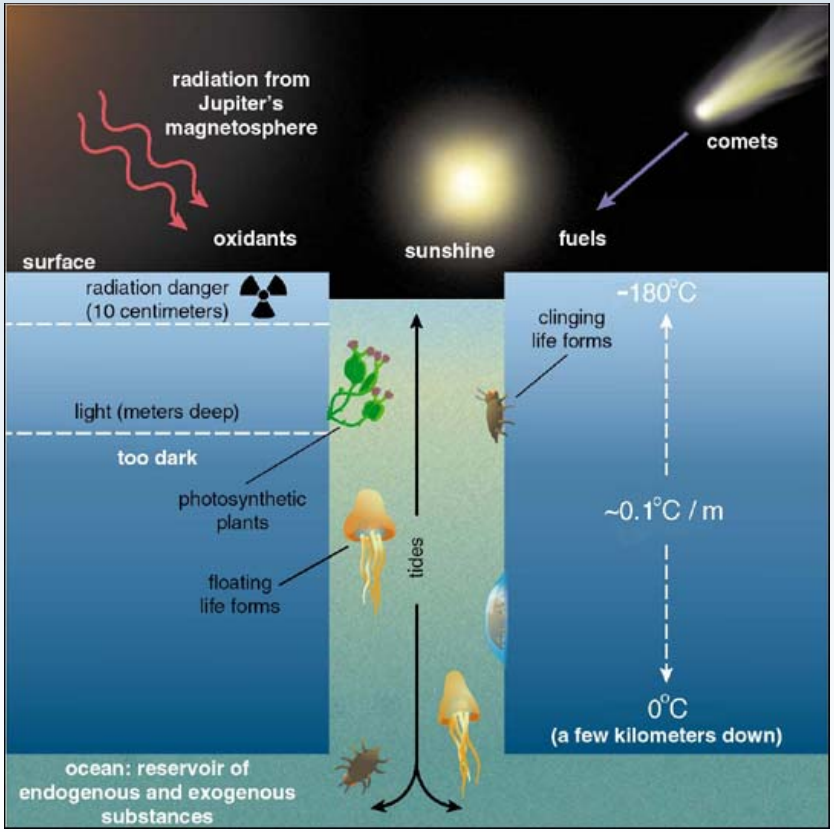
Phase-1 study :
Europa Penetrator ~11 kg
Descent Module ~62 kg



Europa

- Best candidate for life in solar system ?
- Water ice surface thin crust with many cracks, geologically young.
- Evidence of upwelled material from beneath
- Believe warm water subsurface ocean protected from radiation
- Nutrients supply from above or below.

→ Observe upwelled material on surface for life, and habitability conditions of water.



MODEL PAYLOAD SELECTION

Science Requirements

- *In-situ investigations can provide much more capability than from orbit. (close-up, provenance, sample)*

- *Identified 3 main science categories :-*

Astrobiology Science	Score range
Habitability	[0-5]
Astrobiological Materials and Processes	[0-8]
Lifeforms	[0-10]

(a) Habitability (13 areas)	A	P	PS	Instrument Types
Radiation environment	5	3	2	X-ray, ɣ-ray , alpha, electron, proton, neutron and dosimeter sensors. accelerometers
Heat flux	5	1	1	thermometers, tiltmeter
Physico-chemical properties of melted water ice	5	10	5	pH, redox, conductivity
Habitat location and extent	5	5	3	seismometer, magnetometer, radio beacon, geophysical tiltmeter, accelerometers
Planetary body core	5	5	3	seismometer, radio beacon
Seismic activity	5	10	5	seismometer, geophone, geophysical tiltmeter
Magnetic field	5	10	5	magnetometer
Surface morphology	5	10	5	descent camera, landed camera
Temperature	5	5	3	thermometer
Surficial thermal properties	4	3	1	thermometers
Surficial light levels	3	1	1	photometer
Surficial electrical properties	4	5	2	permittivity, conductivity probes
Surficial mechanical properties	3	5	2	accelerometer, penetration probes
(b) Astrobiological Materials and Processes (4 areas)				
Mineral composition	5	10	5	microscope, spectrometers, descent and landed cameras
Elemental composition	7	10	7	Raman, IR, visible, XRS, APXS, LIBS, GRS and mass spectrometer, descent and landed camera
Organic and metabolic compounds	8	10	8	Raman, IR, visible, XRS, and mass spectrometer, thermogravimeter, ɣ-ray sensor, descent and landed cameras
Isotopes	8	10	8	isotope mass spectrometer, tunable laser diode spectrometer
(c) Lifeforms (2 areas)				
Cells	10	10	10	microscope, UV fluorescence imaging, spectrometers
Higher life forms	10	10	10	microscope, UV fluorescence imaging, spectrometers, descent and landed cameras
Maximum score =	107		85	(80% of maximum achievable with penetrator)

Technical Requirements

1. 4 kg E-PAC mass limit
   To include all instruments and sample acquisition mechanisms,
   To include 50% maturity margin and 20% system margin.
   => 2.2 kg without margin.

2. Technology maturity -> to be able to be ready for a flight demonstration in the next decade (2020’s).

3. Survive impact into Europan ice at 300 m/s

4. Provide external access from penetrator

5. Power

Candidate Instruments

- Canvassed 35 institutes as widely across ESA member states as possible + from existing penetrator consortium
- Performed full science and technical assessments on all responses, and on promising existing instruments known to consortium
- Plus, performed abbreviated considerations on all instruments already known to consortium

Main candidate instruments

Instrument	Acronym	Lead Institute
Microseismometer	MSEIS	IC-1
Magnetometer	MAG	IC-2
Habitability Package	HCP	CAB
Biochemistry Mass Spectrometer	BMS	OU
Thermogravimeter	TBS	INAF
Sample Imager	SI	MSSL
Radio Science	PERA	ROB
Raman	HCRS	TNO

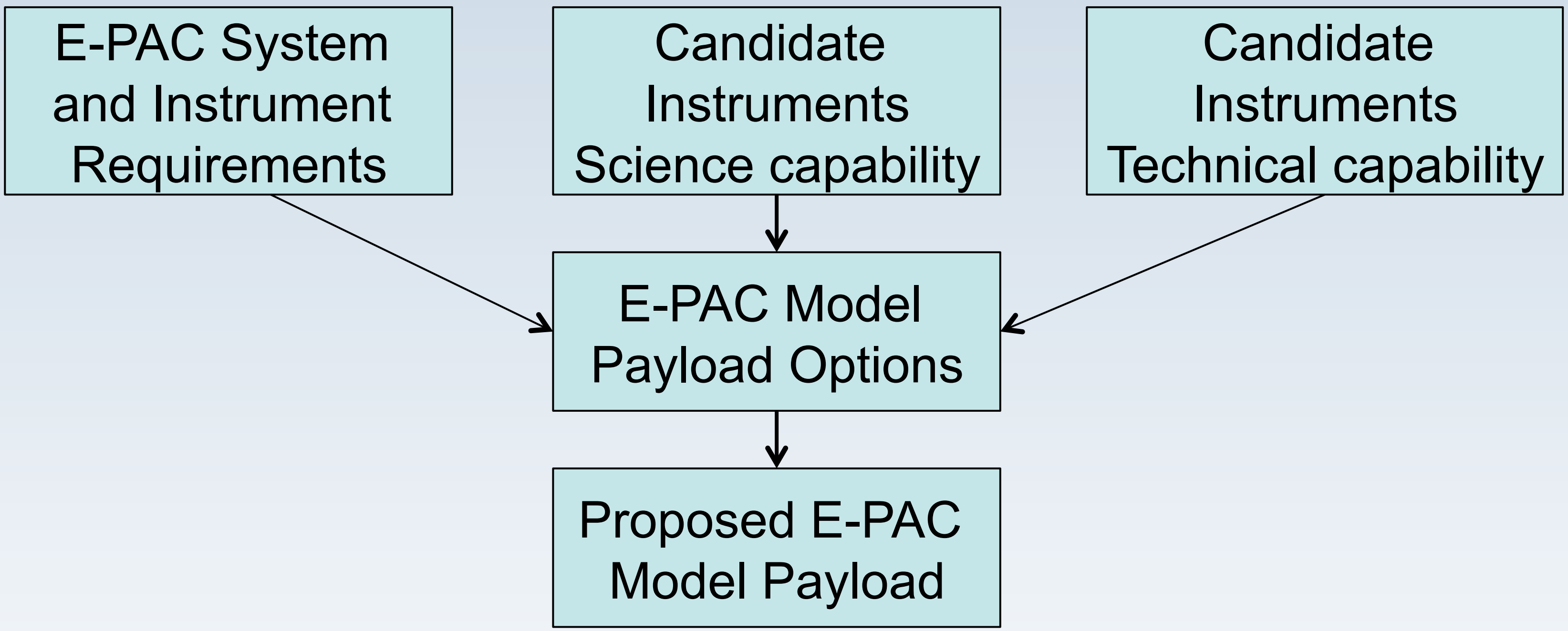
Science Assessment of Candidate Instruments

Astrobiology Science Investigations	Pen. Science value	MSEIS		MAG		HCP		BMS		TBS		SI		PERA		HCRS	
		capability	score	capability	score	capability	score	capability	score	capability	score	capability	score	capability	score	capability	score
(a) Habitability (max science score 5)																	
Radiation environment	3																
Heat flux	1																
Physico-chemical properties of melted water ice	5					10	39										
Habitat location and extent	3	7	5	3	2									5	3		
Planetary body core	3	5	3											5	3		
Seismic activity	5	10	13														
Magnetic field	5			5	7												
Surface morphology	5																
Temperature	3																
Surficial thermal properties	2																
Surficial light levels	1																
Surficial electrical properties	2																
Surficial mechanical properties	2																
(b) Astrobiological Materials and Processes (max science score 8)																	
Mineral composition	5							5	6	3	4	8	10				
Elemental composition	7							4	7			2	4				
Organic and metabolic compounds	8							7	14	8	16	5	10			5	10
Isotopes	8							3	6								
(c) Lifeforms (max science score 10)																	
Cells	10							2	5	2	5	3	8				
Higher life forms	10							3	8	3	8	6	15				
Total instrument science score =			**21**		**9**		**39**		**46**		**33**		**46**		**7**		**10**

Technical Assessment of Candidate Instruments

	Driver/Instrument	MSEIS	MAG	HCP	BMS	TBS	SI	PERA	HCRS
2	Instrument description	-5	0	-10	-5	-5	-10	-10	-10
3	Access to external environment/sample	0	0	-10	-10	-10	-10	0	-10
4	External equipment	0	0	-10	-10	0	0	-10	-5
5	Accommodation	-3	-3	-5	-5	-3	-3	-5	-5
6	Mounting requirements	-3	-3	-3	0	0	-3	-3	-3
7	Ruggedness	-5	-5	-10	-5	-5	-10	-10	-10
8	Operational lifetime	-5	-5	-3	-3	-5	-3	-5	-3
9	Instrument operations	-5	-5	-10	-3	-3	-3	-3	-3
10	Mass	-3	-3	-3	-5	-3	-3	-5	-5
11	Power/Energy	-5	-5	-3	-5	-5	-3	-10	-5
12	Telemetry	-10	-5	-3	-3	-3	-5	0	-5
13	Commanding	-5	0	-3	0	0	0	0	0
14	Thermal environment	-5	-5	-10	-5	-5	-10	-5	-3
15	Electrical environment	-5	-10	-5	-5	-5	-3	-3	-3
16	Radiation environment	-5	-5	-3	-3	-3	-3	-3	-10
17	Planetary protection	-5	-5	-5	-3	-3	-3	-10	-10
18	Instrument heritage	-3	-3	-5	-5	-5	-5	-10	-10
19	Current TRL	-3	-3	-5	-3	-5	-10	-10	-10
20	Developments required	-5	-5	-5	-5	-5	-10	-10	-10
Average scores									
	Average Technical Score	-4	-4	-6	-4	-4	-5	-6	-6
	Average Critical Drivers Score	-4	-4	-6	-6	-6	-8	-8	-8
Converted scores [C=10+average scores] where 10=best.									
	Technical Score [0,10]	6	6	4	6	6	5	4	4
	Critical Drivers Score [0,10]	7	7	4	5	5	2	3	2

Model Payload Selection



Priority Ordered Candidate Instruments

Priority	Instrument		Habitability	Materials and Processes	Lifeforms	Total science score	Technical score	Combined Sci+tech score
1	Mass spectrometer	BMS		**8.4**	3.1	11.6	4.5	**16.1**
2	Habitability package	HCP	**9.8**			9.8	4.8	**14.6**
3	Sample imager	SI		5.6	**5.6**	11.2	2.3	**13.5**
4	Thermogravimeter	TBS		5.0	3.1	8.1	4.5	**12.6**
5	Microseismometer	MSEIS	5.3			5.3	6.5	**11.8**
6	*Descent Camera (Pen)*		*3.3*	*3.8*	*1.9*	8.9		8.9
7	Magnetometer	MAG	2.1			2.1	6.5	**8.6**
8	*Descent Camera (PDS)*		*2.3*	*2.5*	*0.6*	5.4		5.4
9	*Radio Beacon*	PERA	*1.7*			1.7	*2.5*	*4.2*
10	*Raman Spectrometer*	HCRS		2.5		*2.5*	*1.7*	*4.2*
11	*Thermal probes*		*3.5*			*3.5*		*3.5*
13	*Landed camera*		*0.2*	1.3	0.6	*2.1*		*2.1*
14	*Accelerometers*		*1.7*			*1.7*		*1.7*
12	*Radiation monitor*		*1.3*			*1.3*		**1.3**
15	*Electrical instrument*		*1.3*			1.3		1.3
16	*Photometer*		*0.8*			*0.8*		*0.8*

Maximum penetrator science score = 77.4

Recommended E-PAC Model Payload

Instrument	Acronym	Habitat	Materials	Lifeforms	science score	Mass (g)	Cumulative mass (g) (including margins)
(a) Mounted on PDS							
Descent camera		H_{surf}	M	L	5.4	160	288
(b) Mounted within E-PAC (require access to sample, and short lifetime -> hours)							
Sample Handling	SHS					785	1413
Mass Spectrometer	BMS		**M**	L	11.6	1163	3506
Sample Imager	SI		M	**L**	11.3	87	3663
Habitability Package	HCP	$\mathbf{H_{mat}}$			9.8	120	3879
(c) Mounted in Penetrator (do not require sample access, and long lifetime -> ~week)							
Microseismometer	MSEIS	$\mathbf{H_{loc}}$			5.3	300	540
Magnetometer	MAG	$\mathbf{H_{oc}}$			2.1	58	644
Radiation Monitor	RADM	$\mathbf{H_{env}}$			1.3	75	779

Model Payload – Science Coverage

Science Requirement	E-PAC Model Payload Instrument (items,sensitivity)	
1. Assess habitability of subsurface ocean materials		
chemistry, pH, redox, electrical conductivity	BMS HCP	(chemical volatile inventory to 900ºC) (pH, redox, electrical conductivity)
2. Assess habitability context of surface and near surface		
radiation environment	RADM	(external to E-PAC)
3. Assess habitability of subsurface ocean		
depth, extent, salinity/ currents	MSEIS MAG	(external to E-PAC) (external to E-PAC)
4. Determine chemical content of biological interest		
elements, compounds, minerals and isotopes	BMS SI	(chemicals and isotopes) (10-300 Da, sub to few ppm) (minerals, colour imaging to 45 μm resolution)
5. Detect morphological signs of life		
Lifeform shapes, internal structures, and motions	SI	(colour imaging of 10 mm image to 45 μm resolution, UV fluorescence)

Model Payload Selection Conclusions

- Good astrobiology science coverage within 4 kg E-PAC
- Enhanced science coverage if include external seismometer, radiation monitor and magnetometer (for +800g including margins)
- Substantial geophysics return, even if no astrobiological presence.
- Is a preliminary selection which could change.
(depends on impact survivability, evolving technology, and requirements for a real mission)

Model Payload Options	Estimated Astrobiology Return	Estimated Geophysics Return
Recommended Model Payload (E-PAC only)	45%	34%
Recommended Model Payload (full)	65%	62%

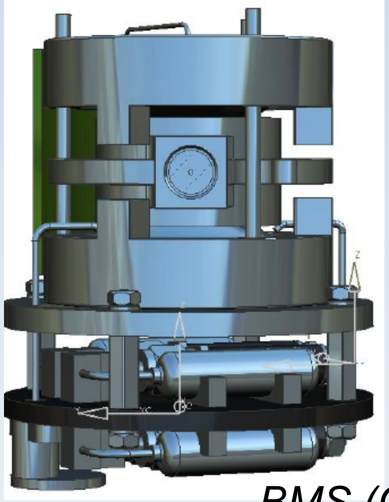
Percentages compare against selection of all possible instruments considered.

E-PAC DESIGN

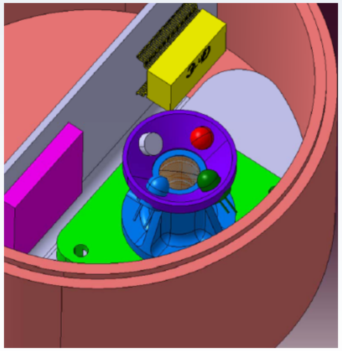
E-PAC Model Payload

- **HCP**
  - Micro-sensors (electrode probes) immersed in 1 ml of melted sample water.
  - Instrument technology is well established on Earth.
- **BMS**
  - Miniature state of the art quadrupole ion trap mass spectrometer.
  - Design heritage from Ptolemy instrument on Rosetta.
- **SI**
  - Design heritage from Pancam instruments on Beagle-2 and developments for ExoMars.
  - Current design is minimum performance

HCP (CAB)

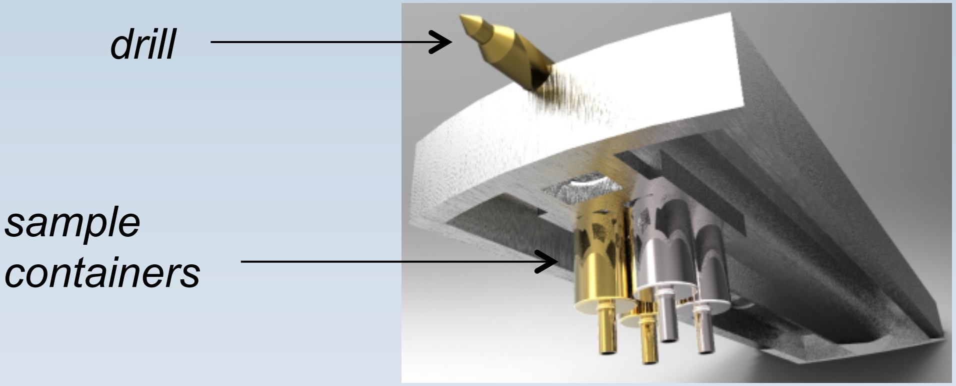


BMS (OU)



Sample Imager (SI) (MSSL)

+ Sample Handling System

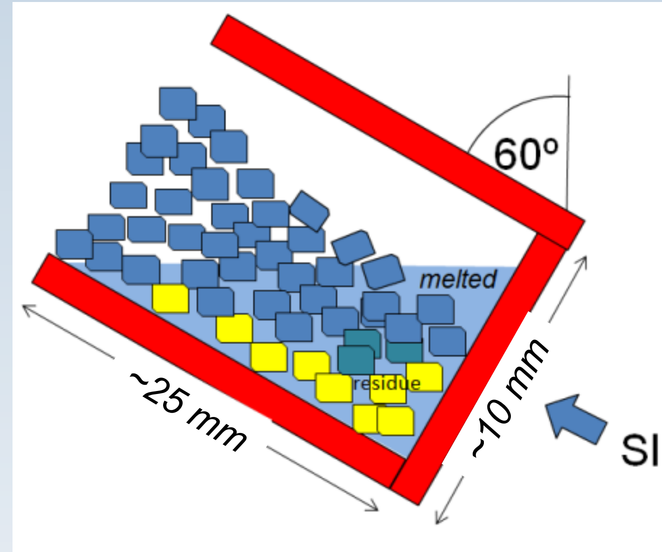


Sample material collection mechanism (Rapid Space Technologies)

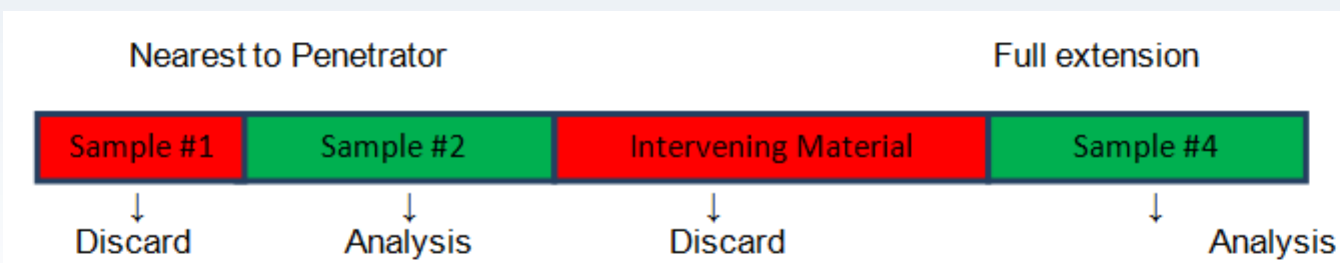
Sample Handling System	
Sample Acquisition and Delivery System	Sample Acquisition System (SAS) (x2) *(drill/auger)*
	Sample container *(x4)*
	Sample container fill system *(gravity/chute/brushes)*
	Sample container sealing system *(pyro)*
Sample Processing System	
	Sample heating system
	Sample temperature and pressure monitoring system
	Sample expelled gases outlet feed system
	Sample expelled exhaust gases removal system

Sample Material Collection System

- To cope with 60º emplacement angle.
- Access materials from opposite sides of penetrator (2 drills -> provide redundancy) (at least one downhill).
- Discard contaminated materials.
- Avoid losing volatiles from sample by drilling process.
- Sample size:
  - SI ≥ 0.1 ml
  - HCP ≥ 1.0 ml
  - BMS ≥ 0.1 ml

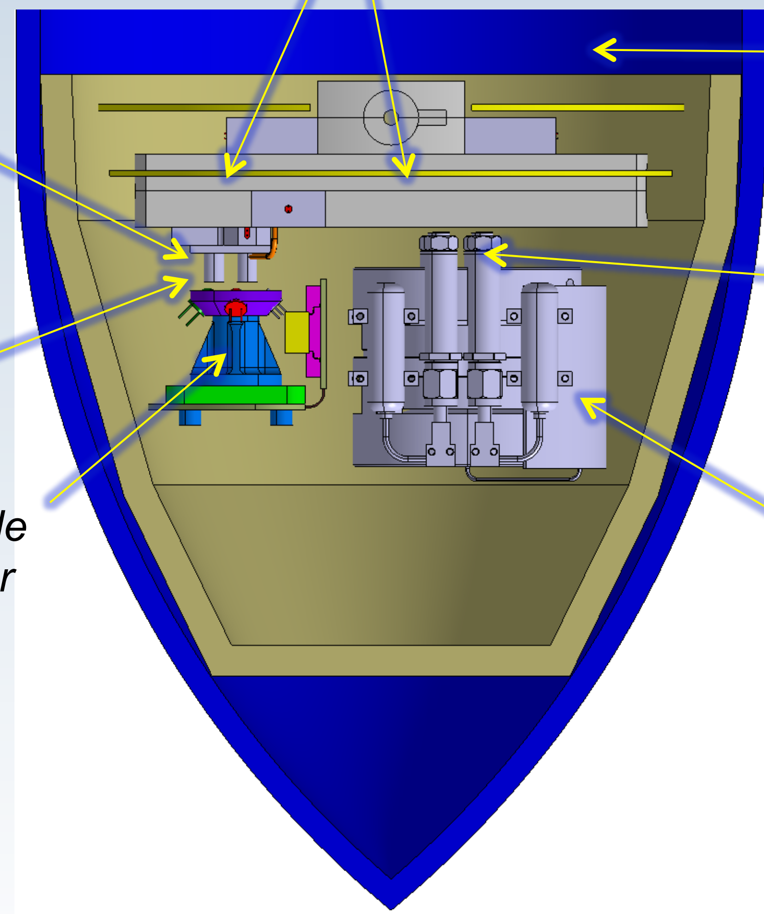


sample container
(Illustrating 60º maximum implantation angle)



E-PAC Design

- E-PAC located in ‘short life’ bay in penetrator nose
- Utilises common electronics
- Thermally isolated from rear of penetrator
- Anticipate inductive electrical interface with rear of penetrator



E-PAC Operations Overview

1. Image sample oven before drill through shell.
   (to ensure container is empty/contamination free from cruise phase or impact)
2. Drill though shell and discard first sample (contaminated with shell material)
3. Acquire a good solid sample into oven.
4. Image sample to confirm sample has been acquired,
   and obtain mineralogy and UV fluorescence images from unmodified sample.
5. Seal oven and heat in stages.
   At each heating stage :-
   1. The evolved gases diffuse into the mass spectrometer (BMS) for chemical analysis.
   2. The HCP is operated continuously to return pH, redox, and conductivity information.
   3. The SI images to detect volatile grains that have been removed from sample.

- *Repeat for extended drill sample*
- *Repeat for other drill samples*

← *provide redundancy/fault tolerance*

Sample Heating Phases in more detail…

Phase-1: Frozen sample -> SI science from unmodified sample

Phase-2: Heat to release volatiles (sublimated gases) -> science BMS,SI

Phase-3: Heating until water ice melts
produces liquid sample (sealed container with pressure control)

- HCP can confirm that liquid phase has been achieved and make pH, redox and conductivity measurements.
- Any high density residues will fall to bottom where they can be imaged by SI.

Phase-4: Heating until water has been evaporated, leaving only a dry material residue.

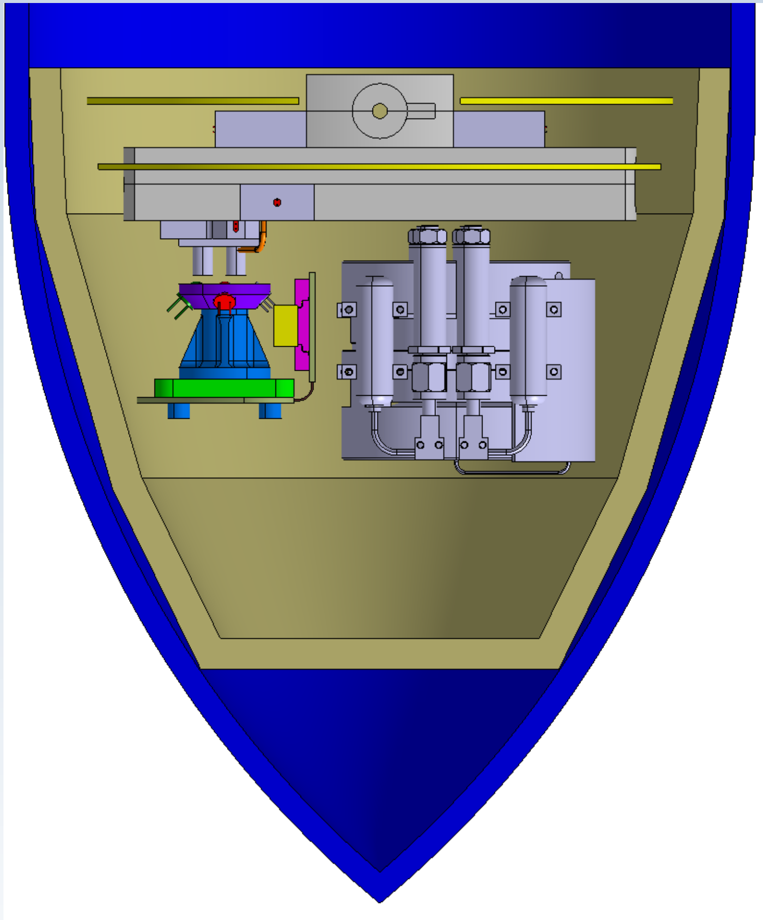
- HCP can detect when liquid is removed
- SI can now detect removal of higher temperature volatiles.

Phase-5: Heat in presence of oxygen to burn sample residue to 900C.

- SI can image remaining residues (TBC)

Conclusion - Next Steps

- Capable E-PAC successfully designed.
- Update Penetrator and Descent Module design -> close to completion !
  -> next presentation
- Small scale impact tests of penetrator equipment –> Oct.
- Full scale impact trials into sand and ice (Europa simulant) –> next March



Thankyou

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