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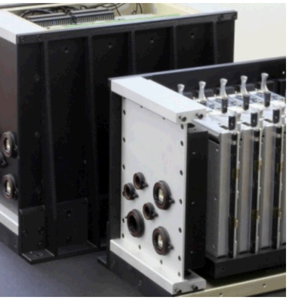

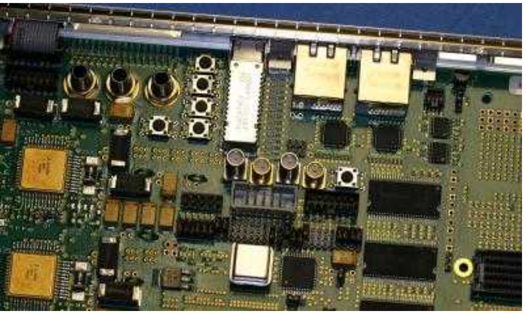

SNL/JPL Europa Lander Project

Termination Sterilization Subsystem (TSS) Alternative Techniques Trade Study
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The Question

- This study answers the following SOW task:
  - Develop system architectures, consisting of appropriate mechanical and electrical interfaces, redundancy, and fault protection, to integrate candidate decontamination devices with the spacecraft (S/C), and to support system decisions and path forward. Architectures will reflect the requirements that the device must operate independently of the S/C systems.
- Because the purely thermal method was considered not feasible, we brainstormed the following alternative ideas
- Each idea is described at a high-level on its own slide in this package
  - Evaluated each idea for feasibility to meet notional Planetary Protection requirements as well as “packageability” and manufacturability
  - The first idea was the one most studied and matured
  - The rest are in no particular order
  - Note: all ideas will utilize the same or very similar electronics architectures as was previously presented unless otherwise noted

Gas Transport

Idea	Pro(s)	Con(s)
Use Gas Transport – rather than pure energetic material, produce gas at a slow enough rate to keep the transport moving through the whole 10 seconds. This idea also includes the layered vault shell and changing materials of component boxes from Aluminum to something like Stainless Steel or Copper to reduce energy requirement. This idea also includes using the circuit boards (and other "free" items of organic nature, i.e., epoxies, resins, conformal coating, wire insulation, etc.) as fuel, providing an oxidizer which upon reaction also produce chemical sterilants (taking credit). References included with this package: • [1] Tyler's slides from 11/21/2016 for detailed description of the idea • [2] Alex's paper from 1/9/2017 for detail on material selection considerations	This is the idea that seems most feasible in terms of mass (presented to JPL on 11/21) (I would suggest that the $KClO_4 + Al \rightarrow KCl + Al_2O_3$ idea is perhaps the most promising because of the pressure generation and limited oxidation rates.) May allow use of more efficient oxidizers (e.g., $LiClO_4$) that are not typically used because they are hygroscopic. May allow use of fewer canisters due to convection and advection. Small canisters with electrically controlled release valves could be placed in strategic locations throughout the payload for optimal dispersion. Release mechanism should be relatively simplistic (i.e. COTS solution). Component would need relatively simple mounting and is passive in nature (i.e. it does not operate until power is sent to valve). Integration of these canisters should be relatively straight forward. Interface to the external vault environment would just be electrical cable to actuate valve.	Pressure generation is relatively severe with gaseous oxidizers and oxidation products. Rate of oxidation is unknown under these conditions. It's not clear whether/how we can control the EM burn to get a slow burn without sacrificing energy density (technical risk). Would still require distributed EM modules (e.g. one per component) Would require extensive experimentation to determine efficiency of combustion. Gas canisters, valving, and electrical cables would add mass to the system. Higher fidelity modeling efforts would be needed to optimize release location quantities to launch mass. Higher fidelity material tailoring and selection would also be required. These two efforts are both well within Sandia's capability.

Gas Transport – Enhanced Surface Condensation

Idea	Pro(s)	Con(s)
To enhance the surface heat transfer with gas transport, we can take advantage of a gas that is condensing in a useful temperature range, perhaps 1000 C to 1800 C. Deposition adds on the order of 1-2 MJ/kg mass deposited directly on the surface. Examples: from $KClO_4$, KCl condensing around 1400 C; from PbO_2+Al, Pb condensing around 1750 C.	Condensing gas avoids more substantial pressure buildup.	Many condensing materials might condense at too high temperatures.

Gas Transport – Aerosol Deposition

Idea	Pro(s)	Con(s)
For cases with gas generation, there is often a metal oxide aerosol, Al_2O_3 in our examples. Aerosol deposition is more effective than gas advection in heat transfer, and this product of our reactants is a key additional heat transfer mechanism.	Condensed aerosol does not contribute pressure buildup, but is advected some distance.	Cluttered environments limit the distance aerosols travel before deposition. Due to the reduced travel distance of this option, it may require more dispersion locations, which equates to more launch mass. This would require more modeling and experimentation to validate. Assuming these gasses are dispersed similarly to those listed above, this option would have similar pro's and con's.

Combined Condensation & Aerosol Deposition

Idea	Pro(s)	Con(s)
Combining the previous two heat transfer mechanisms, $KClO_4$ + Al -> KCl + Al_2O_3 was presented as an example material that takes advantage of both enhanced surface condensation and aerosol deposition.	Limited gas generation, strong transport to surfaces.	Most mass is in Al_2O_3 aerosol having above limits on transport in cluttered environments. This option may require substantial increase in initiation/dispersion sites. More modelling is necessary to define site count.

Replace Vault Mass with EM

Idea	Pro(s)	Con(s)
Replace ballast or structural components in the vault with energetic material, which equates essentially to "free" mass.	Mass efficient.	Need more detail on vault structure to evaluate. All structural elements within these payloads are highly engineered to protect the payload from environments (mechanical, thermal, etc…). This is probably a substantial engineering change/development effort.

Fill Vault with Foam

Idea	Pro(s)	Con(s)
Fill vault volume with foam that is also considered an energetic material that is then ignited when it is time. The foam could be inserted before launch or sometime after.	May get better thermal coverage than the stationary energetic material pellets (Ti/2B) because of the foam's expansion.	Makes rework impossible if foam is inserted before launch. Foam may not fill 100% volume (i.e., may not get into all the cracks and crevices). The time necessary to simply release and expand the foam is unknown. However, to fill 100% of the necessary volume in less than 10s, and then ignite the foam such that the entirety of the vault at 10s has reached 500C for 0.5s during that time frame is likely impossible (just intuition).

Release Sterilant Enroute

Idea	Pro(s)	Con(s)
We could potentially have an additional variant of this option where we release a sterilant gas enroute to Europa, with a secondary gas canister configuration. Would need to be evaluated further.	Potential to take credit for the redundancy factor.	Unknowns associated with the affect these gases may have on vault payloads (i.e., oxidation, corrosion, etc.).

Thermal Shock Pulses

Idea	Pro(s)	Con(s)
High-temperature, short-term thermal shock can kill organisms using millisecond-timeframe heat pulses in the 200-800C ranges.	Likely to be the most effective technique for assuring microorganisms are killed.	Seems difficult to achieve in bulk given the thermal approach infeasibility. May not be achievable in the time constraint of 10s. Would require some very complex electronics to control the pulses.

Radiation Sterilization

Idea	Pro(s)	Con(s)
Considering radiation as an alternative method, Gamma radiation needed for killing the organisms of interest are in the Megarad range. The Europan radiation environment might be able to have some affect if the vault becomes open during end of mission.	Gamma radiation penetrates through many types of materials. This is more than likely a more simplistic component/structure relative to the other ideas listed here.	Probably not mass efficient. Encapsulation during the mission to avoid it affecting the electronics in the vault would be difficult. Radiation source may have integration and safety concerns.

Low-Dose Radiation Enroute

Idea	Pro(s)	Con(s)
A delivery system could be employed to provide a low-dose rate of radiation enroute to Europa.	Time efficient.	Low-dose radiation for the timeframe would adversely affect the vault electronics.

Provide Oxidizer

Idea	Pro(s)	Con(s)
Providing only an oxidizer – NO_2 or CTF being used as a sterilant and/or oxidizer in incineration method	Dual effect, high specific energy Uses onboard organics as fuel; therefore it is mass efficient	Complex delivery system, health hazards prior to launch, potentially high pressure generation if combusted. If high pressure is created, the HEPA filter/depressurization system may need to be re-engineered to accommodate this internal pressure. While this change shouldn't be a complex one for the HEPA system (i.e. once we purge initially, we close that purge channel off for trip to Europa), depending on how high of pressure is created, it could be a very complex problem from a vault design perspective.

Caustic Sterilant Methods

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Idea	Pro(s)	Con(s)
Post-mission sterilants that can be considered. Since it's end of mission, more caustic means can/should be considered because we are not worried about destroying anything at that point.	Materials could be chosen to increase confidence of complete sterilization.	Time to deploy and function is likely substantially longer than the fault scenario the team has been working towards. Some of the payloads inside the vault will likely have penetrations that need to also be sterilized. If the vault is not a "closed" environment, we'll need to worry about leaks, which will impact the quantity of sterilant used to ensure total biological eradication. May not be a huge issue, just something to consider/keep in mind.

Freezing

Idea	Pro(s)	Con(s)
Since Europa's balmy tropics never exceed some -160C, would those temperatures alone kill most bacteria and put the rest into hibernation long enough for radiation to do the rest? Maybe we create a thermal shock on the other end (i.e., crack the case to disperse the material enough to enable this solution?). I think the low-temperature phenomenon that might be of importance here are not only the low temps themselves, but also the high rate of temperature decrease after the end of mission or crash. I'm sure the survivability of organisms at low temperatures has been studied because it is important for cryopreservation, which is a common method for preserving biological material at temperature as low as liquid nitrogen (-196□C). A consideration in cryopreservation is the damage to the cells that occurs particularly during the freezing stage. One technique to prevent the cryopreservation damage is slow freezing. Perhaps we could at a minimum take some credit for the irreversible damage cause by rapid freezing, and then, as Prabal is suggesting, also for the radiation damage to the deep-frozen, and thus inactive, organisms. Even without a crash, if the cold is cold enough to put the organisms into stasis then they can't reproduce before the radiation kills them. What it might mean for us, practically, is we might desire a system that makes sure everything in the vault gets exposed to the cold rapidly and maybe cracks a few boards with deep-seated electronics we want exposed. SNL actually has a lot of experience building high-reliability mini-HEs for board-busting.	Takes advantage of the existing environment. SNL has expertise to develop, build, test.	Unknowns associated with just dispersing everything. What if it falls into a crack and gets covered in ice which shields it from the radiation environment? Unknowns about the effectiveness of this method on biological material.

Microwave Pulses

Idea	Pro(s)	Con(s)
What if we used a powerful but short-lived microwave pulse generator? Use the Faraday-cage nature of the vault as a way to contain those microwaves and cook everything in there quickly?	Electronics system would be relatively straightforward, and SNL has the expertise to develop, build, test such a system.	Unknowns associated with: how large a pulse, how long it would need to run, how much power is needed, etc. for complete sterilization. Electronics system would likely be the driving development cost. It would also be a very different architecture than previously presented. Mechanically speaking this idea would probably require very little in the way of structure and would also likely have very little impact to the existing configuration.