Small Mission Modules

Spacecraft Interiors for Extreme Reliability & Adaptability at Minimal Cost

Kent Nebergall

Goal: 500 Days in Deep Space

Term of Art	Cynical Definition
Rocket Science	The very expensive and time consuming craft of pushing engineering to the ragged edge of physics for a few minutes without a catastrophic explosion.
Crewed Deep Space Flight	Betting astronaut's lives that they can be locked in a van-sized box with no support whatsoever for five hundred days without anything going so wrong that it kills them.
Crew Health	Getting the previous item right the first time with no practice in a largely unknown radiation environment.
Entropy	That which makes the above situation increasingly risky with each day added to the mission.
Casino	A building that costs many millions of dollars that is funded with sucker bets. See also: contractors who claim to solve the above problems.

Why So Expensive?

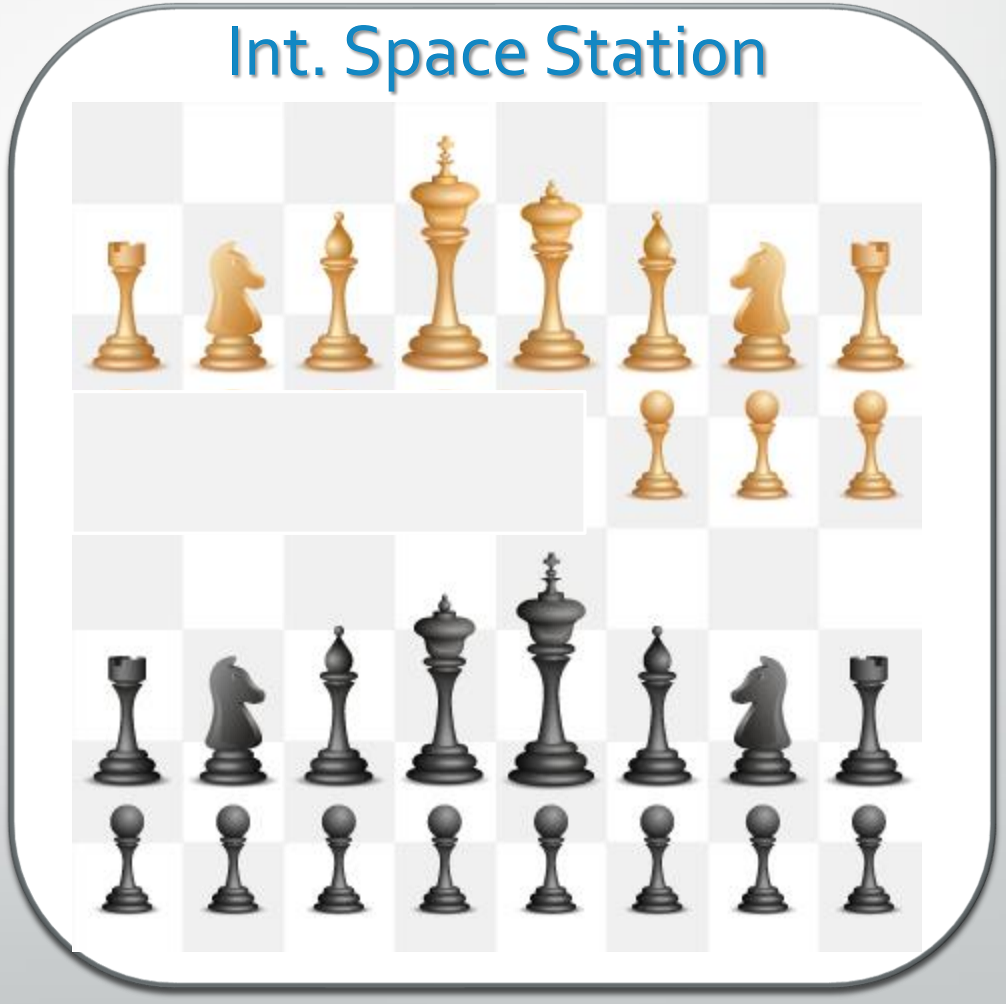
Extended Mission	• Need for Crewed Systems to work for Extended Periods without Failure • Crewed Mission Cost X Ten
Crew Risk	• The low failure rate required below further increased do to safety • Rocketry Cost X Ten
Rocketry	• Very expensive to get right • Rockets are designed like air superiority fighters

r/K Theory (Applied to Engineering)

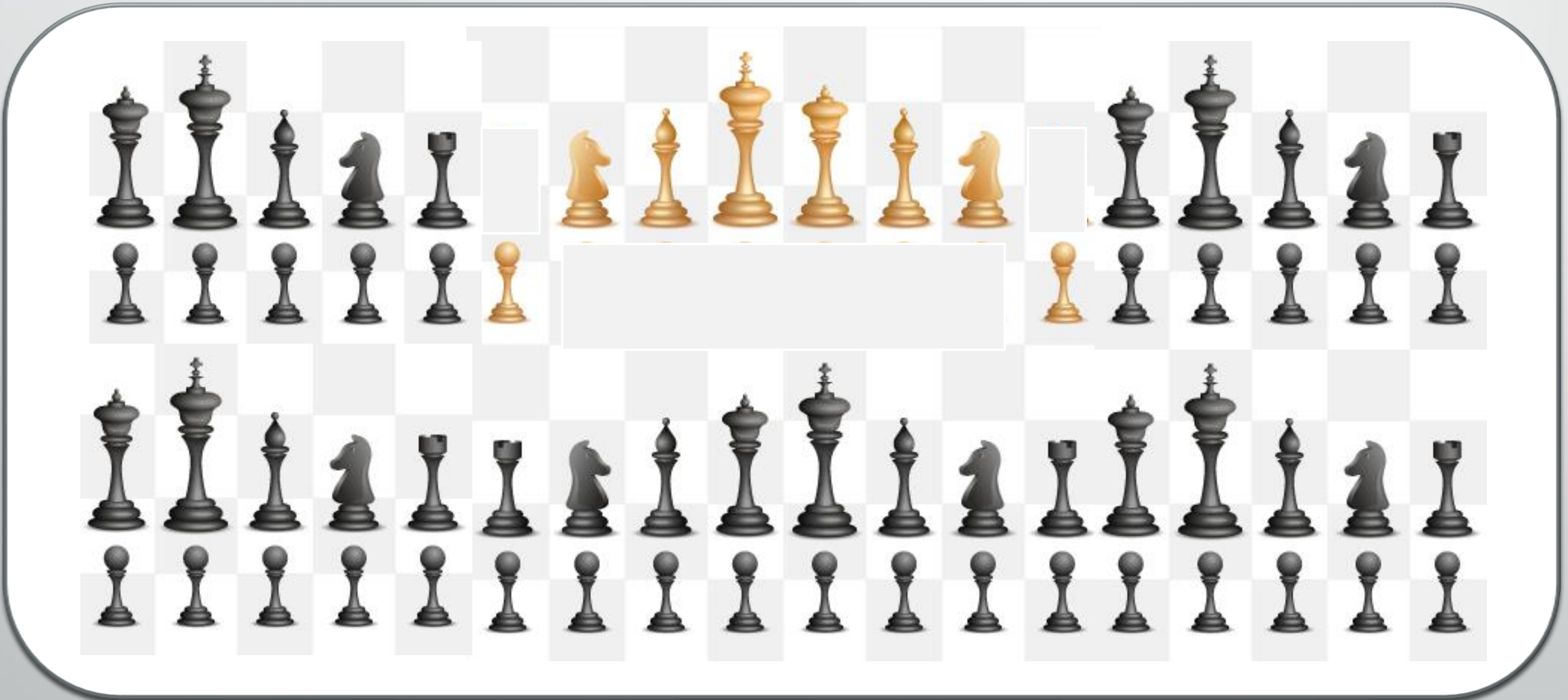
"r-Selected" Systems (Reproduction)	"K-Selected" Systems (Carrying Capacity)
• Rabbits, Mice, Plankton, Grass, Krill…	• Whales, Trees, Elephants, Tigers…
• Short lifespan – many children	• Long lifespan – few children
• Minimal investment in young	• Strong defense of young
• Random breeding (diverse gene pool)	• Strong pair bonds (strong gene pool)
• Migratory	• Territorial
• Death is Individual is Minor Loss	• Death of an Individual is a Major Loss
• Cheap Cell Phones/Tablets, etc.	• Aircraft, Space Probes
• Pawns	• Kings/Queens/Rooks/etc.

System	Examples
	**"Royals"** • The Crew • Highly critical items (hull of vessel, etc.)
	**"Rooks"** • Mission Critical, Monolithic Systems that Cannot be Split or Scaled • Systems can be repaired and maintained, but may have spare system • Restroom Equipment, Some Exercise Equipment, Etc. • Rails – long backbones for fluid/power/ data transfer through the walls
	**"Pawns"** • Systems that can be broken into smaller modules and integrated • Can be scaled in the field and repaired • Can be re-arranged quickly • Individual unit failure is expected and accommodated • Graceful failure of whole system with many salvage/repair options

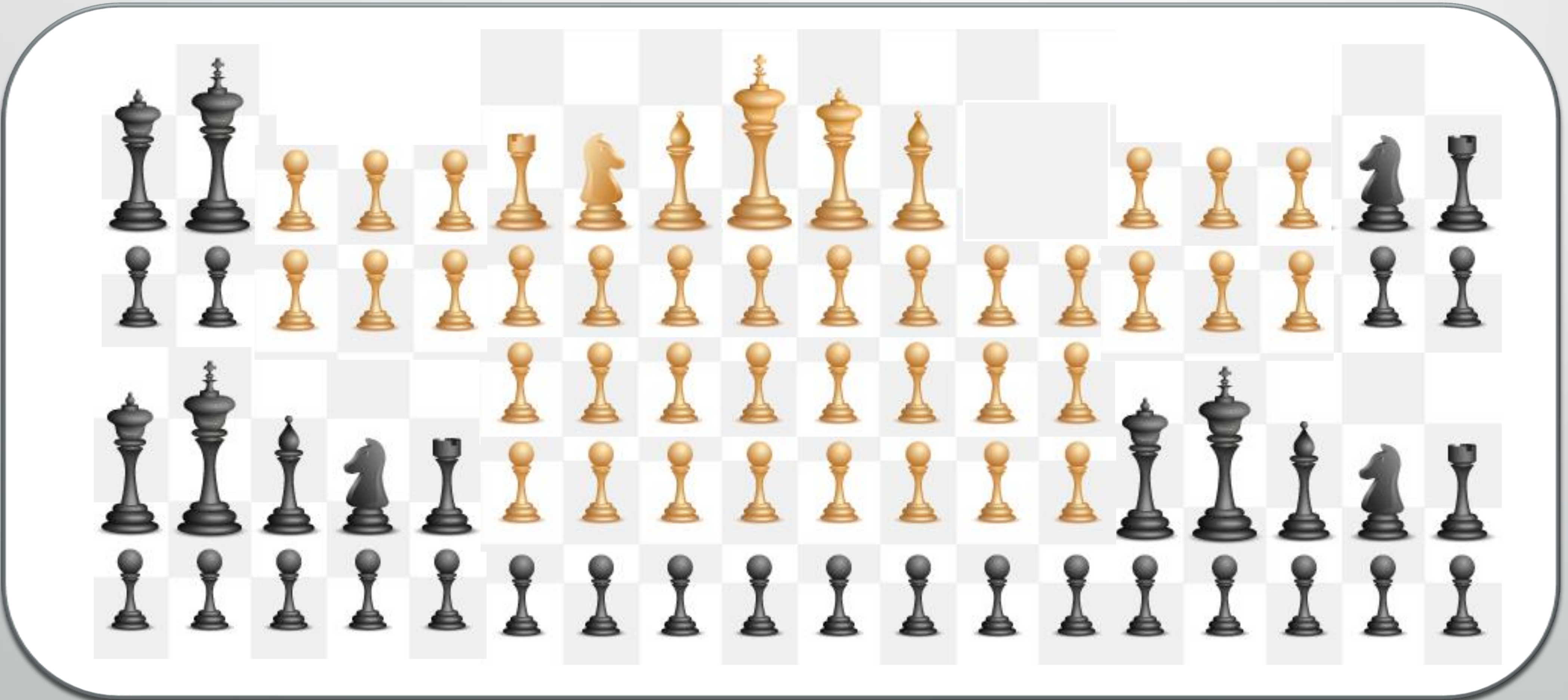
The Chess Game for ISS or Apollo



The Chess Game for Mars (Conventional Logic)



The Chess Game for Mars (r/K Logic)



Attacking the Problems

Current Challenge	Check on that Challenge
Overemphasis on monolithic systems	Break up the systems
Overemphasis on perfect systems	Stratify those things that actually have to be perfect and those that can be repaired in flight
Cover every contingency before closing the hatch	Make it so that it can be improved in flight
Radiation challenge is either not taken seriously or considered near-impossible	Aggressively define the problem based on recent advances in theoretical physics, broken into solvable sub-problems
No one can afford solutions	Democratize the problem solving mechanisms by breaking them into manageable components.

Attacking the Problems

<table>
<tr><th>Check on Challenges</th><th>First Moves</th></tr>
<tr><td>Break up the systems</td><td rowspan="3">• Identify all systems
• Categorize the systems that can be modularized
• Identify the connections between those modules
• Integrate modularity into the non-modular systems</td></tr>
<tr><td>Stratify those things that actually have to be perfect and those that can be repaired in flight</td></tr>
<tr><td>Make it so that it can be improved in flight</td></tr>
<tr><td>Aggressively define the problem based on recent advances in theoretical physics, broken into solvable sub-problems</td><td>• Identify the radiation issues with each module
• Arrange the modules to maximum effect and minimal risk</td></tr>
<tr><td>Democratize the problem solving mechanisms by breaking them into manageable components.</td><td>• Make affordable prototypes and popularize methods for prototyping and arranging modules (crowd source)</td></tr>
</table>

Good Pawn Candidates

System	Modules
Power Management	• Lithium Batteries, Power Management, Electronics, etc.
Air Processing	• Filters, Oxygen Injectors, CO_2 filters, Monitoring, Fans, etc.
Gray Water Processing	• Filters, centrifugal distillers, UV light treatment, etc.
Food and Medication Storage	• Cold boxes, Foods sorted by crew/etc. • Stored closest to crew for radiation protection
Waste storage	• Compacted trash, Desiccated human waste • Stored to the extreme outside of the ship (shielding)
Tools and Science Gear	• Repair parts, tools, first aid, science gear, medical monitoring
Appliances (stored)	• Flashlights, cleaning equipment, toiletries, etc.

20 x 60 cm Module Arrangement

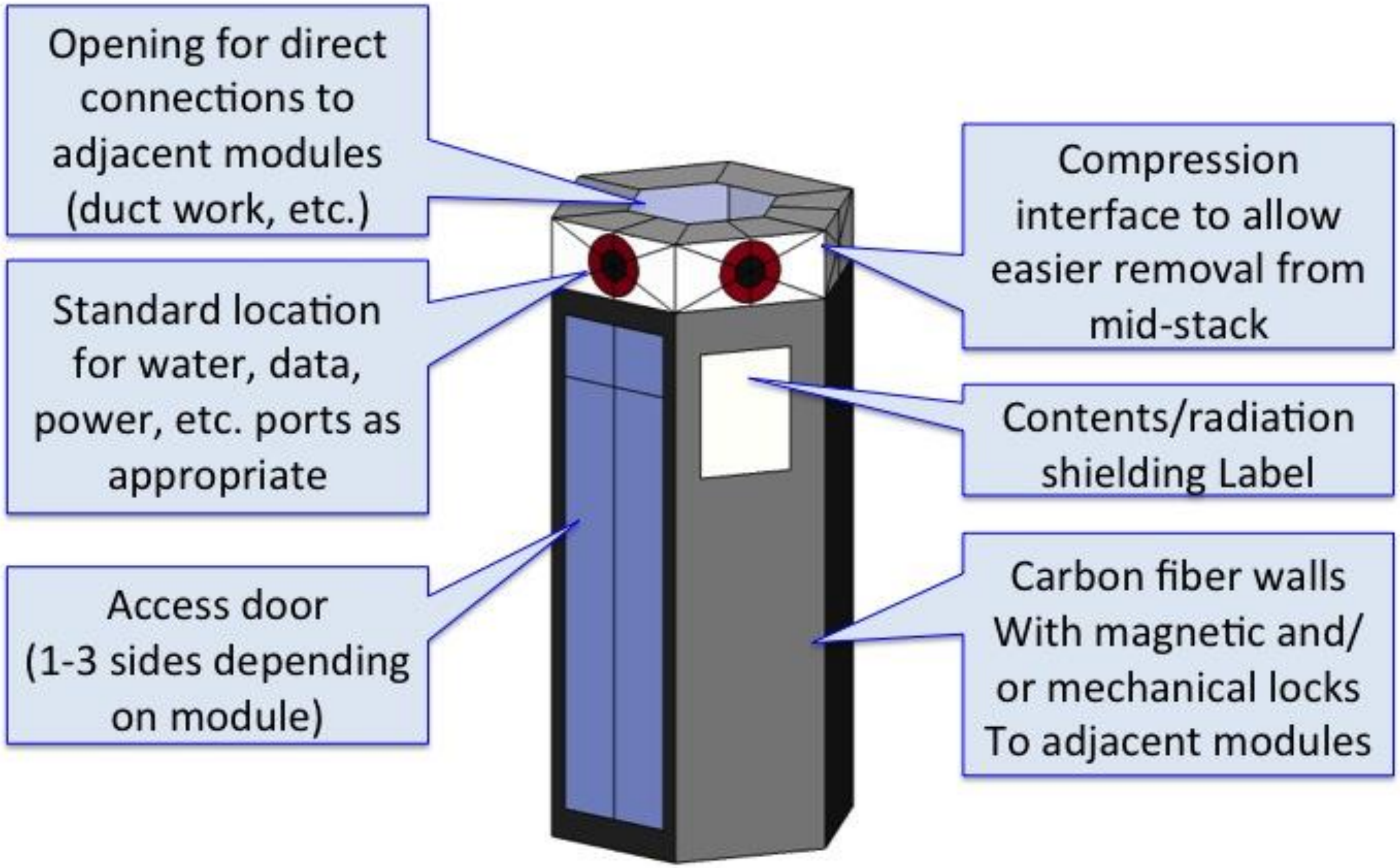


Illustration: Kent Nebergall

Mission Mini-Module (Pawn) Features

System	Modules
Quick Disconnect Interlocks	• Modules are held together with industrial Velcro, magnets or bolts as appropriate
Connections	• Ports for water, data, power, air, etc. go through direct connections to other modules or “rails” in the walls. • Commodities (power, etc.) can be used or passed through any module.
Soft End for In-Line Removal	• One end is spring-loaded to allow one module to be removed without disrupting the entire column.
Service Doors	• One side of module can be opened to allow quick servicing of contents.
Interchangeable Parts	• Module housings, ports, etc are themselves interchangeable to allow broken units to be used for parts to repair or modify other units.

Stack of Modules – Life Support

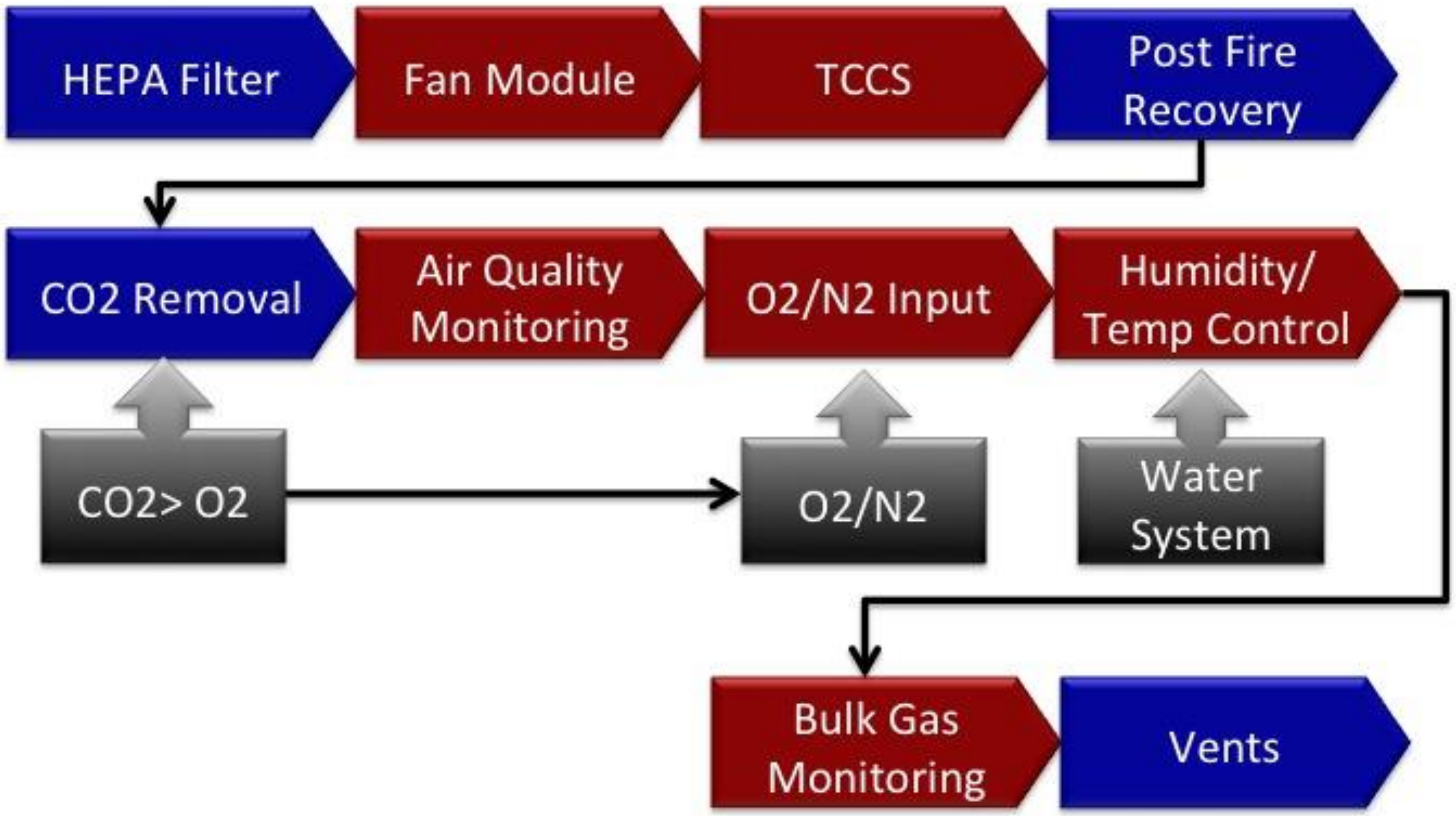


Illustration: Kent Nebergall

Inspiration Mars Section

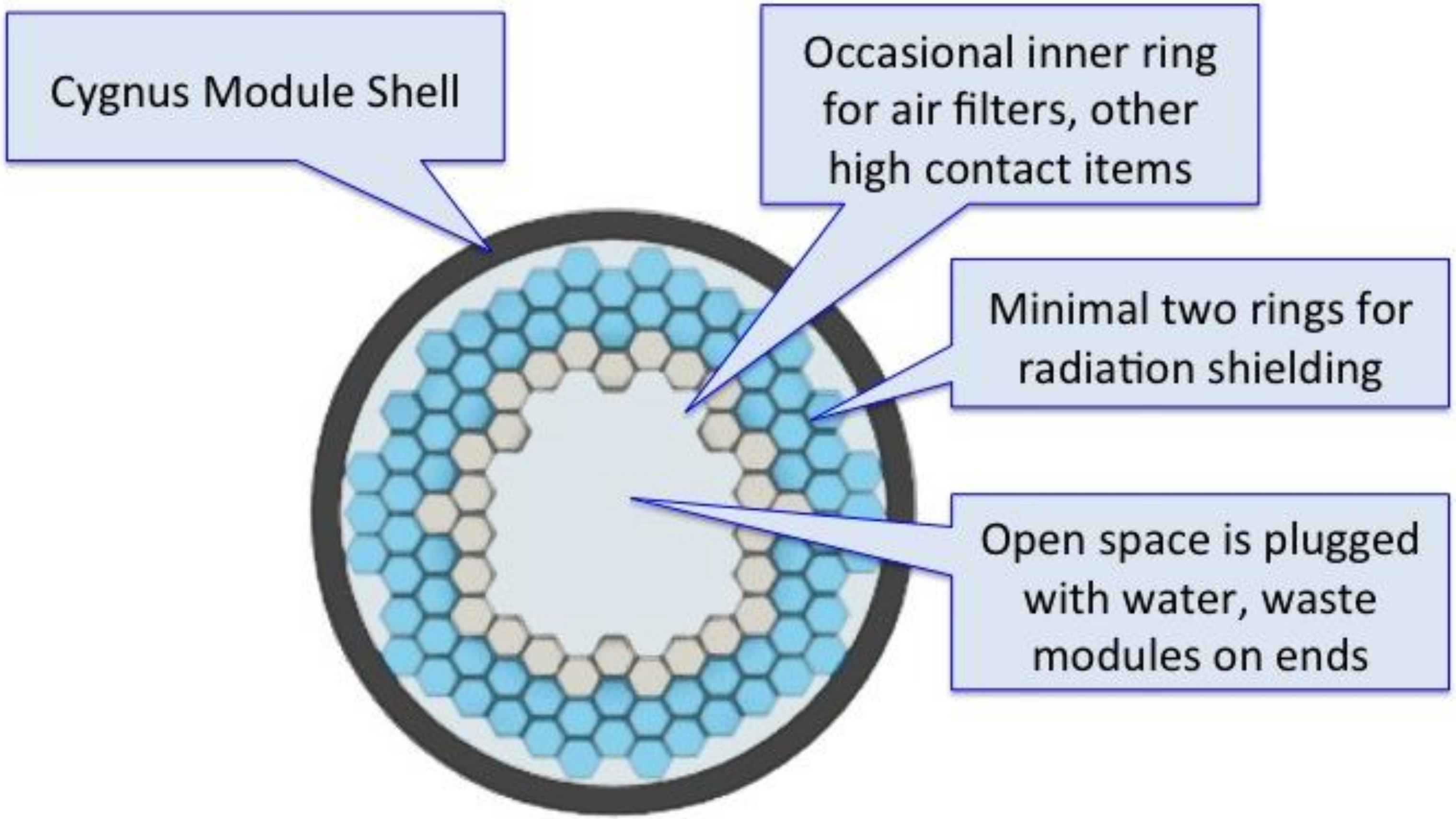
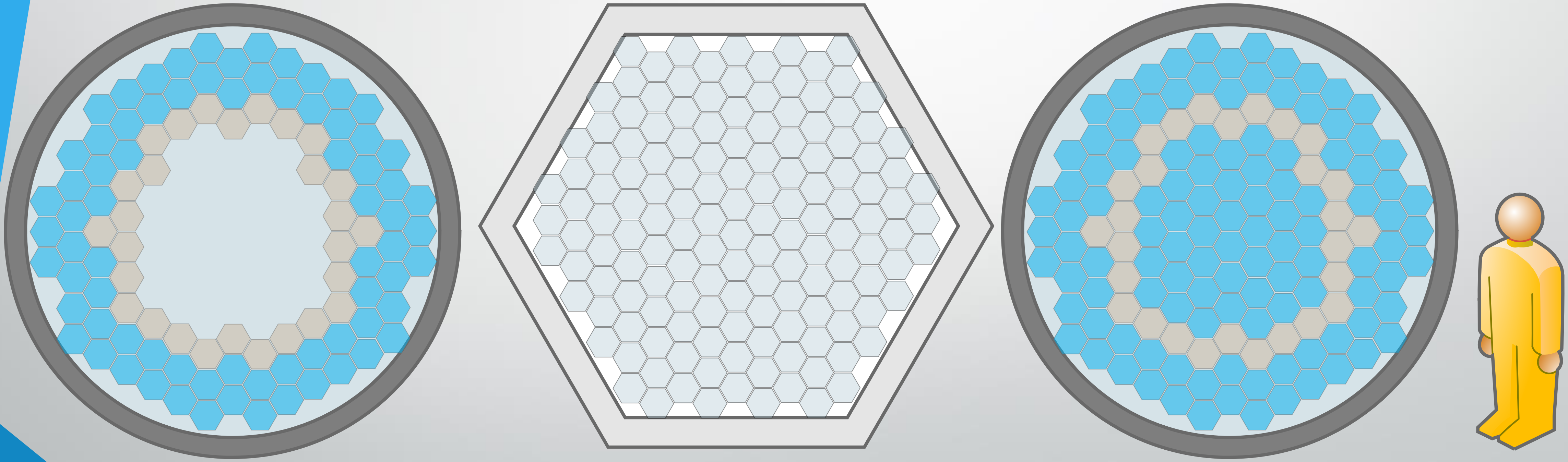
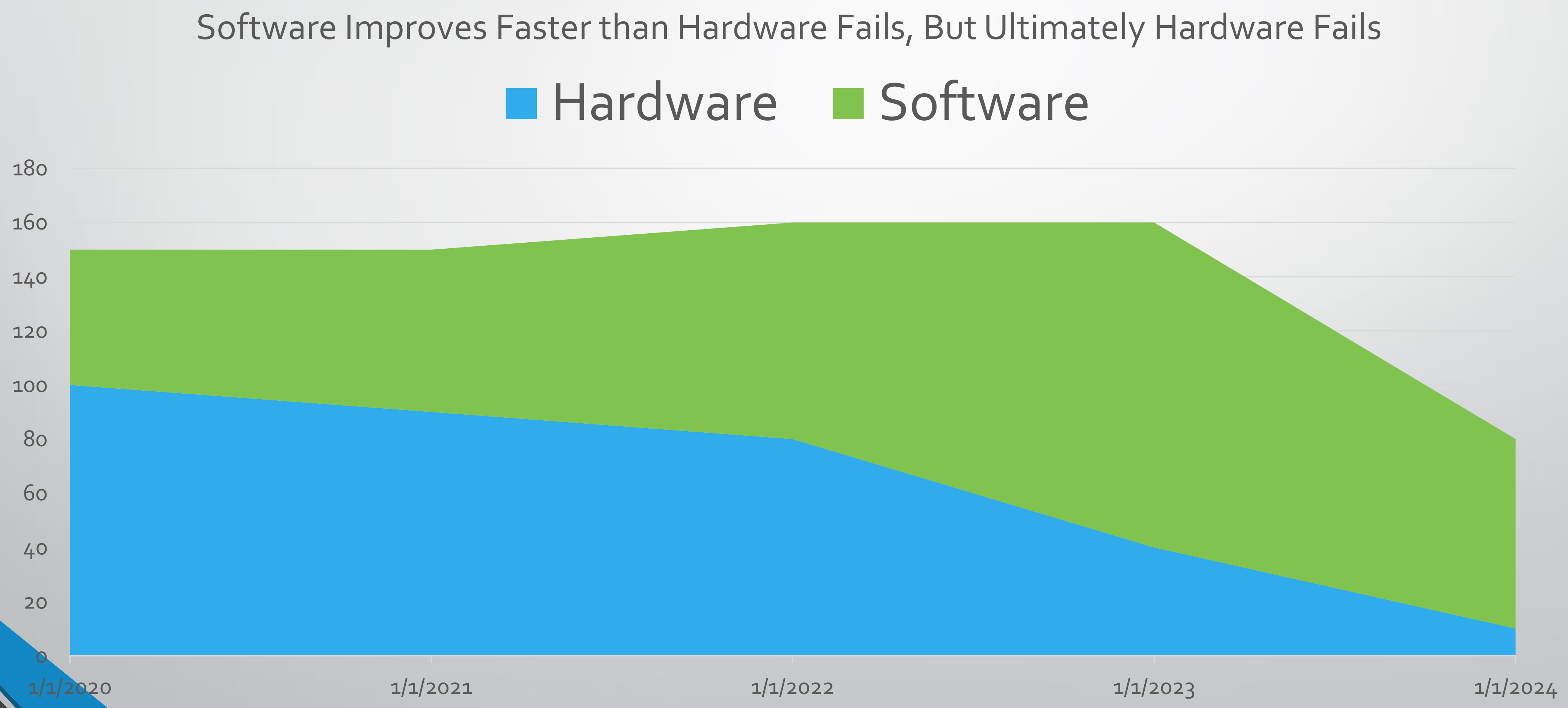


Illustration: Kent Nebergall

Scale Image

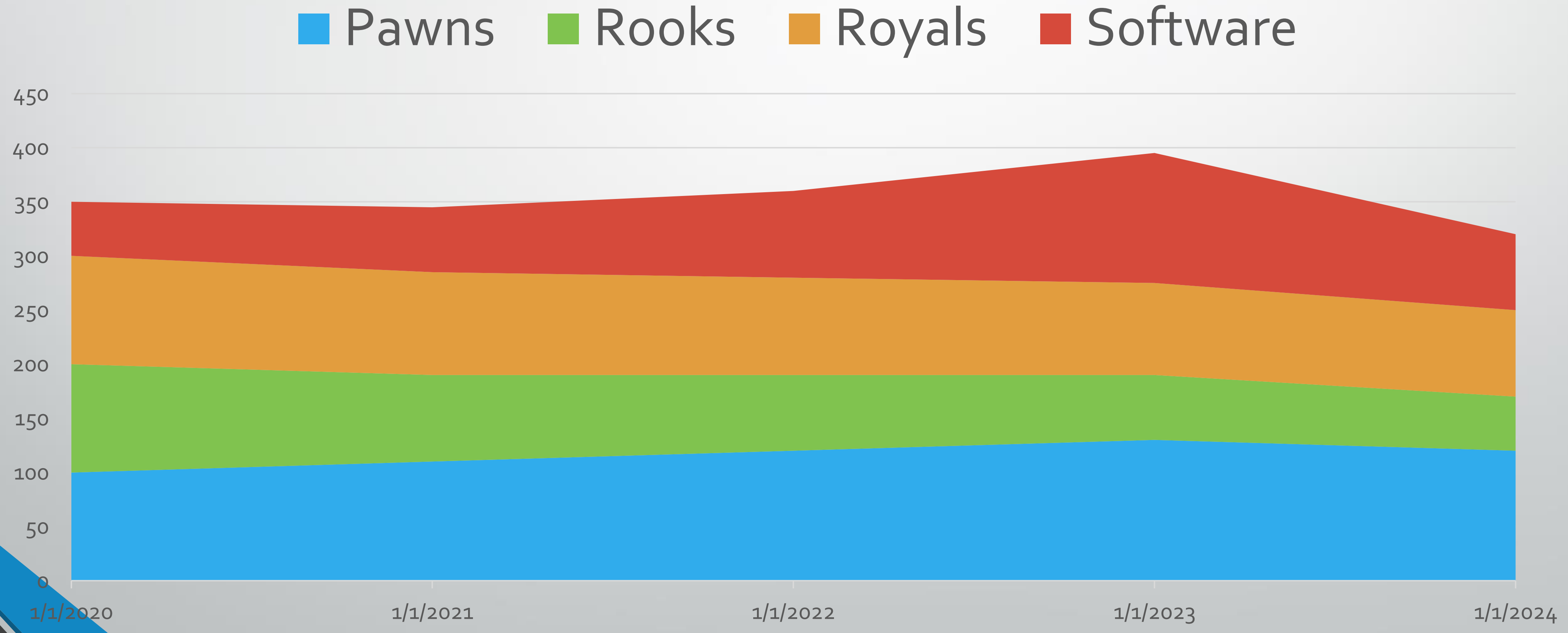


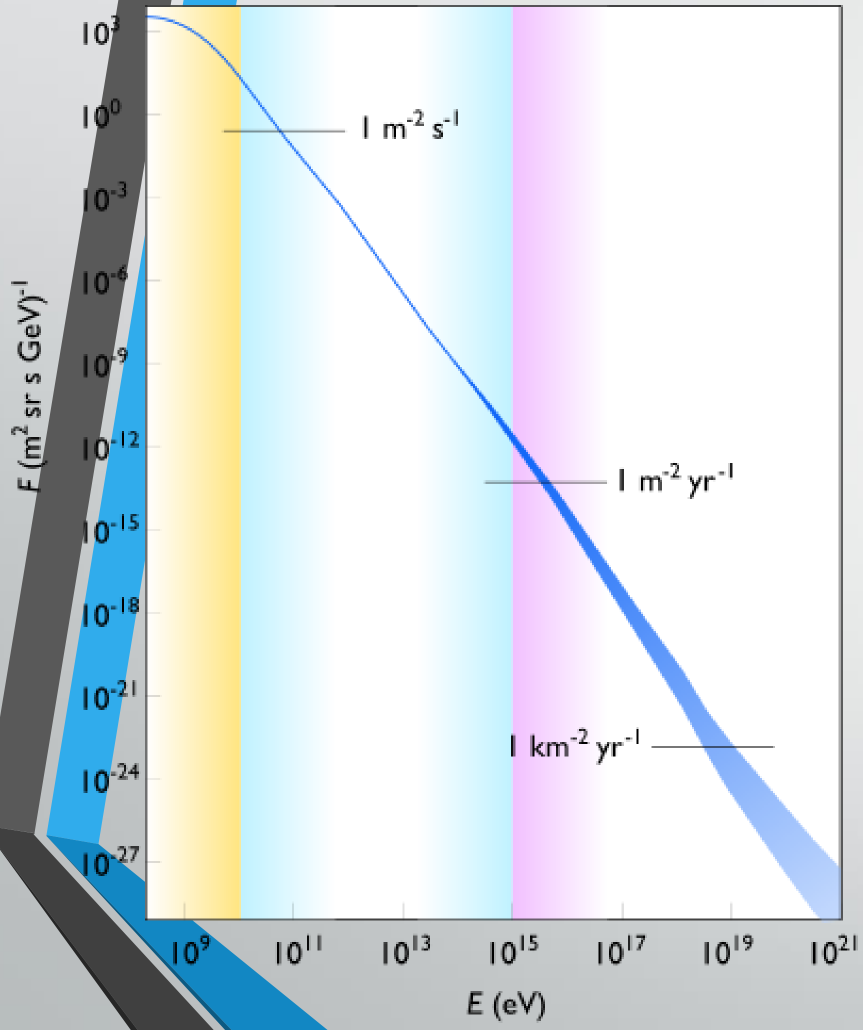
Robotic Probes



Layered Crewed Missions

Hardware Systems can be Repaired and Upgraded In-Flight

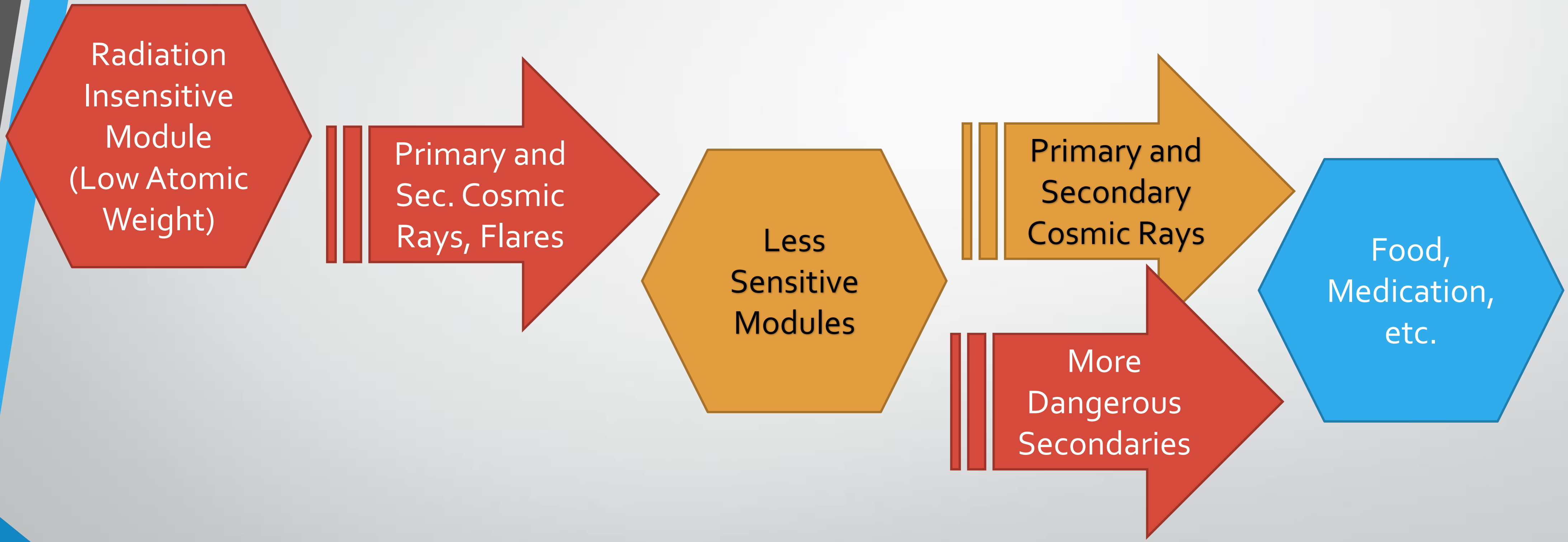




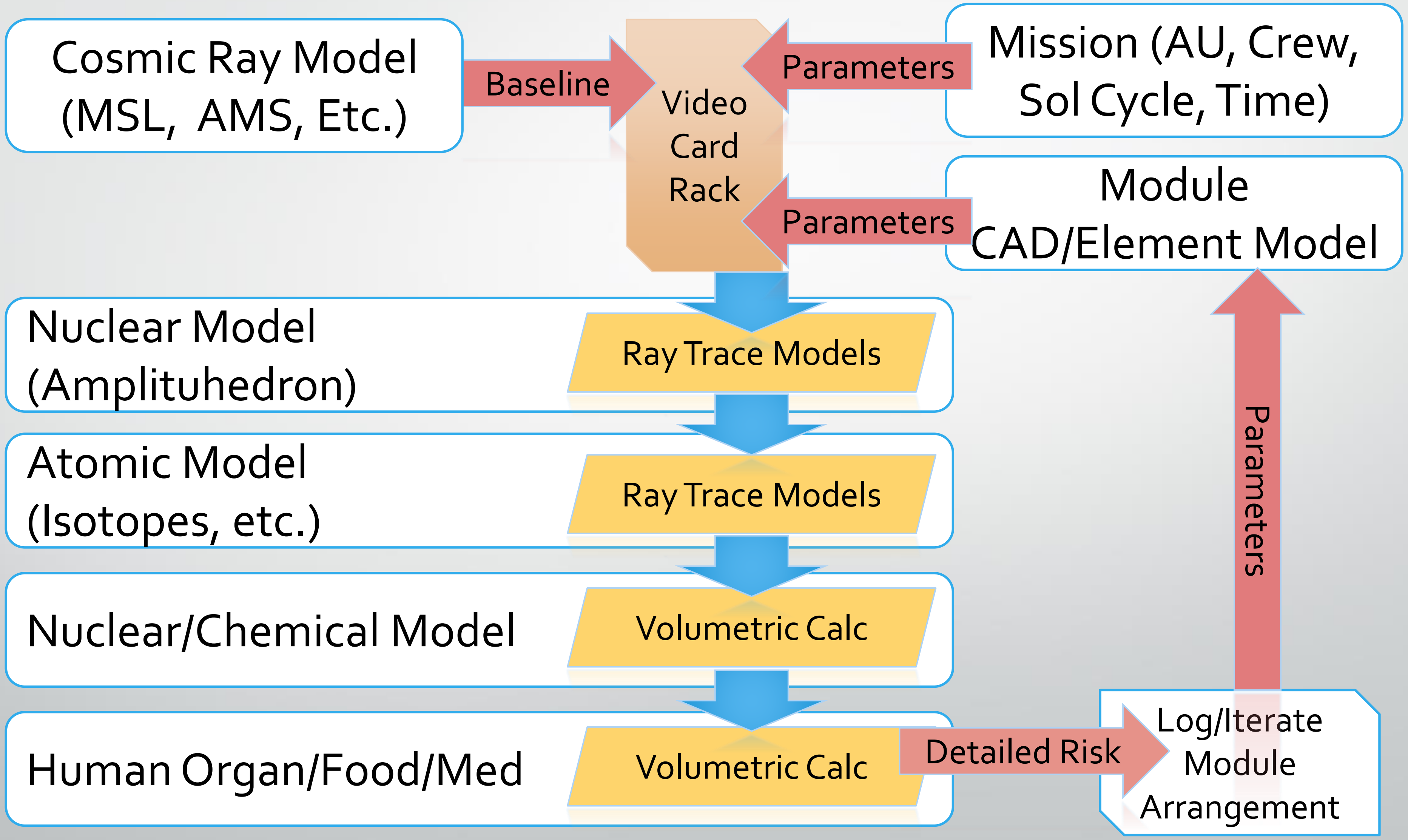
Radiation Modeling

- The most dangerous cosmic rays are also the least frequent.
- Modeling particle collisions used to require thousands of pages of Feynman Equations.
- A recent mathematical advance, called an amplituthedron, reduces this to a single page that can be calculated by hand.
- It should therefore be possible to model radiation impacts at the subatomic, ionizing, kinetic, and thermodynamic levels for each incoming energy and element/thickness

Radiation Shielding



Cosmic Ray Threat Modeling/Design Cycle



Rapid "Object Oriented" Prototyping

- Create specifications for each module and integrate the module designs
- Prototype the cheapest ones first and confirm they meet specifications
- Adjust specifications for more expensive modules and integrate.
- Where the system is scaled incorrectly, adjust the size of the module or the number of modules, until it meets the system requirement
- Test each module to destruction – compare lifespans of components and adjust to mission / each other

Cost and Development Advantages

Category	Conventional Development	Pawn Development

Design	• Design full system as one unit.
	  • Long lead time
	  • Very expensive.
	  • No ability to scale
		• Design system as series of modules
		• Design modules using various technologies
		• Prototype and test each module
		• Create Radiation model by module

Testing	• Built one unit (long lead) and test. If design failure, expensive to start over. • Radiation modeling an afterthought to system design	• Test integrated system with best of modules (design already tested before built) • Vastly simplified radiation modeling, able to change in flight.
Actors	Only government labs, aerospace contractors and universities can afford to operate here	• Anyone specializing in a module component can build and test to the sub-specification

Incremental Advances

Gen	Technology	Flight Time / Station Design
1	• Disposable CO_2 Filter	• 1-2 weeks
2	• Reusable CO_2 Filter • CO_2 Filter Heater/Vent	• 1-6 months
3	• Sabatier Reactor (several Modules)	• 1-6 years
4	• Cryo CO_2 Removal	• If co-located with cryo technology (refueling, etc.)
5	• Algae, greenhouse, etc. (with backup)	• If co-located with greenhouse or algae tanks

Crowd-sourcing Design Work

Category	Conventional Development	Pawn Development
Component Design	• Only aerospace engineers function this space	• Engineers in the specific problems of filters, etc. can be brought into the system.
Integration Testing	• Full systems are tested at once and must work first time or time wasted	• Anyone who can prototype can do first order testing and submit improved versions
Next Versions	• Full systems must start over with new technology as it is accepted	• Any single component can be improved, tested, and replaced- even in flight.
Computer Models	• Advanced CAD software, in house, limited to the team	• Any phone app or game can be used to model a system.

For More Information
(Kindle Book)
Kent Nebergall
kent@macroinvent.com