Planetary Sample Caching System Design Options

Curtis Collins * , Paulo Younse † and Paul Backes *

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, 91109, USA

Potential Mars Sample Return missions would aspire to collect small core and regolith samples using a rover with a sample acquisition tool and sample caching system. Samples would need to be stored in individual sealed tubes in a canister that could be transfered to a Mars ascent vehicle and returned to Earth. A sample handling, encapsulation and containerization system (SHEC) has been developed as part of an integrated system for acquiring and storing core samples for application to future potential MSR and other potential sample return missions. Requirements and design options for the SHEC system were studied and a recommended design concept developed. Two families of solutions were explored: 1) transfer of a raw sample from the tool to the SHEC subsystem and 2) transfer of a tube containing the sample to the SHEC subsystem. The recommended design utilizes sample tool bit changeout as the mechanism for transferring tubes to and samples in tubes from the tool. The SHEC subsystem design, called the Bit Changeout Caching (BiCC) design, is intended for operations on a MER class rover.

I. Introduction

A potential future Mars Sample Return mission would need to acquire surface core samples with a rover and then store the samples in a container that could be returned to Earth.[1] The samples would need to be stored in individual sample tubes which would be sealed.[2,3] Significant care would be required to minimize contamination of the samples by Earth-source contaminants or by cross-contamination with material from other Mars sampling locations. Additionally, the system of sampling tool, sampling tool deployment device, and sample handling and encapsulation system would need to have minimal mass in order to fit on a MER-class rover.[4] Past solutions have been unsatisfactory for various reasons including total system mass, sample contamination, or robustness. This problem applies to various mission architectures for returning samples from Mars to Earth including 1) Mars Sample Acquisition and Return in which a sampling rover and Mars ascent vehicle would be on one lander, 2) Mars Prospector and Sample Fetch in which a Mars Prospector mission would land a sampling rover that would collect the samples in a sample container that could be returned to Earth and a subsequent mission would land a fetch rover to retrieve the sample cache and return it to the lander with a Mars Ascent Vehicle, and 3) an Astrobiology Field Laboratory with Caching mission which would be similar to the Mars Prospector mission but would include in-situ analysis instruments that would require processing of some samples for ingestion into on-board analysis instruments.[5–7]

Technology applicable to potential MSR missions is currently under development at the Jet Propulsion Laboratory. The Integrated Mars Sample Acquisition and Handling (IMSAH) system task takes a unique systems level approach to requirements definition, mission interfaces, and trade space analysis. The objectives of the task are to understand the evolving MSR mission concept requirements for sample acquisition and handling, generate recommended design options, and study the sensitivity of the complexity of the design solutions to the various requirements. The IMSAH system includes the complete end-to-end process of obtaining a core sample using a Sample Acquisition Tool (SAT) mounted on a MER class rover, and preparing the samples for potential return to Earth by encapsulating and storing them in a return canister. A Sample Handling, Encapsulation and Containerization (SHEC) subsystem has been developed in the context of multiple mission interfaces and subsystem integration requirements. The evolution of the SHEC subsystem design options and down-select process will be described in detail in the following sections.

*Mobility and Manipulation Group, M/S 82-105

†Robotic Hardware Systems Group, M/S 107-

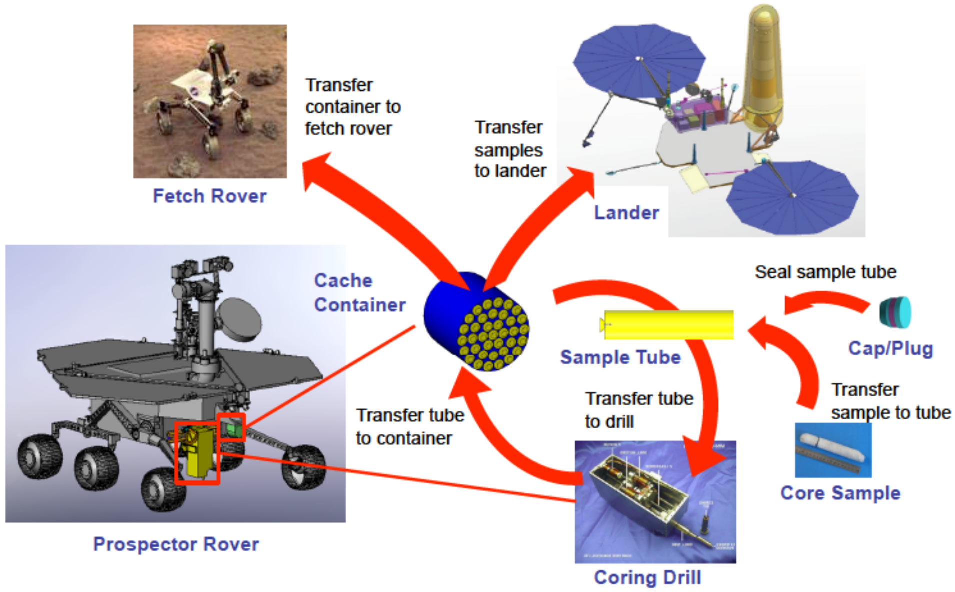


Figure 1. Architecture options for MSR sample acquisition and handling.

II. Requirements and Functional Decomposition

As potential Mars Sample Return mission scenarios have evolved, so has the understanding of the sample acquisition and handling requirements for obtaining and returning a sample of high quality and low contamination for future scientific investigation on Earth. Based on recommendations from MEPAG,[3] and previous development efforts[8] a new set of sample acquisition and handling requirements were created as a first step towards developing a new space of potential design solutions. A partial list of these requirements directly related to sample handling are shown in Table 1.

In general, the requirements specify the basic size and number of core samples to be handled by the subsystem. They also specify that the samples must be enclosed in tubes and sealed (encapsulated) both to minimize contamination and to enable further handling. The sample tool would be required to be able to eject bits in the event one gets stuck. At the system level, there is a requirement that sample volume or mass be measured at some point in the acquisition and handling process. A family of requirements relate to how the system interfaces to different mission scenarios. Depending on the mission, the handling system could be required to transfer individual samples or a whole canister of samples to an external surface system, or transfer individual samples to an internal analysis system. A diagram of of the sample acquisition and handling architecture and mission scenarios is shown in Figure 1.

In addition to the requirement description, we have also included our first impression of the implication of the requirement on the design (see Table 1). Implications highlighted in orange are considered most important. At a high level, the requirements suggest the existence of specific components (tubes, seals, canisters, bits), but are still general enough to admit multiple solution concepts.

As a first step towards developing system level concepts, we first examined the general process by which a sample would be acquired and stored. The sample acquisition and encapsulation process is inherently sequential. A core sample must be taken by removing part of the surrounding rock, and breaking-off the core from the bottom of the hole. Once the sample is separated from the rock formation, it is ready for handling by the system. The end state of the core is that it would be encapsulated in a tube that is sealed and stored in a tightly packed canister. The basic process for this is that the core would be inserted into a closed-end tube, the tube would be sealed and then placed in the sample canister. However, in an attempt to keep the the initial design option space as large as possible, we made an effort to describe the process by a set of high-level functions and characteristics so that we could evaluate the process from both a system and sub-system perspective.

At the highest level we know we would have SAT mounted on some kind of tool deployment device (TDD) that would bring the tool into contact with the rock surface. We also know there would be a sample canister to store the samples once they are encapsulated. To keep the design space manageable, we have

Sample Acquisition		
Number	**Proposed Requirement**	**Design Implication**
Return Sample Size	Acquire rock cores with dimension approximately 1 cm wide by 5cm long	Defines basic size
Number of Samples	Acquire at least 20 rock cores for return.	Need to accommodate extra samples
Bit Ejection	Be able to eject a bit that is stuck in a rock	Need spare bits and tubes
Sample Handling		
Number	**Proposed Requirement**	**Design Implication**
Sample Tubes	Store samples in individual sample tubes.	Must have tubes
Sample Sealing	Seal samples in sample tubes to prevent material loss through the seal.	Must have caps/plugs
Sample Transfer to Lander	Allow for transfer of five cores from the rover to a lander followed by acquisition of more cores from the rover.	Must be able to transfer tubes to external system
Sample Container	Fill the sample container such that it could be returned to Earth	Samples need to be tightly packed in returnable canister
Container Transfer to Fetch Rover	Design for transfer of a full sample container to a fetch rover or dropping the container on the ground.	Must have double walled canister accessible to external system
Sample Tube Repackaging	Sample tubes could be removed from the container for repackaging by another handling system	Re-insertable tubes
Handle In-Situ Samples	The system architecture would allow for transfer of raw rock powder and rock core samples to a future on-board rover handling and analysis system.	Secondary transfer point or transfer mechanism
System		
Number	**Proposed Requirement**	**Design Implication**
Sample on Slopes	Sample on slopes up to 25 degrees	Handle on slopes
Sample Measurement	Measure the sample with 50% volume or mass accuracy.	Could accommodate in SHEC

Table 1. Proposed SHEC-related requirements

made the assumption (as do the requirements) that the samples would be placed in tubes and sealed in some way. This implies that some kind of transfer and mechanization must take place to get the core into a tube and ultimately into a sample canister. Where this takes place is part of the option space. At this stage, we simply identify that something has to be transfered, possibly between the SAT and a SHEC subsystem. We also identify that tubes would need to be stored and possibly moved around, that sealing (encapsulation) must take place before the samples are finally stored, and that sample mass or volume would need to be measured.

An additional challenge that is implicit in the requirements is that we are attempting to design a system that would be compatible with multiple mission scenarios. To this end, we want to also generate and evaluate concepts that would allow samples to be packed into a return canister that would be accessible by an external system, or enable individual samples to be transfered to an external system.

III. Design Trade Space

With the requirements and system functionality taking form, the challenge was then to develop and study design solutions that have the potential to provide the desired end-to-end system functionality. The first step in this process is to create a morphology of design options and evaluate them against both the requirements and a set of additional design criteria. It is not enough for a concept to satisfy the requirements, it must also admit a physical realization compatible with flight system design development and constraints.

III.A. General Design Options

Based on the high level functions and characteristics that would be required of the sample handling system, we developed the morphology chart of design options, shown in Table 2. In it are simple descriptions of design concepts related to each function or characteristic. The morphology chart captures a design space of hundreds of high-level solutions.

Starting at the top, we articulate that the TDD would either be a low degree-of-freedom (DOF) mechanism, or a 5 DOF arm, and that the canister would either be closely or loosely packed. While the actual design of the TDD is not part of our design space, we needed to track the relationship between the handling system and the and deployment device to make sure the final design would be compatible at the system level. This is especially important if any material transfer would take place between the TDD and the handling system in general, and the canister in particular.

The next set of options, highlighted in yellow, all relate to handling and transfer of core samples or samples in tubes. It quickly became apparent that this was the critical set of options that lead to another more detailed level of design concepts (discussed in more detail in section III.B). At the functional level, the issues were essentially what to transfer, how the transfer takes place, and what effect transfer options have on the details of the interface between the subsystems. Basic options include transferring a core or a tube to a rigid or compliant receptacle.

The remaining options relate to tube handling and sealing, and sample measurement and storage. Functions relating to tube storage and exchange, as well as where and how to seal the sample in the tube, lend themselves to a smaller number of straight-forward options.[9,10] One thing to note about all of the transfer, tube, and sealing functions, is that we carry the option of performing all of operations in the SAT. There is also a desire to verify that a proper sample has been obtained by performing some kind of sample measurement. The last set of options relate to how the system would work in different mission scenarios. In a Prospector mission scenario the sample canister would be placed on the ground for retrieval by a Fetch rover while in traditional mission scenarios the canister or individual samples would be transfered directly to a lander containing the ascent vehicle.[6]

Function/ Characteristic	OPTIONS					
TDD (interface mechanism)	2-3 DOF Device	5 DOF Arm					
Canister	Closely Packed	Loosely Packed					
Transfer What	Raw Core	Core in Tube	Core in Bit	Nothing (Keep in tool)			
Transfer To	Tube in Rigid Canister	Tube in Compliant Canister	Tube in Compliant Structure*	Rigid Canister	Compliant Canister	Receptacle in Compliant Structure*	Keep in Tool
SAT Interface	Core out Front	Tube In/Out Front	Tube In/Out Middle	Tube In/Out Back	Keep In Tool		
SHEC Interface	Accepts Cores	Accepts Tubes	Accepts Bits*	Inserts Tubes*	None		
Tube Storage	In Canister	In Separate Rack	In Tool				
Tube Exchange	No Exchange - Keep in Canister	Direct Exchange	Indirect Excahnge*	No Exchange - Keep in Tool			
Encapsulate How	Cap	Plug	Crimp	Other			
Encapsulate Where	In Canister	In Separate Station	In Tool				
Sample Measurement	Mass	Volume	Visual	Other			
Mission Interfaces	Access Canister	Place Canister on Ground	Access Sub-Canister	Access Individual Samples			

* Requires secondary transfer mechanism

Table 2. Morphology chart of design options

III.B. Sample Transfer Concepts

In order to better understand the impacts that sample transfer had on the sampling and handling subsystems, we generated a more detailed set of design concepts based on the assumption that the SAT and SHEC are separate subsystems and that core samples would be transfered between them. The reason for this assumption relates directly to the impact of SAT mass on the TDD requirements. A low mass SAT would more easily enable the use of a 5 DOF arm which is considered a more desirable TDD solution since it would allow more flexible placement of the SAT for science based target selection.

Earlier technology development efforts generated a family of coring tool solutions (MiniCorer and CAT) that could obtain raw core samples and push them out the front of the tool.[11,12] Since the objective of our task is to study the space of design options that could lead to a complete end-to-end system, our morphology chart includes a raw core option. A second major option, which represents a distinct branch in the design options space, would be to transfer a tube containing the core sample. Detailed concepts flowing from these two branches were developed and organized into the focused sample transfer design tree shown in Figure 2.

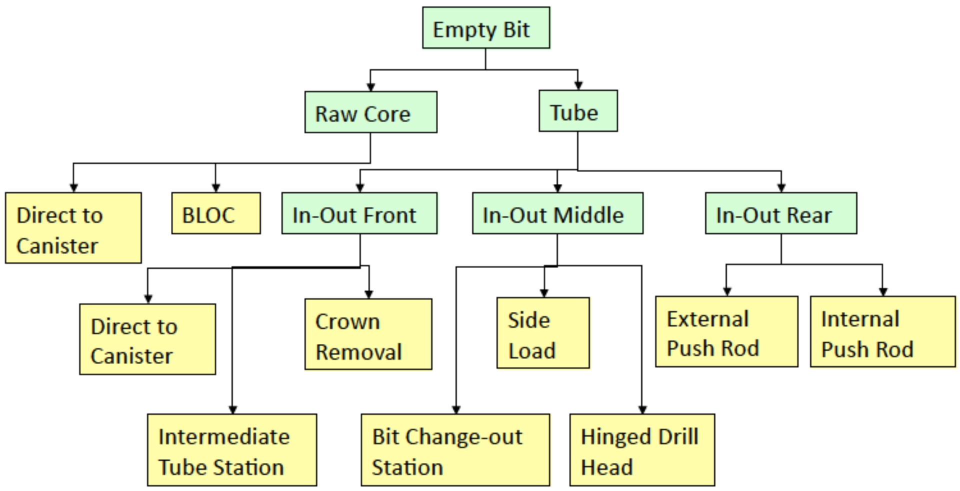


Figure 2. SHEC subsystem transfer options design tree

The design tree captures the idea that starting with an empty bit, we could either transfer a raw core or a tube out of the SAT. Since the detailed solution of pushing a raw core out the front of the tool has already been developed, we generated handling concepts directly from this point (a Direct to Canister concept and the Bottom Loading Caching concept[8]). The idea of collecting a core sample directly into a sample tube and transferring the tube with sample out of the tool was studied in more detail. The next level of options relate to where along the tool the transfer would take place (front, middle or rear). A set of handling concepts was developed for each potential transfer point as represented by the yellow leaves of the tree. It was also recognized that if the tool did not carry a set of spare/empty tubes, one would have to be provided/transfered by the external handling system.

Table 3 shows pictorial representation of core and tube transfer concepts organized by the number of distinct transfers required by the specific solution. Each concept will be described briefly below. One of the key issues the concepts attempt to address in addition to the transfer option is the requirement that the sample canister is sized so that it could be returned to Earth without repackaging. This imposes a constraint that the samples be closely packed with minimum wasted space, in a circular area of 7-9 cm in diameter.[6,13,14] This requirement adds a level of complexity: that the system would have to ultimately enable a precision tube insertion operation.

Transfers out of the front of the tool admit a family of direct-to-canister solutions. The first is the Direct to Canister (Core) concept where the SAT would push the core sample out of the bit using a pushrod into a tube that sits in the return canister. This concept requires a precision alignment between the tool and the canister which could be achieved using a rigid guide (shown notionally) to aid the alignment, or could be achieved if the whole canister were mounted on a compliant interface. Similarly, the Direct to Canister (Tube) concept incorporates the same alignment features but where the tube with sample would be transfered to the canister. This concept requires a bit design that would allow the tube to be pushed out the front of it. In the third option, we imagine a station where the crown of the bit would somehow be removed allowing the tube to be transfered out the front and into the canister in the same way as the previous concept. Both the precision that would be required by the TDD (even with affordances and/or compliance) to perform precision tube insertion, and the complexity associated with enabling the tube to be pushed out the front of the bit make this family of solutions less desirable than others.

The remaining two concepts in which a core or tube would be transfered out of the front of the tool admit what we refer to as a three stage transfer option. In these concepts, three exchanges would occur. The first would be between the tool and a compliant intermediate transfer station; the second would be between

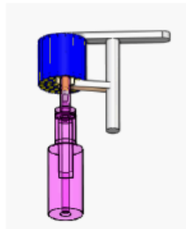
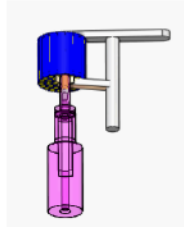
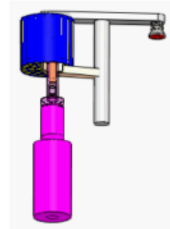
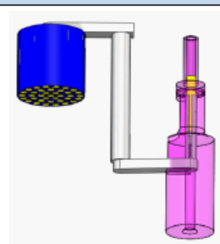
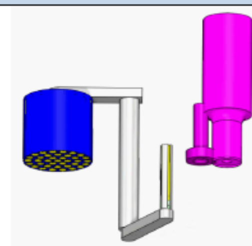
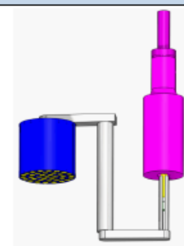
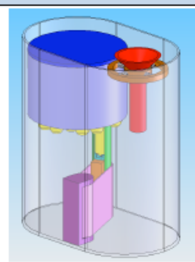
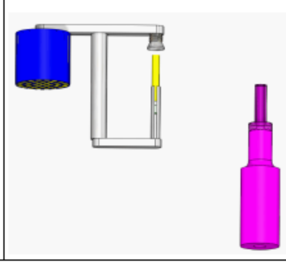
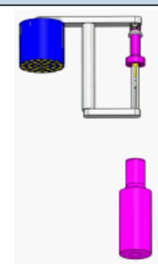
System	Direct to Canister (Core)	Direct to Canister (Tube)	Crown Removal
Direct Transfer Options			
System	Side Load	Hinged Drill Head	Push Rod
Two Stage Transfer Options			
System	Bottom Loading Cache	Intermediate Tube Station	Bit Change-Out Station
Three Stage Transfer Options			

Table 3. Core and tube transfer option concepts

the intermediate transfer station and a precision transfer arm; and the third would be between the transfer arm and the return canister. In the Bottom Loading Caching concept, the tool would be aligned with a compliant funnel containing a sample tube. The tool would push the core into the sample tube and move away. The transfer arm would then take the sample tube from the compliant funnel and insert it into the sample canister. Similarly in the Intermediate Tube Station concept, the tool would align with a compliant station and transfer the tube with sample to it. The tool would then move away, and the transfer arm would pick up the tube and insert it into the sample canister. The use of an intermediate compliant interface would allow reduced accuracy requirements on the TDD while enabling precision sample tube insertion to be achieved by a precision transfer arm. The transfer arm would also provide a natural solution for storing tubes outside the SAT allowing new tubes to be obtained through the tube transfer mechanism.

Other options for getting a tube in and out of the bit would involve going through the middle of the SAT or out the back. A family of transfer concepts compatible with these options would involve a two stage transfer. For the Side Loaded, Hinged Drill Head, and Push Rod concepts the SAT would be aligned with a transfer arm which would remove the tube with sample from the middle or rear of the tool (first transfer). The tube would then be inserted into the sample canister (second transfer). The transfer arm would enable new tubes to be taken from the sample canister or spare tube rack and inserted into the tool. It is unclear in all of these solutions how large the clearances would need to be between the transfer arm and the SAT to account for TDD positioning uncertainties.

The last concept takes advantage of the natural break between the coring bit and the SAT required by the bit exchange requirement. It also naturally lends itself to a three stage transfer operation. In this concept the tool would be aligned with a compliant station that accepts bits. The bit would be released with the tube and sample inside (first transfer). A precision transfer arm would then remove the tube from the bit (second transfer) and insert it into the sample canister (third transfer). The process could be reversed to transfer clean tubes from a canister or storage area to the bit. The tool would then re-engage the bit (with tube inside).

III.C. Concept Evaluation

Function/ Characteristic	Key Decision	Baseline	Reasoning
TDD (interface mechanism)	2-3 DOF Device **vs** 5 DOF Arm	5 DOF Arm	Would allow placement flexibility and improves science return
Canister	Closely Packed **vs** Loosely Packed	Closely Packed Canister	Could be required by interface to fetch rover mission
Transfer What	Raw Core **vs** Core in Tube	Core in Tube	Would reduce risk of transfering broken cores
Transfer To	Canister **vs** Receptacle	Compliant Receptical	Would enable robust alignment with TDD. Requires secondary precision transfer arm.
SAT Interface	Out Front **vs** Out Middle	Tube Out Middle	Would take advantage of natural break in mechanism required by bit exchange
SHEC Interface	Cores **vs** Tubes **vs** Bits	Accept Bits	Would satisfy bit excahnge and tube transfer requirements
Tube Storage	Canister **vs** Separate Rack	Canister and Tube Rack	Would allow fully populated return canister plus extra tubes and additional sample storage
Tube Exchange	Direct **vs** Indirect	Indirect Tube Exchange	Would decouple TDD from precision transfer and handling operations
Encapsulate How	Cap **vs** Plug	Plug Tubes	Plug could seal and restrain sample in tube. Could also be used to measure sample volume
Encapsulate Where	Canister **vs** Station	Sealing Station	Would provide plug placement, sample preload, sample sealing and volume measurement with single hardware station
Sample Measurement	Mass **vs** Volume	Infer Volume	Plug pushed down on sample to infer volume
Mission Interfaces	Fetch **vs** Pedal	Support Both Missions	Canister would be accessable from top, and individual or batches of samples could be transferred via bit-exchange interface

Table 4. SHEC subsystem baseline design decisions

Each of the options represented in Table 2 was carefully evaluated based on the following criteria:

1. Would Satisfy Proposed Requirements - would the concept perform the necessary function or have the necessary characteristic?
2. System Impact - would the concept integrate well with the system architecture?
3. Mass - how do related concepts compare in mass?
4. Volume - how do related concepts compare in volume?
5. Complexity - would concept complexity outweigh its utility?
6. Robustness - could the concept handle environmental and system level uncertainties?
7. Path to Flight - would the concept admit a flight implementation for material selection, fabrication and assembly process, and cleaning processes with acceptable flight margins ?
8. Contamination Control - would the concept minimize contamination? (especially important for scientific value of sample return missions)[15,16]
9. Planetary Protection - would the concept satisfy additional PP requirements? (especially important for sample return missions)[17,18]
10. Flexibility/Adaptability - could the design evolve with changing requirements

The system and requirements imposed the baseline option that the TDD would be a 5 DOF arm and that the sample canister would be closely packed to accommodate a direct return to Earth mission. Once these constraints were imposed, transfer solutions that admitted precision sample insertion were immediately ranked higher.

The next set of evaluations was focused on end-to-end transfer systems. At first, the solution with a raw core being transfered out the front of the tool and handled by the Bottom Loading Cache system appeared

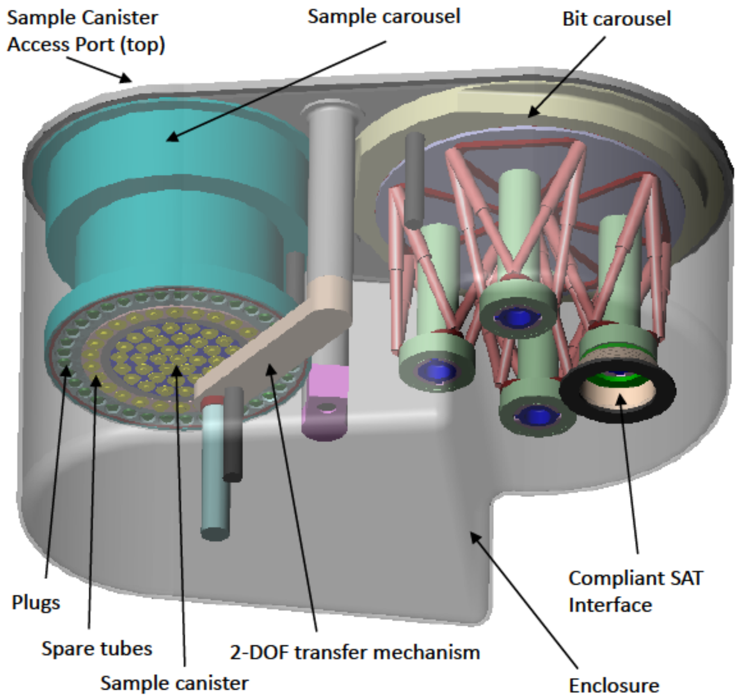


Figure 3. SHEC subsystem baseline design overview

to satisfy all the requirements and was compatible with various encapsulation solutions. However, the risk associated with the transfer of broken cores pushed the design towards a solution where the core would be acquired directly into the sample tube. Transforming the problem of handing cores to handling tubes greatly reduced the risk associated with handling cores of unknown integrity. From here, the Bit Changeout Station concept was chosen as the baseline design and renamed the Bit Changeout Caching (BiCC) concept. While the system based on this concept would more complex (number of parts, number of actuators, etc) and would likely require more mass and volume allocation, it would satisfy all the requirements, simplify the SAT design, allow both precision sample transfer and sample exchange with an external system (through bit changeout), and upon further detail design admit multiple configurations that would allow it to adapt to evolving requirements.

Once the tube transfer via bit exchange was selected, secondary options were quickly evaluated and selected. Tube storage and exchange solutions compatible with the BiCC concept naturally became apparent. Handling the tube also would lend itself to various capping or plugging options for encapsulation. In the end we created a new concept that would combine plug-based encapsulation with sample measurement. The BiCC concept immediately demonstrated its adaptability when evaluating it for compatibility with different mission concepts. While specifically developed for enabling a sample return sized cache retrievable or deployable from the rover-based system, the bit changeout interface could also be used to transfer individual samples to a secondary lander system.

Table 4 shows a summary of the key design decisions (over the generated options) made for the end-to-end SHEC subsystem design. Based on these selected concepts, a more detailed end-to-end concept design was developed.

IV. SHEC Subsystem Design

The base line design concept for the SHEC subsystem is shown in Figure 3. The design consists of two carousels: a bit carousel containing bits mounted on compliant mechanisms, and a sample carousel containing an integrated sample canister (sized for return to Earth) filled with empty tubes as well as a ring of spare tubes and a ring of plugs. A transfer arm with a rotational joint and a prismatic joint would be configured to align itself with any sample tube or plug on the sample carousel or a bit on the bit carousel. The entire

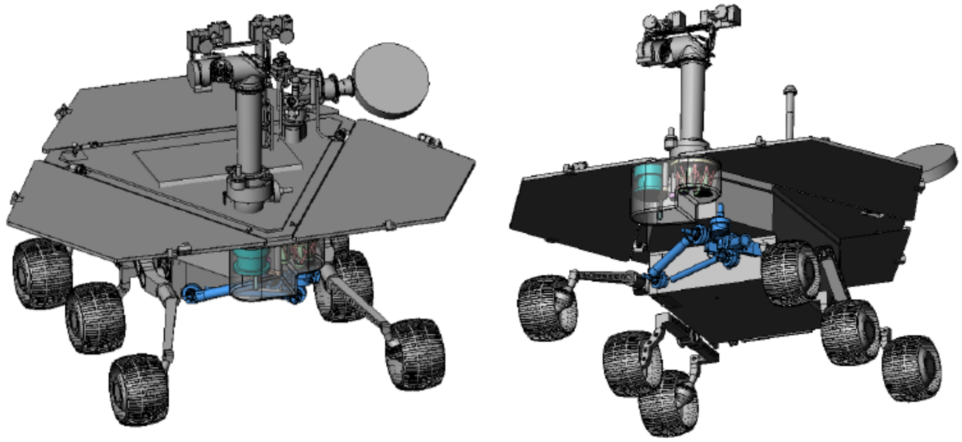


Figure 4. SHEC subsystem mounted on MER class rover

system would be covered by an enclosure with a single opening where the SAT interfaces with it for bit changeout. A door on the top of the sample carousel would allow access to the sample canister.

An example sequence for sample acquisition and handling is provided below.

1. Handling arm would pull an empty tube out of the sample carousel.
2. Handling arm would transport the empty tube to the bit carousel and insert it into a sampling bit.
3. The robotic arm (not shown in the figures) would transport the sampling tool to the insertion bellows below the bit interface, engage the bit and then pull the bit out of the SHEC subsystem.
4. The robotic arm would transport the sampling tool to the planetary surface and acquire a rock core sample.
5. The robotic arm would transport the sampling tool to the SHE subsystem and insert the bit into the SHEC subsystem.
6. The sampling tool would release the bit and the robotic arm would move the sampling tool away from the SHEC subsystem.
7. The handling arm would move to the newly inserted bit and remove the sample tube that would now have a sample in it.
8. The handling arm would move the tube to the sample analysis station to verify that a sufficient sample has been collected, as well as possibly doing some type of sample analysis.
9. The handling arm would move the tube to a plug on the sample carousel and push the tube to force the plug into the sample tube to seal the tube and estimate the volume of the sample.
10. The handling arm would move the tube to the sample carousel and insert the sealed tube into the vacated tube chamber.

The SHEC system is sized so that it could be mounted on a MER class rover as shown in Figure 4.

IV.A. Discussion

The Bit Changeout Caching (BiCC) architecture would be fundamentally sound for the sample handling and encapsulation system for a potential future Mars Sample Return mission and is consistent with the various currently conceived potential mission architectures. The BiCC architecture would utilize bit changeout to transfer the sample from the sampling tool to the sample handling (SHEC) subsystem. A sample tube would be inserted into a sampling bit by the SHEC subsystem when the bit is in the bit carousel and before the sampling tool attaches the bit. The sampling tool would attach to the bit containing the sample tube, then move to the surface where it would acquire the sample. It would then transfer and release the bit back into the bit carousel in the SHEC subsystem. The SHEC subsystem would then remove the sample tube from sampling bit, put a cap on the tube, and store the tube in a sample container. The SHE subsystem would then retrieve an empty sample tube and load it into an empty sampling bit that the sampling tool could attach and use to acquire another sample.

The SHEC system would also have the following key features:

- The sample tube carousel would rotate around a central axis and include the sample container filled with sample tubes, spare sample tubes, and sample tube plugs.
- The sample container would be in the inner part of the sample tube carousel and would be designed to be able to be returned to Earth, meaning that it would be close packed with sample tubes and could be removed from the sample tube carousel after filling.
- Sample tube plugs would be available to inserted in to filled sample tubes to seal the samples, possibly with a hermetic seal, and estimate sample volume.
- The sample measurement station would provide measurement of a sample in a sample tube before the tube is sealed.
- The sample plugging station would put the sample tube plug into a sample tube.
- The sample analysis station would provide analysis of a sample in a sample tube.
- The transfer arm would transport the sample tubes between the various locations in the SHEC subsystem.
- The bit carousel would rotate about a central axis and hold multiple sampling bits. It could receive a sampling bit from a sampling tool which would release a bit and it could provide a sampling bit to a sampling tool that engages a bit.
- Bit chambers would hold individual sampling bits.
- The compliance devices would hold bit chambers and provide a passive compliance platform to accommodate inaccuracies in alignment between the sampling tool and a bit chamber.
- A bellows would provide a compliant seal between the SAT and the SHEC at the insertion point of a sampling bit into the bit chamber.

IV.B. Ongoing and Future Work

With the basic concept design in place, we are proceeding with a detailed proof-of-concept prototype design of the SHEC subsystem. The functional prototype has a central sample canister that can accommodate 19 sample tubes and a ring with 3 spare tubes and plugs for each tube. The bit carousel is configured with 4 compliant bit housings composed of flexures to accommodate TDD misalignment. Each carousel is actuated by a brush DC motor through a spur-gear transmission. The tube transfer arm has a 6-axis force/torque sensor mounted on its base. The rotation joint is actuated by a brush DC motor through a harmonic drive, and the prismatic joint isactuated by a brush DC motor through a combination gearhead and linear screw drive. Critical components are manufactured out of aluminum and rapid prototyping materials are used wherever practical. Sample tubes are stock brass tubing cut to size, and plugs are aluminum with custom Teflon spring seals. Figure 5 shows the first prototype assembly with sample canister removed and a 6 cm long 1 cm diameter sample tube placed provided for scale.

The prototype will be integrated with motor drivers and mounted on a small rover with a representative arm and coring tool. An end-to-end proof-of-concept demonstration is also planned. Once the basic functionality of the system is established, a focused engineering effort is planned to bring the system to TRL 4, for additional Earth based testing in a natural environment.

Figure 5. SHEC functional prototype showing return canister and 6 cm long and 1 cm diameter sample tube.

V. Conclusion

Prior architectures for sample transfer from shallow coring tools utilized sample ejection of the front of the sampling bit. These had the drawbacks of the complexity of having to have a pushrod in the sampling tool and the more problematic feature of requiring handling of a raw sample. Since the characteristics of each sample would be unique and the material properties of samples on Mars cannot be sufficiently predicted for necessary system robustness testing, handing a raw sample would reduce system reliability relative to a solution that would not require handling of raw samples. The BiCC architecture would simplify the sampling tool by removing the need for the pushrod and make sample handling more robust by changing it to handling of sample tubes which is much more repeatable. The BiCC system is the first to provide an end-to-end system design for sample acquisition and handling for the family of proposed Mars Sample Return mission architectures. For in-situ sample analysis a specialized sample tube would be used to allow the SHEC to transfer the sample to an on-rover processing and analysis system.

The BiCC architecture supports the various potential Mars Sample Return mission architectures. For the Mars Sample Acquisition and Return mission architecture concept, a rover would go out and acquire about five samples and return them to a lander and transfer them to the lander. The BiCC system could do this by transferring filled sample tubes in sample bits one-by-one to the lander which would then remove the sample tubes and return the bits to the BiCC system. The Mars Prospector plus Sample Fetch architecture concept would be supported by filling the sample container with samples and then either ejecting the filled sample container onto the ground or providing access to the filled container for a potential future fetch rover to remove.

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