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Characterization of Contaminated Stacks at Nuclear Facilities

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ABSTRACT

The stack decommissioning processes have been explained at irregular intervals in procedural literature; there is almost no complete treatment of dismantling and decommissioning methods for contaminated chimneys. In addition, the International Atomic Energy Agency (IAEA) has published only one technical report that really focuses on this subject. The dismantling of contaminated stacks at nuclear facilities is one of the least topics approached in the decontamination and decommissioning (D&D) field. The demolition of several stacks located at Oak Ridge National Laboratory (ORNL) is on the priority list of D&D activities at this national laboratory. Decommissioning is the final stage of the life-cycle for a nuclear facility after its design, construction, commissioning and operation. The decommissioning process involves decontamination operations, dismantling and demolition. Also, decommissioning techniques are mainly driven by the results obtained in the process of characterization. The main purpose of the characterization process is to gather enough data to evaluate the radiological status of the nuclear plant or facility and to better understand the level of contamination. The whole approach of decommissioning is affected by the accuracy in the estimation of the amount and class of radioactivity in the nuclear facility. In addition, this estimation will establish and drive several factors such as the need for decontamination, waste management and disposal, shielding or remotely operated equipment, and estimating potential radiation exposures to the work force. One of the biggest challenges presented at ORNL is that the stacks are located between buildings that are currently being occupied and three of the five stacks are in deplorable conditions with high levels of contamination. Therefore, the use of remotely controlled equipment is needed.

To characterize a nuclear stack, a systematic procedure is used. First, the stack is divided into four sections by height, each section is zoned into four quadrants, and samples and measurements are taken in each quadrant by wall swiping, core sampling and scanning. These samples and measurements are collected and evaluated to estimate the levels of contamination inside of the stack. This presents an engineering challenge: to design a mechanism capable of swiping, drilling, collecting, and coordinating locations. There are several companies that offer alternative technologies for the characterization process; however, very few are applicable to high elevations and cylindrical structures. For this reason, a conceptual design is presented in this technical report that satisfies the needs for this project and it also opens a new alternative for non-conventional equipment in the process of radiological characterization.

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1. INTRODUCTION

Elevated ventilation stacks are one of the most common structures present at nuclear sites. Their main purpose is to weaken and disperse the permitted airborne release from the active plant system. Environmental regulations stipulate the design of these elevated structures; this is for the safety of the personnel that work at the site as well as for the local area outside the site. The stack's height depends on several factors, such as the surface type and height of nearby buildings, weather conditions, and the potential nuclear capacity of the facility. These factors can result in a needed stack height of over 300 feet. Also, depending on the facility and its use, stacks are made of different materials, such as brick, concrete and reinforced steel.

Stacks become contaminated due to continuous use throughout the life-cycle of the nuclear facility. Depending on the levels of contamination and the physical conditions, the decommissioning of a nuclear facility can vary from a simple to a more complex level of difficulty. For these reasons, characterization is a key factor in the development of a decontamination and decommissioning (D&D) plan at a nuclear site. The characterization process consists of collecting data to identify the physical and chemical characteristics of the structure being analyzed. This database will help the decommissioning planner to choose the best strategy for the specific site. Due to big challenges brought about by D&D activities in the past, several technologies have been developed in the last decades to ease decommissioning operations. However, because of several factors, such as specific shape, height and accessibility, nuclear stacks are a new challenge for this field. In addition, the location of the stacks within the nuclear complex adds another level of complexity into the D&D preparation; in many nuclear facilities, some of the stacks are built next to building offices. For these cases, available technologies are limited and the levels of risk for the workforce within the complex are extremely high. In this technical report, the general process for characterization of nuclear stacks will be summarized as well as all the previous work related to the decommissioning of nuclear stacks in the United States. This report will also summarize the technology available on the market for D&D projects, pointing out the advantages and disadvantages of each.

The dismantling of the nuclear stacks located at Oak Ridge National Laboratory (ORNL) represents a great concern for the safety and protection of the workforce involved in the D&D process as well for the personnel that work in nearby offices. As shown in Figure 1, the stacks at ORNL are located within an office complex, thus requiring more elaborate and specific technologies than the ones actually offered in market. A conceptual design is being developed with the collaboration of the Robotic Department at ORNL and Florida International University (FIU). This technical report will give a detailed explanation of all the requirements involved in the development of this conceptual design, including all the operations to be executed, activities such as contamination detection, core drilling and wall swiping. To make this process automated and remotely controlled, cameras and positioning sensors play a great part in the design. In addition, to make this mechanism economically efficient, one single prototype must fix into all the different size stacks. The use of a crane will be proposed for this first model, which helps in the execution of operations and deployment of this device in these cylindrical elevated structures.

Figure 1. Stack Number 2061 at ORNL.

2. PROBLEM DESCRIPTION

Due to the limited literature information regarding stacks decommissioning, the development of a conceptual design presents an engineering challenge in terms of technical execution. The IAEA has only published one technical report that discusses this matter; however, each case presented in this report represents a completely different test in the decommissioning planning. The stacks located at ORNL are within an active complex office that has been scheduled for demolition in the next ten years. Because of this constraint and the high levels of contamination, the demolition of the stacks must be done prior to the demolition of the nearby buildings. This puts the workforce currently working in the surrounded areas at a high risk. In addition, D&D activities for many of the projects previously completed on stacks by several companies were performed manually with direct human contact. This type of approach is not possible at ORNL due to the deteriorated infrastructure and radiological contamination of the majority of the stacks. Another factor that adds a high level of complexity to this project is the physical difference in materials and dimensions of each stack. The devices that are going to be use in the project must be able to quickly adjust to be successful for all stack sizes and material types.

3. EXECUTIVE SUMMARY

This research work has been supported by the DOE/FIU Science & Technology Workforce Initiative, an innovative program developed by the US Department of Energy's Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2008, a FIU intern spent 10 weeks doing a summer internship at ORNL's Measurement Science & System Engineering Division under the supervision and guidance of Mr. Mark Noakes and Mr. Randall Linn. This internship was organized and directed by the Higher Education Research Experience (HERE) and the Oak Ridge Institute for Science and Education (ORISE). The intern's project was initiated in June 4, 2008, and continued through August 8, 2008, with the objective of analyzing the characterization process of contaminated stacks at nuclear facilities. The process of characterization is the first step in the decommissioning of a nuclear facility. An intensive investigation of all technical literature available and previous projects all around the world was done during these 10-weeks of the internship. For this investigation, all of the IAEA technical publications were reviewed, which permitted the evaluation of several projects related to stacks decommissioning. A great deal of information was taken from the D&D Knowledge Management Information Tool (KM-IT). This DOE web information page permitted the evaluation of all the technology available on the market, as well as the evaluation of several related projects within the DOE complex. For the development of the conceptual design, all of the requirements were given by the Department of Nuclear & Radiological Protection Division at ORNL and a 3D software (SolidWorks) was used for the kinematic analysis and the sketching of the mechanism. The conceptual design of this devise was performed by the summer intern student, William Mendez. The conceptual design did not include a structure and material analysis. The cost to design and build a prototype based on the conceptual design was estimated at $700,000 and $1,000,000.

4. STACK DESCRIPTION

The general structural design of nuclear stacks has evolved over the past century. The design is driven by two major factors: **structural characteristics,** which include all the regulations regarding wind loads, snow, temperature and seismic loading; and **discharge characteristics**, which include the ventilation flow rate and dispersion necessities, which defines the stack's diameter and height. There are four main types of stacks: brick, steel, reinforced plastic, and reinforced concrete.

4.1 Brick Stacks

Brick stacks are considered the oldest type of construction. With the development of material properties, new types of bricks that are more acid resistant are being used. They need a thicker base than conventional stacks and the heights usually do not exceed 330 feet. These stacks are no longer built in new modern nuclear facilities.

4.2 Steel Stacks

There are three main sub-types of steel stacks:

1. Single wall, unlined – guyed and self supported

   These are the simplest sub-type of steel stacks and are used for low temperature requirements. They use cables for support which make them less expensive to construct. Depending on the steel material, they can be very resistant to the nuclear acids.

2. Lined with firebrick, acid resistant brick

   These stacks are built for high temperature requirements and are resistant to heavy acids. For this reason, the structure is internally lined with a special material that protects the steel from these extreme conditions. The stack heights can exceed 400 feet.

3. Dual wall and with interior steel lining

   This particular type of stack is built when the internal discharge needs to be kept at a high temperature to prevent condensation in the stack and close-by areas. They are really limited in height and don't usually exceed 130 feet.

4.3 Reinforced Plastic Stacks

Reinforced plastic stacks are very light and small in size. They have a low thermal conductivity and a good acid resistance. The commissioning and decommissioning can be easily accomplished with a crane.

4.4 Reinforced Concrete Stacks

Reinforced concrete stacks represent the largest number in the nuclear industry. They usually represent a major challenge in their decommissioning due to their height, up to 410 feet, and mass, that in some cases exceed 2000 tons.

5. CHARACTERIZATION PROCESS

Precise physical and chemical characterization is a key factor in the selection of stack dismantling tactics and technologies. Physical characterization gives the essential elements for calculating the residual mechanical properties of the stack and the time period in which the structure can safely remain in place. Nevertheless, accessing an elevated structure to acquire samples for physical or chemical characterization purposes needs cautious consideration of industrial safety for the protection of the workforce and surrounded areas. Characterization activities in contaminated areas will involve radiological protection provisions. Most of the stacks have a port access into the interior of the structure; the opening of this gate can precipitate and disperse the in situ contamination. This is one of the issues that a decommissioning planner has to face for the protection of the personnel. In many cases, remote controlled techniques such as video-graphic and/or robots are deployed to overcome the personnel safety issue.

In the process of characterization, it should be noted that the technical reports related to the material discharged through a nuclear stack may be incomplete or outdated. The data obtained from the characterization process provides information that will help the decommissioning planner to establish whether the stack can be decontaminated in a cost-effective way. The depth of contamination through the inner wall is another important piece of information. The characterization process requires the use of a practical, effective, and efficient method. For example, instead of sampling the entire interior wall of the stack, which is also possible, the decommissioning planner may suggest the coring or swipe sampling of selected areas to obtain an accurate estimation of the level of contamination inside of the stack. As previously mentioned, the stack characterization affects the path of the whole D&D process, from the selection of technologies and techniques to the management of waste resulting from the D&D activities.

5.1 Characterization Techniques and Approaches

There is not a single technology that can attend to the full range of requirements for facility and material characterization. Frequently, characterization techniques are used in combination with one another to take advantage of the strengths and to compensate for the weaknesses of each method. Due to the different needs presented at each nuclear site, there is a large variety of techniques and devices built specifically for the deployment of the characterization process. The technologies on the market vary in their capabilities as well as their limitations. In Table 1, the most important technologies and procedures available in the market have been summarized.

Table 1 Summary of Current Technology Available

Technology	Description	Capabilities	Limitations
Airborne and ground-based laser-induced fluorescence imaging (Fig. 2)	A fast and accurate uranium characterization tool that can easily "see" uranium contamination.	Good screening tool for uranium contamination over large areas or to discretely survey a 2'x 2' area at a time. Best suited as a rapid screening tool to assist planning and operations.	Action limited to uranium contamination. Not suitable for detection of uranium in sunlit areas. Currently cannot be used for regulatory purposes.
2-D linear motion system (Fig. 3)	Robotic platform used to deploy a variety of tools on vertical surfaces.	Suitable for deployment of radiation sensors for wall characterization. Can be used to scabble or otherwise treat wall surfaces.	Works best on flat or slightly curve surfaces. Set up and takedown of the units is time consuming.
3-D Visual and Gamma Ray Imaging System (Fig. 4)	The 3-D Visual and Gamma Ray Imaging System can remotely survey large areas and individual objects for gamma-ray emissions and display the results as combined three-dimensional (3-D) representations of the radiation sources and the equipment.	The system can be positioned outside the radiation area, thus reducing worker exposure and eliminating extensive shielding. This benefit is more pronounced in high radiation areas. Use of the system can provide information on planning a decontamination process that minimizes worker exposure	Operation of the system is relatively simple, but some training is required to ensure that relevant data are obtained. Currently, the use of the 3-D rendering software requires considerable experience in modeling the source distributions.
Decontamination, Decommissioning and Remediation Optimal Planning System (DDROPS) (Fig. 5)	DDROPS is a special computer interface that provides a size reduction and packaging plan for tanks, piping, and other dismantled equipment. From facility drawings, photographs, and video images, a 3-dimensional model using ProEngineer is created.	This 3-D model can be made to visualize the area with colors representing different characteristics for individual components within the structure, such as the level of radiation or the material composition.	

GammaCam™ Radiation Imaging System (Fig. 6)	The GammaCam™ is a gamma-ray imaging system that is capable of measuring and mapping radiation fields. It produces a two-dimensional pseudo-color image of a radiation field superimposed on a corresponding black-and-white visual image.	The system can be positioned outside the radiation area, thus reducing worker exposure and eliminating extensive shielding. Compared to the baseline technology, use of the system leads to reduced labor costs, more reliable data, and significantly less radiation exposure.	It work better only for high level contaminated areas.
In-Situ Object Counting System (ISOCS) (Fig. 7)	The In Situ Object Counting System (ISOCS) is an in-situ gamma spectroscopy system that has been mathematically calibrated to perform a variety of efficiency calculations for a wide variety of shapes, sizes, densities, and distances between the detector and the area of interest.	Provides in-situ, near 'real-time' analytical data, including isotopic results. 79% reduction in labor hours for whole room survey. No hand surveys necessary to satisfy 'free release' criteria. Reduces risk of human error. Reduces worker fatigue and stress.	

Figure 2. Airborne and Ground Based Laser-Induced Fluorescence imaging.

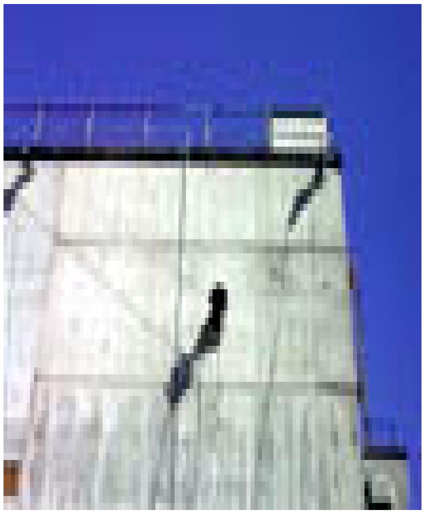

Figure 3. 2D Linear Motion System.

Figure 4. Decontamination, Decommissioning, and Remediation Optimal Planning System (DDROPS).

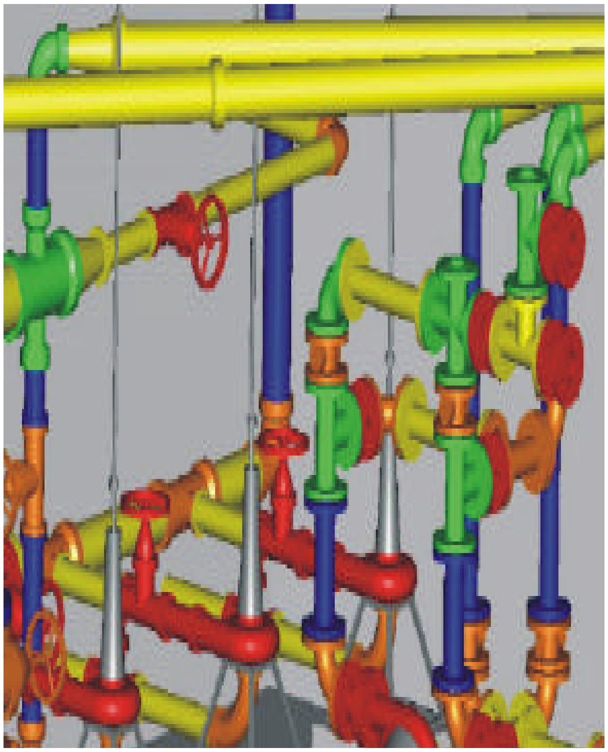

Figure 5. 3-D Visual and Gamma Ray Imaging System.

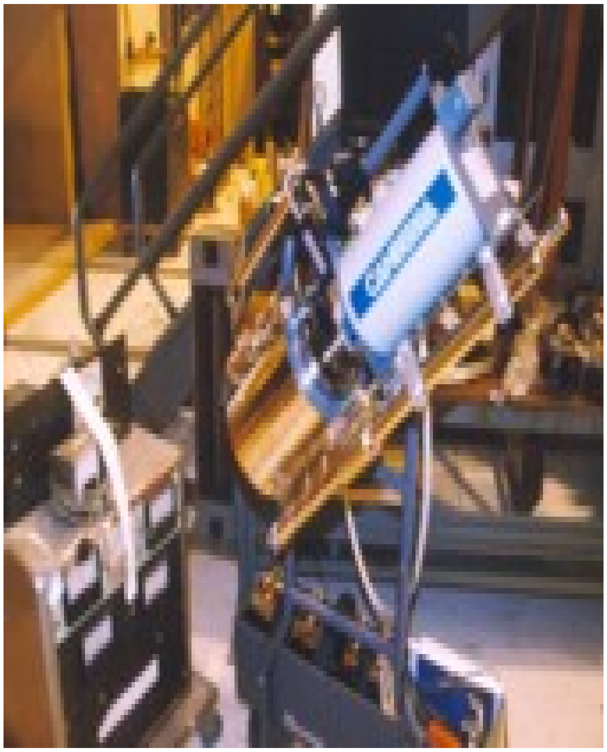

Figure 6. GammaCam Radiation Imaging System.

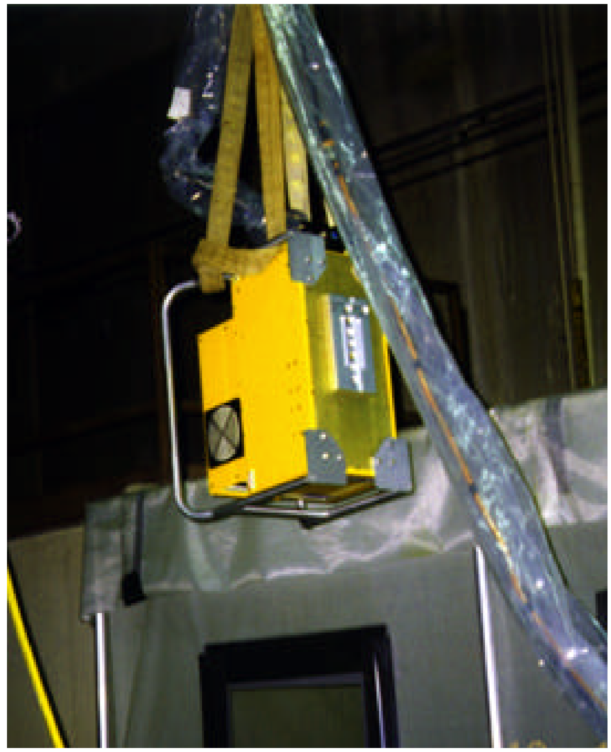

Figure 7. In-Situ Object Counting System (ISOCS).

6. CONCEPTUAL DESIGN

The conceptual prototype presented in this technical report only includes the kinematical design of the mechanism. Also, an alternative deployment system is suggested since the use of a crane would reduce the general cost of operational execution. The main idea of this prototype is to create a mechanism that safely performs the general basic operations needed for stack characterization. These operations include core drilling, wall swiping and scanning for radioactive areas on the surface. To effectively achieve these electro-mechanical functions, several devises must be considered in the design, such as positioning sensors, linear actuators, gear boxes, cameras and stepper motors.

7. DEPLOYMENT

The stack will be characterized at four different heights, as shown in Figures 8 and 9.

Figure 8. 3D representation of a brick stack.

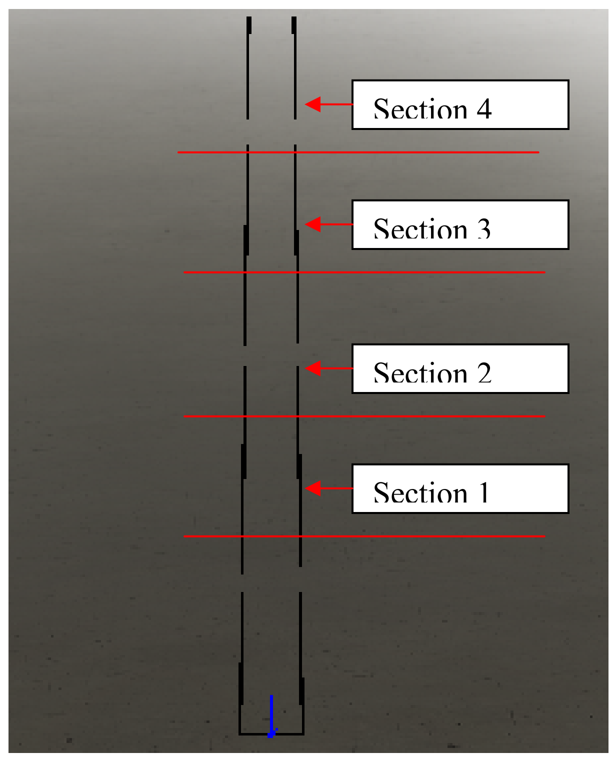

Figure 9. Sampling areas.

At each section, three main operations must be done. First, identify the most contaminated quadrant of the section with a scanning method. Second, wall swiping and core drill sampling are done for the most contaminated quadrant. Third, for the remaining quadrants, just wall swiping is performed. This cycle is repeated for every section (Figures 10 and 11). Each sample collected must be stored and protected from cross contamination. For this reason, the samples are taken from the bottom of the stack to the top. Figures 12-17 illustrate the conceptual design of the stack characterization mechanism.

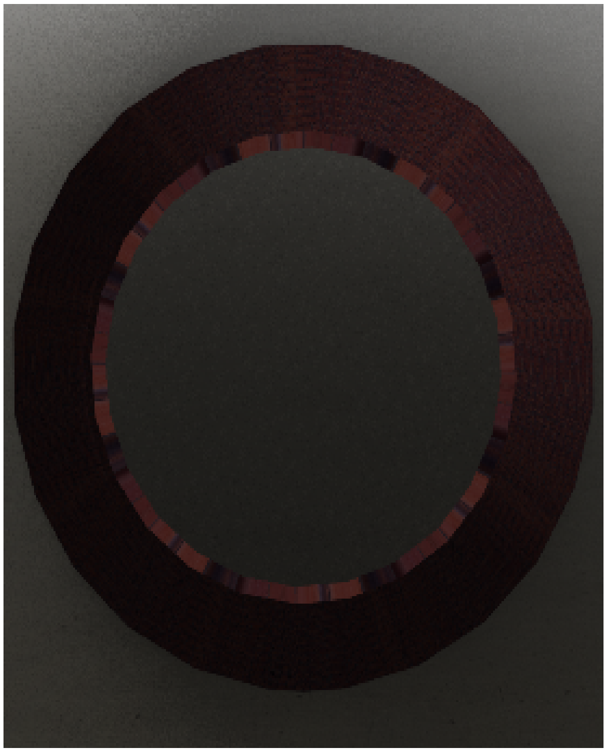

Figure 10. Top view of a nuclear stack.

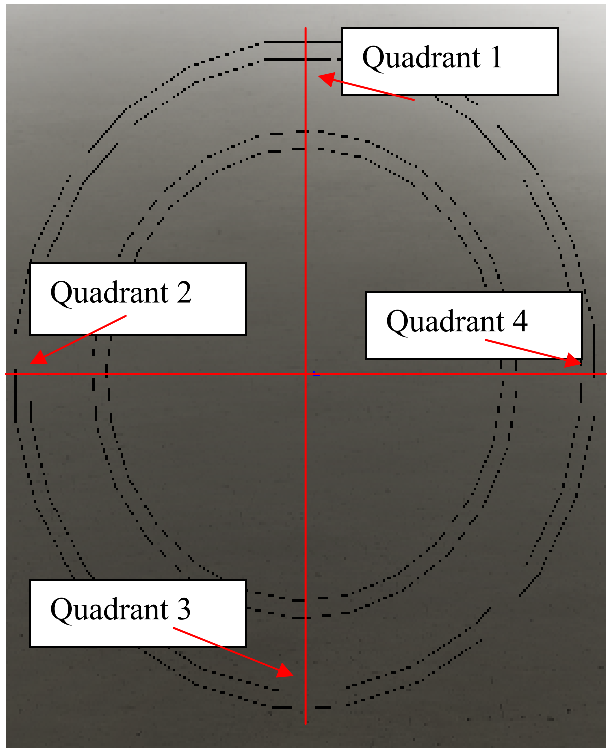

Figure 11. Quadrants of sampling areas.

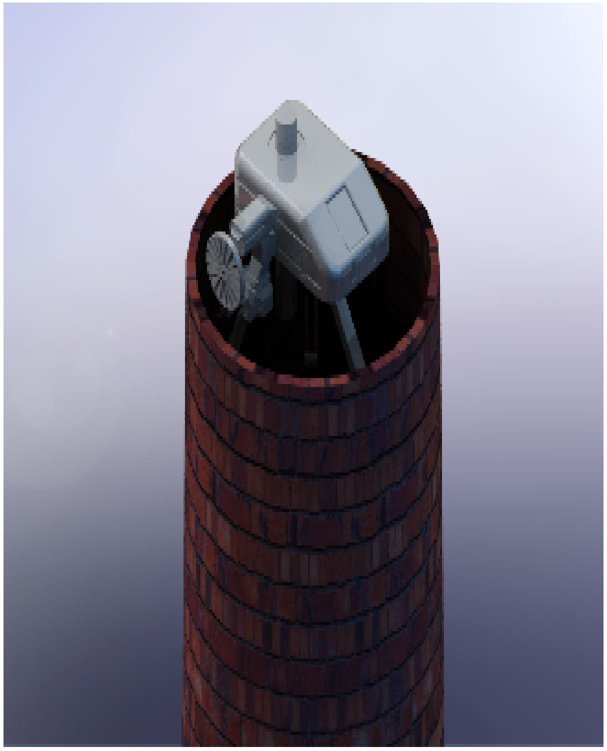

Figure 12. Mechanism being deployed.

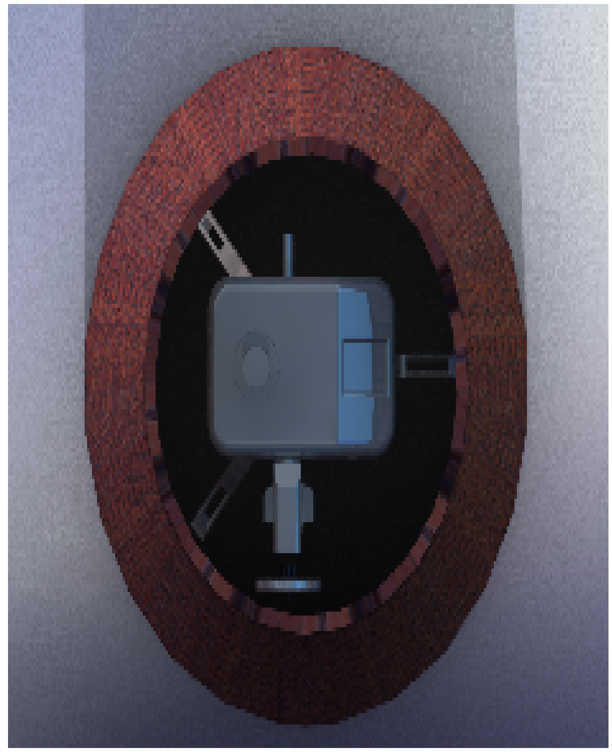

Figure 13. In this figure the mechanism has secured its position on the inner wall of the stack.

Figure 15. Mechanism being held by a crane.

Figure 14. 3D mechanism representation.

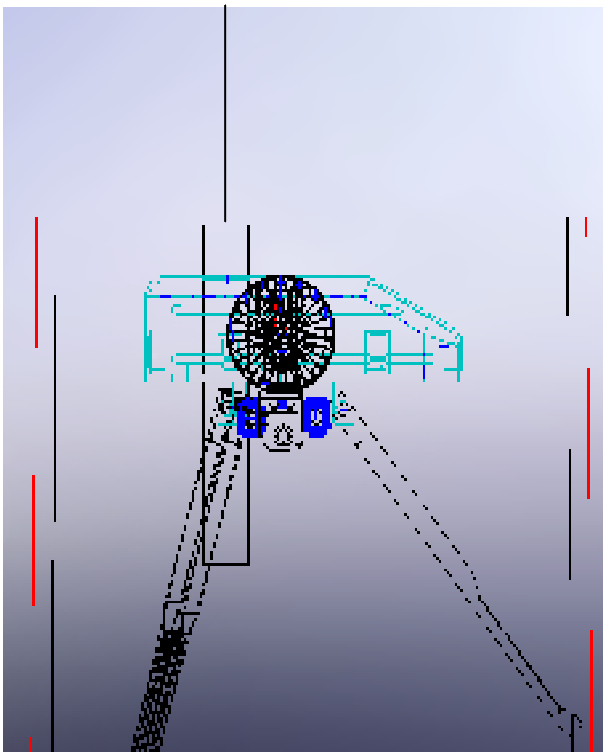

Figure 16. Mechanism inside of the stack.

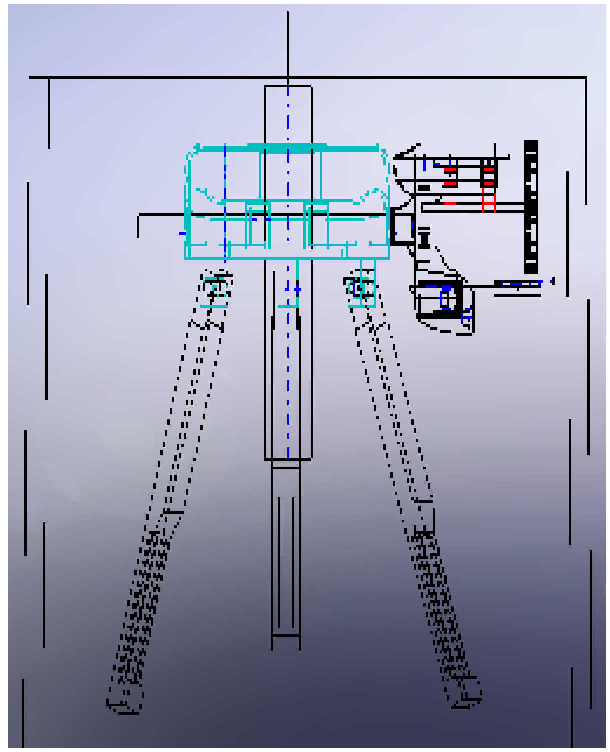

Figure 17. Core drilling about to be executed.

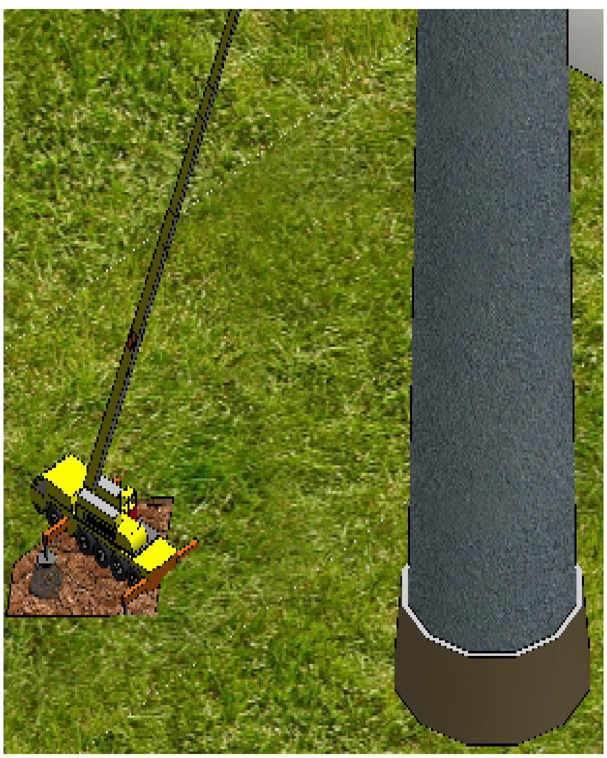

Figure 19. Top view of the crane close to the nuclear stack.

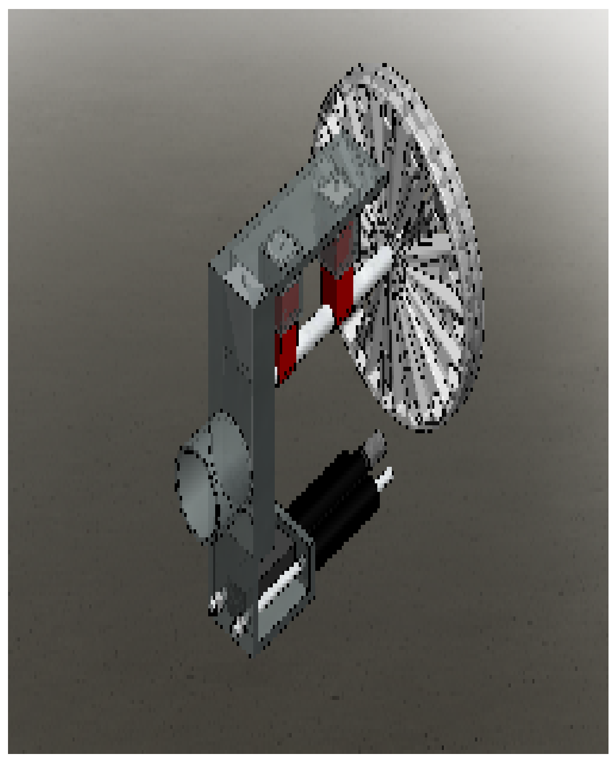

Figure 18. Core drill device.

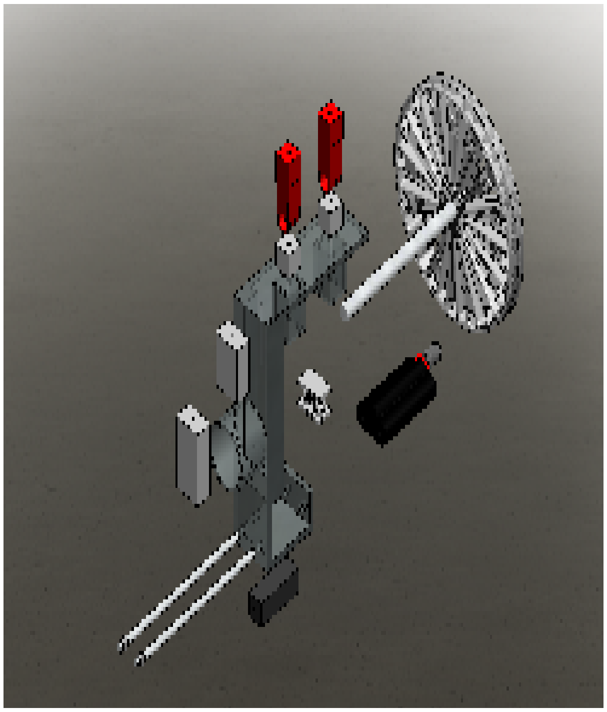

Figure 21. Main components of the core drill.

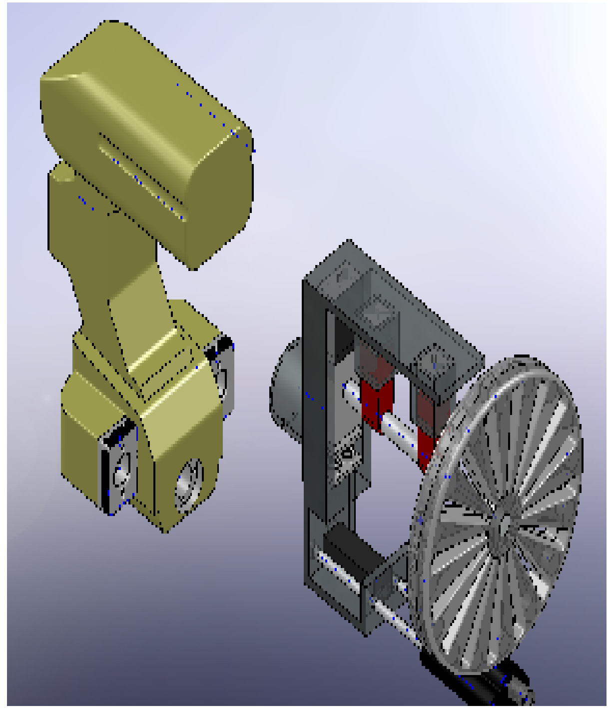

Figure 20. Core drill ant its cover.

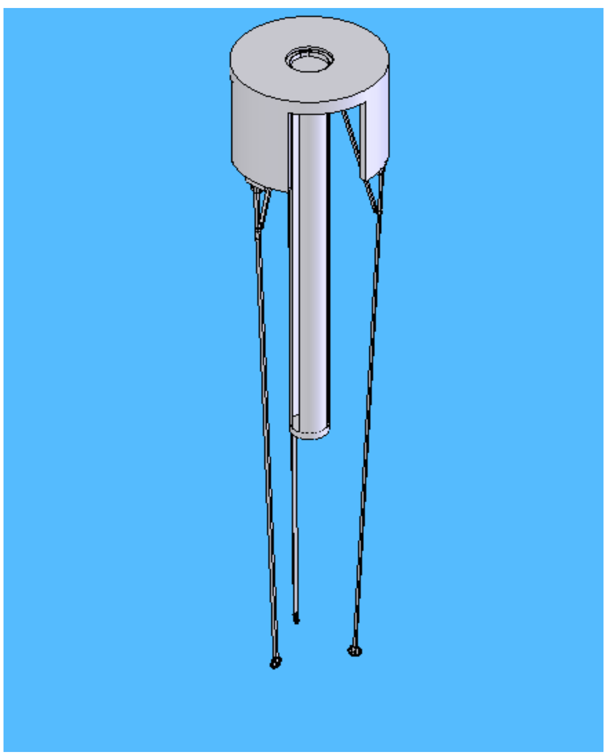

Figure 22. Kinematic representation of mechanism, initial phase.

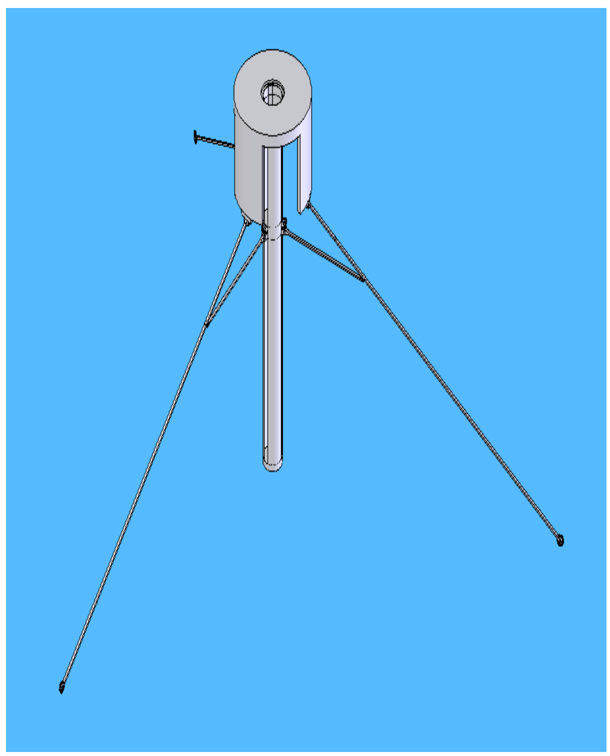

Figure 23. Kinematic representation of mechanism, phase 2.

The mechanism is deployed by a crane to the top of the stack as shown in Figure 18. From there, using the data obtained from the physical characterization of the stacks, a positioning sensor is started at this fixed origin equalized to zero. Slowly, the device is set for the initial section at the base of the stack (Figure 17). The three leg mechanism expands until it reaches stability for the whole devise as shown in Figures 16 and 17. The whole system is able to rotate respective to its axis, enabling it to perform all the previously mentioned operations.

A special mechanism has been designed for the purpose of core drilling. This particular device is capable of taking core samples and storing them to prevent cross contamination between each sample collected (Figure 24). The mechanism is composed of a drill wheel (24a), which holds the drill bits; a main frame (24b), utilized to support all the different components; linear actuators (24c, 24d); a commercial core drill (24e); a shaft (24f); and an external frame (Figure 25) that provides protection from contamination for all the internal components and also serves as a holder for the camera and the scanner. The execution of the core sampling is the most difficult overall operation. Figures (26 - 29) show the characteristics of the mechanism. Once the core drill is placed against the wall, the execution is divided in several steps. First, the axis of the core drill is presented to the axis of the drill bit held by the wheel (Figure 26). The drill bit is taken by the core drill and mechanically locked by pressure (Figure 27). Next, the wheel is held by a shaft that moves in a vertical direction to permit the operations done by the core drill. Also, the wheel possesses a pneumatic system that allows itself to release and hold the drill bit. Once the drilling operation is done, the drill bit is placed back in its corresponding space in the wheel (Figure 28). Then, the wheel is rotated with an angle value corresponding to the next drill bit and the whole operation is repeated (Figure 29). Finally, the whole mechanism is pulled away from the wall.

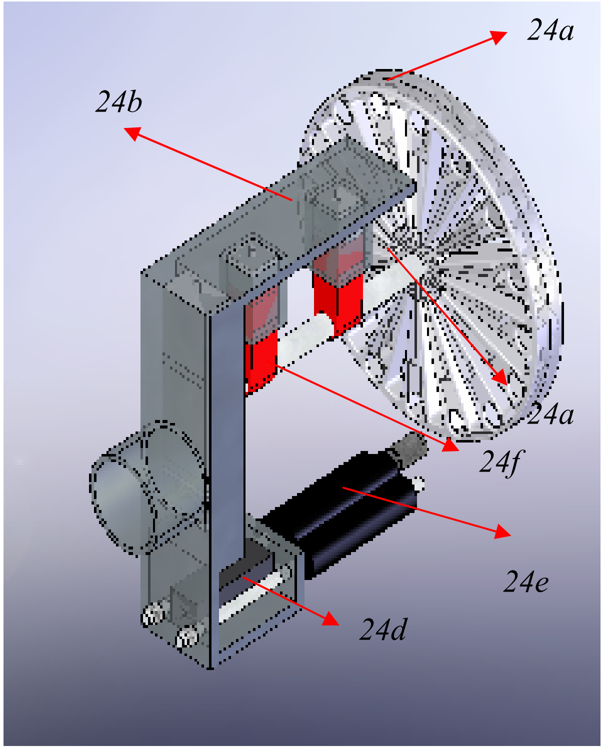

Figure 25

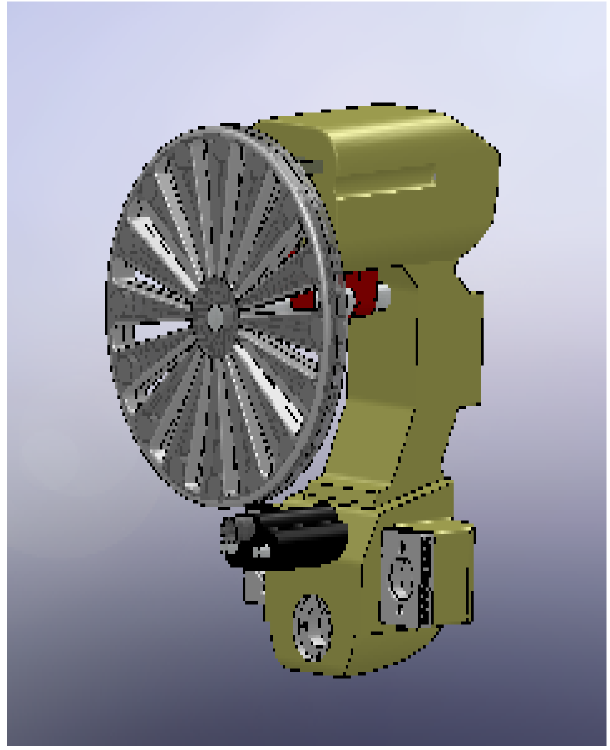

Figure 24

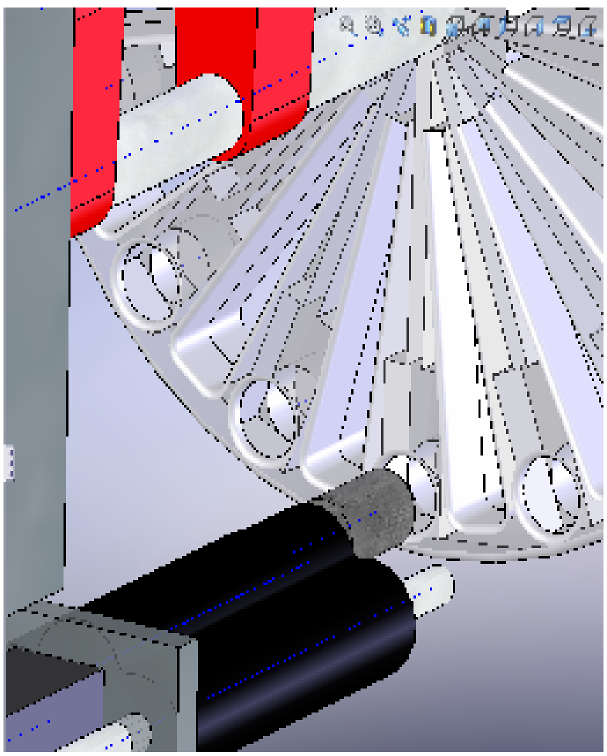

Figure 26

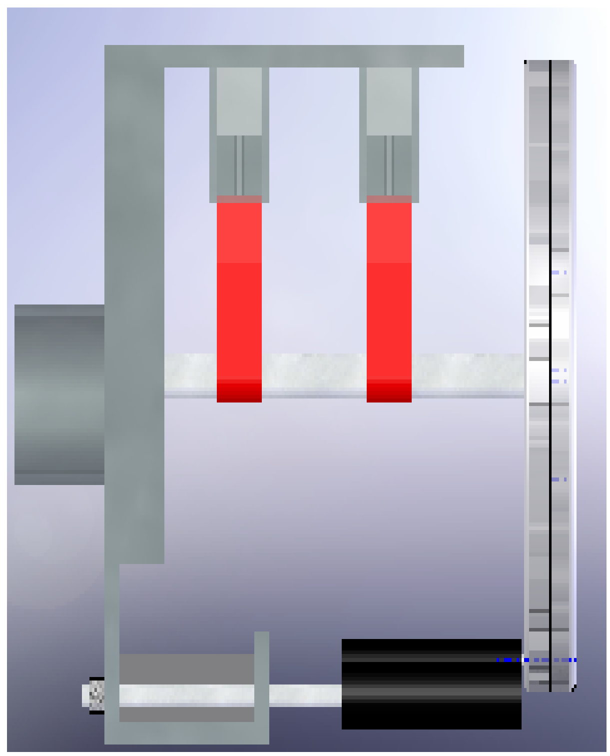

Figure 27

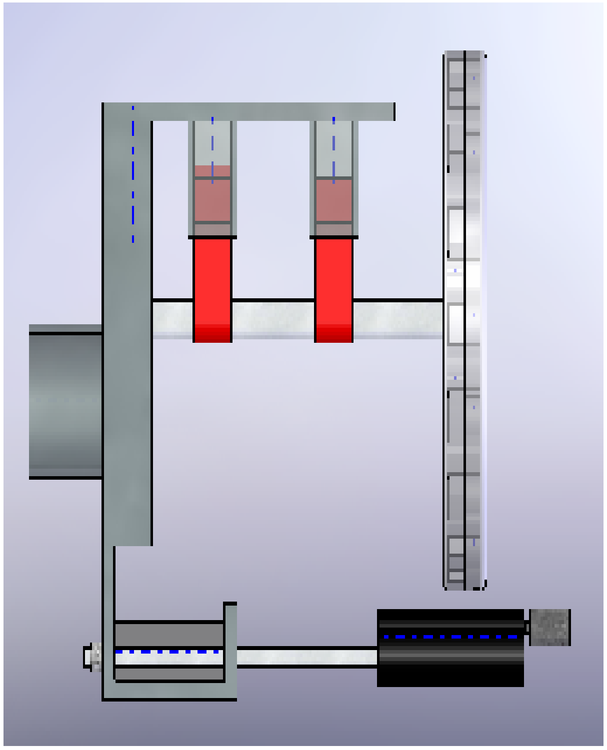

Figure 29

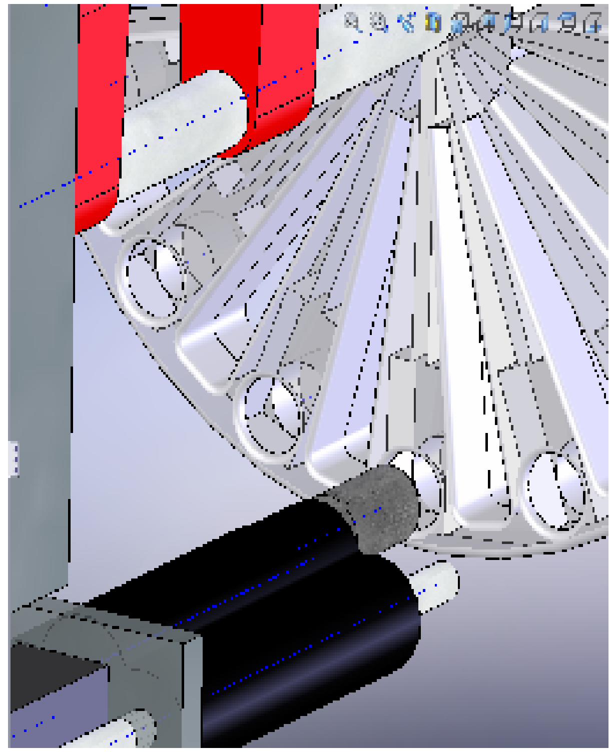

Figure 28

8. POSTERIOR WORK

This kinematical analysis represents 20 to 30 percent of the whole design. Stress analysis is needed to calculate the dimensions of different components and types of material. Also, the maximum and minimum loads that a wall can receive from the core drill and the three-leg mechanism need to be calculated. Another important consideration is the size proportion of the mechanism with respect to all of the stacks. The stack figures presented in this technical report were based on the smallest stack located at ORNL. The diameter corresponding to the biggest stack at ORNL is eight times smaller than the total height of the smallest stack. To solve this design problem, an adjustable size mechanism can be used. After these general considerations are evaluated, the electrical and electronic analysis would be incorporated into the design process. This includes the type and capacity of the actuators and stepper motors, sensors and controllers. All these devices need to be chosen to meet the needs of strength and stability of the whole device.

9. ESTIMATED COST

An estimated cost was approximated based on the experience of previous prototypes developed at ORNL. This estimation includes fabrication, materials, electronic and electrical devices and engineering labor and comes to an estimated cost of $700,000 to $1,000,000. This price can be quickly compensated due to the number of stacks located at all of the DOE sites that also need to be dismantled and therefore initially require characterization.

10. CONCLUSIONS

Physical and chemical characterization are the key elements needed prior to the D&D activities. The dismantling process of nuclear facilities depends on the accuracy of this fundamental step. In the development of this technical report, the following conclusions have been made:

- A well organized characterization plan lays out the path for the whole dismantling process. It determines several factors, such as the selection of deployment technologies, the pre-decontamination process, demolition techniques and waste management.
- The more data and information available, the better the decommissioning planning will become.
- There is not a large amount of experience related to stack dismantling, but with the combination of lessons learned from a few previous projects, a review of the technical literature, and an analysis of the technology currently available in the market, new technology can be developed to meet the requirements of this D&D challenge.
- The dismantling process of nuclear stacks varies according to several factors, including the level of contamination, the physical conditions and the location within the nuclear facility. Other factors are involved but are not limited to technical execution.
- Every nuclear facility uses stacks and they will be eventually required dismantling. Therefore, the development of technologies to ease this process is required.
- An automated technology to handle the difficult task of characterizing nuclear stacks does not yet exist. Currently, direct manual methods by human workers are the preferred approach. This can be accomplished only at great risk for the stacks that are in much deteriorated physical condition or that contain high levels of contamination.
- Several technologies and methodologies are available for the performance of characterization. However, some situations will require special planning and need highly skilled engineering. These non-conventional techniques are expensive but more than justified for the protection and safety of all the personnel involved in the process as well as the areas near the nuclear facility.

11. REFERENCE

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