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ROBOTICS FOR MIXED WASTE OPERATIONS, DEMONSTRATION DESCRIPTION (U)

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DISCLAIMER

Robotics For Mixed Waste Operations Demonstration Description

Introduction

The Department of Energy (DOE) Office of Technology Development (OTD) is developing technology to aid in the cleanup of DOE sites. Included in the OTD program are the Robotics Technology Development Program and the Mixed Waste Integrated Program. These two programs are working together to provide technology for the cleanup of mixed waste, which is waste that has both radioactive and hazardous constituents. There are over 240,000 cubic meters of mixed low level waste accumulated at DOE sites and the cleanup is expected to generate about 900,000 cubic meters of mixed low level waste over the next five years. This waste must be monitored during storage and then treated and disposed of in a cost effective manner acceptable to regulators and the states involved. The Robotics Technology Development Program is developing robotics technology to make these tasks safer, better, faster and cheaper through the Mixed Waste Operations team. This technology will also apply to treatment of transuranic waste. The demonstration at the Savannah River Site on November 2-4, 1993, showed the progress of this technology by DOE, universities and industry over the previous year. Robotics technology for the handling, characterization and treatment of mixed waste as well robotics technology for monitoring of stored waste was demonstrated. It was shown that robotics technology can make future waste storage and waste treatment facilities better, faster, safer and cheaper.

Background

Facilities will be built at many DOE sites to receive containers of mixed waste, remove the contents, characterize the waste, treat the waste and place it into a final form for shipment from the facility. All or most of the material handling and some of the treatment processes in mixed waste facilities can be accomplished by humans in direct contact with the waste. However, humans would have to be dressed in protective clothing, which becomes additional (secondary) waste after use. The protective clothing also takes considerable time to put on and take off and is cumbersome, which reduces the efficiency of manual operation. The handling of heavy containers manually or with manual operation of overhead cranes or other equipment and the manual opening of containers with powered tools and exposure to sharp edges would be safety risks. Manual removal of waste items, including glass and heavy objects, from the containers and manual handling of the items would also be safety risks. Manual operation of treatment equipment, such as blasting equipment for decontamination or plasma arc torches for size reduction, would also be a safety risk, especially in a radioactively contaminated and hazardous waste environment. Remote operation, including robotics, in mixed waste treatment facilities, will reduce the safety risks to operators, reduce the secondary waste generation from protective clothing, increase the efficiency of operations, increase the control and documentation of operations and potentially reduce life cycle costs. In the demonstration the work envelope of the large Telerobot gantry robot (approximately 20 feet by 20 feet in area) represented a contact maintenance cell. Normal operations would be accomplished remotely in this type of cell. Maintenance or unusual situations would be accomplished manually with personnel suited in appropriate personal protective clothing including respiratory protection. The advantages of robotic, remote operations were demonstrated in this cell. Treatment processes that can be accomplished in much smaller volumes, such as decontamination of lead bricks, can be accomplished in gloveboxes. Here, again, robotics technology has significant advantages as was demonstrated by the glovebox gantry robot. In the glovebox normal operations would be performed by the robot and maintenance or unusual situations would be accomplished manually through standard gloveports.

Mixed waste will arrive at these facilities in metal drums, metal bins and wood boxes. There are more drums of mixed waste than any other type of container. There are several categories of mixed waste inside these containers. One of the larger categories by volume is heterogeneous dry solids. Removal and characterization of heterogeneous dry solids from drums and treatment of one type of waste was demonstrated. The demonstration showed how robotics technology can benefit opening of 55 gallon, metal drums with a plastic liner, removal, characterization and sorting of heterogeneous dry solids, and treatment of radioactively contaminated lead bricks. No radioactive, hazardous or mixed wastes were used in the demonstration, only simulated mixed wastes were used.

Purpose of the Demonstration

The main purpose of the demonstration was to show how robotics technology being developed in the Robotics Technology Development Program can make future DOE mixed waste facilities better, faster, safer and cheaper, particularly for DOE employees and government contractors who will be involved in planning, specifying, building and operating these facilities. Since industry must provide this technology for future facilities, a secondary purpose was to demonstrate this technology to industry to encourage their continued involvement in transferring this technology to the private sector and build partnerships in continued development. Another purpose of the demonstration was to indicate to universities the accomplishments and directions of the program to help shape their future research and contributions to the program.

Description of the Demonstration

Characterization of Whole Containers (LLNL)

Many containers of mixed waste are very old and descriptions of their contents are vague, questionable or unknown. Before containers of mixed waste enter a facility, it would be advantageous to know what types and quantities of material are inside. This information would confirm whether the container is acceptable for processing in the facility. It also would allow better planning of treatment of the waste and continuous supply of feedstock to the different treatment processes.

An active/passive neutron interrogation and computed tomography system is being developed for drums of mixed waste. This system can determine the types and approximate quantities of different material, including radioactive material, inside the drum and show the location of the material in a 3-D representation of the drum and its contents. The different types of material are color coded in the 3-D display to provide an easily understood representation of the data. This equipment is at LLNL and requires heavy, bulky shielding as well as radioactive sources, so a video of the results of its operation was shown instead of an actual demonstration. Depending on the resolution and accuracy desired, this operation presently can take hours. However, techniques and equipment modifications to speed the process without a reduction in resolution or accuracy have been proposed.

Drum Conveyor

An inexpensive gravity roller conveyor was used to move drums into the workcell and present a drum to the drum lifter for the demonstration. In an actual facility, sections of powered roller conveyor would probably be used to move the drum from the uncontaminated container receiving area, through air locks, and into the contaminated workcell.

Background on the Telerobot

The Telerobot is unique in that it has 8 degrees of freedom (DOF) and has both teleoperation and robotic capabilities. The extra 2 DOF allow the robot to reach inside, around and under objects, which is not possible with a standard 6 DOF gantry robot. It was built by PaR Systems to SRTC specifications. It has 3 DOF on the gantry and 5 DOF on the jointed arm. The lifting capacity at the wrist is 300 pounds. A JR3 force-moment sensor is mounted at the wrist and attached to it is an Applied Robotics tool changer. A second Applied Robotics tool changer is mounted on the shoulder of the Telerobot and has a lifting capacity of 1,000 pounds. Pneumatic tubing would be difficult to route through the telescoping tubes and through the inside of the jointed arm as has been done with the electrical wiring. Therefore, these are unique, electrically-actuated tool changers. The wrist tool changer allows the Telerobot to pick up many standard electric powered hand tools including a gripper, circular saw, chain saw, reciprocating saw, abrasive wheel grinder and others. The shoulder tool changer allows the Telerobot to pick up a two-armed electric master/slave manipulator made by REMOTEC or the drum lifter.

The Telerobot was installed in 1986. Joysticks are used instead of a standard teach pendant for much faster and easier manual control. Push-button programming and menu-driven selection of programs also simplifies programmed control. This operation has been enhanced and many features have been added by the addition of a graphical interface based on the DOE Generic Intelligent System Control (GISC).

Graphical Interface (SNL, SRTC, LLNL)

Two 3-D robot simulation packages were demonstrated that are both compatible with GISC. One package is Robline, from Cimetrix, and operated the PUMA robot and the IBM robot. The other package is IGRIP, from Deneb, and operated the Telerobot. Both programs ran on Silicon Graphics Inc. workstations. IGRIP included the Low Level Telerobotics Interface (LLTI) that was developed by SNL and transferred to Deneb. LLTI allowed the IGRIP simulation to track movements of the robot in real time. In order to track the Telerobot, PaR systems increased the simultaneous communications available with their Real-time Path Modification (RPM) board from 6 axes to 8 axes.

With both simulation programs, programming of the robots was accomplished directly from menus on the computer screens. Both simulation programs also allowed previewing of each robot program in the simulation, automatic conversion of the program into the robot specific language, downloading of the program and execution along with real-time movement tracking.

Model-based Collision Avoidance (SNL, SRTC, LLNL)

Both simulation packages included collision and near miss detection. The advantages of using this feature to anticipate collisions between the robot and known objects (equipment and material) in the workcell were demonstrated. By preventing these unintended collisions, both in teleoperation and in programmed operation, damage, cost and subsequent downtime can be eliminated. In teleoperation, if an impending collision with a known object is detected by the simulation, control will be automatically taken away from the operator, the robot will be moved away from the object, and control returned to the operator. During off-line programming with the simulation, impending and actual collisions are indicated to the operator by dramatic changes in object and robot colors.

Drum Lifter (INEL)

Tens of thousands of drums of waste will have to be transported in waste treatment facilities. Manual handling would be a safety risk, especially with the large number of drums that will be processed over the life of a facility. There are many options for remote drum transport. However, if a gantry robot similar to the Telerobot is available, it can quickly and reliably move drums in a precise path and precisely locate them in machines that require top loading, such as the drum and liner opener. The drum lifter has been tested with a 55 gallon drum that weighed over a thousand pounds and performed well even with deformed drums. The drum lifter includes an Applied Robotics tool changer that is compatible with the tool changer on the shoulder of the Telerobot. It has sensors that measure relative force and displacement of the lifting straps. These sensors are monitored and used for control during operation. In the demonstration the drum lifter lifted a drum of simulated waste from the drum conveyor and placed it in the drum opener. After the drum was cut, it removed the top of the drum. It then was placed over the exposed 0.090 inch thick liner as it was cut to prevent the liner from falling off after cutting. After the liner was cut, the drum lifter removed the top of the liner. The lifter can also remove the full drum from the drum opener and place it in a drum dumper, or remove the empty drum after it is emptied at the drum opener.

Drum and Liner Opening (SRTC)

Tens of thousands of drums of mixed waste will have to be opened in mixed waste treatment facilities. Many of these drums and their fasteners will be corroded and deteriorated so that removal of the lids would be difficult. Manual opening of the containers would risk injury from exertion, power tools and sharp edges. Remote container opening would reduce risk of injury, reduce secondary waste from personal protective clothing and increase throughput. The drum and liner opening equipment was developed to remotely open drums and liners. It is similar in concept to a design by Merrick & Company for a proposed Waste Characterization Facility (WCF) for INEL. Initial testing of the SRTC equipment has identified tools and techniques that will open drums and liners. After the demonstration, other types of tools and techniques will be tested to optimize the process and the results will be available to aid in the design of actual equipment for the WCF and other mixed waste facilities. The equipment is composed of a powered, rotating chuck that can grip the bottom section of 30, 55 and 83 gallon drums and overpacks. Tools and supports are deployed from opposing masts and can be remotely manipulated up and down on the mast and in and out. In the demonstration a set of idler wheels was brought in contact with one side of the drum and an unpowered, sharp-edged disk was slowly brought in contact with the opposite side of the drum. As the drum was rotated the disk slowly moved into the drum wall until the drum wall was completely cut, much like a huge tubing cutter. After the top of the drum was removed by the drum lifter, a second tool, a rotating saw blade, moved up to contact the exposed 0.090 inch thick polyethylene liner and cut the liner. The drum lifter then removed the top of the liner to expose the contents. The contents could be removed directly from the drum or the contents could be dumped out. Both alternatives were demonstrated.

Singulation (SNL, LLNL)

Manual removal of waste items directly from a drum would expose personnel to radiation and hazardous material, as well as cuts and punctures from sharp edges on the drum and on metal and glass waste items. It would also require an extended reach into the bottom of the drum to remove heavy and bulky items. Some of these hazards could be reduced by dumping the material out of the drum, but that would destroy the orientation and position of specific waste items identified by whole drum characterization. In either case, manual removal would require exposure and present safety risks. Any cuts or wounds to personnel in this environment will be potentially contaminated. Remote removal and placement of individual waste items (singulation) is needed to reduce risk to personnel, to increase throughput and to reduce the secondary waste generated from personnel protective equipment. Remote singulation directly from the drum and from a pile dumped from a previously opened drum was demonstrated.

The singulation system used a PUMA robot with a payload of approximately 40 pounds. A JR3 force sensor was attached to the wrist and a ? tool changer allowed the use of many different end effectors. To provide efficient use of this industrial robot in a teleoperated mode, a GISC compatible software module called SMART (Sequential Modular Architecture for Robotics and Teleoperation) was used. SMART allows the use of many different master input devices, however, a force ball was used to manipulate the PUMA during the demonstration. This device was used by the operator to remotely control the PUMA robot, using cameras on the PUMA and on the Telerobot to find the objects. SMART also used the force sensor to prevent excessive force from being developed during singulation, that could damage the robot, the waste items, or surrounding equipment. The force sensor was also used to determine the weight of the waste item. Waste items from the drum and the pile were deposited in trays at the inlet to the waste item characterization system.

Waste Item Characterization System (LLNL)

There are hundreds of different types of materials (waste streams) that will be processed in mixed waste treatment facilities. Some of the containers will have homogeneous material, while others will have heterogeneous material. Some containers will have unknown or questionable material. Treatment required for the different waste streams will vary. Characterization of the incoming material and segregation for treatment will be required. Even characterization of homogeneous material to confirm records and detect any foreign material may be required. Since there are hundreds of thousands of cubic meters of waste to be characterized, an efficient and reliable technology is required. A characterization system for dry heterogeneous material was demonstrated. The items were characterized without removing them from the single or multiple plastic bags that is typical packaging for heterogeneous, dry, solid, mixed waste. An individual waste item was placed into tray and the tray was conveyed through a series of sensors to determine its properties. The sensors determined if there was significant metal in the item, and what type of metal. Another sensor determined if there was significant radioactive material in the item, and what radioisotopes were present. Another sensor determined the approximate size of the item and with the weight previously determined by the force sensor during singulation an average density was determined. One of the items identified by the characterization system during the demonstration was a simulated lead brick inside a plastic bag. Additional sensors could be added to this system. Active/passive neutron interrogation could be used in this characterization system, but was not demonstrated because a radiation source and shielding are required. However, active/passive neutron interrogation combined with computed tomography would yield much more precise information in this application than the whole drum characterization, because of reduced distance, reduced size and reduce self shielding.

Sorting Conveyor (LLNL)

The information received from the characterization system was used to sort the trays for different treatment options. The trays were automatically diverted from the main conveyor onto side conveyors that would be sent to different treatment processes in an actual facility. In some cases the material could be conveyed into another cell and processed in gloveboxes. In this case, highly contaminated items or specific types of contamination on items could remain inside the plastic bags and only be opened in a specific glovebox to segregate contamination and aid in contamination control. During the demonstration, simulated lead bricks were characterized, sorted and sent to the glovebox robot.

Waste Item Modeling System (ORNL)

The gantry robot removed the simulated lead brick from the tray. This eliminates the dull, monotonous task and physical stress of manual operation. Even though lead bricks were placed in a tray by the PUMA robot so the location in the tray is known, the brick could have shifted during transport. A structured light modeling system moved out over the tray and modeled the brick in the tray. The single structured light unit had two fixed cameras and a fixed laser. A pivoting mirror passed the structured laser light line across the tray. The shape and position of the line as seen by each camera from different angles and the known angle of the mirror were used to determine the shape and position of the lead brick. The laser penetrated the translucent plastic bag, so that the actual brick was modeled. The model of the brick was automatically placed into the Robline graphical simulation system. The structured light system then moved back out of the way to allow the robot to remove the brick from the tray.

Glovebox Robot (LLNL)

The IBM gantry robot was a joint effort between IBM and LLNL. It is sized to be placed in a glovebox so that gloveports may be used for maintenance and to address unusual situations. The robot is electrically actuated and can operate in different types of glovebox atmospheres (air, nitrogen, argon, partial vacuum, etc.). The robot was used to pick up and transport the brick, manipulate it in front of a frozen CO_2 blasting nozzle, manipulate it in front of a radiation detector and palletize it for removal from the glovebox. Manual manipulation of the lead bricks would be monotonous, would risk injury from extended reach and continuous lifting of heavy loads, and risk injury from manipulation in front of the CO_2 blast nozzle. Robotic manipulation would provide uniform manipulation during decontamination for the highest efficiency and be able to blast only those areas determined by the radiation survey to be still contaminated.

The IBM robot is capable of teleoperation as well as programmed operation. It has a lifting capacity of 20 pounds and can operate at speeds up to 10 inches per second. The robot is designed to allow maintenance and replacement of all components through gloveports. A tool changer allows the robot to pick up many different end effectors. A parallel jaw gripper was used in the demonstration to manipulate the brick.

Autonomous Grasping (LLNL)

An autonomous grasping system has been developed to allow complete automation of the lead brick decontamination system. The model information provided by the structured light system was used as input to grasping algorithms to determine the optimum grasp. This system determined the proper grasp to pick up the brick and also be in the correct orientation for blasting. After initial blasting, the robot regrasped the brick to allow blasting of the areas of the brick initially covered by the gripper. After initial blasting the robot could change to a "clean" gripper to avoid recontaminating the cleaned area of the brick. An alternative would be to blast the areas of the gripper in contact with the brick before regrasping.

Scarifying System (LLNL, SRTC)

An Alpheus frozen CO2 blasting system was used to simulate decontamination of a lead brick. The aluminum brick was painted to demonstrate the effectiveness of the process. It propelled small frozen CO2 pellets with air from a nozzle. A low air pressure of 30 pounds per square inch was used during the demonstration. This produced minimum noise, yet was still effective at removal of the paint. Much higher removal rates and more aggressive cleaning could be achieved with higher air pressure. The energy of impact of the pellets and the thermal action have previously been demonstrated to be effective in decontamination of radioactively contaminated surfaces. For decontamination of large surfaces the blast nozzle is usually manipulated over the stationary surface. For lead brick decontamination, the brick was manipulated in front of a stationary blast nozzle. This eliminated the hose management problem (snagging, wear and recontamination) of draping hoses during manipulation. Information on the location of remaining contamination could be used to reblast only those specific areas. Use of robotics for this operation assures complete and uniform blasting of each brick and complete and uniform survey of each brick. One can expect the same improvements in quality of operation as has been experienced by the automotive industry in robotic painting and welding.

Workcell Modeling (SNL, SRTC)

Graphical programming, collision avoidance, path planning and program preview are all based on graphical models of the robots, equipment and material in the environment. Accurate models are required to accomplish this. Material, such as containers (drums, boxes, and bins), will be moving in, through, and out of workcells on a continuous basis. Large waste items such as gloveboxes and vessels will be moved into the workcell and size reduced. In order to maintain the accuracy of the model, an automatic system to update the workcell will be required. SNL has a Cooperative Research And Development Agreement (CRADA) with Mechanical Technologies, Inc. (MTI) on a structured light modeling system. MTI, with assistance from SNL, provided a structured light system that demonstrated automated updating of the Telerobot's workcell model. The workcell was approximately 20 feet by 20 feet in area. A metal box was placed in the workcell but not entered into the model. The structured light system used four identical stations at each corner of the workcell to model the metal box. Each station had two precise stages with very accurate feedback that act as a pan and tilt mechanism. These stages manipulated a camera, laser line generator (laser and lens) and a laser pointer. The laser pointer was used only for initial calibration of the system. One station passed the laser line across the workcell, while the other cameras tracked the line. By repeating this four times, with each station eventually panning a laser line, the shape and location of the box was calculated. This information was then automatically entered into the graphical simulation system as a model of the box. The model was accurate to $\pm$ 1 inch in this application.

Automatic Standoff Control (SRTC)

In waste facilities there will be some large metal objects, such as gloveboxes and vessels, that must be size reduced before they can be put into the final form or placed into a shredder, compactor or other size reduction device or treatment process. Plasma arc cutting is the most popular method for remote cutting of metal. It is a very aggressive process and its control is not very demanding. However, if the geometry of the object to be cut is not well known, it is difficult to control remote plasma arc cutting. In waste facilities we will be challenged by a large number of metal objects that will vary widely in size and shape and will not be well documented. Experience with remote plasma arc cutting of these undefined objects has shown that it is difficult to maintain the arc and keep the torch from hitting the surface.

Industry typically uses torch voltage to monitor and control standoff distance. This technique works well, if the type of material and material thickness are known and uniform. This will not be the case in waste facilities. The model of the box produced by the workcell structured light system is accurate enough to allow the operator to graphically program the start and stop point for the torch, but is not accurate enough and is not updated often enough to control the standoff distance of the torch. Sensor-based control needs to take over from model-based control. A Selcom laser distance measuring sensor added to the torch end effector to measure the standoff distance was demonstrated last year. The laser is unaffected by the plasma arc or the type or thickness of material. The output from this sensor was used to perturb the robot trajectory, using GISC. This year a new, low-cost Selcom laser was used to control the standoff. This laser costs less than $5,000, compared to the previous laser that cost over $17,000. Control has been improved by Clemson University by having the laser measure three points on the surface to be cut to automatically position the torch perpendicular to the surface. Also, the data obtained by the laser is now stored in the computer by its position in space. This allows the torch tip to be manipulated to avoid contact with sloped surfaces or the leading or trailing edge of changes in slope. This control system is also applicable to different types of cutting and decontamination tools that require control of the standoff distance.

Swing-Free Crane Control (SNL, ORNL)

Drums can be transported inside a mixed waste facility by a gantry robot, as was demonstrated, or other types of material handling equipment, such as an overhead crane. Large, heavy containers, such as boxes and bins would likely be transported by overhead crane. Operation of an overhead crane, especially by inexperienced operators, can cause severe swinging of the load which is dangerous to the operator and can damage the load or the facility. Swinging also can significantly increase the time required to move loads, particularly the time required to manually dampen out the swing before a load can be lowered. These problems are increased in a remote facility due to the distance of the operator from the load and restricted vision.

Swing-free operation allows a load suspended from a cable to be moved without inducing any undesired swing. The basic swing-free technology has been patented by SNL and demonstrated on a gantry robot. This technology has been transferred to ORNL where it has been adapted, and demonstrated on a standard gantry crane. The crane is a standard, 30 ton, AC motor-driven crane, using new vector drives recently available from industry. Swing-free operation of this crane was shown on a videotape. Also, a table top model of the swing-free technology was demonstrated. The table top model requires prior knowledge of the period of swing, which is dependent on the pendulum length, and prior knowledge of the desired path of the load. SNL has developed operator-in-the-loop, swing-free control, so that prior knowledge of the desired path is not required and the load can be moved in real time by an operator with a standard crane pendant or other input device. SNL also has developed sensor-based, swing-free crane control where a sensor at the top of the cable measures cable displacement, so that swing-free control can be automatically implemented no matter what the length of pendulum. Operator-in-the-loop, sensor-based, swing-free control of a standard AC crane will be developed by ORNL and will be ready for transfer to industry this fiscal year. This technology will allow an inexperienced operator to move a load of any weight or size, at any height, in real time, without inducing swing.

Stored Waste Autonomous Mobile Inspector (SRTC)

There are tens of thousands of drums of low level radioactive, hazardous and mixed waste stored at each of several major DOE sites. Environmental Protection Agency regulations require weekly inspection of these drums. This is a monotonous, manual task. Manual inspection provides very limited documentation on the condition of these drums and inventories are updated on an infrequent basis. Robotic and vision systems can augment and improve the efficiency, documentation and accuracy of drum inspections and inventory. If a spill of radioactive material occurs, the inspectors can spread the contamination throughout the facility before detecting contamination on their shoes when they monitor at the warehouse exit. It has been shown at SRTC that a mobile robot can detect floor contamination much more reliably and accurately than manual surveys conducted over a long period of time.

A Stored Waste Autonomous Mobile Inspector (SWAMI) is being developed for drum inspection and floor survey and is the first commercial mobile robot to use GISC for operation. The on-board supervisory system was developed by the University of South Carolina. SWAMI can navigate autonomously through drum storage warehouses and capture a video image of each drum, read the bar coded number of the drum and store the image, drum number, time, date and physical location in an on-board computer system. This information can be downloaded into a database at the end of each run, updating the inventory each time an inspection is done. The robot also carries a sensor package to survey for radioactive contamination in the aisle. It will warn operators of high levels of alpha particles and beta/gamma radiation and generate a map of alpha contamination and radiation levels. The robot is based on the Helpmate mobile robot by Transitions Research Corporation.

SWAMI was demonstrated in a drum storage warehouse mockup with typical 55 gallon drums on pallets stacked up to three levels high. SWAMI navigated through the aisles using the radiation detector and six sets of bar code readers, cameras and strobe lights to gather information. The drum images, numbers and a radiation map from a previous mission were displayed. SWAMI also located a radiation source placed in the aisle.

Martin Marietta Astronautics is developing a vision system through a Program Research and Development Announcement (PRDA). This system will analyze the drum images and detect rust spots and streaks (potential leaks). These suspect images will be presented to the operator for disposition. The operator can compare these images to previous images of the same drums to determine if these rust spots were there previously and how they may be increasing in size. This technology added to SWAMI can increase the ability of the operator to locate drums requiring action, determine trends in deterioration of the drums over time and provide documentation of drum appearance over time.

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