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THE WATER-SHIELDED CAVE FACILITY FOR
TOTALLY ENCLOSED MASTER-SLAVE OPERATIONS
AT LAWRENCE RADIATION LABORATORY

BERKELEY, CALIFORNIA

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Patrick W. Howe, Thomas C. Parsons, and Leonard E. Miles

October 9, 1961

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WATER-SHIELDED CAVE

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ABSTRACT

An efficient, flexible, and relatively simple system of enclosures for the handling of multicurie amounts of alpha, gamma, and neutron-emitting isotopes has been developed by the Health Chemistry Department at Lawrence Radiation Laboratory, Berkeley. It has been in operation since April of 1961. This system consists basically of interlocking 4-ft water tanks that form the shielding around the leaktight primary enclosure in which operations are conducted by means of totally socked master-slave manipulators. This facility has been successfully used for procedures ranging from multicurie chemical separations to highly refined microtechniques. It has served equally well for metallurgical examinations and remote machining and welding procedures. The cost of this totally equipped facility was approximately \$60,000.

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INTRODUCTION

Historically, the processing of irradiated slugs for recovery of americium, curium, berkelium, californium, einsteinium, and fermium at the Lawrence Radiation Laboratory was conducted in leaktight enclosures behind a 6-in. lead shield, by means of Castle manipulators and special remote-control equipment designed by the Health Chemistry Department. During the earlier years of transplutonium processing, this system proved satisfactory, and radiation exposures and (or) contamination from this operation were quite low. Later, when significant quantities of Cm^{242} and Cf^{252} were to be handled, the processing took on a different complexion. Whereas previously the problem consisted of containing high alpha concentrations and providing an adequate beta-gamma shield, the situation now involved not only exceedingly high levels of these radiations but also neutron radiations. Cm^{242} and Cf^{252} undergo fission, with Cf^{252} releasing 1.7×10^8 neutrons per min/ μg . The neutron activity from the spontaneous fission of Cm^{242} is 1.4×10^6 neutrons/min/mg. In addition to the neutrons originating from spontaneous fissioning, there are neutrons released by the α, n reaction, which varies with the process steps.

During the processing of 7 micrograms of Cf^{252} in May of 1959, there was evidence that neutron emission approached the maximum safe operating level with the 6-in. lead shield. At this point it became necessary to change the concept of shield design and start a study leading to a design that would protect personnel from neutron exposure in future operations.

REQUIREMENTS FOR THE NEW SYSTEM

After an extensive literature search and laboratory investigation for an exotic neutron moderator,^{1,2,3} we concluded that water was still one of the most effective moderators to be found, in addition to being readily available at very low cost. Based on this conclusion and on calculations for neutron shielding, a system of interlocking 4-ft-thick water tanks was designed for the shielding enclosure. With wall thicknesses of this magnitude, Castle manipulators were obviously inadequate; we undertook an evaluation of master-slave manipulators vs remote control or electromechanical systems. After extensive investigation, we decided to use Model 8 master-slave manipulators operating within a total primary enclosure through socks.

This step led us next to consideration of the primary operating enclosure, which--in accordance with the Berkeley philosophy--would be a totally enclosed low-leak system. Once total enclosure was decided on, the next consideration was suitable socking for the protection of the master-slaves from a contaminated environment within the primary enclosure. Again, we made a thorough search of the literature and of socking techniques employed at other installations. This search revealed that no existing socking was compatible either with our primary enclosure or with our philosophy of operations. It was therefore necessary for the Health Chemistry Department to develop a suitable socking for our new cave facility.

Having decided upon the four principal components of our new system--water shielding, master-slave manipulators, total primary enclosure, and socking on the manipulators--we then established the following design criteria.

(a) The cave facility should have shielding sufficient to allow processing of 1 mg of Cf^{252} and many curies of gamma emitter without unreasonable radiation exposure.

(b) The cave facility should be located in the northeast corner of Room 141 of Chemistry Building 70. Maximum use should be made of the existing overhead shielding and the hillside.

(c) The cave should be designed with a broad range of capabilities for a maximum number of programs.

(d) All radioactive operations performed within the cave should be within primary enclosures.

(e) The primary enclosures should be of "quick change" design to allow maximum flexibility in programmatic operations.

(f) The shielding should be so designed that it could easily be relocated if necessary.

(g) Manipulations within the primary enclosure should be with Model 8 master-slave manipulators.

(h) Master-slaves should be so socked as to protect all components from contamination except the slaves' fingers, which should be considered sacrificial.

(i) Viewing should be by means of a large "picture window" at the front of the cave and a smaller picture window on the side of the cave.

(j) Detailed examination of operations within the primary enclosure should be by means of a Model 301 Kollmorgen Periscope equipped with 2- or 10-power and 6- or 30-power magnification.

(k) In accordance with the "quick change" philosophy, a shielded area should be provided for the storage of radioisotopes, thus allowing workers to enter the cave.

(l) The primary enclosure should be equipped with a remotely operable plastic-bag passout system for the removal of active waste, isotopic fractions, or contaminated material.

(m) A transfer system should be so designed that material could be conveniently introduced into or removed from the primary enclosure.

(n) The shield should be equipped with a sliding door large enough to allow convenient transfer of primary enclosures.

(o) The primary enclosure should be equipped with ventilation equipment of such nature as to operate at a negative pressure of 1/2 in. of water with a recirculating purifying system.

(p) The rear part of the cave should be provided with a separate ventilation system such that with the cave closed and operating, the confined space would be at lower pressures than the room atmosphere, and such that, in case of emergency, the discharge rate from that space could be increased tenfold. The air discharge from the cave should pass through an "absolute filter" before being released to the atmosphere.

(q) Remotely operable instruments for monitoring radiation levels should be installed in the back area of the cave.

STRUCTURAL DETAILS

Once the design criteria were established in terms of function it was in order to consider how these were to be met in terms of structure.

Shielding

Space limitations and the need to bring the shielding tanks in through narrow doorways and hallways helped determine the size of the interlocking tanks that were to make up the shielding. Figure 1 indicates some of the structural limitations. We had decided to retain the existing 6-in. lead shield, which immediately limited the width of the proposed facility. The east ceiling of Room 141 had been thickened at the time of building by 18 inches of high-density concrete to serve as additional shielding for operations in the earlier cave. By placing the 4-ft water cave in the northeast corner of this room, we could utilize this shielding. The topography of the Berkeley site is such that the east side of Room 141 is actually recessed into a hillside, thus giving additional shielding at the top and rear of the room. With the new cave placed in this location, rear shielding would not be necessary. Advantages of the hillside for an isotope storage chamber also influenced the selection of this location. By utilizing the shielding properties of the north wall of Room 141, which is a high-density concrete load-bearing wall, we were able to achieve the necessary shielding in the north wall of the new cave with only 2 ft of water. The dimensions of the proposed primary enclosure (discussed later in this paper) together with the maximum reach of the master-slave manipulator, established the interior cavity at 5 ft wide by 8 ft deep by 12 ft high. With these interior dimensions and the necessary shielding thickness, we arrived at a configuration whose outside dimensions were 11 ft wide and 12 ft deep, reaching an elevation of 13.5 ft in the front and 12 ft in the rear.

Having determined the outside dimensions of the cave facility, we now directed our attention to an examination of the necessary number and sizes of tanks for this configuration. It became readily apparent that tank dimensions would be dictated by (a) maximum size transportable through the building, (b) window height and size, (c) master-slave location, (d) Kollmorgen periscope location, (e) turntable location, and (f) sliding-door location.

With these factors provided for, final configuration consisted of fourteen main tanks which give a vertical assembly up to 10 ft 8 in., plus a series of lightweight tanks that occupy the remaining space and form the surge-tank system (see Fig. 2 and 3). These various tanks ranged from 8X4 ftX45 in. down to a small surge tank 12X18X24 in.

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Fig. 1. Floor plan of passageways leading to cave location.

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Fig. 2. Front of water-shielded cave, showing picture window and manipulators.

ZN-2944

Fig. 3. Side view of water-shielded cave, showing glove box for receiving items passed out through transfer turntable.

All the major tanks in this configuration were fabricated of 3/16-in. hard-rolled steel with interior reinforcements.

The adjoining surfaces of all tanks were shaped as broad V's 4 in. deep, each fitting into the next, to prevent radiation shine. Each tank was secured to the adjoining tanks by means of protruding ears on each tank connected by 5/8-in. steel bolts. The entire tank assembly was given additional stability by being secured to the structural walls of the building with anchor bolts.

The exteriors of all tanks were painted with two coats of vista green Alchemite #5446. In order to prevent corrosion within the tanks, all tanks except the window tanks were filled with 20 ppm sodium dichromate solution.

Access to the interior cavity is by means of a sliding water-tank door which is 3 ft 11 in. wide, 4 ft thick, and 6 ft 7 in. high. It operates on ball-bearing rollers running on a steel track. The door is easily operable by two men. The edge of door is not stepped and overlapped in the usual fashion, as the area of operation is located well forward of the door. Tests showed no neutron or gamma leakage around the door seam. This choice of access was later proven, under actual high-level radiochemical operations, to be a correct one. Contained within the sliding door is a viewing window (discussed in more detail in another section of this report).

We thought it desirable to have three operational locations for master-slave manipulators. These insert ports are welded penetrations consisting of precision-bored tubing which minimize any radiation leakage from the interior of the cave. Two are located 10 ft from the floor and above the main viewing window, and the third is mounted above the sliding door on the right-hand side of the configuration. For maximum utilization of the Kollmorgen periscope, there are three insert ports positioned 7 ft off the floor--one on each side of the viewing window on the front of the cave, and the third on the right-hand side of the cave several feet from the front. When not in use, these ports are sealed with water-filled vinyl tubes, which are easily removable. Special shielding is incorporated in the insert tube of the master-slave manipulators and in the Kollmorgen periscope. (This is discussed in more detail in a later section of this paper.) The introduction of utility lines is facilitated by means of twelve offset insert ports, 2 in. i.d.

The service tubes consist of pipe of lazy s-shape extending through the outer and inner walls of the tank and welded to the skin at each end. One of the desirable features of the tank system is the ease with which through tubes can be added: it is relatively simple to drain one of the tank units and weld in an additional through tube or other desired access port. A similar advantage of the metal-skin tanks is that they allow easy attachment, by welding, of brackets for the support of additional equipment.

To maintain the integrity of the shielding, a surge-tank system was incorporated, which provided for expansion and contraction of the water due to temperature variations. The tanks were linked together by feed lines, and the main tank system was pressurized by the head of the surge tanks at the ceiling level. Each tank is filled with water by means of inlet and outlet valves. Water is added at the lower valve, and air is bled out through the upper valve

before the upper valve is connected to the surge system. This technique has proven most satisfactory in insuring against voids within individual tanks.

To minimize the voids between the tanks in the V configuration, the reinforcing of the tanks was so designed as to maintain the flexibility of the 3/16-in. metal skin on the top and bottom of each tank. Therefore, as the tanks filled with water, they tended to sag slightly into each other and minimize any gap. This system has proven effective, for no radiation has been detected, either in tests or during actual operation.

The temperature is controlled in the cave room, and once equilibrium had been established in the tank system there was very little movement between the tanks and the equalizing surge system. Actually, in the case of the sliding door, it was found that a 500-ml polyethylene bottle just above the door level was adequate as a surge system.

Storage Recess

Having established as part of the design criteria of this facility that primary enclosures should be easily replaceable, we recognized that it would occasionally be necessary to remove major isotopic fractions from the primary enclosure and store them while replacing the operating enclosure. Inasmuch as the primary box has a remotely operable plastic-bag passout unit, and as the rear area of the cave is served by a master-slave manipulator, we decided to utilize the natural shielding in the rear of the cave room for a storage vault. A recess was excavated in the hill behind the primary operating box and lined with concrete, and in this recess was placed a rotating drum--a Lazy Susan configuration (see Fig. 4). The drum, made of steel and filled with water, is 4 ft. in diameter and in one side contains a cavity 8X8 in. X18 in. high. When there is need to enter the cave, a high-level isotopic fraction can be passed out of the primary enclosure in a sealed container, sealed in a plastic bag, and deposited in this cavity by means of the master-slave manipulators. The Lazy Susan can then be rotated 180 deg thus interposing 3.5 ft of the drum between the activity and the cave, and giving the same shielding as afforded by the main cave system.

Primary Enclosure

Two principal factors influenced the final dimensions of the primary enclosure to be used in this facility (a) space limitations already described, and (b) a survey of past operational requirements. We concluded that the optimum box size for this facility would be 33 in. deep by 49 in. wide, and 40 in. high.

We considered a variety of structural materials for the fabrication of this enclosure. We rejected many on the basis of cost, vulnerability to radiation damage, interference with viewing, incompatibility with chemical reagents, and a variety of other reasons. We decided to have a box which would allow maximum visibility, both through the cave window and with the Kollmorgen periscope. Our conclusion was that the top and sides of the

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Fig. 4. Diagram of water-shielded cave.

enclosure should be made of 1/4-in. -thick molded Lucite, with the ends of the box of 16-gauge mild steel painted with two coats of Alchemite #5446. The bottom was to be constructed of 14 gauge stainless steel.

For ease of fabrication and to eliminate the problem of joining dissimilar materials and the attendant difficulties with gaskets, the Lucite top and the stainless steel bottom are molded into pans, 2 in. deep, with coved corners and radius sides. These are joined to the side sections by the use of a molded aluminum H bar and an epoxy resin. The final product is shown in Fig. 5.

Access to the box for introducing and removing apparatus or material is provided by an interchange on the right side of the box. This interchange is 18 in. high and 8 in. wide, and allows an object 6 in. in diameter by 16 in. high to be passed into the box without exposing the box interior to the atmosphere. This interchange is designed to mate with a transfer turntable (described later) in the right-hand section of the 4-in. water shield, which provides a means of passing materials and apparatus through the shield.

The primary enclosure is also equipped with a remotely operable plastic-bag passout unit for removing isotopic fractions for storage in the rear Lazy Susan or removing radioactive waste for placement in the waste storage containers. See Fig. 6. This passout unit, in the center of the rear box panel, is accessible by both the primary enclosure master-slaves and the service area master-slave.

Access to the primary enclosure for the original installation of equipment (into a cold enclosure) is provided by a removable, gasketed cover plate, 22 in. diameter, on which the rear bag passout is mounted. The primary enclosure is also equipped on the rear panel with standard glove-box rings and fitted with standard Berkeley Box gloves. These allow final decontamination by hand of any enclosure after the major radiation contributors have been removed.

The primary enclosure rests on a hydraulic-lift table, which allows the box to be lowered for the easy extraction or insertion of the master-slave manipulators. The table also serves as a transportation dolly for the box.

Electrical leads are brought into the box through its metal side wall by use of sealed electrical connectors, and service lines are brought in through the Lucite sections.

Socking

Having established the structure of the primary enclosure and wishing to maintain contamination-free master-slaves, we surveyed existing master-slave socking techniques. In general, those socks which we examined proved unacceptable for our purposes owing to excessive weight, bulk, cost, and restriction of manipulation. We therefore embarked on a development program for the fabrication of a light-weight durable sock, which would offer minimum restriction of the slave movement and could be easily fabricated. This sock and its fabrication are discussed in detail in a separate report.⁵

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Fig. 5. Primary enclosure for use within water-shielded cave.

ZN-2940

Fig. 6. View inside cave, showing plastic-bag pass-out unit attached to primary enclosure.

The socking consists basically of four principal components. The first is a large-area bellows system which occupies the major portion of the top panel of the primary enclosure (see Fig. 7). This bellows arrangement is suspended on a swivel-mounted spring system which allows free movement of the slave. The second component is the sock bellows, which is a large-area funnel-socked section necessary for maximum reach by the slaves. The third component is a multiple-pleat vinyl sock which facilitates the extended vertical motion of the master slave. This portion is made very similar to a camera bellows, so that as the slave is elevated there is not an excess of material tending to drape over the hand of the slave. The fourth component is the slave mitt, which is of molded vinyl. This is so designed as to cover all components of the lower portion of the slave except the hand, which is considered expendable. The large volume of the upper portion of this socking array serves quite successfully as an expansion bellows or pressure regulator to compensate for changes in box pressure due to motion of the slaves. It should be pointed out that no claim is made for extensive durability of these socks, as part of the cave concept is for short-term use of boxes. Radiation and chemical exposure tests, however, showed these socks to be quite durable even when exposed to up to 10^7 r. The adequacy of these socks was further confirmed during the processing of 32+ micrograms of Cf^{252} and hundreds of curies of fission products.

Recognizing that a rupture of the sock, or even a slight penetration of the sock, in conjunction with the pump action of the slave would tend to release activity to the cave, we placed air samplers in the bellows of the slave socks. These were 1/2-in. Tygon lines passed through the shielded wall to a Millipore sampling device. Samples from this unit were taken at frequent intervals and counted to determine if activity was escaping via the socks. The results of these counts were alpha-negative, but some beta-gamma activity was detected, perhaps due to diffusion of I^{131} .

MANIPULATION

As mentioned earlier, we conducted a rather extensive investigation for the purpose of comparing master-slave with electromechanical manipulators. Our selection of standard Model 8 master-slave manipulators was based upon the following reasoning:

(a) We wished maximum use of this facility for many programs, but it appeared to us that electromechanical manipulators would be subject to severe contamination problems. In some of the commercially available electromechanical manipulators the units themselves were not only quite vulnerable to corrosion damage but also contained many inaccessible mechanisms that would be extremely difficult to decontaminate. Even so, no provisions had been made for socking such units. Once they were used, they would be rather irrevocably committed to a given program or would require extensive decontamination. However, with our socking technique, standard Model 8 master-slaves could be used in a variety of programs without extensive decontamination or the possibility of cross-contamination between programs.

(b) We made a detailed geometric study comparing the loss of "usable" space within an enclosure when equipped with a master-slave manipulator or with an electromechanical manipulator. This study indicated that, because of

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Fig. 7. Sock assembly in primary enclosure.

the elbow configuration of most electromechanical units, several critical areas within the enclosure were totally inaccessible, and others were accessible only through rather contortionistic maneuvers. A great deal of valuable box space would be lost in providing room for the movement of the electromechanical manipulators.

(c) We also considered the natural motions used in manipulating the master-slave in contrast with the rather unnatural motion required by the operator in some electromechanical systems.

(d) In examination of these two systems, we emphasized reliability. The use of master-slave manipulators in the nuclear field is well established. Our survey indicated, further, that standard-duty Model 8 master-slave manipulators have an extremely high reliability factor. Considering the initial program to which this facility was to be committed (processing of Cf^{252}), we were unwilling to try manipulation systems that had not survived extensive use tests. We also recognized that all mechanical systems are subject to certain inevitable breakdowns. Our comparative analysis indicated that a master-slave could be more easily withdrawn from our enclosure for repair than could an electromechanical system. Being limited in the financing available for this facility, we thought this a worth-while consideration.

(e) A survey of proposed use established the need for maximum flexibility and sensitivity of manipulation rather than the need to support excessive weight, thus establishing preference for the standard Model 8 over the heavy-duty Model 8 manipulator.

(f) A final (but significant) factor in our selection of standard-duty Model 8 master-slave manipulators was their lower cost. We found, in general, that the price of a pair of master-slaves was approximately half the cost of a single electromechanical unit.

On the basis of the above investigations, two standard-duty Model 8 master-slave manipulators were selected as the means of manipulating within the primary enclosure. These units, as originally purchased, were standard with one exception. Both neutron and gamma shielding were provided in the through-tube barrels to prevent shine. This shielding took the form of 2-in. -thick alternate layers of Lucite and lead, giving a total length of 12 in. In the early test runs of the installation, it was found desirable to be able to operate the slaves at a higher elevation than normally provided. For this reason, the slave arm extension tubes were shortened 8 in., which allowed operation 32 in. above the bottom of the standard box, as opposed to the original 24 in. This allowed the placement of specialized equipment in the upper part of the box. The only other alteration made was a small V notch cut in the rubber grip at the fingers to aid in holding small objects.

The structure of the cave facility is such as to allow a major portion of the support equipment to remain outside the primary enclosure, but within the shielded area. This feature greatly reduced the total quantity of contaminated equipment and extent of contamination, yet retains it within a contained ventilation area. Because we realized that this "service area" would contain equipment requiring adjustment during operations, in addition to a variety of other apparatus requiring some form of manipulation, this rear service area was equipped with an unsocked heavy-duty master-slave manipulator (Fig. 4). This slave differed from the standard Model 8 principally in its ability to lift much heavier objects. This slave is so

located as to provide access to all portions of the rear service area. One of its principal functions is to manipulate the rear plastic-bag passout unit, and subsequently transfer isotopes to the storage Lazy Susan and radio-active waste to the waste containers.

This slave has also had shielding added as in the standard Model 8's, but no other alterations have been found necessary. Although the heavy-duty manipulator does lack the sensitivity found in the standard Model 8, this has not proven critical, as operations served by this manipulator are not extremely delicate or sensitive. The use of this heavy-duty manipulator has proven invaluable in the rear service area, particularly in conjunction with a small half-ton remotely operated chain hoist. This has made possible the removal of the lids of heavy shielded shipping containers and shielded waste containers.

The operational experience gained thus far in this facility thoroughly justifies the selection of master-slave manipulators. It has already been decided that in future cave facilities the same basic approach will be used.

TRANSFER SYSTEMS

The problem of introducing and removing equipment, reagents, assay fractions, and other apparatus from the primary enclosure of the 6-in. lead cave facility had always presented innumerable problems in our previous operations. As one of the primary uses of the new facility was to be chemical separation programs, it was obvious that, because of the large number of assays required in these programs, a convenient, expedient, and safe means of introducing and removing material from the primary enclosure was essential. We studied a variety of systems for such operations, and finally selected a Lazy Susan-type pass-through system. Operating experience with this system has proven it to satisfy all requirements. A great many assays have been removed from primary enclosures by this technique without release of contamination. The structural details of this array constitute, in our opinion, a refreshingly simple approach to the pass-in problem.

The turntable is a 4-ft-diameter drum with a cavity 8×8×18 in. high in one side of the drum (Fig. 4). A 5/8-in. -diameter hole through the drum accepts the shaft of a handling tong. Standard ice-cream cartons can be placed in the jaws of the tong and held in the recess in the turntable while the turntable is rotated into operating position. At this point, an extension handle is added to the tong, which allows movement of the tong and ice-cream carton into the interchange of the primary enclosure. The carton can then be released from the tong and the tong withdrawn into the turntable. In a similar manner, an ice-cream carton can be removed from the interchange and rotated to the exterior of the 4-ft shield, where it is accessible through a standard Berkeley glove box. The turntable with its enclosing box is so designed that it is mounted as a unit and can be withdrawn for overhaul. For easy insertion and removal, a 1-in. gap was left above and on each side of the unit between it and the main shield structure. Thin bags of 40-mil vinyl were tailored to fit into this void and, when water-filled,

completed the shield. The turntable is rotated by a small gear motor and is easily controlled by the operator. As previously mentioned, a similar turntable in the rear wall of the cave provides shielded storage of isotopic fractions. Material can be introduced to the primary enclosure from either turntable system. The box interchange provides access to the primary enclosure from the side turntable, and the rear pass-out system provides access from the rear (storage) turntable.⁴

VIEWING

In previous cave facilities at Lawrence Radiation Laboratory, Berkeley, the lack of sizable viewing windows was an inconvenience and, at times, a technical handicap. We therefore decided at the inception of this cave to design a "picture window" which would offer simultaneous unrestricted viewing by several operators. Two rather obvious locations were selected for viewing windows. The front window is located 43 in. from the floor and 28 in. from the left wall of the facility. The side window is an integral part of the sliding door, allowing one to view operations in the rear service area.

The front viewing window is a transparent section through a tank. The tank is 45 in. high and 60 in. wide; the actual viewing area is 30×53 in. The front and rear surfaces of the tank window are constructed of 2-in. -thick Lucite mounted on the interior of the tank and secured to the frame bolted to the tank wall. Leakage around the window is eliminated by means of a soft rubber gasket drawn against the reinforced tank skin by means of the backing plate. The water pressure within the tank facilitates sealing. The interior metal surface of the tank is painted with two coats of Rustoleum #472 orange primer to prevent corrosion and two coats of Rustoleum #479 flat black to minimize reflection. The tank is filled with distilled water, which is kept clear by being periodically recirculated through an adaptation of a carborundum swimming pool filter, using Cellite as the filtering medium. This system has proven extremely effective in preventing cloudiness, which would tend to obstruct the view of operations within the primary enclosure.

The picture window allows a large number of observers without disturbing the operators, and has given unobstructed visibility to all areas within the primary enclosure. The window is extremely effective as neutron shielding and a very acceptable gamma shield. If it is desired to use the cave for extremely high levels of gamma activity, sodium bromide may be added to the viewing tank, and still further gamma shielding in the form of lead glass sections could be added to the rear of the tank window. Based on experience with the current cave, there is evidence that windows up to 6 ft thick are quite feasible for tank arrays of this type. If additional windows were desired, it would be relatively easy to construct them within any of the existing tanks of the shielding array.

The window located within the sliding door of the cave is of similar construction, and has a viewing area 30×43 in. It has been satisfactory for observing operations in the rear area, but we plan to increase it from 30 to approximately 60 in. in height so as to see operations at floor level more easily.

We like to emphasize that this approach to cave window construction represents considerable financial saving over the casting of very large lead glass windows, while at the same time providing the necessary personnel protection. We were initially worried that crazing might diminish visibility through this window. This, however, has proven a needless concern, as no crazing has been encountered after one year of operation. Should crazing eventually occur, it would be relatively simple to replace the Lucite panels. As an example of the economy of this approach, the Lucite used in the front window cost approximately \$300, in contrast to something like \$30,000 for suitable glass.

Although the picture window affords excellent viewing of operations within the primary enclosure, there are occasions when extremely detailed examinations are necessary within it. These examinations can be made by means of a Kollmorgen periscope, Model 301, equipped with 2-, 6-, 10-, and 30-power magnification. The scope is mounted with its rotating optical head above the primary enclosure, and can be focused on any operation through the Lucite top of the box. This scope has been useful, for example, for reading the meniscus on micropipettes in chemical separations programs, and for other semimicroscopic operations. As in the case of the master-slave manipulators, special layered shielding, placed within the bore of the periscope through tube, limits the unshielded penetration to an optical viewing path 1-5/8 in. in diameter. Including this shielding within the bore tube eliminated the need for bulky exterior shielding on the Kollmorgen periscope (see Fig. 2).

FIRE AND SAFETY CONSIDERATIONS

In the construction of this cave facility, our safety considerations were not restricted solely to the radiological hazards. Recognizing that a fire could result in an extremely serious release of activity, we endeavored to minimize this possibility. The interior of the cave area is equipped with a corrosive-proof sprinkler and alarm system (Globe upright spray 160 deg). The water-filled steel cave structure itself of course offers no fire potential. Equipment used within the primary enclosure and within the service area was critically evaluated with respect to its fire potential, and substitutions were made wherever possible for equipment that contributed to such a potential. The low-leak technique for ventilation within the primary enclosure has been shown by experimental investigation to be very effective in suppressing fires within enclosures. All ventilation equipment is on an emergency circuit, which operates in the event of a failure of standard power service.

All electrical services within the cave can be de-energized at a central control panel at the operating face of the cave.

In addition to the structural safeguards, the cave room is under frequent inspection by the Patrol Force, and is also equipped with an alarm system.

VENTILATION

In considering ventilation systems for this facility, we followed the standard principle of diminishing pressure differentials. Building 70 is at a negative pressure with respect to the environment, and the rooms and laboratories are at a negative pressure with respect to the corridors. Thus air movement is from the outside inward, i. e., from cold area to hot area. There are approximately ten complete air changes per hour in the room in which the cave facility is located. The atmosphere within the room is sampled by means of several modified Filter Queen vacuum cleaners equipped with HV-70 filter collection media. These samples are checked routinely, and more frequently during actual operations.

In considering the construction of the cave, we wished the cavity to be at a negative pressure with respect to the room, so that, in the event of a release of contamination, material would be retained within the cavity and would not escape to the room. A dual-speed exhaust system serves the cavity with an air movement of 75 cfm for normal operation and an optional 830 cfm for emergency operations, which would bring the cavity to 1/2 in. negative pressure (water-gauge) with respect to the room. Air from the cavity is discharged through its own duct system after treatment by a fire-resistant AEC-1 high-efficiency filter. This filter measures 2×2 ft × 5-7/8 in.

In the event of a serious emergency within the cave, the AEC-1 filter could be replaced by means of the rear-service-area slave. In order to protect and maintain the integrity of the large filter face, a perforated metal screen is placed in front of the filter housing. This is easily removable by the service slave if it is necessary to replace the filter. Air being discharged from the cavity, having passed through the 2×2-ft×5-7/8-in. filter, is again monitored at the point of discharge from Bldg. 70 by means of two modified Millipore stack samplers. The cavity is continuously sampled by a Filter Queen vacuum cleaner equipped with a "clam shell" sampling head. This unit is mounted outside the cave for convenient servicing and filter check. A sampling tube extends through a service port into the cave for sampling.

The ventilation of the primary enclosure is completely independent of the cavity. Again, it is based on the concept of inward flow, and the enclosure is maintained at 1/2 in. negative pressure (water-gauge) less than the interior of the cavity. It is based on the use of a low-leak system, taking advantage of the increased collection efficiency of high-efficiency filters at low flow rates.

Attendant upon most low-leak systems is the problem of corrosion in a relatively dormant atmosphere owing to buildup of acid and water vapor during process chemistry. For this reason, the primary enclosure has an additional closed-cycle air-cleaning system. This consists of two parts. The first is an "air conditioning" train⁶ capable of recirculating 18 cfm through a Venturi scrubber; a refrigerated, buffered sodium hydroxide-flooded "Saran" filter pad; a demister unit; and--for a portion of the air--a glass fiber filter (Fig. 8). This unit is mounted outside the cave proper behind suitable shielding and is connected to the primary enclosure by heavy-wall 2-in. polyethylene tubing. It has been extremely useful in neutralizing,

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Fig. 8. Scrubber unit used in ventilation system for primary enclosure.

partially decontaminating, and dehumidifying the process air, and in preventing the formation of clouds of ammonium chloride smoke that can arise in processing. This air-conditioning train, though effective, is expensive to fabricate. Therefore, a second unit was developed: a small totally enclosed system utilizing molecular sieves⁷ as the absorbent for off-gases and water vapor that arise in chemical processing (Fig. 9). Full advantage is taken of close-capture hoods in operations where fumes are generated, such as evaporation, dissolution, or other process chemistry that involves acid fumes. In the low-leak system using molecular sieves, it is possible to maintain a dry atmosphere inside the primary enclosure, thus materially reducing the corrosion problem. The availability of these two systems allows complete ventilation coverage, each being used as conditions warrant.

For normal operation the close-capture molecular sieve system serves quite satisfactorily, and aids in localizing and concentrating contamination in an easily disposable unit. If fission gases are expected to be released in operations such as slug dissolution, small evacuated, refrigerated activated-charcoal bombs (-76°C) are used to back up the molecular sieves. These are usually handled in a lightly shielded secondary enclosure, outside the main shield, connected to the interior of the cave and to the molecular sieves by Tygon lines.

As mentioned earlier in this paper, material can be introduced into or removed from the operating enclosure by means of the transfer turntable. When this system is used, material being introduced is first placed into a modified glove box which is mated with the Lazy Susan housing. From there, the material follows the steps previously listed. The reciprocal of this operation is used in removing material from the operating enclosure. Thus material is not brought directly into the open room in either step.

In order to maintain a negative pressure on the glove box, but not go below the negative pressure on the operating enclosure, an interchange system is interposed between these two units. With this interchange, we avoid any direct connection between the operating enclosure atmosphere with the room atmosphere. In order to minimize the amount of contamination that might be transferred from the operating enclosure to the interchange, and hence to the transfer turntable, an air-flush system was installed on the interchange. During both the introduction to and removal of material from the operating enclosure, a high-velocity air flush is maintained on the interchange while the exterior door is open. When the exterior door is closed again air flush is discontinued and the interchange is allowed to reach a pressure only slightly higher than the operating enclosure before the interior door was opened. This system served well as an air barrier against the spread of contamination within the cave. The air discharge from the interchange, both in normal operations and in flushing operations, was via a fire-resistant high-efficiency filter unit. A sample line was attached to this unit and surveillance maintained for contamination in interchange exhaust. All other ducts involved in the system were continuously sampled.

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Fig. 9. Molecular sieve unit used in ventilation system for primary enclosure.

INSTRUMENTATION

For matter of convenience in this paper, instrumentation used in conjunction with this facility is described by categories of alpha, beta-gamma, and neutron measurement or detection.

Alpha Measurement

For alpha monitoring in and around cave operations, the Health Chemistry alpha survey meter⁸ is used routinely. This is an all-transistorized air proportional instrument having a detection range of 0 to 10^5 counts per minute of alpha particles. This unit is used for routine monitoring work such as checking floor swipes, making personnel checks, and other conventional monitoring operations. A modified form of this instrument was employed in conjunction with a glove box attached to the outside of the cave to receive material through the transfer turntable. In this case, the meter was mounted outside the glove box, while the probe was within the glove box, connected to the meter by means of a feed-through connector. This probe is a standard Health Chemistry type of probe, of the air proportional variety, with 18 in.² of sensitive area. This instrument was used to check material that had been passed from the operating enclosure via the transfer system to the receiving glove box before the material was removed from the glove box to the room environment. Owing to the efficiency of the ventilation system and techniques employed in this cave facility, the activity within the receiving glove box was never at such a level as to contaminate the probe.

Beta-Gamma Measurement

For portable beta-gamma monitoring, Anton V-700 survey meters with a range of 0 to 50 mr/hr are used. For monitoring above 50 mr/hr, standard CP's and Junos are used. In the rear cave service area, a high-level remote ion chamber (with a range of 0 to 250 r/hr of gamma) was available for use with the service slave. The readout for this ion chamber was at the receiving glove box. A second ion chamber (range 0 to 2.5 r/hr) was used in the receiving glove box for monitoring passed-out material. In actual practice, any material coming out of the primary enclosure was first monitored by the rear-cavity ion chamber before insertion into the Lazy Susan. As the material was brought to the glove box position, it was again monitored with the lower-level ion chamber, and if it was above this level, it was returned to the primary enclosure for further processing.

Neutron Measurement

For routine personnel monitoring, a moderated BF_3 tube portable fast-neutron survey meter is employed. This unit consists of essentially the same electrical circuitry as employed in the Anton survey meter, but is calibrated against a known quantity of Cf^{252} and National Bureau of Standards Po-Be and Pu-Be sources. These survey meters have been very useful in personnel monitoring and in neutron experiments. Additional personnel monitoring is available in the form of a large and more sensitive moderated BF_3 tube with scaler readout. This unit is mounted on a lab dolly and can conveniently be rolled to any location. Attached to the front of the cave

above the viewing window is a semipermanent moderated BF_3 neutron detector with strip-chart read-out; this gives a continuous recording of the neutron levels in the front of the cave throughout operations. It is interesting to note that, at the maximum neutron level occurring in this facility thus far, there has been no measurable neutron penetration of the shield. This instrument measures 0 to 10 mrem per hour.

During chemical separations within the primary enclosure, it is highly desirable to be able to determine neutron levels of special aliquots of the separations stream. Determination of these neutron levels is both an additional personnel safeguard, prior to passing slugs out of the primary enclosure, and a convenient qualitative measuring device for determining the location of Cf^{252} and Cm^{242} and Cm^{244} on the separation columns. For obtaining these measurements, a "pickle barrel" neutron-detection system is installed in the floor of the operating enclosure. This is a fission counter, of annular cross section. The exterior is cadmium, clad to absorb thermal neutrons. Detection is by fast-neutron capture in a U^{235} coating on the inner wall. The inner and outer walls form the sensitive volume of a proportional counter. This counter conveniently receives objects up to the size of a 40-ml cone, and is capable of detecting 2×10^5 neutrons per second from the sample, with a background of approximately 10^8 neutrons per second. The signal from the counter is fed through the shield to an amplifier and a scaler located near the viewing window.

WASTE DISPOSAL

In keeping with our philosophy of quick-change operating enclosures for this facility, it is necessary to minimize the levels of activity within the operating enclosure so that persons can enter the cave at the time of box change. The rear-wall Lazy Susan described earlier in this paper serves as a repository for the storage of isotopic fractions at such times. Operating experience has shown, however, that in transplutonium chemistry the higher levels of activity are frequently associated with waste products rather than with the final products of the separation. Therefore we recognized that it would be highly desirable not to accumulate the radioactive waste within the enclosure, but rather to remove waste frequently from the operating enclosure to a shielded storage area. We felt that this would reduce problems when workers had to enter the cave. The following solid and liquid waste systems were therefore incorporated into this facility.

Solid Waste

One of the principal uses of the remote plastic-bag passout unit on the rear of the operating enclosure is removal of solid waste from the operating enclosure. Active waste generated within the enclosure is placed in a primary carton and is then deposited in the remote plastic-bag passout unit, where it is sealed in a plastic bag. This package is then transferred by means of the rear service area slave to a shielded transport container in the cave service area. This shielded transport container is a shielded receptacle, $22 \times 22 \times 20$ in. (4 in. of lead shielding), containing a removable metal lining. The top of this unit is hinged and is operated by the chain

hoist in this area. This unit is easily transportable to the waste disposal facility for final processing.

Liquid Waste

Liquid waste is disposed in a 2-gallon polyethylene container encased in 1 in. of lead, which fits into one of the 4-in. lead-shielded containers described above. This large polyethylene bottle, connected directly by Tygon lines to the primary enclosure, has a funnel connection inside the enclosure for receiving waste, and a return line to vent displaced air from the polyethylene container back into the primary enclosure. These lines were so constructed that they could be welded off when the waste container was to be removed.

In using a system of this type, it is necessary to maintain a volume inventory of all active waste disposed of in this manner. The technique usually employed in processing operations at Berkeley is to temporarily store liquid active waste in a 500-ml polyethylene bottle within the primary enclosure until an aliquot has been assayed, before dumping it into the 2-gallon bottle.

After the lines from the large bottle have been welded off and the bottle separated from the primary enclosure, the shield and its contents are taken to the waste disposal area and processed. Provision is always made in the large polyethylene container for extra lines for the purpose of sampling or for adding reagents to the container before solidification.

OPERATIONAL EXPERIENCE

Five major programs of quite varying nature have been conducted within the water-shielded cave since its completion in April 1961. A brief description of these programs illustrates the successful use of this cave.

The first program employing this new facility was a prototype separation chemistry program performed in May 1961 as a prelude to the major californium separation program. This program consisted of processing, separation, and purification of 24 mg of Cm^{244} . The chemistry of this curium operation closely paralleled the anticipated setup of the californium separation program, and a dummy dissolving procedure helped us to fully evaluate the equipment involved. This prototype run gave us a great deal of valuable operating experience, and led to some relatively minor alterations on the equipment to be used for the californium program. At no time during the curium operation was any contamination released, nor was there any leakage of ionizing radiation through the shield.

Upon completion of this prototype chemistry operation, the primary enclosure was replaced with a new enclosure, and the facility was used at this time for accurate check of the dimensions of several high-level neutron sources used by the Health Physics Department. This operation required manipulation of micrometers by means of the master-slaves, and visual checks by means of the Kollmorgen periscope.

The next use to which the facility was put was a detailed examination of three irradiated slugs containing a total of 500 mg Cm²⁴⁴, 800 mg of Am²⁴³, 800 mg of Pu²⁴², and approximately 200 curies of mixed fission products. These slugs, a portion of the national californium production program, had been irradiated at Materials Testing Reactor in Idaho Falls, Idaho. There had been some indications of damage to these slugs, and extensive metallurgical examinations were necessary to determine their integrity.

The above examinations showed that rejacketing and rewelding of the slugs was desirable. A new primary enclosure, equipped with a slave-operable microwelding unit, was installed in the facility, and the three slugs were successfully rejacketed and rewelded.

The most recent utilization of this facility--and the major one, so far--was the californium separation program performed in July 1961. This operation involved extensive separation and purification processing. The material consisted of 32 µg of Cf²⁵² and 100 mg of Cm²⁴⁴, approximately 200 curies of mixed fission products, and smaller amounts of Bk²⁴⁷ and E²⁵³. The success of this run far exceeded the most optimistic predictions of either the Health Chemistry or the Chemistry Department. Details of the chemistry of this program are to be given by Dr. Sherman Fried in The Extraction of Heavy Elements from Irradiated Cm²⁴⁴, UCRL-9881, (in preparation).

CONCLUSIONS

It is the unanimous opinion of those concerned with this water-shielded cave that it has met all the requirements established for such a facility. On the basis of the experience gained thus far in the five months of varied operations of this facility, we expect that this design will accommodate a broad variety of complex programs at a high level of activity. We now feel that this facility, with minor modifications, can accommodate even higher levels of activity in the future.

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* Postdoctoral Fellow from Eidgenosse Institut für Reaktorforschung, Würenlingen-A.G., Switzerland.

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