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EFFECTIVE ACCESS MONITORING AT GEOLOGICAL REPOSITORIES: A SYSTEMS STUDY

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Abstract

Access points at a geological repository (GR) for the disposal of spent nuclear fuel and other nuclear wastes present potential diversion paths for nuclear material. Such access points can include one or more ramp entrances for fuel-emplacement and construction operations, elevator shafts for moving personnel and equipment, ventilation shafts, and other design features that can provide access to and from the GR's underground workings. While considerable attention and effort has gone into identifying long-term surveillance measures for monitoring activities at or near a GR, much less progress has been made on identifying reliable containment and surveillance (C/S) measures that can dependably detect movements of nuclear material through the variety of GR access points. Furthermore, given the likely lack of C/S measures underground, GR access points will require unprecedented reliance on C/S measures to maintain continuity of knowledge (CoK) on nuclear material buried underground, especially during operations when people, equipment, and materials will be entering and leaving the repository. Reliable and redundant C/S measures will be required for all declared access points leading from the repository's surface to its underground. Declared access points will require C/S measures such as radiation detectors and surveillance cameras, but could also include complementary or novel methods to increase confidence in maintaining CoK on nuclear material emplaced underground. Sandia National Laboratories has performed a system study of conventional and potentially novel C/S measures that can be applied to a geological repository with multiple access points to optimize the application, placement, and use of C/S measures. The study helps to inform decisions about implementing efficacious safeguards technologies at geological repositories as part of an overall safeguards-by-design approach.

1. INTRODUCTION

The disposal of spent nuclear fuel in geological repositories presents a unique challenge for international nuclear safeguards. Whereas conventional safeguards approaches for other stages of the nuclear fuel cycle rely on nuclear material accountancy (NMA) supplemented by containment and surveillance (C/S), this conventional approach cannot be strictly applied to the disposal process. This is because, unlike conventional safeguards approaches by which NMA can be re-verified if supplementary C/S measures fail, re-verifying NMA for spent fuel that has been permanently encapsulated in disposal canisters is not realistic, and becomes impossible once disposal canisters have been emplaced in a geological repository. Thus, maintaining CoK on encapsulated fuel assemblies will rely on C/S measures to a degree unprecedented in other stages of the nuclear fuel cycle [1,2].

As emphasized in a recent report for the IAEA's Application of Safeguards to Repositories (ASTOR) expert group [3], access points at a geological repository (GR) present potential diversion paths for nuclear material (NM). Yet few C/S measures have been examined for monitoring these access points, and recommendations for effective application of C/S measures remain to be developed. Given the potential likelihood that C/S measures will not be implemented underground, a GR and its access points at the surface will require C/S measures that can reliably maintain continuity of knowledge (CoK) on spent fuel buried underground. Effective C/S measures will be especially crucial during GR operations when people, equipment, and materials (both nuclear and non-nuclear) will be regularly entering and leaving the repository. Reliable and redundant containment and surveillance (C/S) measures will be required for all declared access points leading from the repository's surface to its underground. Such access points can include one or more ramp entrances for fuel-emplacement and construction operations (such as waste-rock removal and backfill delivery), personnel and equipment access and egress, elevator and ventilation shafts, and other access points, depending on GR design.

Sandia National Laboratories performed a system study of C/S measures that can be applied to a geological repository with multiple access points to optimize the application, placement, and use of C/S measures. The study helps to inform decisions about implementing efficacious safeguards technologies at geological repositories as part of an overall safeguards-by-design approach. The study reported here examines C/S measures for access points and assumes the repository is designed and operated as declared by the State/operator, as verified thorough design information verification (DIV) inspections and has none of the following capabilities or equipment: to

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open disposal canisters; to disassemble spent fuel assemblies; to remove spent fuel pins from fuel assemblies; to reprocess spent fuel and recover plutonium. Thus, C/S measures described here are designed to detect movements of intact disposal canisters containing spent nuclear fuel.

2. MODEL REPOSITORY ACCESS POINTS

The system study begins with a review of available national repository designs used to develop a representative "model" repository system. The model repository developed for this study is based primarily on designs reported by countries with Comprehensive Safeguards Agreements (CSAs) in force. The study emphasized surface features and facilities, with special emphasis on those features with access to the underground workings that could provide potential (undeclared) diversion pathways for removing spent-fuel from the emplacement horizon underground. These and related features and structures are described in Table 1 and illustrated in Fig. 1.

TABLE 1. MODEL REPOSITORY SURFACE FEATURES AND ACCESS POINTS

Facility	*Function*
Receiving & Buffer Storage	Transportation casks containing disposal canisters will be received and stored in the buffer-storage area until each disposal canister is ready to be emplaced. Design verification assures no undeclared access to the repository from the receiving and buffer storage areas.
Ventilation Station and ventilation shafts	Provides fresh-air circulation between underground workings and the surface. Two shafts supply fresh air to, and exhaust air from, the underground. The ventilation station at the surface houses ventilation equipment. Shafts may contain additional equipment (e.g., electric cables, diesel supply lines).
Ramp Entrance & Ramp	Ramp is used to transport disposal canisters from the surface to the underground during repository operations; ramp entrance is at the surface. Transportation casks or other vehicles used to transport canisters down the ramp will return (empty) to the surface via the ramp. Safeguards seals on transportation casks are verified and removed under surveillance before moving disposal canisters underground.
Skip shaft entrance & shaft	Connects the operations area at the surface to an excavation staging area underground. The skip-shaft must accommodate the movement of rock debris (tailings) excavated during repository construction, as well as buffer and backfill materials to be moved underground
Elevator shaft entrance	One or more elevators provide transport for personnel (and small materials) between the surface and the underground. Each elevator shaft will have room for one or two elevators.
Tailings (rock waste) Pile	Surface storage of mine tailings (crushed rock waste) that has been removed from the underground workings of the repository via the skip shaft is transported to the tailings pile by a conveyor or a suitable vehicle. The tailings pile is outside the repository's perimeter. Design verification assures no undeclared access to the repository from the tailings pile.

Facility	*Function*
Perimeter & Access Control	A security perimeter, erected by the State/operator limits access to the surface area of the repository facility to authorized equipment and personnel only though access-control (A.C.) points (e.g., gates). Access-control points include personnel entrance(s), gateways for transportation casks (entering with disposal canisters and exiting empty), and passage of rock waste (tailings) from the skip shaft to the tailings pile. Design verification, remote monitoring (e.g., passive acoustic-seismic monitors) and periodic site inspections assure no undeclared access to the repository's underground from outside the perimeter.
Administration (including personnel and equipment-storage buildings)	Administrative and other buildings or structures that do not handle nuclear material (spent fuel), casks or canisters. Design verification assures no undeclared access to the repository's underground from administration, personnel, or other buildings, and that all surface buildings are built and operated as declared (e.g., absence of undeclared reprocessing capabilities).

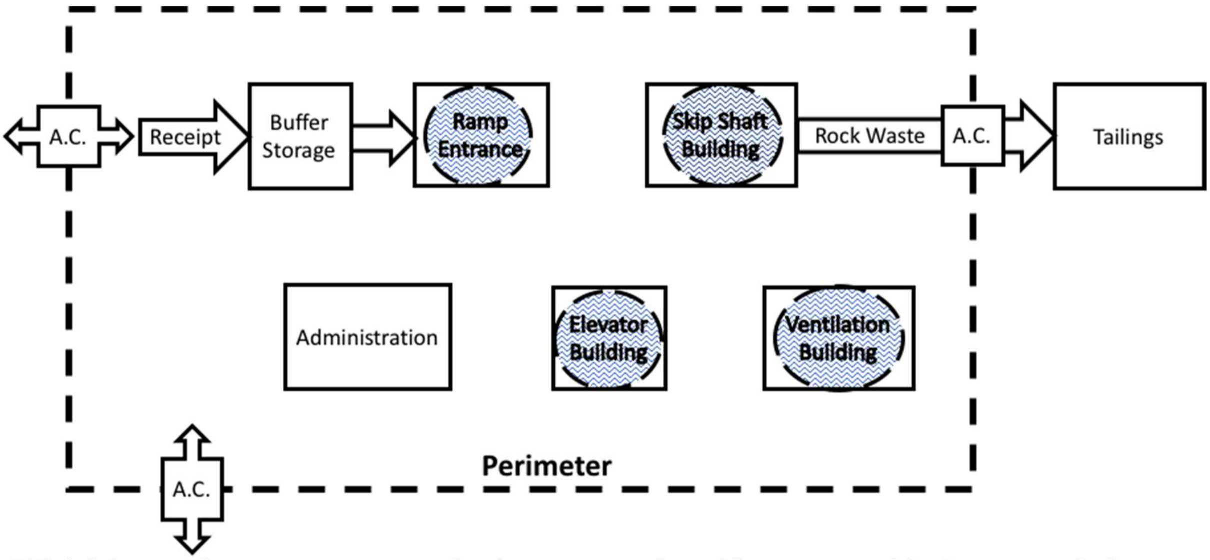

FIG. 1. Schematic plan-view representation of surface structures of a model repository used for the system study. Structures (rectangles) with dashed and shaded circles represent access points between the surface and the repository's underground. The perimeter limits access to the repository facility to authorized equipment and personnel only. Boxes labeled "A.C." indicate access control through the perimeter for authorized ingress and egress (e.g., gates). Arrows show flow directions for disposal canisters ("Receipt") and rock waste. Potential undeclared flows are not shown (cf. Fig. 2).

2.1. Geologic containment: The Restricted Zone

For safeguards purposes containment refers to "structural features of a facility, containers, or equipment used to establish the physical integrity of an area or items and can be used to maintain the continuity of knowledge (CoK) of the area or items by preventing undetected access to or movement of material, or interference with the items" [4]. The geological formation or host rocks within a "restricted zone," as defined by the State, forms the repository's containment; no mining operations are permitted within or through the restricted zone. Two periods during a repository's lifetime are critical for containment. The first period includes the pre-operational and operational phases, when there will be open access between the surface and the underground workings (although NM will be at the facility during the operational phase only). The second, indefinite period is the post-operational (or post-closure) phase when the facility has ceased operations and all access points have been closed and sealed shut.

During the pre-operational and operational phases, containment will include the ground surface plus the geologic formation (host rocks) within a *restricted zone* defined by the State. The restricted zone surrounds the repository on all sides and below. In addition to monitoring for potential breach of the restricted zone, C/S measures during the pre-operational and operational phases will also include restrictions on and detection of movements of NM into (and out of) declared access tunnels and shafts, as well as identifying undeclared activity or unreported access points. Successfully applying such measures require detailed design information verification (DIV), knowledge about all operational capabilities underground, as well as the ability to detect undeclared activities. After a repository has ceased operations, C/S measures will be limited to monitoring for (undeclared) attempts to access the repository's emplacement zone through the restricted zone or from the surface above the repository by mining through closed and filled access tunnels and shafts.

3. OPERATIONAL COMPONENTS

3.1. Surface Operations

Emplacing disposal canisters underground is the crucial operation for a geological repository; however, a variety of operations will occur at the surface, including temporary storage of as-received canisters, maintenance, movement of personnel and equipment, and mining and other construction-related activities (e.g., rock removal). Many of these operations require access between the surface and the underground, and are of potential safeguards concern because each access point corresponds to a potential diversion pathway.

3.2. Receiving and Buffer Storage Operations

The receiving and buffer storage area of the repository (Table 1) is where spent fuel canisters in sealed transportation casks are received after being offloaded from a transportation vehicle (ship, rail or truck). Transportation casks containing disposal canisters are sealed at the point of shipping (e.g., an off-site encapsulation plant). Transport casks with disposal canisters may remain in buffer storage while awaiting emplacement in the repository. Because the number of transportation casks is likely to be limited, any such waiting period is expected to be short. Seals on loaded transportation casks might remain intact while in buffer storage. One or more areas in buffer storage will be used for storing empty transportation casks that will be returned to the shipping point, as well as potential (but rare) reverse shipments of transportation casks that contain disposal canisters that need to be returned for repackaging (e.g., damage or other safety concerns).

3.3. Emplacement operations

When the operator deems a disposal canister ready for emplacement, the canister is moved from buffer storage to the ramp entrance by means of a dedicated transport vehicle. From the ramp entrance, each disposal canister is transported down the ramp to the repository's underground emplacement area, where the canister is emplaced in a tunnel/drift that will be closed and sealed when the tunnel has reached its design capacity.

3.4. Mining/construction operations

Excavation of underground workings (emplacement tunnels, drifts, etc.) will continue throughout the facility's lifetime, including during emplacement operations. Waste rock will therefore be moved from the underground to the surface via the skip shaft (Table 1) and transported to and stored on the tailings pile (Table 1). Waste rock may be moved by vehicles or by a continuously operating conveyor (e.g., belt). The tailings pile in the model repository is outside the perimeter, which requires monitored access control for passage through the perimeter.

3.5. Backfill operations

Emplacement tunnels and other mined drifts in the repository will be progressively closed and sealed as they are filled with disposal canisters. Backfill materials include engineered clay backfill (e.g., bentonite blocks) and waste rock that has been crushed and returned to the underground from which it was mined. These materials will be delivered to the underground emplacement area via the skip shaft. Backfill and mining operations can be expected to proceed concurrently.

3.6. Closure operations

Once the repository has been filled to capacity, all remaining open tunnels and drifts, as well as the ramp and all shafts, will be filled and sealed by using waste rock and/or other engineered materials. Equipment within these tunnels, shafts, and drifts (e.g., ventilation ducts, mechanical equipment, elevators, etc.) will be removed before they are backfilled. Final closure of the repository will include removing all buildings and other structures on the surface. All C/S safeguards equipment at the surface will be also removed when the repository access points are closed, filled and sealed, and the buffer storage area has been emptied and removed.

4. CRITICAL AREAS FOR C/S AND SAFEGUARDS

By using the model repository and its operations, the study reveals several structures and features that are critical for C/S safeguard measures. These are illustrated in a cross-sectional schematic of surface structures, described in Table 1, with declared and potential undeclared NM flow paths via access to the repository's underground emplacement zone (Fig. 2). The objective of C/S measures is to detect both declared and undeclared movements of NM (spent fuel) from the underground emplacement area to the surface and beyond the repository's surface boundary, as defined by the State's security perimeter (labelled "P" in Figs. 1 and 2).

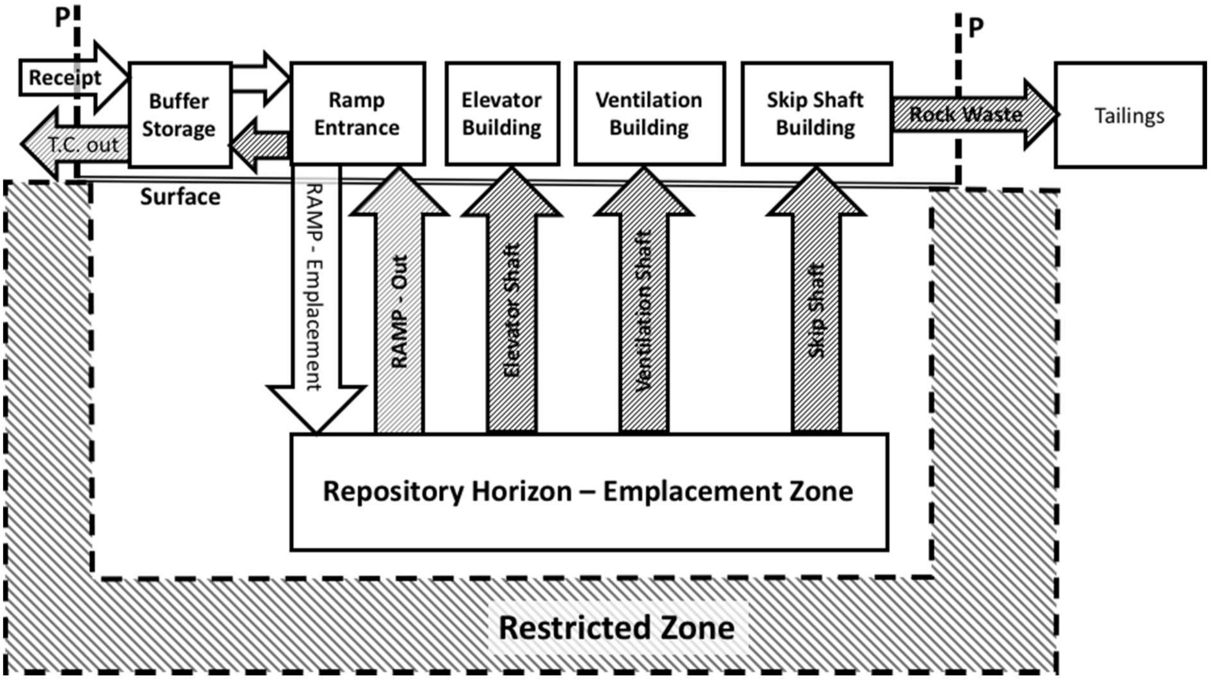

FIG. 2. Schematic cross-sectional representation of repository structures of safeguards concern (cf. Table 1 and Fig. 1). Horizontal arrows show flow directions at the surface for disposal canisters (left) and rock waste (right), and vertical arrows show movements of spent fuel into or out of the repository's underground (emplacement zone), both declared (pointing down) and potential undeclared (pointing up). Shaded arrows indicate potential undeclared diversion pathways. Horizontal arrow at left labelled "T.C. out" shows removal pathway for empty transportation casks (without disposal canisters); vertical dashed lines labelled "P" indicate the repository's Perimeter (cf. Table 1 and Fig. 1).

4.1. Spent fuel receiving and buffer storage

Transport casks containing disposal canisters will arrive at the repository under seal, the seals having been applied to transportation casks at the shipping point. Casks will cross the security perimeter and proceed to the buffer storage area.

4.2. Ramp Entrance

The ramp entrance is the declared access point through which canisters enter the repository for emplacement underground. The ramp leads from the surface to the underground workings of the repository. Empty transportation casks returning from underground to the surface via the ramp would need to be verified as empty before exiting the ramp entrance. Disposal canisters that must be returned to the surface for safety reasons (e.g., damage and other safety concerns) will be rare, but must be accommodated.

4.3. Skip/excavation shaft

The skip shaft is used to move mined rock debris from the repository underground to the tailings pile; it is also used to transport buffer and backfill materials from the surface to the underground, and may also be used to house equipment for use underground (e.g, electric cables, refuelling pipes).

4.4. Ventilation shaft

One or more ventilation shafts are used to circulate fresh-air from the surface through the underground workings of the repository. Entry points for these shafts are inside the building that houses the ventilation station. Ventilation shafts will not be equipped with lifts or elevators, as confirmed through periodic DIV inspections.

4.5. Elevator Shaft Entrance

The elevator is used to transport personnel and small equipment from the surface to the underground workings. One elevator shaft is envisioned, which may contain one or two elevators.

4.6. Other Surface facilities: Tailings pile and conveyor

Underground drifts, tunnels and boreholes will continue to be constructed while disposal canisters are being emplaced underground. Mined rock debris will be hauled to the surface via the skip shaft and stored in a tailings pile on site but outside the security perimeter (Fig. 1).

5. C/S OPTIONS

5.1. Spent fuel receiving and buffer storage

Recommended C/S measures for the buffer storage area include video surveillance and radiation monitoring (e.g., neutron monitoring of disposal canisters by using a MUND detector). The buffer storage could also be placed under seal by using active electronic seals (e.g., EOSS) that can record opening, closing, and tampering, transmitting such information to a local receiving station or via a secure connection to the inspectorate. Seals may remain on individual transportation casks until its disposal canister is to be removed for emplacement; if so, a storage-area active seal might be unnecessary.

5.2. Ramp Entrance

If safeguards seals on transportation casks are not removed at the buffer-storage area, they would be removed at the ramp entrance before moving the canisters down the ramp for emplacement underground. Safeguard seals are envisioned to be removed by the operator under video surveillance, with the removal process monitored remotely by the inspectorate. The inspectorate informs the State/operator whether CoK has been maintained on each disposal canister's contents and approve emplacing each canister for which CoK has been maintained. The inspectorate must give the State/operator an unambiguous and timely "pass" or "fail" decision about going forward with emplacing each canister. A fail would require a transportation cask be set aside or resealed and returned to buffer storage until the discrepancy can be rectified. If CoK cannot be re-established, the (re)sealed transportation cask would be returned to the encapsulation plant for repackaging.

Verifying transportation casks that are returning from underground to the surface via the ramp as being empty before exiting the ramp entrance can be accomplished by installing radiation monitors (and possibly infrared [IR] cameras) at the ramp entrance to help ensure that no spent fuel can be returned to the surface undeclared. A weighing scale at the ramp entrance is recommended, as it can provide additional assurance that transportation casks returned to the surface are empty. Portal monitoring of the ramp entrance will include surveillance cameras and radiation monitors to ensure that canisters go down into the repository and cannot return to the surface undetected. Directional (paired) radiation monitors can be installed just inside the ramp entrance for this purpose.

Disposal canisters that must be returned to the surface for safety reasons would pass through surveillance and monitoring equipment at the ramp entrance, where they would be verified to contain spent fuel assemblies. Re-establishing CoK on spent fuel assemblies inside such canisters would likely require a unique identification for each disposal canister, but such systems are still under development. Compromised disposal canisters would be returned to transportation casks, which would be sealed (under surveillance if performed by the State/operator) for return to the encapsulation plant for repackaging; these return shipments may need to be kept at the buffer storage area to await return shipment, during which time, the transport casks would remain under video surveillance and be monitored.

5.3. Skip/excavation shaft

Because the skip shaft will be used to transport mined rock debris (tailings) from areas under construction below ground to the rock heap at the surface, C/S measures comparable to those employed for the ramp and ramp entrance are recommended to be installed at the skip shaft entrance, including radiation monitors, video surveillance and mass measurements. Radiation monitors might readily detect disposal canisters hidden within rock debris: infrared, or IR, cameras, could be especially useful for this purpose, although these would need to be performance tested.

5.4. Ventilation shaft

Entry points for the ventilation shaft(s) should be monitored by surveillance cameras and radiation monitors. Radiation monitors installed at each ventilation shaft's surface entrance would seem sufficient for detecting undeclared removal of spent fuel, and surveillance cameras could be set to respond to a trigger from a radiation detector. Indeed, raising a disposal canister up a ventilation shaft would require installing hoisting equipment, a process that should be detectable and deterrable by means of random on-site inspections.

5.5. Elevator Shaft Entrance

The elevator shaft entrance will be monitored by surveillance cameras and radiation detectors. The absence of capabilities below ground to open casks, verified through DIV inspections, helps to ensure that neither isolated assemblies nor their components can be removed via shafts. As for the ventilation shaft entrance(s), radiation monitors installed at the elevator shaft's surface entrance would seem sufficient for detecting undeclared removal of spent fuel canisters, and surveillance cameras could be set to respond to a trigger from a radiation detector.

5.6. Other Surface facilities

5.6.1. Tailings pile and conveyor

Assuring no NM (spent fuel) can be hidden in waste rock can be accomplished by installing radiation detectors and possibly IR cameras at the top of the skip shaft or along the conveyor (if used) carrying waste rock to the tailings pile.

5.6.2. Security Perimeter Access Control

Placing radiation detectors and mass-measuring scales at access-control points in the security perimeter could enhance confidence in detecting (undeclared) movements of NM through the security perimeter. However, unless the entire security perimeter can be design as a suitable containment barrier for safeguards purposes, these limited detection points could be bypassed, rendering them insufficient for safeguards.

6. OPTIMIZATION OF C/S APPROACHES

Optimizing C/S effectiveness should examine the potential redundant use of video surveillance and radiation monitoring. For example, installing a minimal number of video surveillance cameras at strategic locations to view multiple access points (building entrances and exits) could significantly reduce the accumulation of large data sets. Then a radiation-detector "alarm" at any shaft entrance could trigger the strategically located surveillance cameras and maximize available video information in the event of any potential diversion.

Design considerations: If possible, shafts and vents might be designed to restrict or prevent removal of disposal canisters to the surface by designing shafts to be to be smaller than a disposal canister's diameter. However, constraints due to construction costs and performance requirements, may require that shaft sizes be larger than the diameter of disposal canisters. Nevertheless, some design alternatives might be considered that could reduce or eliminated the need to monitor a shaft's surface entrance. For example, if only small-diameter ventilation shafts intersect underground tunnels, these could merge into larger ventilation shafts leading to the surface that together would accommodate required air flow.

As noted above, designing the security perimeter as a suitable safeguards containment barrier could substantially reduce C/S measures at all access points through the security perimeter by reducing the need for such measures to be at access control points only. The details of how to accomplish this is beyond the scope of the current study, but might be worth pursuing as a significant cost-savings measure consistent with safety, security, and safeguards (3S) by design.

TABLE 2. RECOMMENDED C/S APPROACHES FOR INDIVIDUAL ACCESS POINTS

Facility	*Function*
Receiving & Buffer Storage	Video surveillance, portal radiation monitoring, possibly IR cameras, mass-measuring scale at entrance
Ventilation Station and shafts	Radiation detectors, video and IR cameras (triggered by radiation and/or motion detectors)
Ramp Entrance & Ramp	Video surveillance, portal radiation monitoring, possibly IR cameras, mass-measuring scale at entrance
Skip shaft entrance & shaft	Radiation detectors, video and IR cameras (triggered by radiation and/or motion detectors)
Elevator shaft entrance	Radiation detectors, video and IR cameras (triggered by radiation and/or motion detectors)

7. SUMMARY

Sandia National Laboratories conducted a system study of C/S measures for access points at a geological repository for spent nuclear fuel. Maximizing C/S effectiveness requires that DIV inspection ensure that a repository is constructed and operated as declared. The model repository used for this study has no capabilities to open disposal canisters, disassemble fuel assemblies or remove individual fuel pins, or to conduct spent-fuel reprocessing. C/S measures will include video surveillance cameras, radiation monitors, mass-measurement scales, motion detectors, and possibly, IR (thermal) cameras. The use and placement of these C/S measures can be optimized by using a safeguards-by-design approach that accounts for the facility's layout and operations.

8. ACKNOWLEDGEMENTS

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