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Value Impact of Vault Automation in Special Nuclear Material Storage

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VALUE IMPACT OF VAULT AUTOMATION IN SPECIAL NUCLEAR MATERIAL STORAGE

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ABSTRACT

Cost/benefit studies in this report indicate that automation of storage systems is the most favorable approach to gaining safeguards benefits in special nuclear material (SNM) storage vaults. The studies are based on the SNM storage vault of a conceptual 200-metric tons (MT)/year mixed-oxide fuel fabrication facility. Two alternative nonautomated vault concepts are developed and evaluated for safeguards benefits. One emphasizes the use of additional security/surveillance personnel in SNM storage vault operation; the other emphasizes structural and procedural barriers to achieve isolation of SNM from operating personnel. The costs of each alternative are estimated and the cost/benefits compared with those of the conceptual fully automated vault developed in the earlier desirability and feasibility study.

1. INTRODUCTION

In recent years, the safeguarding of special nuclear materials (SNM) in the nuclear fuel cycle has become a significant problem of national concern. As quantities of fissile materials become separated and purified, great care must be taken to prevent their unauthorized diversion and improper use.

SNM is protected by a number of methods that can generally be grouped under three headings: (1) physical protection, (2) accountability, and (3) control of operating procedures. Each site that stores and operates with SNM in its process utilizes all three methods to varying degrees. Recently, new methods for increasing safeguards protection of SNM have been proposed for fuel cycle facilities. Because one of these involves automation of the vault in which these materials are stored, NRC initiated a study to determine the advantages and disadvantages of automating a vault to increase its safeguards benefits. This study has resulted in a series of reports. The first considered the desirability and feasibility of automating an SNM storage vault and was published in October 1977.[1]

This current report is the second in the series and develops two nonautomated storage vault concepts in detail to compare their safeguards value and the cost impact of achieving this value. A third report (yet to be completed) will describe the criteria by which vaults must be designed in order to achieve the required degree of safeguards protection.

2. SUMMARY

An earlier study[1] has shown that the automation of storage vaults to provide additional safeguards for special nuclear material (SNM) is both desirable and feasible. In that study, three concepts were developed featuring various degrees of mechanization, including full automation of a vault storage system envisioned as a part of a conceptual 200-MT/year mixed-oxide fuel fabrication facility, were developed. Each concept was evaluated for safeguards values as defined and determined using the methodology described in that report. Results showed that the automation approach is not only feasible but could gain significant safeguards benefits over the type of vault storage system currently in use (termed the manned/manual vault concept). To determine if a nonautomated system can show a safeguards value comparable to that of the fully automated system, this second study addresses two alternative SNM storage vault concepts for the conceptual 200-MT/year fuel fabrication plant. The cost-impact of achieving as high a safeguards worth in the alternative concepts is then compared with the cost of the fully automated system.

The first of these nonautomated alternatives, the guarded manned/manual vault concept, has been devised to provide the simplest (and presumably the least expensive) vault design and the maximum surveillance by security personnel of SNM-handling operations. The second alternative, the secure manned/manual vault concept, is based on a combination of procedures and mechanization to isolate vault operations personnel from SNM.

The two nonautomated alternative concepts plus the fully automated system are compared in Table 2.1 on the basis of total annual costs and safeguards benefits (numerical values assigned using the methodology described in ref. 1). This table indicates that the use of numerous security guards (the guarded manned/manual vault concept) yields a lower safeguards benefit (4.0) than does isolation of SNM from personnel, as in both the secure manned/manual concept (6.3) and the fully automated system (6.4). Based on the assumptions made in this

Table 2.1. Comparison of cost benefits of various vault concepts

Vault concept	Capital cost ($)	Total annual cost ($)[a]	Overall relative safeguards benefits	Average dose to operating personnel (% tolerance)[b]
Manned				
Guarded manual	2,860,000	4,319,400	4.0	100
Secure manual	12,467,000	3,279,400	6.3	20
Fully automatic[c]	2,350,000	703,100	6.4	0

[a]Operating cost including straight-line recovery of capital costs over a 30-year period.

[b]Percent of 1.25 rem/qtr, the operating limit specified in ref. 2.

[c]Data for this concept are taken from ref. 1.

study, the annual operating costs of both nonautomated alternative concepts are higher than those for the fully automated system. This differential in cost is attributed to the fact that fewer operating and maintenance personnel are required to operate the fully automated system, which has been designed to be highly reliable through the redundancy of critical equipment and an effective program of preventive maintenance.

The results shown in the last column of Table 2.1 reveal an important additional benefit of reduced radiation exposure where isolation is used to achieve safeguards benefits. In fact, a large part of the high cost of the guarded manned/manual concept is due to the need to limit the amount of direct work with SNM by operations and security personnel in order to limit their radiation exposure. Similarly, however, exposure of maintenance personnel to radiation in the fully automated system must be limited by providing a high degree of equipment reliability. This high degree of system reliability is achieved by using redundant equipment in critical areas and designing the system such that maintenance of these items is conducted in relatively low-radiation-level areas.

3. ALTERNATIVE VAULT CONCEPTS

The generalized structure of an SNM storage vault safeguards system is shown in Fig. 3.1. The areas of responsibility (security, process operations, and material control) and the functions of the three interacting elements (surveillance and personnel control, materials handling, and materials measurement) are identified along with the flow of information (light lines) and control (heavy lines). Specific safeguards systems differ in the manner in which administrative and procedural techniques and specialized equipment are employed to implement the functions and responsibilities of each element.

Details of the two alternative nonautomated SNM vault concepts in this study, sufficient to estimate the costs and to evaulate the safeguards benefits, are given in Appendix A, Sect. 7.1.

The first alternative concept developed, the guarded manned/manual vault illustrated schematically in Fig. 3.2, emphasizes extensive use of security personnel (guards) to maintain a high degree of surveillance of all SNM transactions. It is assumed that two vault guards are required for each 8-hr shift to ensure the degree of surveillance required in this concept and that at least one must be present for *every* SNM transfer. Additionally, a more effective current materials-control program, featuring frequent item-inventory measurements and audits, is provided. This concept is easily adapted to existing SNM vault storage systems, since most of the improvements are administrative and procedural.

The second alternative, the secure manned/manual vault illustrated schematically in Fig. 3.3 and as an artist's sketch in Fig. 3.4, utilizes an engineered safeguards system that completely isolates SNM from operations personnel in all vault transactions. This concept was developed on the premise of achieving total isolation of SNM through some combination of mechanization and manual operation. This requires a unique design for the vault structure and storage unit, remotely controlled transport vehicles, and a material control center (MCC) housing a computer, display panels for indicating the status of the storage systems, and several control consoles. The operations personnel would not have access to the SNM but would operate the fork-lift-type vehicles that move into and out of the vault to transport SNM. Assuming a 200-MT/year mixed-oxide fuel fabrication plant with each SNM storage container holding 8 kg of SNM, a total of 13 vehicles are required—all of which are in service each shift to maintain plant throughput.

ORNL Dwg 77-18631R

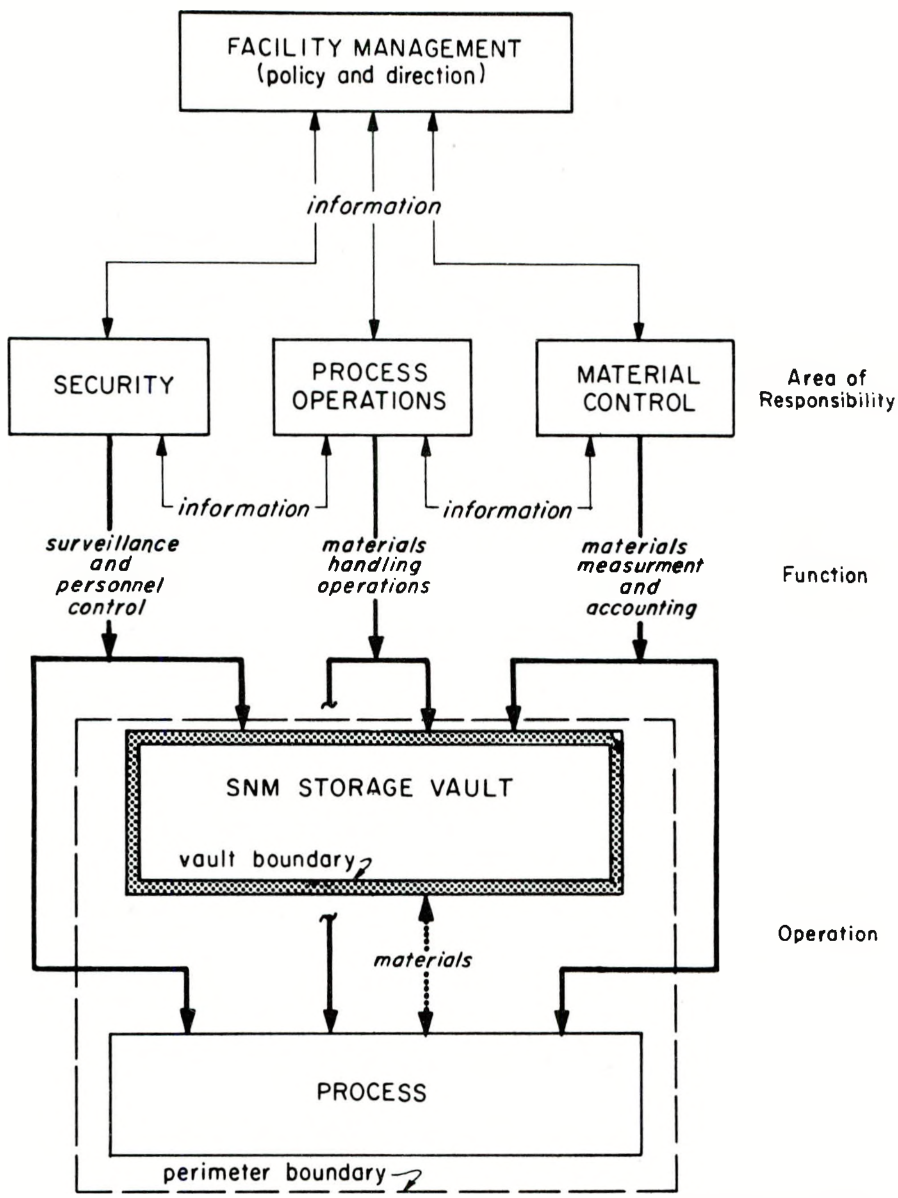

Fig. 3.1. Generalized structure of vault safeguards systems.

ORNL Dwg 77-7833

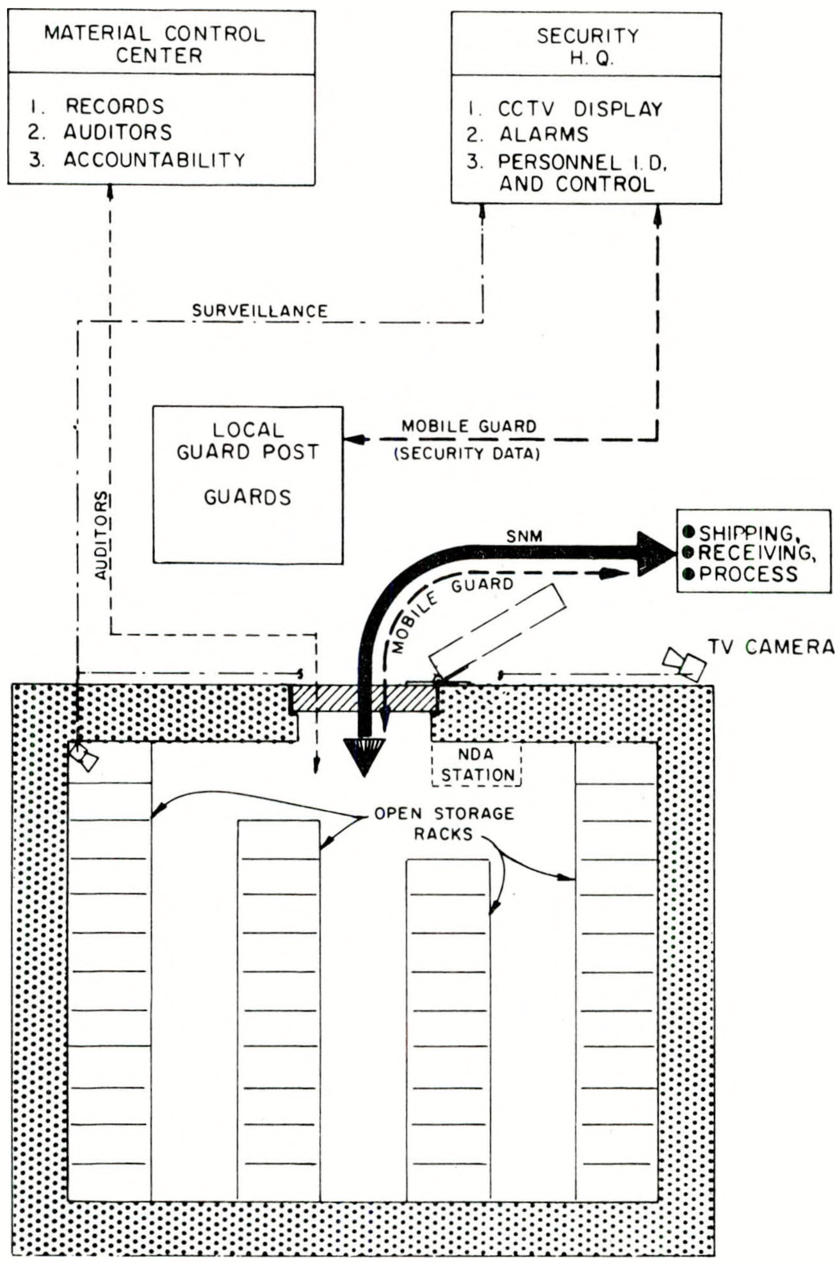

Fig. 3.2. Guarded manned/manual vault.

ORNL Dwg 77-7834

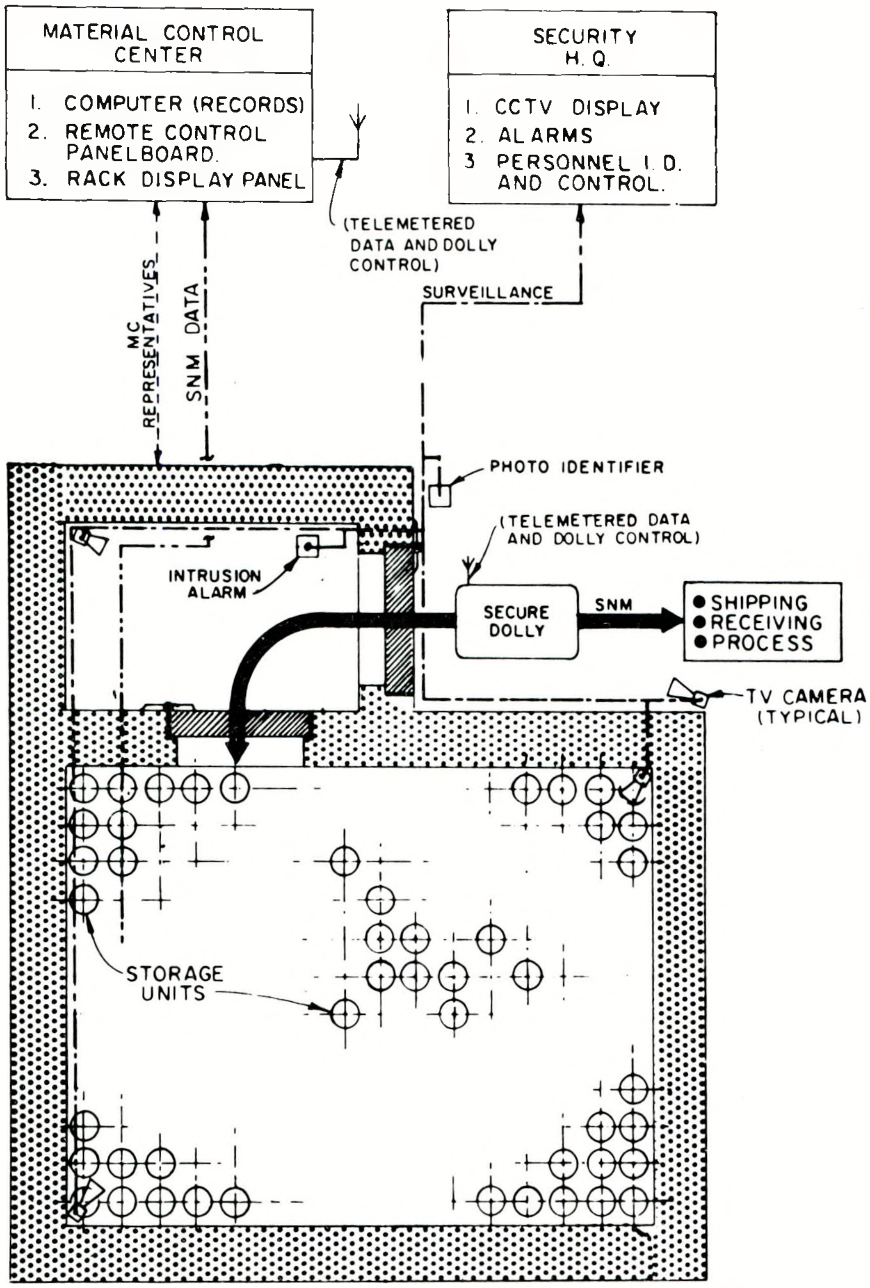

Fig. 3.3. Secure manned/manual vault.

ORNL Dwg 77-14163

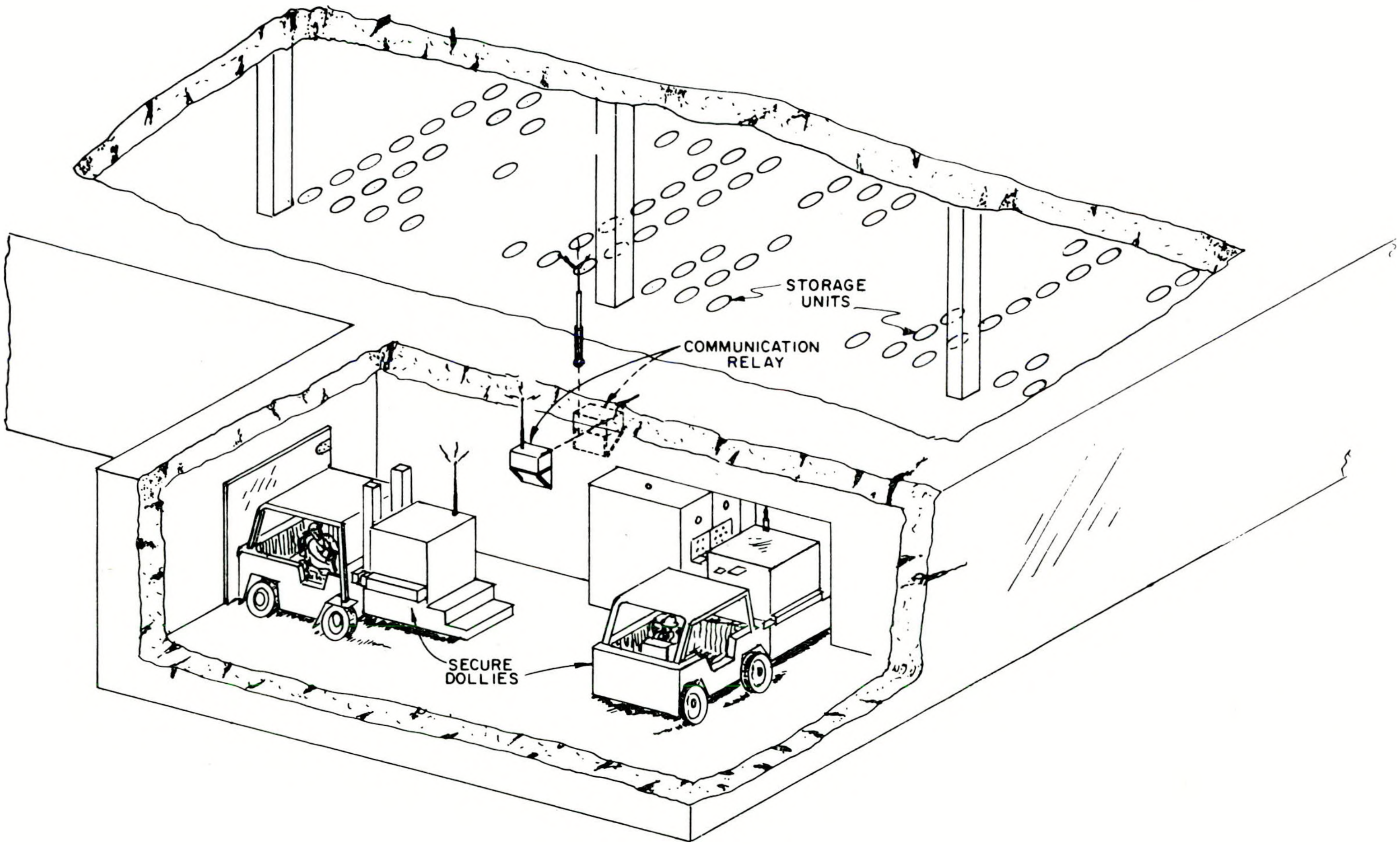

Fig. 3.4. Artist's sketch of a secure manned/manual vault system.

4. VALUE/IMPACT ANALYSIS

The principal value that accrues in an SNM vault system is the degree of safeguards advantages or benefits it has over alternative systems. On the other hand, the impact on the cost of the vault system caused by efforts to achieve these benefits must be examined to permit a reasonable design to be selected.

4.1 Safeguards Benefits

Maximum safeguards benefit is provided by the vault storage arrangement that ensures maximum overall effectiveness in the safeguards functions: detection, delay, and deterrence. In this section, the three SNM vault storage system options are evaluated with respect to these performance criteria.

The evaluation methodology[1] is based on specifying the safeguards-related factors or characteristics that have an effect on the overall criteria for system performance. Each factor is then considered with respect to the three vault storage options in order to identify principal differences between the options.

Upon identification of these main differences in a vault safeguards performance factor as a function of the type of vault considered, a subjective numerical value has been assigned. It is recognized that the absolute values of these benefits are individually meaningless. Nonetheless, they do serve to grade the particular performance factor with respect to the three options in a relative sense. After all of the performance factors have been graded relatively in this numerical fashion, they are combined in arithmetic averages to establish (1) the effectiveness of each of the detection, delay, and deterrence functions, and then (2) the overall safeguards effectiveness (benefit). Weighting factors have also been used (for detection only) to force a relative ranking among subfunctions. These factors are applied prior to calculating the performance factor averages.

The relative nature of this benefits evaluation should be emphasized. Further, it is based on exhaustive enumeration of vault performance factors that have an effect on safeguards. The correctness of the overall safeguards benefits grading of the four vault storage options depends upon (1) averaging out gross errors in assigning values, and (2) a suitably comprehensive enumeration of vault safeguards performance factors.

While not specifically addressed as such, nevertheless, the relative protection of each conceptual vault system against overt attack is taken into consideration using this methodology to evaluate the safeguards benefit values. The effect is achieved through penalities applied in assigning values in the delay and deterrence functional performances of the vault boundary walls, design, etc. An example is seen in Tables 4.1 - 4.4 where almost identical overall values are obtained for the automated and the secure manned/manual vault even though the functional values differ.

Results of the evaluation of the two nonautomated vault concepts considered in this report are shown in Tables 4.1 - 4.4 compared with that of the automated vault concept given in ref. 1. As can be seen, the extensive use of security personnel in the guarded manned/manual concept produced a smaller safeguards benefit (relative value, 4.0) than might be expected. In contrast, in the secure manned/manual vault concept (in which operations personnel have access to the vault interior, but their direct access to SNM is restricted), the relative safeguards benefits realized (value, 6.3) almost equal those of the fully automated vault storage system (value, 6.4).

Table 4.1. Safeguards benefits: Detection

Safeguards performance criteria	Vault safeguards performance factors	Manned/manual[a]	Guarded manned/manual	Secure manned/manual	Automated (fully)
1. DETECTION					
1.1 Vault inventory material balance discrepancies	1.1.1 Vault inventory accuracy (1) SNM measurement accuracy	Reference: conventional NDA, wet chemical analysis and weighing; manual data acquisition	Same	Automated NDA system computerized data acquisition Reduced reading and calculational errors	Same
		Value = 5[b]	Value = 5	Value = 8	Value = 8
	(2) Inventory data management accuracy	Reference: manual maintenance of SNM accountability records	Same	Computerized data management, recordkeeping, and reporting Reduced bookkeeping errors	Same
		Value = 5	Value = 5	Value = 8	Value = 8
	1.1.2 Vault inventory timeliness				
	(1) SNM measurement frequency	Reference: container contents measured (weighed) only at shipping, receiving, or transfer to process	Inventory team: Item count by shift: shift-end material balance	Automated NDA operation, computerized book inventory Continuous inventory display	Same, except inventory verification by direct measurement such as weight or NDA
		Value = 2	Value = 4	Value = 7	Value = 8
	(2) Inventory data measurement	Reference: manual (1) Item inventory time >8 hr for MOX fabrication plant (2) Physical inventory time >1 day	(1) Item inventory: <4 hr (2) Physical inventory time: 36 hr	(1) Continuous dynamic inventory display	Same
		Value = 1	Value = 2	Value = 9	Value = 9
	Overall value[c]	3.3	4	8	8.5

Table 4.1. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Manned manual[a]	Guarded manned/manual	Secure manned/manual	Automated (fully)
1. <u>DETECTION</u> (cont'd)					
1.2 Unauthorized personnel activities					
1.2.1 Unauthorized personnel in vital vault-related areas	1.2.1 Surveillance effectiveness				
	(1) Vault interior	Continuous intrusion monitoring during secure state (vault closed)	Same, but includes continuous closed circuit TV (CCTV)	Same	Same
		Value = 5	Value = 8	Value = 8	Value = 8
	(2) Vault input/-output ports	Personnel access controls: multiple vault custodians plus locks. Entry provides access to all containers (negative effect)	(1) Personnel access controls (2) Security guards present during transactions (3) Continuous CCTV	(1) Personnel access controls (2) Continuous CCTV surveillance of vault door enclosure (3) SNM not accessible	Personnel entry not required
		Value = 2	Value = 5	Value = 8	Value = 10
	(3) Vault system control room	Not applicable (positive effect)	Not applicable (positive effect)	Required; integrity of computer-based data management and controls essential. Control room under continuous CCTV security surveillance	Same
		Value = 10	Value = 10	Value = 5	Value = 5
	(4) Vault/process material transfer	Not realistically possible	Continuous surveillance by attendant security guard(s)	(1) SNM in secure dolly (2) Continuous CCTV along route	Vault physically integrated to process line; continuous surveillance feasible
		Value = 2	Value = 6	Value = 8	Value = 10
	Overall value[c]	4.8	7.3	7.3	8.3

Table 4.1. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Manned/manual[a]	Guarded manned/manual	Secure manned/manual	Automated (fully)
1. DETECTION (cont'd)					
1.2.2 Unauthorized use of system operational features (i.e., controls, computers, etc.)	1.2.2 Operations surveillance effectiveness				
	(1) Container handling	Reference: manual, verbal instructions, administrative control	Same, plus continuous surveillance by security guard and material control representatives	Fully mechanized, remotely controlled, continuous surveillance feasible (more collusion required)	Fully mechanized and computer controlled continuous surveillance of all handling feasible (more sophisticated collusion required)
		Value = 3	Value = 7	Value = 8	Value = 9
	(2) Inventory data management	Manual and administratively controlled	Audit team detects errors and discrepancies	Computerized; continuous surveillance feasible. Inventory data base and software programs suitably secured	Same
		Value = 5	Value = 5	Value = 10	Value = 10
	(3) Equipment maintenance	Virtually nonexistent (positive effect)	Same	Significantly increased equipment complexity requiring increased maintenance	Same with even greater complexity
		Value = 9	Value = 9	Value = 4	Value = 4
	Overall value[c]	5	7	7.3	7.7

Table 4.1. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Manned/manual[a]	Guarded manned/manual	Secure manned/manual	Automated (fully)
1. <u>DETECTION</u> (cont'd)					
1.3 Unauthorized SNM					
1.3.1 Location	1.3.1 SNM surveillance effectiveness				
	(1) SNM not contanierized but within vault boundary[d] (anomalous condition in which SNM has been accidentally or purposely removed from a container at the wrong time)	Conventional radiation monitoring in some locations feasible (depends greatly on specific radiation characteristics and background)	Same	Same, but low radiation background in vault is normal condition	Same
		Value = 8	Value = 8	Value = 8	Value = 8
	(2) Containers in storage rack area (surveillance instrumentation built into storage rack)	Access seals, no active surveillance on individual basis, open shelf rack	Same, but storage rack under continuous CCTV surveillance	Continuous alarmed surveillance of storage rack (holes) (load cells)	Same, nuclear integrity surveillance feasible; also compatible with level of computerization
		Value = 1	Value = 3	Value = 7	Value = 7

Table 4.1. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Manned/manual[a]	Guarded manned/manual	Secure manned/manual	Automated (fully)
1. <u>DETECTION</u> (cont'd)	1.3.1 (cont'd)				
	(3) Containers being handled within vault interior (surveillance instrumentation built into container handling system)	Automatic surveillance not practical. Buddy system used.	Security guards present. Continuous CCTV feasible. Material control personnel presence required.	Containers handled in secure dolly; continuous monitoring feasible	Continuous monitoring as integral part of mechanized handling system
		Value = 1	Value = 3	Value = 5	Value = 5
	(4) Containers in transfer (i.e., to/from process)	Surveillance not practical, would not be compatible with traffic flow in normal operation	Security guard present	Continuous transferred secure dolly; continuous surveillance feasible	Continuous surveillance feasible
		Value = 0	Value = 5	Value = 7	Value = 7
	Overall value[c]	2.5	4.8	6.8	6.8
1.3.2 Shielding materials (i.e., an amount which would compromise detectability threshold)	1.3.2 Shielding surveillance[e]				
	(1) "Large" amounts of shielding crossing vault access ports	Possible	Same	Same	Same
		Value = 5	Value = 5	Value = 5	Value = 5

Table 4.1. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Manned/manual[a]	Guarded manned/manual	Secure manned/manual	Automated (fully)
1. DETECTION (cont'd)	1.3.2 (cont'd)				
	(2) "Large" amounts of shielding present during container transfer	Required for radiation exposure control.[f] Cannot discriminate unauthorized use.	Same	Localized shielding not required. Discrimination feasible.	Same
		Value = 0	Value = 0	Value = 5	Value = 5
	Overall value[c]	2.5	2.5	5	5
Detection Summary					
1. Vault inventory material balance discrepancies	Weighted overall value[g]				
	$\overline{W}$[h] = 1	3.3	4.0	8	8.5
2. Unauthorized personnel activities	Weighted overall value				
	$\overline{W}$ = 1	4.8	7.3	7.3	8.3
	$\overline{W}$ = 0.8	4.0	5.6	5.8	6.2
3. Unauthorized SNM presence	Weighted overall value				
	$\overline{W}$ = 0.8	2.0	3.8	5.4	5.4
	$\overline{W}$ = 0.8	2.0	2.0	4.0	4.0
	A[i] =	3.2	4.5	6.1	6.5

Table 4.1. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Manned/manual[a]	Guarded manned/manual	Secure manned/manual	Automated (fully)

Notes for Detection:

[a]Reference Vault Storage System: see Sect. 2 of ref. 1.

[b]Value = subjective quantification of safeguards benefit on a scale of 0 to 10, 10 being most desirable.

[c]Overall value = arithmetic average of values in this subsection of Table 4.1.

[d]Vault boundary: storage area to process interface.

[e]Shielding issue is intended as a relative argument, performance of heavy-metal detectors may be a major problem.

[f]In the case of recycle fuel.

[g]Weighted overall value = overall value of subsections multiplied by weighting factor.

[h]$\underline{W}$ = weighting factor.

[i]A = arithmetic average of weighted overall values for Detection.

Table 4.2. Safeguards benefits: Delay

Safeguards performance criteria	Vault safeguards performance factors	Manned/manual[a]	Guarded manned/manual	Secure manned/manual	Automated (fully)
2. DELAY (OF) • Adversary access to vault areas • Adversary use of vault systems functions (i.e., controls, equipment, etc.) • Adversary physical access to SNM					
	2.1 Active delay mechanisms				
	(1) Imposed adverse vault conditions (e.g., inert gas purge)	Not possible; unencumbered human access necessary for operation Value[b] = 0	Same Value = 0	Possible; secure in vault remotely controlled access to storage holes feasible Value = 3	Possible; also includes container space volume Value = 6
	(2) Normal vault entry access denial (e.g., automatic closure and securing of doors)[c]	Not possible assuming unmechanized entry Value = 0	Continuously manned guard post at vault door Value = 6	Mechanized entry feasible remotely controlled backup locks in redundant vault door in addition Value = 7	Automatic deactivation and closure of access port(s) to the extent that special "reset" procedures required. This could permit the access ports to supply a delay time equivalent to the principal physical barrier. Value = 7

Table 4.2. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Manned/manual[a]	Guarded manned/manual	Secure manned/manual	Automated (fully)
2. DELAY (OF) (cont'd)	2.1 (cont'd)				
	(3) Operating control system use denial (e.g., all operating software and stored data would be irretrievably erased, thus rendering the automated functions inoperable. Backup software would be stored at a distant geographical location).	Not applicable (negative effect)	Same	Delay is equivalent to principal vault barrier	Same
		Value = 0	Value = 0	Value = 7	Value = 7
	Overall value[d]	0	2	5.1	6.7
	2.2 Passive delay mechanisms				
	(1) Principal physical (structural) barrier	Compromised by normal human entry ports (depending on timing of threat); door closed	Continuously manned local guard post reduces the threat	Redundant vault doors (one always closed)	Improved; encloses entire vault boundary area (i.e., it also encloses transfer region)
		Value = 2	Value = 4	Value = 5	Value = 5

Table 4.2. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Manned/manual[a]	Guarded manned/manual	Secure manned/manual	Automated (fully)
2. DELAY (OF) (cont'd)	2.2 (cont'd)				
	(2) Storage container design	Must accommodate manual operation (negative effect) Value = 2	Same, but presence of armed guard reduces negative effect Value = 4	Container is inaccessible to in-vault operating personnel (positive effect) Value = 7	Mechanization of container filling/emptying feasible. Therefore, container design can preclude unassisted operation. Equivalent delay would be that of container destruction. Value = 5
	(3) Container storage area design	Must accommodate manual utilization (negative effect) Value = 0	Same, but presence of armed guard reduced negative effect Value = 3	Container storage inaccessible to in-vault personnel Value = 7	Can be designed to preclude human entry Value = 5
	(4) Vault input/output port design	Normal human entry access ports through principal barrier (depends on timing; attack occurs when door is opened) Value = 2	Same, but presence of armed guard reduces negative effect Value = 5	Same, but redundant vault doors and secure storage system increase equivalent delay to greater than that of prime vault barrier Value = 6	Normal human access not required, Input/output port can be designed to structurally complicate human entry Value = 7
	(5) Maintenance access ports	Not applicable (use normal entry; positive effect) Value = 10	Same Value = 10	Maintenance access to storage area required; effect reduced because of secure storage and redundant vault doors. Value = 7	Maintenance access to container storage area required (negative effect which could be reduced by designing in cumbersome operation and barrier delay) Value = 5
	Overall value[e]	3.2	5.2	6.4	5.4

Table 4.2. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Manned/manual[a]	Guarded manned/manual	Secure manned/manual	Automated (fully)
Delay Summary	2.1 Active delay mechanisms	0	2	5.7	6.7
	2.2 Passive delay mechanisms	3.2	5.2	6.4	5.4
	B[f] =	1.6	3.6	6.1	6.1

Notes for Delay:

[a]Reference Vault Storage System: see Sect. 2 of ref 1.

[b]Value = subjective quantification of safeguards benefits on a scale of 0 to 10, 10 being most desirable.

[c]Normal vault access controls assumed (i.e., today's practice).

[d]Overall value = arithmetic average values for active delay mechanisms.

[e]Overall values = arithmetic average values for passive delay mechanisms.

[f]B = arithmetic average of overall values for delay benefits.

Table 4.3. Safeguards benefits: Deterrence

Safeguards performance criteria	Vault safeguards performance factors	Manned/manual[a]	Guarded manned/manual	Secure manned/manual	Automated (fully)
3. DETERRENCE					
• Potential overt adversary actions					
• Potential covert adversary actions					
	3.1 Detection system effectiveness[b]				
		Value = 3.2	Value = 4.5	Value = 6.1	Value = 6.5
	3.2 Delay system effectiveness[c]				
		Value = 1.6	Value = 3.6	Value = 6.1	Value = 6.1
	3.3 Response system effectiveness[d]				
	3.4 Intrinsic system characteristics				
	(1) Material access and isolation (during normal operation)	Material is totally accessible when vault entry door is open and during transfer	Same, but under armed guard surveillance at all times	Material is isolated at all times (both in the vault and during transfer)	Material is isolated at all times within the vault boundary
		Value = 1	Value = 5	Value = 6	Value = 6
	(2) Material handling time	Time dominated by transfer time from vault to process shipping or receiving (negative effect)	Same, but effect is reduced by presence of armed guards	Normally no direct handling within vault boundary or during transfer	Handling time minimized. Virtually no direct handling within vault boundary
		Value[e] = 1	Value = 4	Value = 9	Value = 9

Table 4.3. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Manned/manual[a]	Guarded manned/manual	Secure manned/manual	Automated (fully)
3. DETERRENCE (cont'd)	3.4 (cont'd)				
	(3) Collusion vulnerability				
	(1) Number and skills of people involved				
	Operations	High	High	High	Low
	Maintenance	Low	Low	High	High
	Skill level	Operators and technicians	Operators, technicians, and guards	Operators, technicians, material control, computer programmers, engineers (higher ratio of white collar types)	Same
	(2) Mixture required[f]	Craft workers only	Craft, guards, plus some professionals	Same	Same with higher ratio of professionals
		Value = 3	Value = 5	Value = 6	Value = 6
	(4) System complexity				
	(1) Functional (e.g., operating controls, computer security, surveillance)	Low	Low, but surveillance is high, positive effect	Higher	Higher
		Value = 2	Value = 4	Value = 7	Value = 7

Table 4.3. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Manned/manual[a]	Guarded manned/manual	Secure manned/manual	Automated (fully)
3. DETERRENCE (cont'd)	3.4 (cont'd)				
	(2) Physical (barriers, vault internal structure, etc.)	Low, assuming conventional entry door Value = 2	Same Value = 2	Highest, vault plus transfer system totally enclosed Value = 6	Highest, vault plus transfer system totally enclosed Value = 6
Deterrence Summary	C[g]	2.0	4.0	6.6	6.7

Notes for Deterrence:

[a]Reference Vault Storage System: see Sect. 2, ref. 1.

[b]Refer to Table 4.1, Detection Summary, weighted overall values.

[c]Refer to Table 4.1, Delay Summary, weights of overall values.

[d]Response system effectiveness is an important factor in deterrence; however, in this study, vault storage systems are considered an internal function and, as a result, are independent of response force characteristics and dynamics.

[e]Value = Subjective quantification of safeguards benefits on a scale of 0 to 10, 10 being most desirable.

[f]It is assumed that collusion requiring collaboration between individuals with varying societal characteristics (salary, education, etc.) is less likely to succeed than collusion by groups having common societal bases.

[g]C = arithmetic average of deterrence values in Sect. 3 of Table 4.1.

Table 4.4. Safeguards benefits: Summary

Safeguards performance criteria	Vault performance performance factors	Manned/manual[a]	Guarded manned/manual	Secure manned/manual	Automated (fully)
Overall Summary					
1. Detection	A	3.2	4.5	6.1	6.5
2. Delay	B	1.6	3.6	6.1	6.1
3. Deterrence	C	2.0	4.0	6.6	6.7
4. Response	—	—	—	—	—
	Total safeguards relative value[b]	2.3	4.0	6.3	6.4

Notes for Summary:

[a]Reference Vault Storage System: see Sect. 2, ref. 1.

[b]Arithmetic average of overall values for Detection, Delay, Deterrence, and Response in Tables 4.1-4.3.

4.2 Non-safeguards Benefits

A non-safeguards benefit realized in remote (automatic) operation of vault storage systems is a reduction in exposure of personnel to radiation. This aspect of the two alternative vault concepts developed in this report is examined in Appendix D, Sect. 7.4, and the results are compared in Table 4.5 with similar results for the fully automated vault concept.

The effectiveness of vault automation in reducing total dose to personnel is more striking than would be surmised from only a comparison of the doses given in Table 4.5. A vault transaction study for the secure manned/manual vault concept shows that 52,104 transactions are required (Appendix B, Sect. 7.2), compared with 8580 for each of the other concepts. The reason for the larger number needed for the secure manned/manual concept is that the vault storage unit is designed to hold one can containing about 8 to 9 kg of PuO_2 as received from the reprocessing facility. This design choice achieves the objective of providing total isolation of all SNM during all handling and storage while continuously displaying the most information on its location, identity, and weight. In contrast, at many of the intermediate steps in the other concepts, much larger containers (up to 150-kg capacity) can be used.

Table 4.6 shows the net effect on the size of the operations groups imposed by regulations[2] that limit the radiation dose to each individual to 1.25 rem/quarter year (qtr). To meet this limit, the size of the operations group for the guarded manned/manual vault must be increased from 13 (based on time-motion studies) to 92.6. No increase in size is required for the secure manned/manual or the automated vault because more than 95% of the transactions take place behind the heavy shielding walls of the vault away from the operations personnel.

A further important aspect of dose limitation is the ALARA regulation[3] that stipulates that radiation dose to each individual shall be reduced to "as low as reasonably achievable." Automated vaults not only demand fewer operations personnel but also limit the dose per man to the lowest radiation level; hence they would appear from this study to be within the limits imposed by the ALARA regulation.

4.3 Economic Assessment

The costs given in this section for each of the vault concepts are the results of engineering estimates based on past experience in the design, construction, and operation of radiochemical processing facilities and related equipment.

The total cost of operating a storage vault system can be broken down into capital costs, maintenance costs, and direct operating costs. The capital costs include those associated with the vault structure and with the installed equipment designed and scoped for the conceptual 200-MT/year mixed-oxide fuel fabrication facility. Maintenance costs result from efforts to minimize equipment downtime and extend the efficient life of the equipment. The direct operating-labor costs are those related to the operations personnel necessary to operate the system on a 3-shift/day, 5-day/week basis.

The results of the cost study (Table 4.7) show that the total annual operating costs of the two alternative vault systems are 5 to 6 times higher than that of the automated vault ($703,100). The assumptions made and the details of determining these cost estimates are given in Appendix C, Sect. 7.3.

Table 4.5. Radiation dose experienced in each vault concept

Vault concept	(mrem/tr)
Manned	
Guarded manual	12.5
Secure manual	0.55
Fully automatic[a]	0.42

[a]Data taken from ref. 1.

Table 4.6. Operating personnel requirements considering dose limits

Vault concept	Number of operating personnel required based on: Time-motion studies	Dose constraints[a]	Actual[b]
Manned			
Guarded manual	13.0	92.6	92.6
Secure manual	39.7	25.8	39.7
Fully automatic	7.0	0[c]	7.0

[a]As set forth in regulations given in ref. 2 (i.e., 1.25 rem/qtr).

[b]Represents the larger number of operating personnel required.

[c]Essentially no exposure during in-vault operations.

Table 4.7. Estimated cost as a function of vault concept

	Capital cost ($)			Annual costs ($)			
Vault concept	Structural	Equipment	Total	Amortized[a] capital	Maintenance	Operating labor	Total
Manned							
Guarded manual	2,700,000[b]	160,000[b]	2,860,000	95,300	0	4,224,000	4,319,400
Secure manual	10,467,000	2,100,000	12,567,000	418,900	128,500	2,732,000	3,279,400
Fully automatic[b]	1,070,000	1,280,000	2,350,000	78,300	64,800	560,000	703,100

[a]Straight-line recovery over 30 years.

[b]Data taken from ref. 1.

4.3.1 *Structural costs*

The $1,070,000 capital cost for the vault structure in the automated vault concept is taken from ref. 1 and is based on an engineering estimate of $240/ft^2. For the guarded manned/manual concept, it is assumed that the vault structure and hence the $2,700,000 cost (based on an estimate of $220/ft^2) is identical to that of the manned/manual vault in ref. 1. The lower cost of the fully automated vault structure stems from the fact that it is a two-story design that more efficiently utilizes the area (i.e., less area is required for a given throughput, even though the unit cost is higher). The vault structure in the secure manned/manual concept is designed along similar lines, but owing to its greater complexity, an estimated unit cost of $350/ft^2 was used, based on an engineering assessment. The structural cost of $10,467,000 includes the $3,087,000 cost of the system of vault storage units, which is based on an engineering assessment indicating that the 2205 storage-unit liners, covers, and accessories needed could be fabricated and installed for $1400 each. Also included is the cost of the shipping package unloader, similarly estimated at $75,000.

4.3.2 *Equipment costs*

The cost of equipment installed in a vault is assumed to be part of the cost of the specific vault concept. The guarded manned/manual concept requires no additional equipment over the $160,000 listed for the manned/manual concept of ref. 1. The secure dollies and much of the equipment in the MCC are essential components for the operation of the secure manned/manual vault and are included in the costs of that vault concept. Equipment installed in the MCC directly relating to vault operation includes two computers, six operating consoles, six display panels, and a communications unit for telemetry and voice. The total cost of these items is estimated at $800,000.

The cost of the secure dollies is estimated at $1,300,000, bringing the total cost of installed equipment to $2,100,000.

The $1,280,000 for the fully automated vault includes equipment described in ref. 1, Sect. 6.

In each vault concept, no additional cost for emergency power is assessed because emergency power systems serving the facility complex are available for use in the vault and MCC.

4.3.3 *Operating costs*

Direct operating costs are estimated (Appendix C, Sect. 7.3.3) for each vault concept. Each cost estimate reflects the effect of expected radiation exposure to operations personnel, assuming a unit personnel cost of $40,000/man-year (includes overhead costs for administration, utilities, materials, etc.).

The size of the operations group was first established from time-motion studies; then the effect of compliance with radiation dose regulations[2] was considered. Dose restrictions increased the estimate of the size of the operations group in the guarded manned/manual concept as described in Sect. 4.2 above.

It is recognized that the facility management would minimize the effect of radiation dose on the number of operations personnel (1) by installing shielding and (2) by rotating the duties of the members involved in the vault operation such that they would all perform some tasks where radiation dose is low or negligible. However, in the absence of detailed overall design data for each facility it is difficult to determine what fraction of the personnel cost to attribute to the vault operation. Rather, it appears prudent to identify the problem and to assess the magnitude of its effect.

Table 4.7 lists the estimated annual direct operating labor costs for the fully automated vault concept and the two alternative concepts. It can be seen from the table that the fully automated vault at $560,000/year costs less to operate by a factor of 5 to 8 than the alternative vault systems.

4.3.4 *Maintenance costs*

Maintenance costs for the guarded manned/manual vault are essentially nil, since no special mechanical equipment is associated with its operation. The procedure followed in arriving at the estimate of the annual maintenance costs for the secure manned/manual vault ($128,500) is given in Appendix C, Sect. 7.3.4. The maintenance costs for the fully automated vault were estimated and reported in Sect. 6.3 of ref. 1 at $64,800, a factor of 2 lower.

5. CONCLUSIONS

A comparison of the total costs and the safeguards benefits, as indicated by the relative values, is given in Table 5.1. These results indicate that, based on the assumptions outlined in Appendix A, Sect. 7.1, the automated vault has a decided cost advantage over the secure manned/manual concept, which itself has safeguards benefits comparable to those of the automated vault concept. The table shows that in order to achieve a high safeguards rating, an SNM storage vault system must separate personnel from the SNM. Any such system, automated or not, must be complex, requiring significant amounts of equipment and personnel.

On the other hand, it is also apparent from Table 5.1 that replacing equipment with operations and security personnel, does not achieve nearly the level of safeguards benefit as does the fully automated system. Of additional interest is the fact that vault storage systems designed to achieve maximum safeguards benefit are also likely to achieve the minimum exposure of personnel to radiation. In addition, automated vault systems are most likely to be in compliance with regulations[2,3] respectively limiting radiation dose to personnel and stipulating that such dose be reduced to "as low as reasonably achievable."

Table 5.1. Comparison of cost/benefits as a function of vault concept

Vault concept	Capital investment ($)	Annual operating cost ($)[a]	Operating personnel		Relative overall safeguards benefit[c]
			Number	Skills required[b]	
Manned					
Guarded manual	2,860,000	4,319,400	105.6	Low	4.0
Secure manual	12,467,000	3,276,900	68.3	50% high	6.3
Fully automatic	2,350,000	703,100	14	50% high	6.4

[a] Includes straight-line recovery of capital over a 30-year period.

[b] "High" is regarded as a quality typical, for example, of a computer technician, console operator, auditor, etc., where a higher degree of training and exercise of judgment is required than in "Low," where essentially little or no exercise of judgment is required and the degree of training required is much less.

[c] On a scale of 0 to 10, proceeding from lowest (or no) safeguards to the highest and most desirable benefit as defined in Sect. 2 of ref. 1.

5.1 Acknowledgments

The contributions of A. S. Pruitt, R. M. Peach, and F. E. Stapel in developing the conceptual designs and the related drawings and sketches are gratefully acknowledged. In addition, the technical advice and counsel of L. B. Shappert in the evaluation of the vault concepts for safeguards benefits and the assistance of F. N. Browder in the preparation of this report is acknowledged.

6. REFERENCES

1. W. R. Hamel and L. B. Shappert *Desirability and Feasibility of Vault Automation in Special Nuclear Material Storage*, ORNL/NUREG-20 (NUREG-0318) (August 1977).

2. Chapter 10, Part 20.101, *Code of Federal Regulations.*

3. Chapter 10, Part 50.34a, *Code of Federal Regulations*, see also Appendix I.

4. Chapter 10, Part 70.51, *Code of Federal Regulations.*

7. APPENDIXES

7.1 Appendix A: Alternative Vault Concept Development

The engineering features of the two alternative vault concepts developed in this study are presented in Sects. 7.1.1 and 7.1.2. The operating procedures are given in Sect. 7.1.3.

7.1.1 *Guarded manned/manual vault*

The vault structure in this concept is identical to that of the manned/manual vault (ref. 1), but the surveillance system has been expanded to include continuous monitoring of the vault interior by closed-circuit TV (CCTV) (Fig. 3.2). Redundant cameras and video-tape recording equipment are assumed to be included, and a continuously manned guard post is located at the vault door.

Shipments, vault transactions, and SNM transfers are handled as described in ref. 1, Sect. 3.3.1, but material control representatives are present continously to verify the records, examine security seals, and to observe all transactions. In addition, a security guard accompanies each transfer of SNM to and from the vault.

An audit team conducts an item inventory (including security seal inspection) every 8 hr and strikes a balance based on an item count including transactions. These data are correlated with accountability records maintained in the material-control center (MCC).

7.1.2 *Secure manned/manual vault*

This concept incorporates a number of unique design features described in some detail below. The interaction between the elements of the safeguards system in this concept and the engineered features included in its design are shown in Fig. 3.3. An artist's sketch of the vault is shown in Fig. 3.4.

Vault door enclosure. To maintain integrity of the vault boundary while permitting authorized entry into the vault, the design includes an enclosure with a penetration resistance equal to that of the vault. The enclosure includes two doors oriented at right angles to each other (one door to the outside and the other giving entry into the vault) which would prevent a single projectile or explosive charge from simultaneously penetrating both doors. This arrangement achieves penetration delay and reduces the probability of successful entry by stealth. Both doors have the same penetration resistance as the vault walls. The doors are mechanically interlocked in such a way that only one can be opened at any time. Each is equipped with an independent, backup locking system controlled from the MCC and a locally operated primary lock.

The enclosure is continously monitored by CCTV and intrusion alarms. Both systems alarm and/or display in security headquarters (SEC); only the CCTV displays, which play a role in operating the vault system, are duplicated in the MCC.

Personnel access control. Personnel access to the vault interior is limited to authorized individuals. Each person who is to enter the vault is required to submit a photo-comparison identification card that is remotely scanned and displayed simultaneously in the MCC and SEC.

Identification of authorized individuals is required before the MCC personnel will retract the remotely operated secondary backup locks, clearing the way for the primary security locks to be operated by the vault team.

Two individuals, each a member of a different group and having knowledge of the operating sequence of only one of the two access doors, make up a vault team required to enter the vault together. One individual is a designated member of the process operations group and will have the key to the outer door given him by his supervisor. The second member of the vault team is a designated member of the material control group and will be given the combination of the inner door by his supervisor.

Surveillance. The interior of the vault is well lighted and kept under continuous CCTV surveillance with displays in both the SEC and the MCC. Intrusion alarms are provided which sound in the SEC.

Vault storage system. SNM is received from the processor in the tared and sealed "primary" containers (i.e., containers in which the container walls are in contact with the SNM). These containers are stored in the vault storage units (Fig. 7.1) that are located in the floor of the vault. Placement and removal of SNM in the vault storage units are accomplished by a secure dolly which, by its design, never permits direct access to the primary container by the operations personnel during handling operations.

The design of the "storage unit" includes a cylindrical steel-lined hole in the vault floor that is closed with a flush-mounted cover held firmly in place by a latch when in the secure mode. The operation of the latch is controlled from the MCC. A frame mounted on the underside of the cover holds the SNM cans. The base of the frame (pan) has an opening slightly smaller in diameter than the SNM can. A load cell is mounted in the bottom of the hole such that it protrudes through the opening in the pan when the cover is in position, and the SNM can then rests upon the load cell. The signal from the load cell is transmitted via hard-wired circuitry to the MCC for display.

Secure Dolly. The secure dolly is used to transfer SNM into and out of the vault storage system. It consists of a steel-walled, penetration-resistant transfer box (Fig. 7.2) and its transporter, a fork-lift-type vehicle (Fig. 7.3). The transfer box houses mechanisms for (1) locking the box onto the storage unit, (2) lifting the hole-cover assembly (including the SNM can) into the box interior, (3) operating the box bottom-closure system (including the latches), and (4) transferring the SNM can to and from the cover assembly and the pedestal. The box also contains the following systems: (1) the detector element of an on-board nondestructive assay (NDA) system, (2) a load cell located in the pedestal, and (3) an electronics package that consists of both a telemetry system and a communications system. The telemetry system receives control signals from the MCC for operating the mechanical devices in the transfer box.

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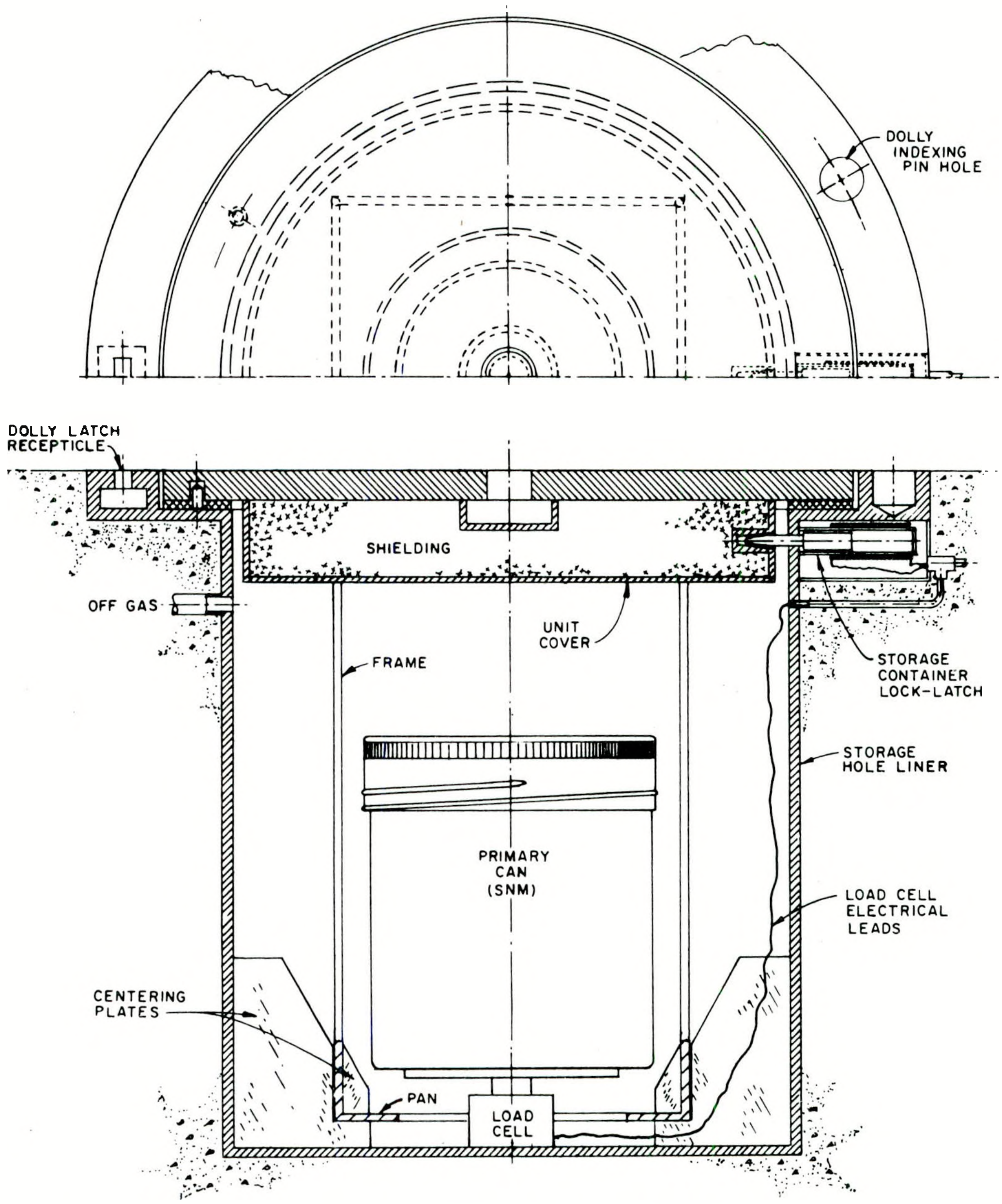

Fig. 7.1. Vault storage unit.

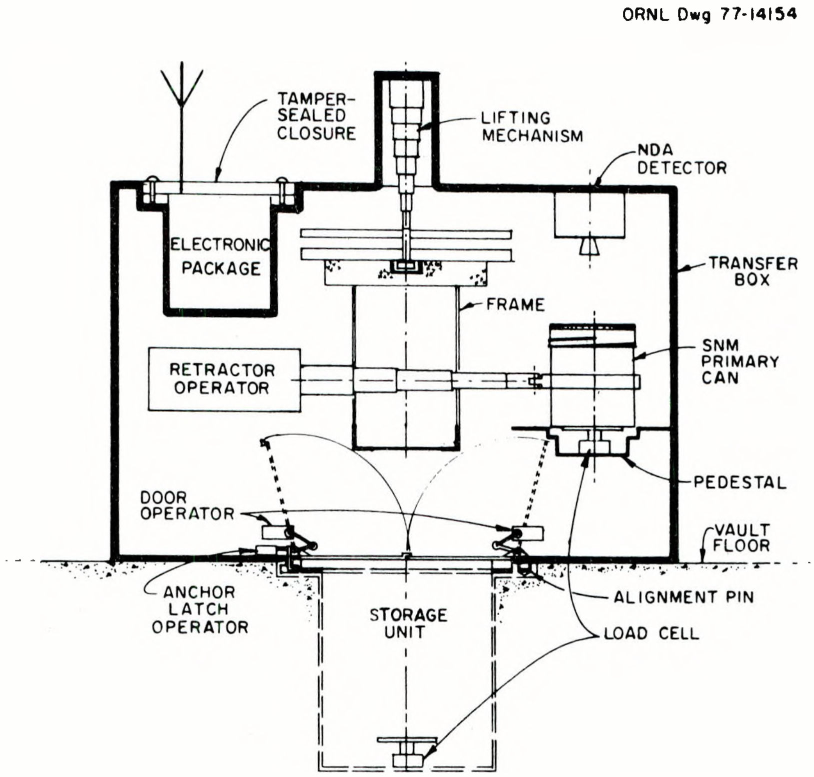

Fig. 7.2. Transfer box.

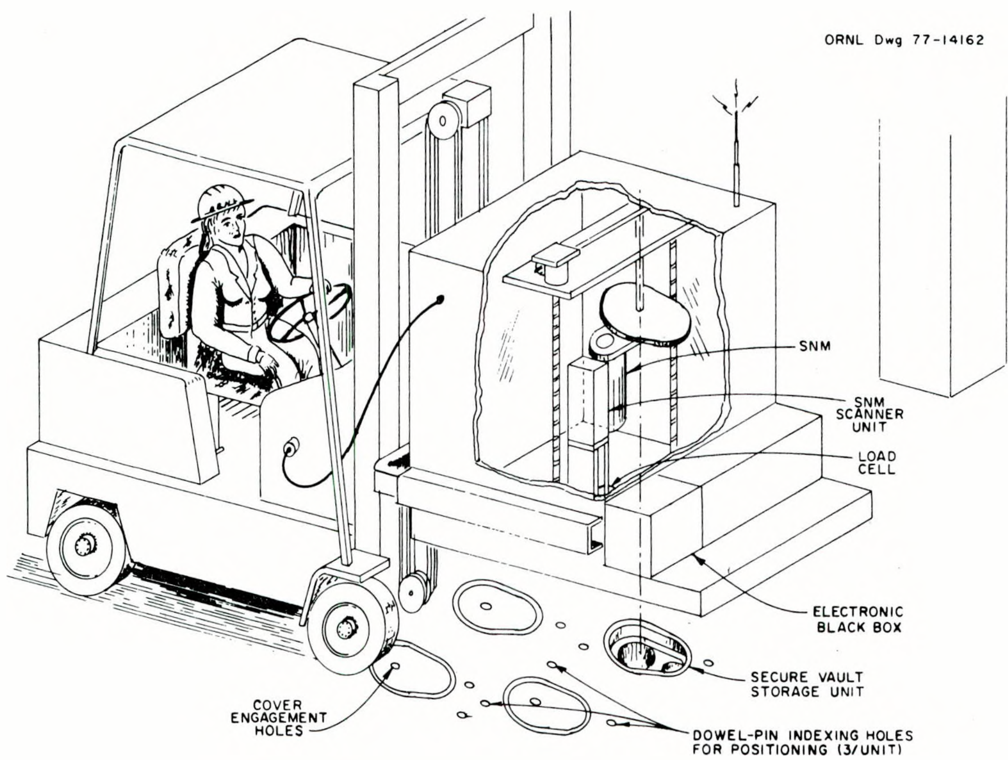

Fig. 7.3. Secure dolly system.

In addition, those signals from the NDA systems are transmitted to the MCA. The purpose of the separate communication system is to provide voice contact between the MCC and the driver of the secure dolly.

Power to the box is supplied by the transporter, a fork-lift-type vehicle modified to include a power supply (generator) and to adapt it for handling the transfer box. Indexing pins attached to the bottom of the box mate with the indexing holes in the storage unit so that the service openings in each are aligned. The latching device that anchors the box to the floor is operated from the MCC.

The storage unit hole-cover lifting mechanism is designed to extend down through the bottom opening of the box to capture the cover of the storage unit. The lifting mechanism then moves back into the box with the cover attached (including the can of SNM held on the pan). Once in the fully retracted position, a transfer mechanism (retractor) then moves the can of SNM to the pedestal. The pedestal includes a load cell that automatically registers the weight of the can of SNM as it is placed upon the pedestal; this information is continuously transmitted via telemetry to the MCC. All on-board mechanisms are operated from the MCC.

The opening in the bottom of the box is secured by a pair of sturdy doors (controlled from the MCC) which provide the same degree of shielding and penetration resistance as the box walls.

One or more NDA detector units is mounted inside the box oriented above the pedestal to permit measurement of the SNM. The primary signals are telemetered to the MCC for analysis and conversion to SNM weight.

The box is fabricated of steel plate thick enough to provide adequate shielding, both to minimize interference of background noise during the assaying operation and to reduce exposure of in-vault operations personnel.

Shipping package unloader. The shipping package unloader (Fig. 7.4) is designed to unload shipping packages and transfer the primary cans of SNM to the secure dolly while at the same time reducing direct access by personnel. Typically, shipping packages (usually containing two or more cans of SNM) arrive at the receiving dock of the fuel fabrication plant, where operations personnel (1) remove them from the transport vehicle by direct handling, (2) move them inside the plant, and (3) place one of them on the elevator of the unloader. The elevator lifts each package into the unloader chamber, where a remotely operated manipulator removes the package cover and the inner flange that seals the SNM primary containers within the package. The manipulator then lifts and transfers one primary container at a time into the secure dolly by positioning it inside the frame of a storage unit cover (Fig. 7.4), which then is raised inside the dolly. At this point, the can of SNM, along with the storage unit cover and frame, can be moved to the vault and lowered into a storage unit.

Input-output station. The input-output station is a mechanism for transferring SNM into and out of the process enclosures (Fig. 7.5). It is compatible with the secure dolly and maintains isolation of SNM from personnel.

Communications systems. Communications between the in-vault personnel and those in the MCC play an important role in this concept. Separate systems provide voice contact between

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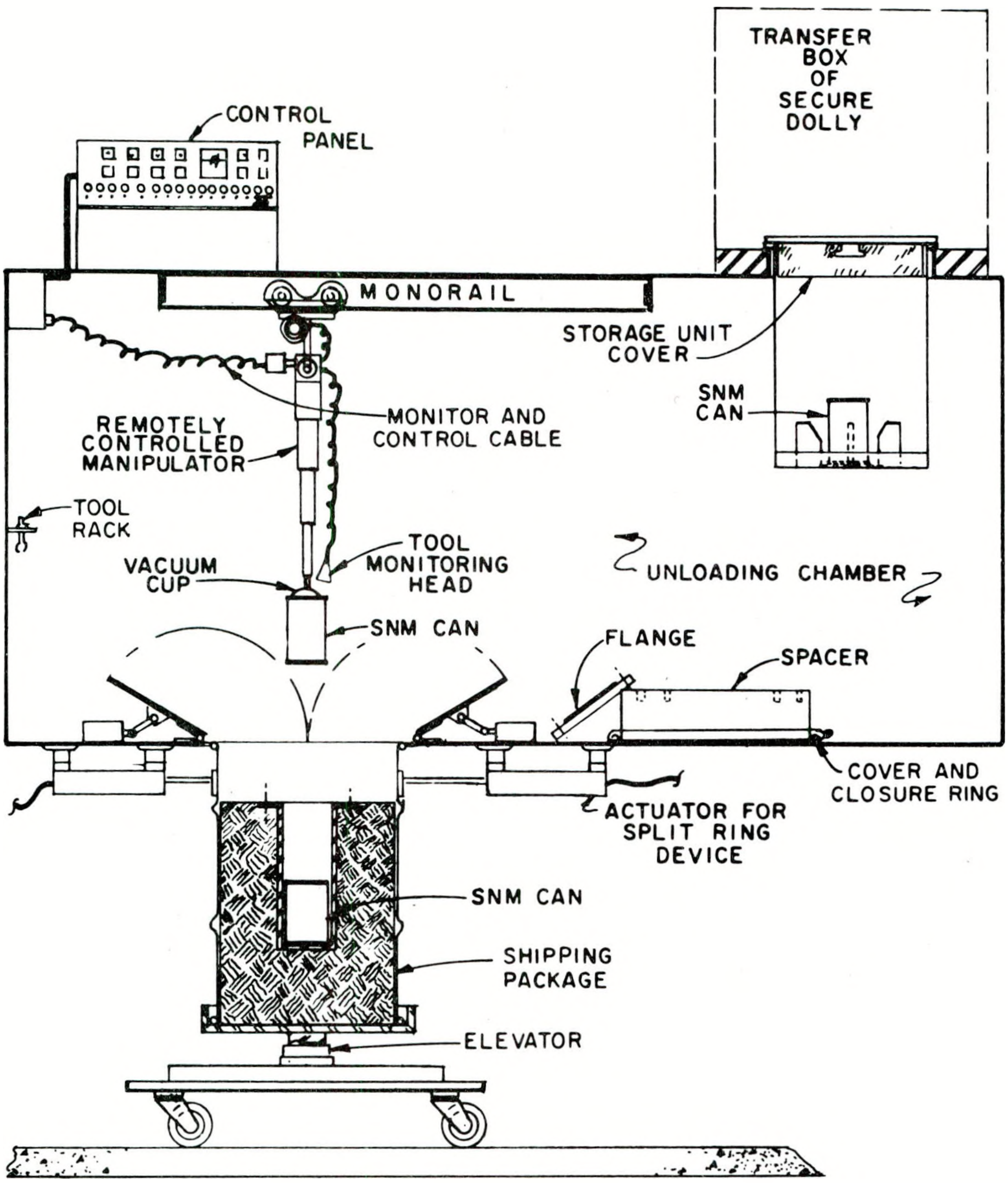

Fig. 7.4. Shipping package unloader.

ORNL Dwg 77-14157

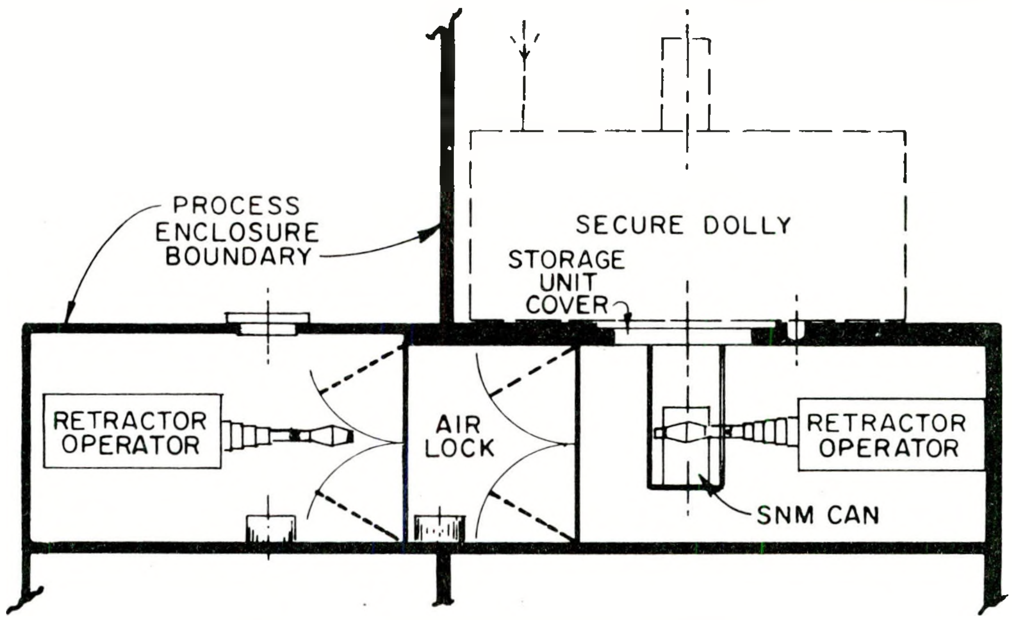

Fig. 7.5. Input-output station.

the dolly operators and personnel in the MCC and transmit telemetry signals that operate and control the onboard systems of the secure dolly. A signal relay system is included in the vault design to maintain communication between the MCC and the secure dollies while they are behind the heavily reinforced concrete vault walls.

The telemetry equipment in the MCC has sufficient capacity (channels) to allow operation of 12 secure dollies simultaneously.

Material control center. The MCC is located in a high security area remote from the vault. All accountability-related records are maintained by the MCC. Inventory records are recorded automatically as SNM is transferred into and out of the vault. All operations within the vault are controlled by the MCC.

Four important components of the vault operation control system located in the MCC are: (1) the control consoles, (2) the display panel, (3) a communication system, and (4) computers.

Control consoles. Six consoles comprise the system by which the MCC operators control the secure dollies, two of which can be controlled simultaneously from each console without interference. Each console consists of the systems for selecting the dolly, the storage unit, and the operation to be executed. This information is transmitted to the secure dolly and its operator, and at the appropriate time, the storage unit is unlocked to permit the SNM transfer.

Also located at each console are cathode-ray tube terminals (CRT) that enable the console operator to relay specific data from the computer for display and to gain assistance in conducting the dolly operation. Two TV-monitor display units located at each console permit

MCC operators to monitor dolly operations both in the vault and along the paths followed by the dollies.

Display panel. A system of CRT terminals will be used to display vault data and alarm conditions, providing a means of quickly assessing the state of the vault inventory storage system. On command, the following data could be displayed for any storage unit: (1) the date the unit was charged and the identity of the SNM container, (2) the current gross weight of the container sensed by the load cell, (3) the gross weight indicated when the container was charged to the storage unit, and (4) an indication of the number of times the cover of the storage unit had been in the access mode (i.e., the number of times the cover had been unlatched since the hole was charged). Alarms are initiated if differences are detected in the two gross-weight measurements. Thus without interfering with vault operations in progress, an item inventory can be made, any change in gross weight of any stored container quickly noted, and an immediate check on whether the unit has been opened since the container was charged can be made very rapidly.

Computers. Taking a conservative approach, two minicomputers (one for backup) maintain an up-to-date record of the vault SNM inventory and its distribution. To achieve this, keyboards are provided for manual input of data by the MCC personnel and to transmit commands. As already mentioned, the computer output can be displayed on the CRTs at the consoles.

Signals from NDA equipment and load cells are received by the computer and automatically converted into weight units. Signals from the storage unit cover-latch counter are also received. The computer is programmed to compare weights of SNM containers at various steps as they proceed through loading, movement into the vault storage units, etc.

The purpose of the storage unit cover-latch counter is to provide an indication of when and if the cover was placed in the secure mode. Whenever the cover latch is operated, the counter advances one unit. These counts are totaled for each storage unit, and the total is retained in the computer whenever a latch is operated. During operation, when a container of SNM is placed in a storage unit, the current latch count is automatically registered and associated with that container in the computer data storage. When the SNM container is to be removed from a storage unit, the computer compares the present latch count with that taken when the SNM was placed in the unit. An unexplained differential indicates that an unauthorized access to the SNM may have occurred.

Communication systems. The communication systems in the MCC provide the following:

(1) voice communications by radio between the secure dolly and the MCC,

(2) transmission of control signals and measurement data from the secure dolly to the MCC by radio telemetry, and

(3) transmission of data from the vault storage unit load cells and the cover-latches by a hard-wired system.

Emergency power. Emergency power for the vault equipment and the MCC is available from the facility-complex emergency power system.

7.1.3 *Vault operating procedures*

Shipments of SNM are transported from the fuel reprocessing facility in sealed trailers. Upon arrival at the fuel fabrication plant, the trailers are directed to the loading-receiving area where a member of the MCC inspects the security seal on the trailer for tampering. The trailer is then opened, and each shipping package and its security seal are identified and compared with the bill of lading. Each security seal is inspected for tampering. The shipping packages are then moved to an interior protected area, opened, and the primary SNM containers are removed, indentified, and weighed. These data are reconciled with the detailed accountability records accompanying the shipment.

At this point, the only estimate of the SNM content of the shipment is that of the shipper (given in the shipping records). The receiver is required by regulation[4] to verify the SNM content with a specified precision; this is done by sampling each SNM container followed by wet chemical analysis of the sample for SNM content. Each container is reweighed and moved to the vault for storage.

The specific procedures followed in accomplishing each of the above steps will differ depending on the vault concept. A description of each is given below.

Guarded manned/manual vault. The goal in this concept is to achieve increased safeguards benefit through increased surveillance of vault transactions by personnel. A security guard is always present during the receipt, inspection, unloading of shipping packages, sampling, and transport of the SNM container to and from the vault.

Access to the vault is continuously monitored by security guards at the post located at the vault door. Possession of the combination to the vault door is controlled and restricted to authorized members of the material control group. All operating, material control, and security personnel who have in-vault responsibilities are identified prior to opening the door. While in the vault, they remain under the continuous surveillance of a security guard as well as by CCTV which displays on monitors in security headquarters. Upon entering or leaving the vault interior, the team assays each of the primary cans of SNM on the pallets (see above) using NDA equipment located in the vault. The cans of SNM are then returned to the pallets and placed in the vault storage racks or moved to the process. All accountability records including measurements are kept manually by personnel of MCC.

In-vault item inventories (i.e., a physical count and identification of all containers of SNM) are taken at the end of each work shift by the material control audit team, and the results are reconciled with the accountability records to detect discrepancies or indications of diversion. If any should appear, a more thorough audit of the preceding transactions is begun by an independent audit team made up of material control personnel who supervise the physical inventory of the vault contents. This includes reverification of tamper-indicating seals, sampling, and/or reweighing of selected items. The NDA equipment will be used extensively for a quick check; later if the results of these measurements justify it, a more accurate procedure that includes sampling and chemical assay will be followed on suspect items.

Secure manned/manual vault. In this concept, the goal is to eliminate direct access to SNM by personnel as much as possible at every step in the process. After the operations personnel inspect the incoming shipment of SNM and remove the shipping packages from the trailer, they place the packages one at a time on the elevator cart under the unloader. The unloader then lifts each package to its interior and removes the top, the spacer, and the cover flange, exposing the cans of SNM. These cans are transferred in the secure dollies from the unloader to the vault and placed in the vault storage units. The operators of the secure dollies plus the representatives from the material control group (MC representative) constitute the authorized personnel who make up the in-vault team. These personnel are identified at the outer door of the vault enclosure by means of a photo-comparison device. One of the operations group (the dolly operator) is authorized to possess the key to the outer door (under continuous CCTV surveillance); the other, the MCC member is authorized to possess the combination to the inner door. The backup locks, controlled from the MCC console, operate independently of the combination and key locks such that when the one door is open, the other door cannot be opened under any circumstances. Once the vault entry team is in the enclosure, the outer door is closed, and the backup lock is closed. After the inner door combination is dialed by the MC representative, the backup lock is released by the MCC console operator. The vault team, along with their secure dollies, can then move into the vault.

A secure dolly containing a can of SNM is placed in position above the storage unit. Once the transfer box is locked to the floor of the vault, the can of SNM is moved from the pedestal (Fig. 7.2) into the frame attached to the under side of the hole cover. The storage unit cover is then lowered into the storage unit and locked into position. With the cover in place, the can of SNM rests on the load cell in the bottom of the storage unit, and a weight signal is transmitted to the MCC.

The following reverse sequence of events is used in removing a can of SNM from a storage unit: (1) the secure dolly is spotted over the specified storage unit and locked down; (2) the cover is then unlatched and lifted, along with its load, into the transfer box; and (3) the can of SNM is placed on the pedestal.

The data obtained from the following may be correlated at the MCC using the computer: (1) the shipper's records, (2) information from the MC representative present at the shipping-can unloading station, (3) the NDA measurements for a primary can of SNM in the secure dolly handled during transit to and from the vault enclosure, (4) the secure dolly load-cell output, and (5) the hole storage unit load-cell output. Cross checks on the gross weights of the cans of SNM are made from the load-cell readings. The NDA measurements provide a good estimate of the SNM content and a means of promptly detecting substitution of inert material for SNM in a stored container.

The console operator initiates the accountabiltiy for each SNM container received in a shipment by manually entering the following data (taken from shipping records) into the computer: (1) name of shipper, shipper's lot number, receipt date, SNM can number., and material type; (2) gross weight, net weight of SNM, and isotopic distribution (if known); (3) storage unit location (hole number); and (4) sample number (if sampled).

From the above data, the computer is programmed to maintain and update the inventory record as transactions occur. Any of the data may be called for, either as a display or a print-out; detailed inventory listings showing composition, isotopic content, item location, and a record of transactions for specific time periods and locations may be called.

When a complete physical inventory of the vault contents is to be taken, the contents of each can of SNM in each storage unit is assayed using the NDA equipment aboard the secure dollies. An "item inventory," continuously stored in the computer and based on previous mesurements of SNM content, is valid provided no unauthorized operation of the storage unit latch has occurred since the can of SNM was placed in the unit.

7.2 Appendix B: Transaction Study— Secure Manned/Manual Vault Concept

The results of a transaction study of the secure manned/manual vault assumed as a part of a 200-MT/year mixed-oxide fuel fabrication facility are shown in Fig. 7.6. Assumptions made in developing the material flows are as follows:

1. The plant operates 24 hr/day, 5 days/week.

2. The reject-recycle rate in the pelletizing step is 18% of the throughput at that stage of the process; similarly, in the inspection step, 20% of the pellets are rejected for recycle.

3. The dimensions of the primary SNM containers are 6 in. in diam by 18 in. long, and each storage unit holds one container.

4. The PuO_2 is received in the containers described in item 3; each contains 8 kg of powder (density, 1.5 g/cc).

5. The density of pressed mixed oxide is 5 g/cc; the green pellet density is 10 g/cc, and that of the sintered pellets is 10.5 g/cc.

6. The dimensions of the pellets are 0.5 in. in diam by 0.5 in. long; the weight of a pellet averages 16.5 g.

From these data, the average transaction time is determined to be 108 sec, and the minimum required number of vault storage spaces is 2138.

Two types of operations using the secure dolly were investigated to determine if sufficient time for NDA measurements would be available during transit. Results are as follows:

Transfer operation	Time (hr)	
	Transfer	Available for NDA[a]
1. Truck to storage	0.099	0.044
2. Storage to process	0.135	0.035

[a]Time required for NDA = 0.016 hr.

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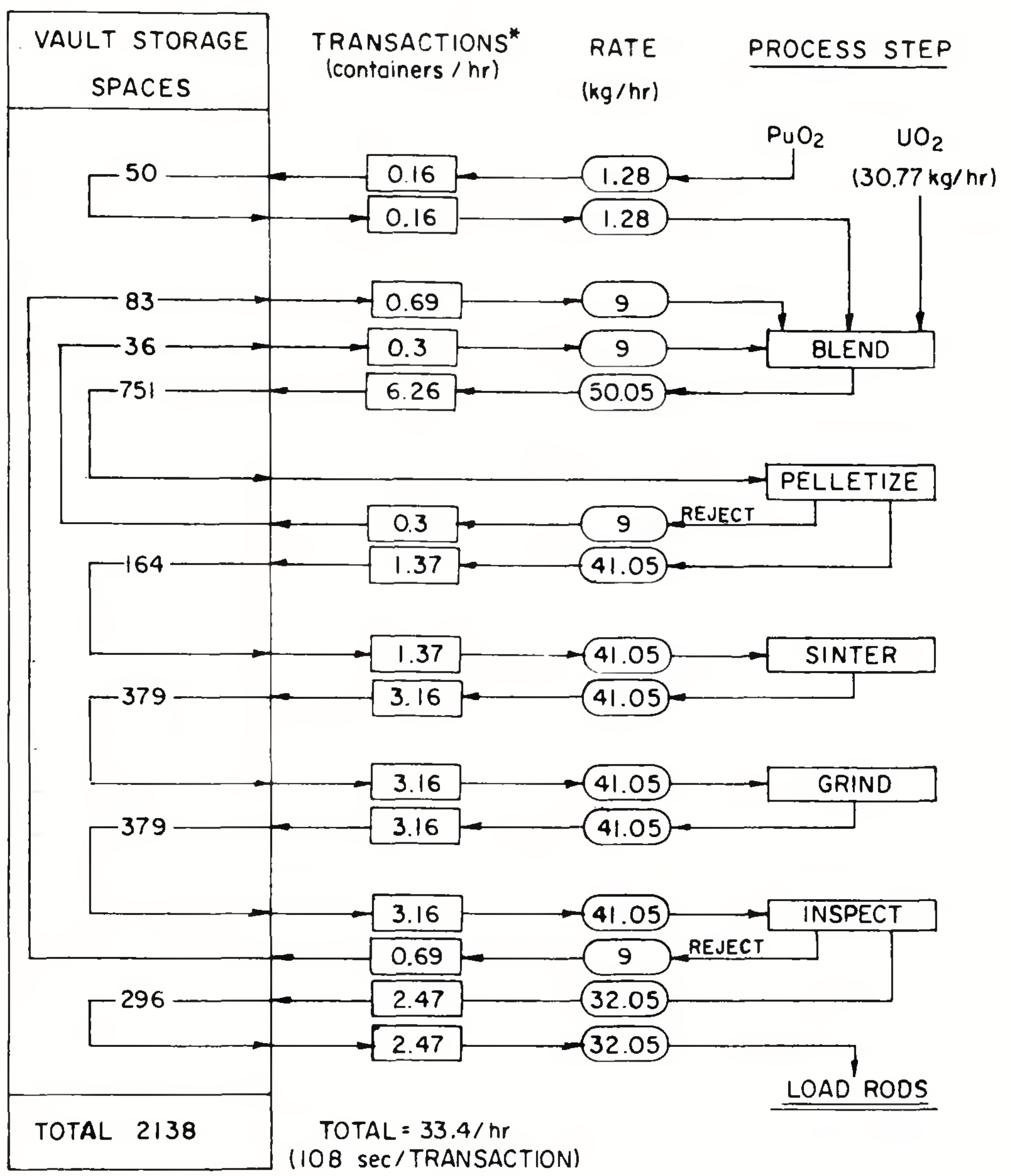

*HANDLING A CONTAINER CONSTITUTES A "TRANSACTION"

Fig. 7.6. Transaction study: secure manned/manual vault.

7.3 Appendix C: Cost Estimate – Secure Manned/Manual Vault

The cost estimates given in this section are engineering estimates based on past experience with the design, construction, and operation of radiochemical processing facilities and related equipment.

7.3.1 *Structural costs*

Vault structure. Based on the transaction study (Appendix B), the vault must have at least 2138 storage spaces, each 7 in. in diam by 24 in. deep. The conceptual design of the vault provides 2205 spaces on a 26- x 33-in. pattern to be compatible with the secure dolly. This translates into a total of 19,992 ft^2 of floor area occupied by the storage system. The vault door enclosure, which is designed to accommodate two secure dollies simultaneously, is assumed to occupy a floor area of 880 ft^2. Based on previous experience with the construction of vault type structures and taking into account the added complexity of the storage system, a unit construction cost for the structure (including doors) of \$350/ft^2 was derived. Therefore, the cost of the structure becomes

$$(20{,}872\ ft^2)\ (350\ \$/ft^2) = \$7{,}305{,}000.$$

Storage system. Each storage unit (Fig. 7.1) consists of a hole lined with stainless steel, measuring 7 in. ID x 24 in. deep, and located in the floor of the vault. The cover of the storage unit is stepped for radiation shielding and is secured by means of a latch device operated from the MCC. A load cell is located in the bottom of each hole; the readout is displayed in the MCC. A unit cost of \$1400/storage space was derived which includes the costs of the load cells, latching devices, wiring, and the liner. Therefore, the installed cost of the storage system becomes

$$2205\ \text{spaces} \times 1400\ \$/\text{space} = \$3{,}087{,}000.$$

Shipping package unloader. It is estimated that the unloader can be fabricated and installed for \$75,000.

7.3.2 *Installed equipment costs*

Secure dollies. From time-motion studies (Sect. 7.3.3), it was determined that two teams, each operating six active dollies, are required on each shift; one spare dolly is provided to assure the appropriate availability. Therefore, the total cost of the dolly fleet is:

13 transporters (modified forklift), $25,000 each	$ 325,000
13 transfer boxes, fully equipped, $75,000 each	975,000
Total	$1,300,000

Material control center: Since all vault operations are handled from the center, its equipment is assumed to be a part of the vault. Therefore, the costs are:

7 display panels, $50,000 each	$ 350,000
6 operating consoles, $50,000 each	300,000
2 computers, $50,000 each	100,000
Communications system (voice, telemetry surveillance)	50,000
Total	$ 800,000

Summarizing, the capital costs are:

Structural	
1. Structure	$ 7,305,000
2. Storage system	3,087,000
3. Shipping package unloader	75,000
Total	$10,467,000
Installed equipment	
1. Secure dolly fleet	1,300,000
2. Material control center	800,000
Total	$ 2,100,000
Overall total	$12,567,000

7.3.3 *Direct operating labor costs*

The direct operating labor costs are those due to the operations personnel required to conduct the vault operations. Capital recovery and maintenance costs are excluded. In the calculations which follow, it is assumed that those components of the direct operating costs, such as utilities, services, and administrative supervision, are included in the assumed annual man-year cost of $40,000.

The manpower requirements were determined based on results of a time-motion study that established the makeup of the shift team given in Table D-1. The constraints due to radiation dose limitations (ref. 2) were then considered, and the number of operations personnel required was determined on this basis as shown in detail below. Results are summarized in Table D-2.

The time required to complete a transaction (tr) is referred to as transaction cycle time. A cycle consists of the time required by a team of operators (opr) to complete a trip into the vault to pick up a SNM container, a trip back out of the vault, plus a trip delivering the container to the process. The trip times and radiation levels in each of the vault areas of the guarded manned/manual vault are the same as those for the manned/manual vault system described in ref. 1, Appendix C, Sect. 9.3.2. Those for the secure manned/manual vault are developed here. The calculations made to estimate the size of the operations personnel group are given below.

A. *Guarded manned/manual*

Transaction rate:	5.5/hr (from Ref. 1)	
Vault operating team:	2.33	operators
	1	guard
	0.1	supervisor
Guard post team:	2	guards
Material control team:	1.3	auditors
	0.7	accountability technician
	0.3	accountability supervisor
Trip times (hr/tr):		
To pick up load	0.0834	
To return with load	0.0834	
Delivery	0.062	

Transaction cycle time is

$$(2 \times 0.0834 \text{ hr}) + (0.062 \text{ hr}) = 0.23 \text{ hr/tr}.$$

Table D-1. Makeup of operational teams

Vault concept	Material control		Vault operation		Guard post
Manned					
Guarded manual	1.33	auditors	2.33	operators	2
	0.67	accountability technicians	0.1	accountability tech.	
	0.33	accountability supervisor	1	accountability super.	
Total	2.33		3.43		2
Secure manual	3	console operators	6.33	dolly operators	None
	1	supervisor	0.1	supervisor	
	0.67	systems engineer			
Total	4.67		6.43		
Fully automatic	2	computer technicians	2	operators	None
	0.33	systems engineer	0.33	supervisor	
Total	2.33		2.33		

Table D-2. Number of personnel required for material control center, vault operations, and the guard post

Vault concept	Material control center	Vault operations based on:		Guard post[a]	Total[b]
		Time-motion studies	Dose constraints		
Manned					
Guarded manual	7	13[c]	92.6[c]	6	105.6
Secure manual	28.6[d]	39.7	25.8	None	68.3
Fully automatic	7	7	7	None	14

[a]These guards are stationed at the guard post and do not routinely enter the vault; the number listed is not included in the group under vault operations.

[b]Based on the higher of the two vault operating requirements.

[c]Includes those guards assigned to the vault operating group who enter the vault on a routine basis.

[d]Consists of 18.6 console operators, 6 supervisors, and 4 engineers based on time-motion studies.

The number of teams required is

(5.5 tr/shift-hr)(0.23 team-hr/tr) = 1.26 teams/shift.

Hence the manpower required from time-motion considerations becomes

(3 shifts) (1.26 teams/shift) (3.4 men/team) = 13 men.

Each member of a vault operating team conducting a transaction is exposed to radiation which regulations (ref. 2) limit to 1250 mrem/quarter (qtr). Therefore, each team member will receive the following dosage:

(50 mrem/hr)(0.062 hr/tr) + (10 mrem/hr)(0.0834 hr/tr) = 3.93 mrem/tr.

Therefore, during any quarter, a team can conduct the following transactions:

(1250 mrem/team-qtr)/(3.93 mrem/tr) = 318 tr/team.

However, there are 2860 tr/qtr to be conducted, so that the number of teams required is expressed by

(2860 tr/shift-qtr)/(318 tr/team-qtr) = 9 teams/shift.

The total manpower required, constrained by dose limit, then is

(3 shifts)(9 teams/shift)(3.43 men/team) = 92.6 men.

B. *Secure manned/manual*

Transaction rate:	33.4/hr (Appendix B, Sect. 7.2)	
Vault operating team:	6.33	dolly operators
	0.1	supervisors
Material control center team:	3	console operators
	1	supervisor
	0.67	engineer
Trip time (hr/tr):		
To pick up load	0.0299	
To return with load	0.0299	
Delivery	0.0023	
Radiation level (mrem/hr)	3	

Transaction cycle time is

$$(2 \times 0.0299 \text{ hr/tr}) + 0.0023 \text{ hr/tr} = 0.0621 \text{ hr/tr}.$$

The number of teams required is

$$(33.4 \text{ tr/shift-hr})(0.0621 \text{ teams-hr/tr}) = 2.07 \text{ teams/shift}.$$

The total manpower required for in-vault operation becomes the following:

$$(3 \text{ shifts})(2.07 \text{ teams/shift})(6.43 \text{ men/team}) = 39.7 \text{ men}.$$

In the MCC, one console operator operates two dollies; therefore,

$$(3 \text{ shifts})(3 \text{ console operators/team} + 1 \text{ supervisor/team} + 0.67 \text{ engineer/team})(2.07 \text{ teams/shift}) = 28.6 \text{ men/shift}.$$

The exposure to each member of a vault operating team is

$$(3 \text{ mrem/hr})(0.0299 \text{ hr/tr}) + (3 \text{ mrem/hr})(0.23 \text{ hr/tr}) = 0.0966 \text{ mrem/tr}.$$

Each team can conduct the following transactions:

$$(1250 \text{ mrem/team-qtr})/(0.0966 \text{ mrem/tr}) = 12{,}940 \text{ tr/team-qtr}.$$

The total number of transactions required in a quarter is

$$(33.4 \text{ tr/hr})(40 \text{ hr/shift-week})(13 \text{ weeks/qtr}) = 17{,}368 \text{ tr/shift-qtr}.$$

Therefore, the number of teams required is

$$(17{,}368 \text{ tr/shift-qtr})/(12{,}940 \text{ tr/team-qtr}) = 1.34 \text{ teams/shift}.$$

The total manpower required becomes

$$(3 \text{ shifts})(1.34 \text{ teams/shift})(6.43 \text{ men/team}) = 25.8 \text{ men}.$$

Thus it is seen that the dose limit to individuals is not controlling in this vault concept, since time-motion studies show 2.07 teams are required as compared to 1.34 when the dose limitations are considered.

C. *Fully automatic*

Vault operating teams:	2	operators
	0.33	supervisor
Material control team:	2	computer technicians
	0.33	systems engineers

In Appendix F, ref. 1, the time required to complete a transaction in the automated vault was estimated to be 2 min 45 sec = 0.0458 hr/tr.

Therefore, the number of teams required is

(5.5 tr/shift-hr) (0.0458 team-hr/tr) = 0.25 team/shift.

This indicates that one team can conduct all of the vault operations required on a shift in about 2 hr, and one team is sufficient for each shift. Accordingly, the manpower needed becomes

(3 shifts)(1 team/shift)(2.33 man/team) = 7 men.

Dose consideration. Since all transactions are conducted within the boundary of the automated vault, there is no exposure to operating personnel. Therefore, one team/shift is sufficient.

From these calculations it is seen that the vault operating personnel requirements are dependent on (1) the vault concept and (2) the degree to which the operating personnel are exposed to radiation. Where radiaton exposure is present, it is realized that a practical facility management would, undoubtedly, reduce the radiation background by installing shielding and rotating the larger numbers of required personnel through other areas of the facility where radiation is absent or very low. However, in the absence of detailed design of each facility, it is difficult to determine what fraction of the added cost of the additional vault-operating mapower should be attributed to actual operation of the vault. In practice, a facility manager would exercise considerable effort in optimizing the process, the facility design, and its operational procedures to achieve the most efficient and economic operation consistent with the conditions under which the facility operates. It is thought best at this point to define the limits of the in-vault manpower requirements (Table D-2) and, determine the operational costs on the basis of the maximum manpower required as constrained by dose limits. These costs are compared in Table D-3 for each vault concept.

7.3.4 *Maintenance costs*

The maintenance costs of the guarded manned/manual vault are zero, since no installed equipment is associated with this concept. The annual maintenance costs for the automated vault concept are given in ref. 1, Sect. 6 as $464,800.

Table D-3. Annual personnel operating costs[a]

Vault concept	Annual personnel operation costs based on:	
	Time studies($)	Dose limitation($)
Manned		
Guarded manual	1,040,000[b]	4,224,000[b]
Secure manual	2,732,000[c]	2,172,000
Fully automatic	560,000	560,000

[a]Based on $40,000/man-year.

[b]Includes the costs of additional security guards.

[c]This will be the cost that is required based on the minimum number of personnel that can physically accomplish the tasks.

Maintenance costs for the secure manned/manual vault concept are estimated below, based on the following assumptions:

1. Two percent of the load cells will fail annually; it requires two craftsmen 1 hr to replace or repair each, or

   (0.02 x 2205 failures/year)(2 men)(1 hr/failure) = 88 man-hr/year.

2. Five percent of the storage-unit cover latches will fail annually, and it requires two craftsmen 1 hr to repair each.

   (0.05 x 2200 failures/year)(2 men)(1 hr/failure) = 220 man-hr/year.

3. Five failures of the communication system will occur annually requiring 16 hr of craft effort for each failure.

   (5 failures/year)(16 man-hr/failure) = 80 man-hr/year.

4. One and one-half instrument mechanics are required full time to maintain the MCC display panel and the operating consoles.

   (1.5 men)(8 hr/day)(5 days/week)(52 weeks/year) = 3120 man-hr/year.

5. Each transport-vehicle will require 2 hr/month of preventive maintenance and 10 hr/year of extended maintenance by an automotive mechanic.

   (1 man)(13 vehicles)(2 hr/vehicle-month)(12 month/year) +
   (1 man)(13 vehicles)(10 hr/vehicle-year) = 442 man-hr/year.

6. Each box of the secure dolly fleet will require 8 hr/month of preventive maintenance, plus 32 hr/year of extended maintenance by mechanics. Additionally, one electronics technician, half time, is required to maintain all of the electronics packages of the fleet of secure dollies. Therefore, the total effort will include

   (13 boxes)(1 man)(8 hr/month-box)(12 months/year) +
   (13 boxes) (32 man-hr/box-year) + (0.5 man)(2080 hr/year) =
   (1248 + 416 + 1040) = 2704 man-hr/year.

7. Vault door interlocks are assumed to require 12 man-hr of preventive maintenance plus 16 man-hr of extended maintenance annually.

   (12 + 16) man-hr/year = 28 man-hr/year.

Summary: Total maintenance effort = 6682 man-hr/year.

Maintenance cost =

(6682 man-hr/year) ($40,000/man-year)/(2080 man-hr/man-year) = $128,500/year.

7.4 Appendix D: Radiation Exposure in Vault Operations

The following assumptions were made regarding radiation conditions in the guarded manned/manual and the secure manned/manual vault:

1. The makeup of the vault operating teams is shown in Table D-1.

2. The average radiation level in the guarded manned/manual vault is the same as for the manned/manual vault given in ref. 1 (i.e., 50 mrem/hr in the vault and 10 mrem/hr in the corridor leading to the process).

3. The audit team (two auditors from the material control group) are in the guarded manned/manual vault on the average of one shift/week (i.e., 8 hr during the 120 hr available). This is associated with (120 hr/week)(33.4 tr/hr) = 4008 tr/week. Accordingly, each of these individuals is exposed to

   (8 hr/week)/(4008 tr/week) = 0.002 hr/tr.

4. No maintenance is required in the guarded manned/manual vault, since it contains no installed equipment.

5. The radiation background in the secure manned/manual vault is 3 mrem/hr because of the storage unit design.

6. The shielding of the transfer box of the secure dolly reduces the radiation due to its contents to the background of the vault (i.e., 3 mrem/hr). The route from the vault to the process input/output stations is assumed to be 3 mrem/hr.

The maintenance time required with the secure manned/manual vault is estimated based on the following assumptions:

1. The dollies are repaired in the shop, and no exposure to maintenance personnel occurs.

2. In-vault maintenance is estimated as follows, assuming the failure rates given in Appendix C above:

Load cell:	0.02 x 2200 x 1 = 44 hr/year
Latch failures:	0.05 x 2200 x 11 = 110 hr/year
Relay station:	8 x 5 = 40 hr.

Total maintenance time (sum of the 3 preceeding items) = 194 hr/year

The total number of transactions completed annually is

(260 day/year)(24 hr/day)(33.4 tr/hr) = 208,416 tr/year.

(194 maintenance-hr/year)/(208,416 tr/year)(2.5 men) = 0.0023 maintenance-hr/tr.

(This assumes that an average of 2 craftsmen plus 0.5 supervisors are required.)

With these assumptions and the results of the transaction study (Appendix B), the total radiation dose expected in the various vault concepts is calculated as follows:

Guarded manned/manual vault

(2 opr + 1 guard)(50 mrem/man-hr)(0.062 hr/tr) +

(2 auditors x 0.0002 hr/tr)(50 mrem/man-hr) +

(2 opr + 1 guard)(10 mrem/man-hr)(0.0834 hr/tr) =

(9.8 + 0.2 + 2.50) = 12.5 mrem/tr.

Secure manned/manual vault

(0.0299 hr/tr)(6 op)(3 mrem/man-hr) +

(0.0023 man-hr/tr)(3 mrem/man-hr) =

(0.538 + 0.007) = 0.55 mrem/tr.

Fully automatic vault

0.42 mrem/tr (taken from ref. 1).

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