NUREG/CR-0372
ORNL/NUREG-44

Design Criteria for Vault Automation in Special Nuclear Material Storage

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Prepared for the U.S. Nuclear Regulatory Commission
Office of Standards Development
Under Interagency Agreement DOE 40-543-75

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION · FOR THE DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161

NUREG/CR-0372
ORNL/NUREG-44
Dist. Category RS

Contract No. W-7405-eng-26

CHEMICAL TECHNOLOGY DIVISION

Pilot Plant Section

DESIGN CRITERIA FOR VAULT AUTOMATION IN SPECIAL NUCLEAR MATERIAL STORAGE

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*On loan from Instrument and Controls Division.
**On loan from UCC-ND General Engineering Division.

Manuscript completed: August 1978

Date published: November, 1978

Prepared for the
U.S. Nuclear Regulatory Commission
Office of Standards Development
Washington, D.C. 20555
Under Interagency Agreement DOE 40-543-75
NRC FIN No. B0215

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
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DEPARTMENT OF ENERGY

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ACKNOWLEDGMENT

The assistance of F. N. Browder in preparing this document for publication is gratefully acknowledged.

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ABSTRACT

Design criteria for safeguards benefits derived for candidate designs of automated special nuclear material storage vault systems are developed. These are based on the safeguards benefit evaluation methodology reported earlier[1] that is used in establishing performance standards for each element of the safeguards functions. Numerical values between 1 and 10 are obtained which minimize the effect of personal preferences or differences in judgment. Specific minimum values for each safeguards function, as well as for the overall safeguards system, are chosen that constitute the criteria for designing vault storage systems.

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1. INTRODUCTION

This is the third report in a series on the automation of storage vaults for special nuclear material (SNM). The first report, on studies that evaluated vault concepts featuring various degrees of automation, established feasibility and desirability. The second report established the safeguards value and the cost impact of achieving this value for vault automation.[2] This, the third report on automated SNM vaults, discusses design criteria developed by applying the safeguards worth-evaluation methodology to candidate vault concepts and the establishment of a basis comparison of the candidates.

2. SAFEGUARDS OBJECTIVES

To make decisions with respect to SNM vault storage design options, the safeguards-related performance must be quantified in some fashion. In this work, performance is measured by the effectiveness of the basic safeguards functions of detection, delay, and deterrence at the conceptual design stage. To evaluate this effectiveness, it is first necessary to enumerate the vault design parameters that can affect the basic safeguards functions. After the design parameters are identified, they are evaluated by using a numerical evaluation scheme which will permit a designer to perform design trade-off studies. This evaluation methodology[1] should be sufficiently well structured to ensure repeatability among different designers. This is particularly difficult because of the inherent complexity and subjectivity of safeguards functions and design parameters.

In the following sections, a procedure to evaluate safeguards parameters for SNM vaults in terms of the basic safeguards functions is presented. The evaluation methodology was structured to provide a reliable tool for use in the quantitative ranking of design options with respect to generalized design criteria. Now that the methodology is in hand, a set of performance standards can be established if the boundaries of each element of a system that contribute to the performance of the safeguards functions are defined conceptually and numerically.

2.1 Safeguards Functions

To maximize safeguards objectives at an SNM storage vault, a system of hardware, personnel, and operating procedures must be established which, to the fullest degree possible, performs the basic functions of the safeguards systems shown in Table 2.1.

These four basic safeguards functions are closely interrelated. For example, knowledge of the existence of a safeguards system that effectively detects, delays, and responds to attempted diversions will in itself help deter rational individuals from considering theft of SNM. It is also clear that increasing the time required to remove SNM increases the likelihood of detection and interruption of such an attempt.

Thus the engineer charged with the task of designing an SNM vault system has a great deal of freedom in choosing an overall design, provided the conceptual safeguards system effectively performs the four basic functions. His problem is how to evaluate the advantages and disadvantages of various design options with respect to their safeguards effectiveness. This requires the development of a methodology that will permit a numerical ranking of the option studied and criteria, or set of goals, toward which the designer must strive.

Table 2.1. Basic functions of the safeguards system

Function	Problem addressed
Deterrence (of)	Potential adversary actions
Detection (of)	Material balance discrepancies; unauthorized activities
Delay (of)	Unauthorized activities until appropriate response can be made
Response (to)	Unauthorized activities and material balance discrepancies in a timely manner

2.2 Safeguards Effectiveness

The safeguards effectiveness, or value, of potential SNM vault storage automation design options must be estimated with respect to the basic safeguards functions. In an overall sense, SNM vault storage functions and equipment are complex. The basic safeguards functions, on the other hand, represent rather general and broadly defined concepts. It is highly unlikely that consideration of the effects of various design alternatives directly based on the basic functions will lead independent evaluators to similar conclusions. An effectiveness evaluation that is reliable and repeatable demands that more detail be introduced into the process. The basic safeguards functions must be expressed in terms of SNM vault storage system design parameters, or performance factors, which properly characterize the effects of design alternatives. For example, the safeguards function of delay basically reflects how much obstruction an adversary must overcome along a particular pathway to SNM access. A vault safeguards performance factor that contributes to this overall obstruction is the thickness and construction (physical barrier) of the walls enclosing the SNM storage area. All four of the basic safeguards functions can be similarly resolved into sets of performance factors of this type which are more meaningful when coupled to the SNM vault design alternatives. By relating system design options (through safeguards performance factors) to the basic safeguards functions, a foundation is established for the determination of safeguards design performance effectiveness. Measured safeguards design performance can then be used as a fundamental acceptance criterion.

3. EFFECTIVENESS EVALUATION

In the methodology presented in this section, all design trade-offs pertaining to vault storage automation are evaluated at the conceptual design level of detail. The major steps of this procedure are shown in Fig. 3.1, and to evaluate the safeguards value of a particular vault concept, the conceptual design must generally address the system features outlined in Table 3.1.

A standardized procedure has been developed which can be used in the analysis of design options to establish safeguards value and relative ranking.[1] This evaluation methodology is built on a standard set of vault safeguards performance factors that have been defined in terms of the basic safeguards functions. Generally, these safeguards performance factors are assigned a numerical value of 0 to 10 based on the attributes of the particular vault concept being considered. To alleviate some of the subjectivity associated with the process of assigning values, each performance factor was given a "standard" lower and upper bound concept and assigned specific values that quantify the effectiveness of the performance of these boundary concepts. In this way, the endpoints of the safeguards value scale are defined. The purpose in establishing these performance standard bounds is to provide all persons performing evaluations with the same reference. Under the assumption that all evaluations are made with sound engineering judgment, the numerical safeguards values become a reasonable basis for universal comparison of designs.

Once values are assigned to each of the safeguards performance factors, combined performance values for the basic safeguards functions and the overall safeguards value can be calculated using weighted arithmetic averages (Sect. 3.2). Weighting factors are introduced to emphasize, or de-emphasize, certain groups of performance factors.

Upon completion of the evaluation process, the performance values obtained for each of the safeguards functions would be allowable minimum value criteria, which can be considered also as "acceptance criteria." A minimum overall allowable value ensures suitably effective integrated safeguards capability. The criteria for the individual safeguards functions ensure a balanced capability.

3.1 Safeguards Performance Factors

The relative safeguards value, or benefit, of various vault concepts is estimated with respect to the safeguards performance criteria referred to above. Specific safeguards performance factors that relate vault systems' parameters to the safeguards evaluation criteria are defined and explained below. Each element of the general safeguards performance criteria is considered in conjunction with the details of the conceptual vault storage system and its operation.

3.1.1 *Detection performance factors*

The overall safeguards detection function is broken down into the detection of (1) material balance discrepancies, (2) unauthorized personnel activities (such as unauthorized removal of SNM through restricted input/output ports in a vault), and (3) the presence of SNM at any

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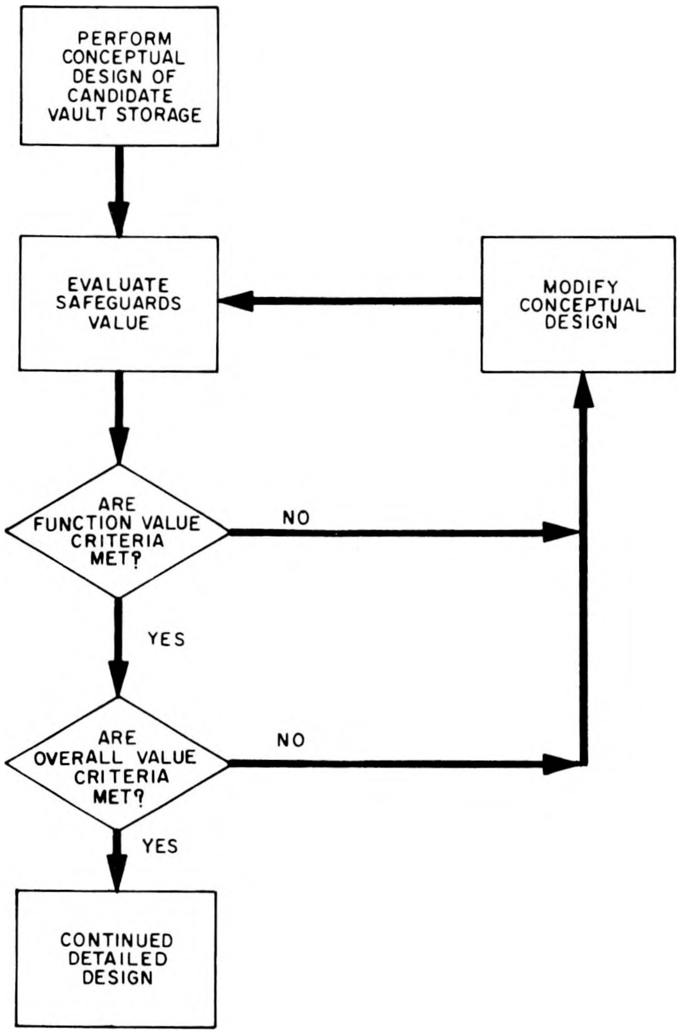

Fig. 3.1 Effectiveness evaluation procedure.

Table 3.1. Vault conceptual design content required for safeguards evaluation

1. Facility/process integration

   1.1 Vault/layout

   1.2 SNM handling dynamic requirements

2. Storage container design

3. Storage container handling system design

4. Information management istrumentation and controls system design

5. Safeguards system

   5.1 Physical protection

   5.2 SNM inventory control

   5.3 Personnel control

6. Reliability assessment

unauthorized location. The performance of these three subfunctions depends on the speed and sensitivity with which evaluations and decisions can be made. An example of the speed characteristic is the amount of time required to perform an updated inventory calculation. Detection sensitivity is a function, for example, of the minimum detection threshold of SNM monitors.

3.1.1.1 *Detection of material balance discrepancies.* The detection of a material balance discrepancy is dictated by (1) the timeliness (frequency) and accuracy of SNM measurements and (2) the timeliness (computational time) and accuracy of SNM inventory calculations.

3.1.1.2 *Detection of unauthorized personnel activities.* Unauthorized personnel activities include (1) misuse of the vault storage operational features, such as an attempt to use a control panel to perform unauthorized (disguised) SNM acquisition and (2) unauthorized presence in vital vault-related (material access) areas.

In the first case noted above, detection of personnel depends on the spatial surveillance effectiveness (how good) that can be achieved in the vault interior, input/output ports, container transfer region, and the control room. Detection of unauthorized activities by authorized personnel depends on the surveillance effectiveness achieved for container handling, inventory-data management, and equipment-maintenance activities.

3.1.2 *Delay performance factors*

The overall safeguards delay function is intended to provide a requisite magnitude of delay time (generated by functional and physical obstructions) under actual attack conditions. In the case of SNM vault storage systems, the delay function includes (1) delaying adversary access to vital areas, (2) delaying adversary use of the vault system, and (3) delaying adversary access to SNM. These delay functions are implemented through both active and passive mechanisms.

3.1.2.1 *Active delay mechanisms.* For a particular conceptual storage vault, active delay systems' performance depends on the extent to which the active delay mechanisms are implemented. Examples of the active delay concepts are: (1) imposition of vault environmental conditions adverse to humans (i.e., inert gas purging), (2) denial of normal vault entry access, and (3) denial of the use of operating controls.

3.1.2.2 *Passive delay mechanisms.* Passive delay mechanisms are realized through the structural attributes of the various vault components. For this evaluation, the delay aspects of the structural design features to consider include (1) principal physical barrier (i.e., vault walls), (2) storage container design, (3) container storage area design (i.e., shelves, racks, etc.), (4) vault input/output port design, and (5) maintenance access port design.

3.1.3 *Deterrence performance factors*

The safeguards deterrence function is, to a great extent, subjective in nature because it is closely coupled to the human characteristics of potential adversaries. For example, a satisfactory safeguards deterrent to a marginally motivated adversary may be of little consequence to a highly motivated and emotional (perhaps irrational) adversary. As a result, deterrence performance factors are defined based on the general notion of complicating the adversary's preparatory activities. The hypothetical perspective of the potential overt or covert adversary is used as a base in defining these performance factors, which include (1) detection system effectiveness, (2) delay system effectiveness, (3) response system effectiveness, and (4) intrinsic system characteristics.

3.1.3.1 *Detection system effectiveness.* The performance, both actual and perceived, of the detection system serves as a major deterrent to both overt and covert assaults.

3.1.3.2 *Delay system effectiveness.* The delay system performance similarly serves as a major deterrent to adversary plans and preparations.

3.1.3.3 *Response system effectiveness.* The visible magnitude (people and weapons) of the response force (security guards, local police, etc.) at a given facility serves as a major deterrent to potential overt attacks. Since it is generally assumed that this safeguards function is essentially independent of vault storage options, response system effectiveness will have little effect on vault deterrence contributions and, therefore, is included here for completeness only.

3.1.3.4 *Intrinsic system characteristics.* A number of inherent vault system parameters, or characteristics, contribute significantly to deterrence. These pertain primarily to covert assault and include (1) material access and isolation, (2) material-handling time, (3) collusion vulnerability, and (4) system complexity.

(*Material access and isolation*). The accessibility of SNM is an obvious prerequisite for theft. Design features that reduce accessibility and increase physical isolation represent deterrence.

(*Material-handling time*). In any system, some direct handling of containerized SNM will be required as either a part of normal operation or equipment maintenance operations. Since during these conditions individuals have direct access to material, keeping these times to a minimum complicates covert assault intentions.

(*Collusion vulnerability*). Mechanization and automation will generally require that more than one individual make preparations for theft. Collusion vulnerability, therefore, is considered a function of the number of people to be involved and their social mixture (i.e., the cross section of the types, professional training, and the responsibilities of the personnel). Collusion vulnerability decreases as the number of people required increases and the mixture varies; hence, these factors serve as a deterrent. Thus, as storage systems tend to become more automated and complex, the number of people who have some awareness or control over SNM transactions increases and, based on the above assumption, the vulnerability of the system to collusion decreases. These people include security guards in the immediate vault area, those involved in monitoring closed-circuit television (CCTV), the vault (computer) operators, the operations group, the SNM-accounting group, the personnel control group, etc.

(*System complexity*). The functional and physical complexity of the vault storage system will also serve as a deterrent to overt and covert assaults. Complexity implies that greater knowledge (and collusion) is required to manipulate or defeat a particular system and, therefore, represents deterrence. On the other hand, system complexity could also be used to hide overt actions by the "insider" who has knowledge of the system.

3.2 Performance Evaluation Methodology

The evaluation methodology described below[1] is based on specifying each of the safeguards-related factors that have an effect on the overall system performance and assigning a value to each. Table 3.2 may be considered a work sheet for evaluating a vault storage system concept. In the first column ("Safeguards performance criteria") are the various performance criteria arranged under the three safeguards functions that are considered. In the second column ("Vault safeguards performance factor") are the safeguards-related performance factors discussed below that have an effect on the overall criteria for system performance. Each of these factors is considered by the design engineer and assigned a numerical value which, in his judgment, lies at the appropriate point between those boundary values defined in the third and fourth columns of the table. This assigned value is entered in the fifth column. (In the table, the fifth column is headed "Example" for illustrative purposes; it is in fact the "concept under evaluation.")

After all the performance factors have been graded numerically, they are averaged arithmetically, establishing (1) the effectiveness of each of the detection, delay, and deterrence functions and then (2) the overall safeguards effectiveness (benefit) of the system. Weighting factors are also used (for detection only) to force a relative ranking among subfunctions. These factors are applied prior to calculating the performance factor average. The procedure for averaging and weighting is as follows.

Calculation of overall safeguards value

1. *Performance factors* are averaged with respect to performance criteria:

$$PC_n = \frac{1}{m_m} \sum_{i=1} PF_{ni} \quad .$$

For example, in the case of the performance criteria "vault inventory material balance discrepancy detection" dependence on inventory accuracy; $n = 1$, $m = 4$.

2. *Performance criteria* are averaged and weighted with respect to safeguards functions:

$$SF_k = \frac{1}{n_k} \sum_{n=1}^{m_k} PC_n \cdot \overline{\underline{W}}_{kn} \quad .$$

For detection; $k = 1$, $n_k = n_1 = 5$.

3. *Safeguards functions* are averaged with respect to overall safeguards value:

Overall safeguards value

$$\frac{SF_1 + SF_2 + SF_3}{3} \quad .$$

Table 3.2. Safeguards performance standards

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Example
1. DETECTION (SF_1)				
1.1 Vault inventory material balance discrepancies (PC_1, PF_{1i}; $i=1,\ldots 4$)	1.1 Vault inventory accuracy			
	(1) SNM measurement accuracy (PF_{11})	Measurement system comprised of conventional nondestructive assay, wet chemical analysis, and weighing with manual data acquisition. Process measurements >0.5% and laboratory measurements ≤0.4	Direct (e.g., nondestructive assay) measurement of all SNM flows and storage continuously to within 0.1%	Same as lower bound but with computerized data acquisition which reduces reading and calculational errors
		Value[a] = 5	Value = 10	Value = 8
	(2) Inventory data management (calculations) accuracy (PF_{12})	Human-based line entry accountancy with no computerization	Entirely computer-based with all physical data obtained from instrumentation electronically interfaced to the computer. Automatic calibration and verification of sensors	Computerized data management, record keeping, and reporting with principally manual data entry
		Value[a] = 5	Value = 10	Value = 8
	1.2 Vault inventory timeliness			
	(1) SNM measurement frequency (PF_{13})	SNM measurements only performed in association with transactions at shipping, receiving, and transfer to process	Continuous SNM measurement during canister handling and storage	SNM measurement of canisters at the beginning and conclusion of transactions
		Value = 2	Value = 10	Value = 6
	(2) Inventory data processing (PF_{14})	Manual (human-performed) vault item inventory requiring greater than two 8-hr shifts Physical inventory requiring a number of days from time of request	Vault item inventory based on direct verification of storage container integrity and all transactions initiated or completed Physical inventory within a few hours of request	Same as upper bound but with item inventory only and not direct SNM verification
		Value = 1	Value = 10	Value = 7
$PC_1 = 1/4\ (\sum_{i=1}^{4} PF_{1i})$	Overall value	NA	NA	$PC_1 = 1/4(8+8+6+7) = 7.3$

[a] Footnotes at end of each section of table.

Table 3.2. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Example
1. <u>DETECTION</u> (cont'd)				
1.2 Unauthorized personnel activities				
1.2.1 Unauthorized personnel in vital vault-related areas (PC_2, PF_{2i}; i=1,...4)	1.2.1 Surveillance effectiveness			
	(1) Vault interior (PF_{21})	No surveillance instrumentation utilized	Multiple (at least two) types of continuous volumetric intrusion monitors which scan 100% of sensitive area	Continuous volumetric monitoring which must be deactivated for normal operator entrance to vault
		Value = 0	Value = 10	Value = 5
	(2) Vault input/output ports (PF_{22})	Same	Same	Manually operated vault which requires normal operator traffic across input/output ports (doors)
		Value = 0	Value = 10	Value = 2
	(3) Vault system control room (PF_{23})	Same	Continuous identification (or discrimination of unauthorized) of authorized control room personnel	Manually operated vault which does not have a control room (positive effect)
		Value = 0	Value = 10	Value = 10
	(4) Vault process material transfer	Same	Same as (1) above	Continuous volumetric intrusion monitoring of a vault with mechanized material handling and physically isolated (from normal operating personnel) material transfer space
		Value = 0	Value = 10	Value = 10
$PC_2 = 1/4 \left(\sum_{i=1}^{4} PF_{2i}\right)$	Overall value	NA	NA	PC_2=1/4(5+2+10+10)=6.8

Table 3.2. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Example
1. DETECTION (cont'd)				
1.2.2 Unauthorized use of system operational features (i.e., controls, computers, etc.) (PC_3, PF_{3i}; i=1,...3)	1.2.2 Operations surveillance effectiveness			
	(1) Container handling (PF_{31})	Total human operator container handling with essentially no additional administrative controls (e.g., operation which is totally at process operations integrity and convenience)	Container surveillance using independent and protected instrumentation of a system with automated container handling operations	Manually operated vault with only administrative operating procedure controls
		Value = 0	Value = 10	Value = 3
	(2) Inventory data management (PF_{32})	No routine surveillance of inventory data bookkeeping functions	Continuous surveillance of secured *on-line computer-based inventory system.* Password control of all users (operators) and programmers	Computer-based inventory data *managementt* with only password control of programmers and users
		Value = 0	Value = 10	Value = 9
	(3) Equipment maintenance (PF_{33})	No surveillance of a situation in which maintenance personnel require unencumbered access to complex equipment in vital areas and when key safeguards equipment is disabled 10% of the time	Situations that involve no equipment maintenance in vital areas	Manually operated vault with no active internal hardware other than safeguards instrumentation
		Value = 0	Value = 10	Value = 9
$PC_3 = 1/3\ (\sum_{i=1}^{3} PF_{3i})$	Overall value	NA	NA	PC_3=1/3(3+9+9)+7

Table 3.2. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Example
1.3 Unauthorized SNM				
1.3.1 Location	1.3.1 SNM surveillance effectiveness			
	(1) SNM not containerized but within vault boundary[2] (anomalous condition in which SNM has been accidentally or purposely removed from a container at the wrong time) (PF_{41})	No surveillance instrumentation utilized Value = 0	Continuous radiation monitoring instrumentation which can discriminate uncontainerized (exposed to vault interior) SNM instantaneously Value = 10	Continuous alpha-gamma radiation monitor; no discrimination Value = 5
	(2) Containers in storage rack area (surveillance instrumentation built into storage rack) (PF_{42})	No passive locks, seals, or other methods utilized Value = 0	Continuous SNM container assay for all storage rack container positions Value = 10	Continuous container bulk weight monitoring of all storage rack positions Value = 7
	(3) Containers being handled within vault interior (surveillance instrumentation built into container handling system) (PF_{43})	Manual handling of containers by individual process operators without security guard present and no other surveillance instrumentation Value = 0	Mechanization of container handling such that human contact is not required and with continuous SNM container assay during time out of storage rack Value = 10	Same as upper bound but only with nuclear signature verification rather than assay Value = 9
	(4) Containers in transfer (i.e., to/from process) (PF_{44})	Same as above Value = 0	Same as above Value = 10	Same as above Value = 9
$PC_4 = 1/4 \left(\sum_{i=1}^{4} PF_{4i}\right)$	Overall value	NA	NA	$PC_4 = 1/4(5+7+9+9) = 7.5$

Table 3.2. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Example
1.3 Unauthorized SNM (cont'd)				
1.3.2 Shielding materials (i.e., an amount which would compromise detectability)	1.3.2 Shielding surveillance[3]			
	(1) "Large" amounts of shielding crossing vault access ports (PF_{51})	No surveillance instrumentation utilized	Continuous surveillance of all vault access ports with instrumentation which will detect presence of significant quantities of materials with shielding properties which would defeat SNM portal monitors	Manually operated vault with conventional metal detection at doorway
		Value = 0	Value = 10	Value = 5
	(2) "Large" amount of shielding present during container transfer (PF_{52})	Same as above	Same as above except detection region is vicinity of handling equipment	Same as above
		Value = 0	Value = 10	Value = 5
$PC_5 = 1/2\ (\sum_{i=1}^{2} PF_{5i})$	Overall value	NA	NA	PC_5=1/2(5+5)=5
Detection Sumary				
1. Vault inventory material balance discrepancies	Weighted overall value W^4=1	NA	NA	(1.x7.3)=7.3
2. Unauthorized personnel activities	Weighted overall values			
• Unauthorized personnel in vital vault areas	W=1	NA	NA	(1x6.8)=6.8
• Unauthorized use of system operational features	W=0.8	NA	NA	(0.8x7)=5.6

Table 3.2. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Example
<u>Detection Summary</u> (cont'd)				
3. Unauthorized SNM presence	Weighted overall values			
• Location	W=0.8	NA	NA	(0.8x7.5)=6.0
• Shielding materials	W=0.8	NA	NA	(0.8x5.)=4.0
Average overall weighted value	Overall value = A	NA	NA	1/5(7.3+6.8+5.6+6+4)=5.9

<u>Notes for detection</u>:

(1) Value = subjective quantification of safeguards benefit on a scale of - to 10, 10 being most desirable.
(2) Vault boundary: Storage area to process transfers.
(3) Shielding issue is intended as a relative argument; performance of heavy-metal detectors may be a major problem.
(4) Weighting factor.

2. <u>DELAY (OF)</u> (SF_2)				
(1) Adversary access to vault areas				
(2) Adversary use of vault systems functions (i.e., controls, equipment, etc.)				
(3) Adversary physical access to SNM (PC_2, PF_{2i}; i=1,...8)				

Table 3.2. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Example
	2.1 Active delay mechanisms			
	(1) Imposed adverse vault conditions (e.g., inert gas purge) (PF_{21})	Not utilized	Active system which is capable of rendering the vault environment to humanly debilitating conditions within minutes	Continuous nitrogen purge to less than 2% oxygen of vault interior and container transfer region
		Value = 0	Value = 10	Value = 6
	(2) Normal vault entry access denial (e.g., automatic closure and securing of doors) (PF_{22})	No active denial mechanization utilized	Active system which is capable of securing within seconds all vault maintenance and normal entry points to a physical barrier delay effectiveness equivalent to that of the principal physical barrier. Reset function to require hours	Manually operated vault with motorized door opener under remote control
		Value = 0	Value = 10	Value = 5
	(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) (PF_{23})	Manually operated vault with no mechanization or control systems which could be deactivated for use denial	Completely automated vault storage system in which all equipment control features can be irreversibly deactivated (required hardware and software repair to reactivate)	Computer-based vault material handling control with all software stored in volatile memory
		Value = 0	Value = 10	Value = 8

Table 3.2. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Example
2. DELAY (OF) (SF_2) (cont'd)				
	2.2 Passive delay mechanisms			
	(1) Principal physical (structural) barrier (PF_{24})	Vault structure which can be easily compromised with conventional tactics (i.e., explosives, etc.)	Vault structure which encompasses all storage and transfer regions and requires hours to penetrate using conventional military tactics	Earthquake-proof vault structure with 2- to 4-in. metal door entry.
		Value = 0	Value = 10	Value = 3
	(2) Storage container design (PF_{25})	Container designed for human operation without special tools or machines	Container design requiring special machines for opening operation and handling (bulk weight > hundreds of pounds) and which physically would require hours to penetrate using conventional military tactics	Polyethylene bottles
		Value = 0	Value = 10	Value = 0
	(3) Container storage area design (PF_{26})	Storage area design for unassisted human direct container handling (neg. effect)	Storage area structural geometry which precludes human (of any conceivable size) entry and movement	Storage racks secured with key-operated padlocks. Human access required
		Value = 2	Value = 10	Value = 4
	(4) Vault input/output port design (PF_{27})	Manually operated vault with normal human-entry access ports through principal physical barrier. Access door remains open for large fraction of day	Input/output structural geometry precludes human use and provides a delay effectiveness comparable to that of the principal physical barrier	Double-vault doors are always locked. Human entry but pass through input/output station requires collusion of two or more people
		Value = 2	Value = 10	Value = 6

Table 3.2. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Example
	2.2 Passive delay mechanisms (cont'd)			
	(5) Maintenance access ports (vault opening used for maintenance of internal equipment) (PF_{28})	Vault designs which require maintenance access accommodations which compromise the delay effectiveness of the principal physical barrier to minutes Value = 0	Vault designs which require no maintenance access for internal equipment Value = 10	Maintenance access to internal equipment (monitors) occasionally required; double-vault doors (one always Value = 2
Delay Summary $PC_2 = 1/8\ (\sum_{i=1}^{8} PF_{2i})$	Overall value = B	NA	NA	PC_2=1/8(6+5+8+3+0+4+6+2)=4.3
3. DETERRENCE (SF_3)				
(1) Potential overt adversary actions	3.1 Detection system effectiveness[1] (PF_{31})	Value = 0	Value = 10	5.9
(2) Potential overt adversary actions (PC_3,PF_{3i}; i = 1,...7)	3.2 Delay system effectiveness[2] (PF_{32})	Value = 0	Value = 10	4.3
	3.3 Response system effectiveness	NA	NA	NA
	3.4 Intrinsic system characteristics			
	(1) Material access and isolation (during normal operation) (PF_{33})	Manually operated vault in which SNM containers are easily accessible when vault door is open Value = 1	Material is completely isolated at all times in a vault system Value = 10	Maintenance access to equipment required under security surveillance Value = 3

Table 3.2 Safeguard performance standards (cont'd)

Table 3.2. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Example
	3.4 Intrinsic system characteristics (cont'd)			
	(2) Material handling time (PF_{34})	Manually operated vault on which SNM containers are easily accessible when vault door is open	Material is completely isolated at all times in a vault system which requires no maintenance access	Maintenance access to equipment required under security surveillance
		Value = 1	Value = 9	Value = 2
	(3) Collusion vulnerability	Manually operated vault	Fully automated vault	Semiautomated vault
	(a) Number and skills of people involved			
	• Number of operations people	High	<2 people/shift	>3
	• Number of maintenance people	Low	Maximum; high	
	• Skill level	Operators and technicians	Engineers, computer programmers	Engineers, computer programmers, operators
	(b) Mixture required[3]	Crafts only	Maximum number of professionals/number of crafts	Professional/craft = ∿ 1/2
		Value = 3	Value = 6[3]	Value = 4
	(4) Functional system complexity (e.g., operating controls, computer security, surveillance) (PF_{36})	Manually operated vaults	Fully automated, including material transfer to process	Semiautomated
		Value = 2	Value = 7	Value = 5

Table 3.2. (continued)

Safeguards performance criteria	Vault safeguards performance	Lower bound	Upper bound	Example
	3.4 Intrinsic system characteristics (cont'd)			
	(5) Physical system complexity (barriers, vault internal structure, etc.)(PF_{37})	Conventional earthquake-proof construction Value = 0	Internal geometry which precludes movement of average-size humans. Special barrier design to provide hours of delay when attacked with advanced weapons Value = 9	Conventional earthquake-proof construction with armor plate liner Value = 5
Deterrence Summary $PC_3 = 1/7 \left(\sum_{i=1}^{7} PF_{3i}\right)$	Average deterrence values = C	NA	NA	PC_3=1/7(5.9+4/3+3+2+4+5+5)=4.2
Overall safeguards summary				
1. Detection	A			5.9
2. Delay	B			4.3
3. Deterrence	C			4.2
Total safeguards relative value				4.8

Notes for deterrence:

(1) Refer to Sect. 1, Dectection summary.
(2) Refer to Sect. 2, Delay summary.
(3) It is assumed that collusion requiring collaboration between individuals with varying societal characteristics (salary, education, etc.) is less likely to succeed compared with groups having common societal bases.

4. *Indexing key*

Overall safeguards value

Safeguards functions: SF_k $k = 1, \ldots 3$

Performance criteria: PC_n $k; n = 1, \ldots n_k$

Performance factors: PF_{ni} $k; n; i = 1, \ldots m_n$

The weighting factors to be applied are tested below.

Safeguards functions (SF_k)	Performance criteria (PC_n)	Weighting factors ($\underline{\overline{W}}$ kn)	$i = 1, \ldots m_n$ Performance factors
Detection; $k = 1$, $n_k = 5$	Material balance discrepancies $n = 1$	$\underline{\overline{W}}_{11} = 1$	$m_1 = 4$
	Unauthorized personnel in vital areas $n = 2$	$\underline{\overline{W}}_{12} = 1$	$m_2 = 4$
	Unauthorized use of operating features $n = 3$	$\underline{\overline{W}}_{13} = 0.8$	$m_3 = 3$
	Unauthorized SNM location $n = 4$	$\underline{\overline{W}}_{14} = 0.8$	$m_4 = 4$
	Unauthorized presence of shielding $n = 5$	$\underline{\overline{W}}_{15} = 0.8$	$m_5 = 2$
Delay; $k = 2$, $n_k = 1$	Delay effectiveness $n = 1$	$\underline{\overline{W}}_{20} = 1$	$m_1 = 8$
Deterrence; $k = 3$, $n_k = 1$	Deterrence effectiveness $n = m$	$\underline{\overline{W}}_{30} = 1$	$m_1 = 8$

The physical location of SNM can be "unauthorized" if it is in a vault area where it should not be or if it is in a specific place where shielding materials could disguise its presence. Detection of SNM at an unauthorized location suggests a need for some sort of surveillance of (1) areas where SNM should not be and (2) areas where SNM should remain. Thus, detection effectiveness is a function of surveillance effectiveness. In particular, surveillance of (1) uncontainerized SNM within the vault boundary (assuming that one ground rule is that all SNM will be containerized before being placed in the vault), (2) integrity of SNM containers in the vault storage rack, and (3) integrity of SNM containers during handling (both within the vault and during transfer to/from the process) is considered and included.

The detection of materials that could mask the presence of unauthorized SNM is of equal importance. Surveillance effectiveness is a measure of performance and includes detection of "significant" quantities of shielding which (1) cross the vault entry or access ports (without this provision, once inside, SNM could exit undetected) and (2) are present during container transfer.

4. SAFEGUARDS PERFORMANCE CRITERIA FOR SNM VAULT STORAGE SYSTEMS

The overall effectiveness of a safeguards system depends on how effectively it performs each of the functions of detection, delay, deterrence, and response. As mentioned earlier, the response function is independent of the design options of the vault concept. Consequently, in comparing the overall effectiveness of vault-safeguards-system concepts, the response function is not considered.

Since any safeguards system involves physical structures, equipment, operating philosophy, and procedures, each of these must be considered and evaluated for its performance functions against the performance criteria established in Sect. 2 in order to arrive at the effectiveness of the system as a whole.

With this method of evaluating the performance of vault systems on a common basis, it is practical to establish minimum criteria to which a candidate conceptual vault system must be designed. Minimum performance-level value criteria at both the safeguards function level and for the overall system are shown in Table 4.1 as acceptance criteria. A candidate vault concept must meet criteria at both levels to be "accepted" by the engineers for developing into a final design. Otherwise, the concept is rejected until it is refined to strengthen its performance of the basic safeguards functions.

Table 4.1. Acceptance criteria: safeguards performance

	Minimum acceptable value
Safeguards function performance (each)	4
Overall system safeguards performance	6

4.1 Functional-Level Criteria

The methodology employed in evaluating vault concepts for performance of the safeguards functions makes use of averaging the values for each element of the performance factors to minimize the effect of errors in judgment of and differences among individuals evaluating the same concept. There is some hazard in this technique, however, because it decreases the sensitivity in identifying weaknesses in the performances of some element of the vault system and, perhaps, could result in an overall safeguards benefit value that would be misleading. For example, in an extreme case, a system might grade high (e.g., value = 10) in performing the detection and delay functions and grade very low (e.g., value = 1) in performing the deterrence function; yet the overall rating might be high (value = 7) because of averaging. Such a high overall value would, in itself, lead to the conclusion that the concept is very attractive from a safeguards point of view, whereas, in fact, the concept has a highly undesirable "designed-in" weakness.

To minimize the potential for designing a weakness into a conceptual vault system, minimum performance values for each safeguards function must be established as acceptance criteria. Although the numerical value of this minimum is at present somewhat a matter of judgment, in the absence of an established body of experience with actual vault systems, it appears prudent to insist that, as an acceptance criterion, the effectiveness as represented in the performance value of each function should be set at a minimum of 4. As experience is gained with actual vault systems, the minimum criteria for performance values should be adjusted accordingly.

4.2 Overall Criteria

The safeguards value (benefit) of a safeguards system as evaluated using the methodology in ref. 1 and above is aimed at obtaining a relative value on which effects of personal preferences and prejudices have been minimized. Such values provide a suitable basis for comparison of various systems.

Although somewhat arbitrary, a minimum overall value of 6 is suggested as the acceptance criterion. As experience is gained with actual systems, this value may be changed to a level that better reflects actual performance as opposed to that predicted by the evaluation procedure.

5. EXAMPLE SYSTEM AND CALCULATIONS

The purpose of the example presented here is to illustrate how the evaluation methodology is applied to a representative conceptual vault design. The acceptance criteria are constraints against which the evaluation results are compared.

The efforts involved in the task of designing a vault system will generally progress as shown in Fig. 5.1. In the example presented here, the items in the first block of the logic diagram have been completed. Implied in the management decision is a manufacturing facility sized to fabricate fuel rods containing 200 metric tons (MT) of 4% PuO_2-96%UO_2 mixed oxide (MO) per year using a "dry" blend process. Whereas the hypothetical facility chosen for this example is a PuO_2-UO_2 MO fuel fabrication facility, the choice does not imply that such a facility is to be built or, if built, will necessarily operate as shown or even manufacture MO fuel. Any manufacturing facility handling SNM, regardless of whether or not it included plutonium, would serve equally well. The first step in designing the manufacturing process is to develop a material flow diagram from which the points at which the manufacturing process must interface with the storage vault are determined along with the vault storage requirements.

Up to this point the requirements are common to all vault concepts. Once a vault concept is chosen, the remaining steps shown in the logic diagram (Fig. 5.1) follow in sequence. It is at this point that the example begins.

The chosen vault concept is developed in sufficient detail to apply the safeguards performance evaluation methodology and obtain values using the performance standards for comparison with criteria at both functional and overall levels.

The following sections describe the hypothetical manufacturing facility, design details of the selected vault concept, and application of the evaluation methodology using the proposed performance standards.

5.1 Manufacturing Facility

The hypothetical fuel fabrication facility in this example is assumed to be similar in concept and in capacity to the proposed Westinghouse-Anderson MO_2 recycle fuel fabrication facility. Some basic plant operating characteristics of that facility[3] are shown in Fig. 5.2. Whenever departures from those in Fig. 5.2 are assumed, these will be noted. The assumed annual throughput is 200 MT of MO_2 having an average composition of 4% Pu_2-96% UO_2.

The automated vault system must interface with the following process operations: receiving, blending, pelletizing, fuel-rod loading and inspection, fuel element fabrication, and shipping.

Of the two feedstock materials received at the plant – PuO_2 and natural (or depleted) UO_2–only PuO_2 requires storage in the SNM storage vault; the UO_2 will be stored in bulk outside the vault. The PuO_2 is shipped in canisters containing 8 kg each. Shipments of about 38 canisters (307 kg PuO_2) are received every other week; sufficient storage space for this quantity of PuO_2 is provided.

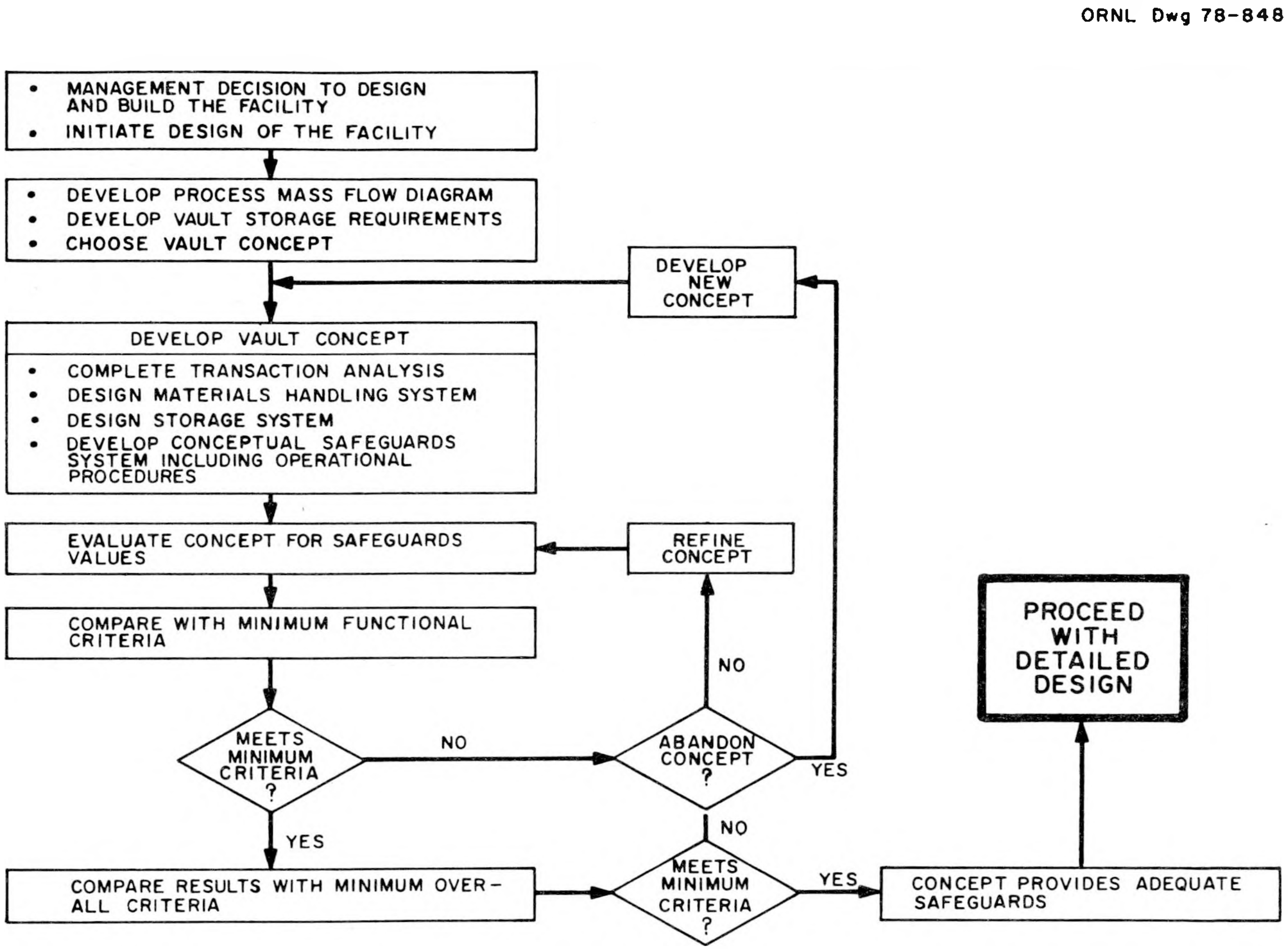

Fig. 5.1 Generalized logic diagram: SNM vault design.

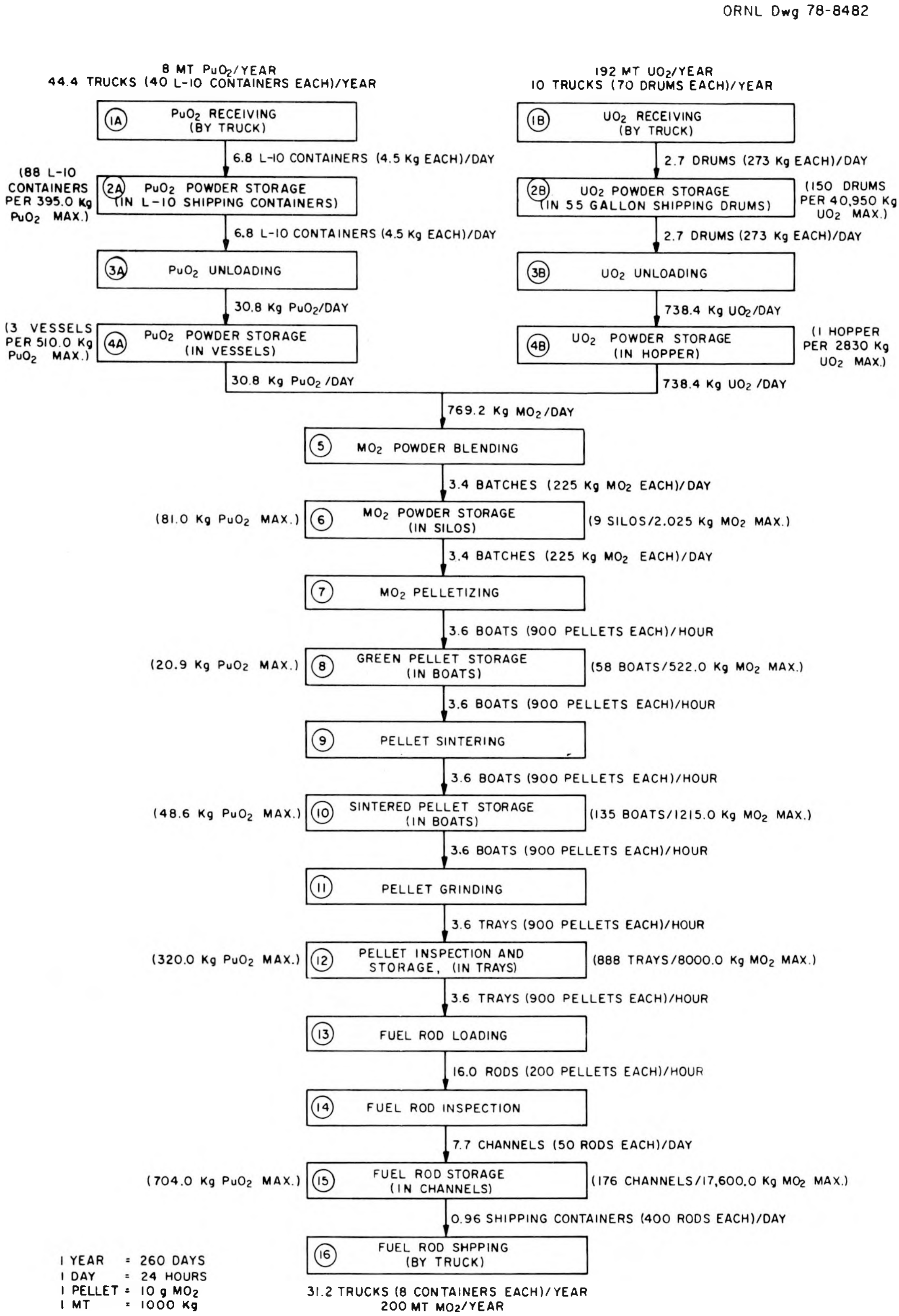

Fig. 5.2 Material flow rates and storage capacities for mixed-oxide fuel-rod fabrication plant.

5.2 Conceptual Automated SNM Vault

It is assumed in this example that an automated power and free conveyer system (PFCS) is being considered for the handling and storage of all SNM within the conceptual vault. Commercial applications of such systems are widespread and a considerable body of user-experience data on their operation, characteristics, reliability, and maintenance is available.

5.2.1 *Power and free conveyer system*

A PFCS is an overhead rail system on which small trolley vehicles move freely with the payload suspended below (Fig. 5.3). The trolleys are equipped with a remotely operated device which moves them by a chain mounted above the rails. The rail system can include any number of tracks interconnected by switches so that the trolleys can transfer from any one track to another.

In an advanced system, each trolley is uniquely identified by a plate attached to it on which an electromagnetic pattern has been impressed. Reading heads that monitor the trolleys are mounted at switches and various other points along the tracks; the heads send signals to a small computer which is programmed to control switch positioning and the engaging devices (dogs) on the trolleys. Any specific trolley can be called automatically at any position and transferred to any other position. In the conceptual automated vault system of this example, the operation of this small computer is supervised by the large supervisory computer(s) which is a part of the automated vault safeguards system (AVSS). In addition to controlling the PFCS, the supervisory computer maintains an updated record of the vault inventory.

5.2.2 *Input-output stations*

In this example, all material is assumed to enter or leave the vault via an input/output (I/O) station (Fig. 5.4). Canisters of SNM are placed in or removed from the suspended carriers by a remotely operated manipulator. An inventory station composed of a weighing and an automatic nondestructive assay (NDA) system is located in each I/O station. The gross weight of each canister and its SNM content can be determined automatically and recorded/computed by the computer in the AVSS. Each storage container can be moved to any specified storage track upon the command of authorized personnel recognized by the supervisory computer which simultaneously retains a record of the location and the identity of the carrier and its contents. A remotely operated TV-viewing system located at each I/O station permits visual inspection and identity verification of each storage container.

The size and storage capacity of the PFCS is governed by the storage requirements which depend on the production rate of the manufacturing facility and the design of the storage container.

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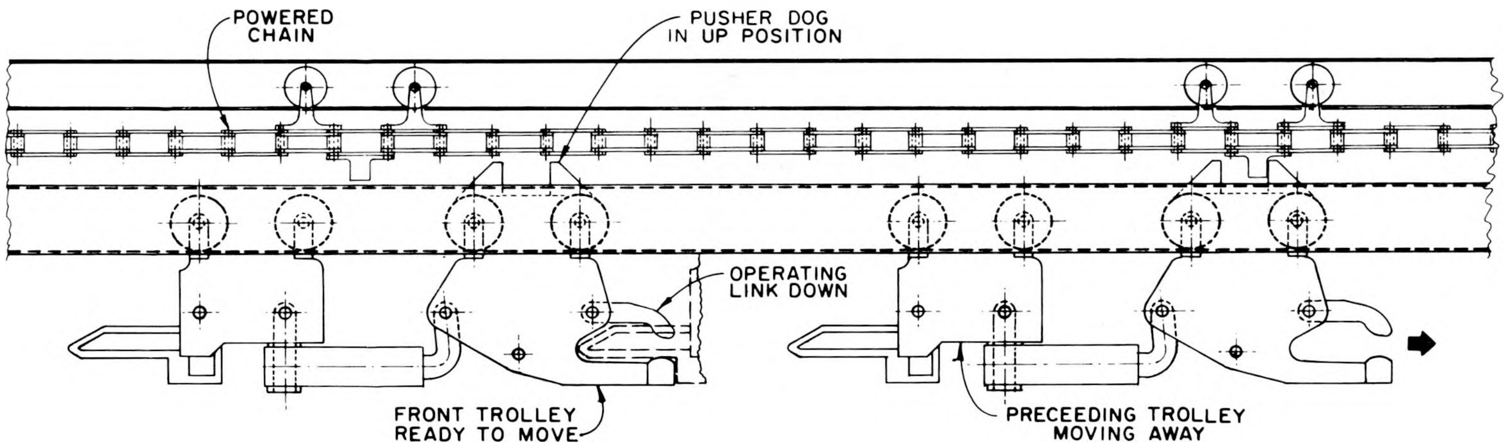

Fig. 5.3 Power and free conveyer.

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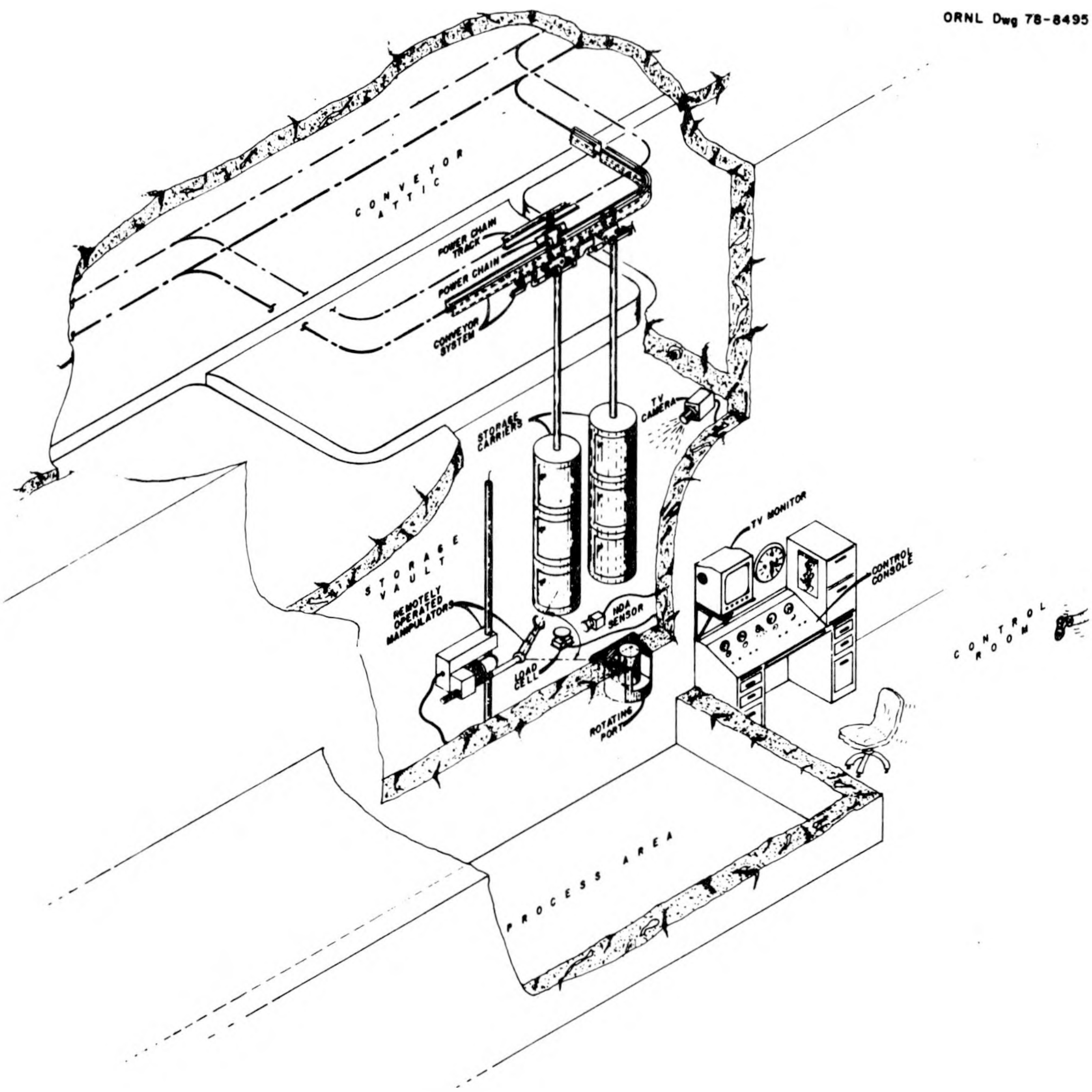

Fig. 5.4 Input-output station.

5.2.3 *Facility and process integration*

The manufacturing facility interfaces with the vault system at each part where SNM input or removal is required. This will govern the number of I/O stations that are provided for raw material input, inspection for quality of product at intermediate steps of the fabrication process, and for final product removal.

The layout of the vault provides for a total of nine I/O stations for transferring material to and from vault storage. In the normal mode of operation, an operator requests through the control panel at each I/O station that specific materials be delivered to his I/O station by the PFCS. The supervisory computer mentioned above is programmed to monitor and control such transactions. The principal safeguards features of the AVSS are included in this supervision and transaction control. For each operation that involves a transfer of SNM to or from the vault, a specific set of material flow paths and operational sequences are programmed into the supervisory computer; a departure from the sequence will halt the operation and sound an alarm in the AVSS. Similarly, specific types and forms of materials should enter and/or exit at particular I/O stations within a specified time. Further, operators need only have access to conduct such material transfers as pertain to the operation of their part of the process and at specific I/O stations. Thus the supervisory computer restricts vault operation to only permissible transfers. In normal operation, the supervisory computer is programmed to allocate storage locations for carriers in a categorized fashion, based on the contents. Actual storage locations and stored SNM information (e.g., SNM concentration and isotopic information) would not be accessible to I/O station operators.

5.2.3.1 *Vault layout.* In the conceptual vault of the example, all SNM is assumed to be transported and stored in carriers (Sect. 5.2.5) that are suspended from the trolley vehicles of the PFCS. Based on the material throughput shown in Fig. 5.2 and the assumption that storage space is provided in the vault for the material produced during a week's operation at each process step, the vault includes 420 storage spaces (Sect. 5.2.3.2) arranged in two banks of 10 tracks each. In each bank the tracks are arranged on 4-ft centers (Fig. 5.5), and each track provides 21 storage spaces. The two banks of storage tracks occupy an area 120 ft long by 100 ft wide which opens into a 232-ft-long by 44-ft-wide corridor where the I/O stations are located. There are nine I/O stations included in the vault.

The PFCS (i.e., the rails, trolleys, and the power chain) is located in a controlled-access area above the vault and corridor, which is separated from the vault storage area by a thick ceiling in which there are narrow slots (Fig. 5.6). The carriers that remain in the vault hang on rods extending through the slots into the access area above and are attached to the trolleys. The advantage of this arrangement is that it permits maintenance of the PFCS while excluding the maintenance personnel from access to the SNM in the vault, thus minimizing their exposure to radiation.

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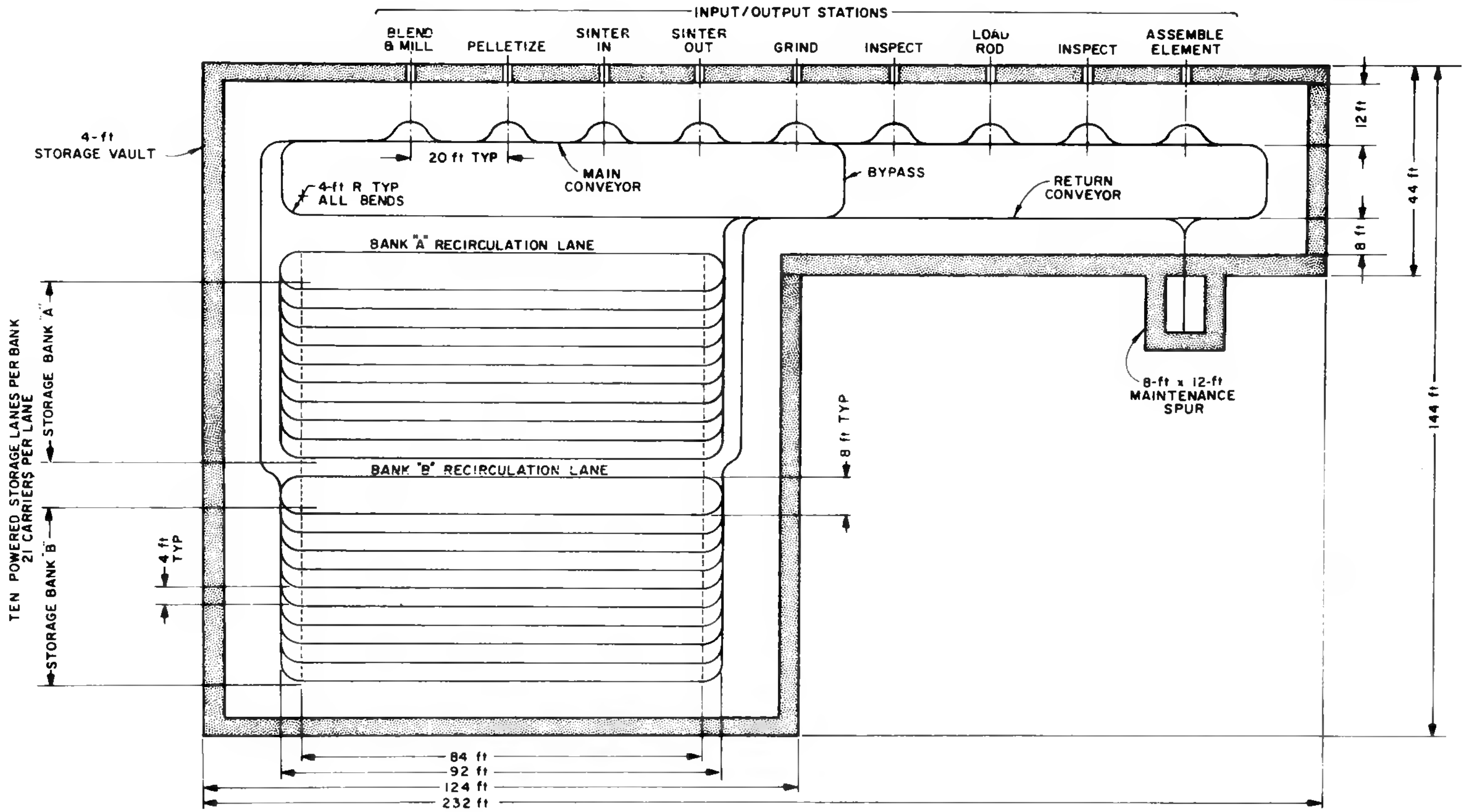

Fig. 5.5 Conceptual layout of storage vault with a power and free conveyer system for handling and storing special nuclear materials.

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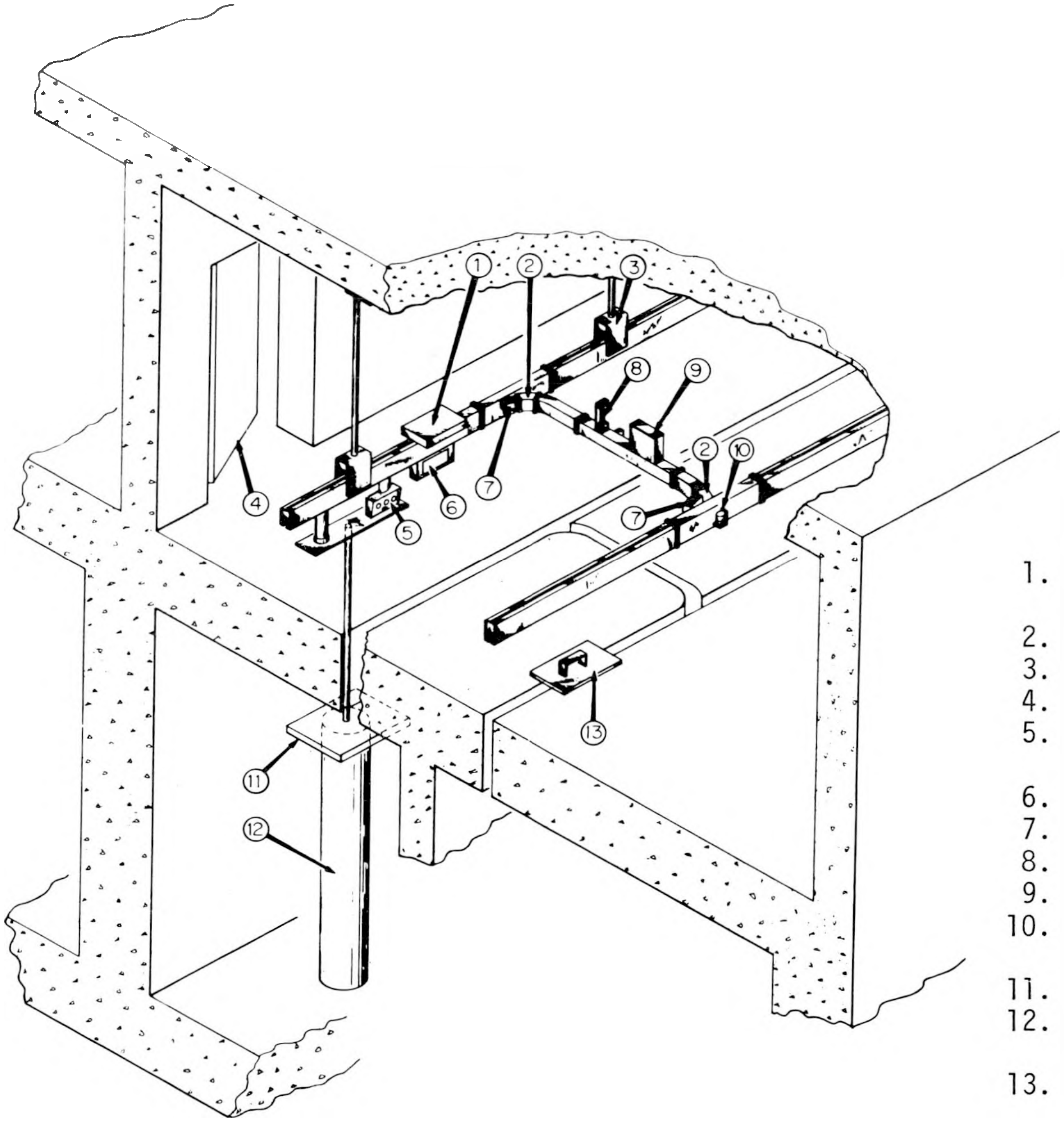

LEGEND

1. SENSING HEAD CONTROL BOX
2. RAIL SWITCH
3. TRACK SUPPORT
4. SEALED ACCESS DOOR
5. CARRIER IDENTIFICATION SWITCH
6. IDENTIFICATION SENSING HEAD
7. SWITCH ACTIVATOR
8. RE-ENTRY TROLLEY STOP
9. RE-ENTRY CONTROL BOX
10. TROLLEY SENSING SWITCH
11. RADIATION SHIELD
12. SNM TRANSPORT & STORAGE CARRIER
13. PORTABLE PERSONNEL SHIELD

Fig. 5.6 Storage vault showing power and free materials handling system.

The ventilation system of the vault maintains a negative pressure in the vault with respect to the upper level where the PFCS is located. The upper level, in turn, is maintained at a negative pressure with respect to the pressure of the atmosphere surrounding the vault system. This design keeps the upper level essentially free of the contamination that would hamper efforts to maintain the PFCS.

5.2.3.2 *Material handling dynamics.* Taking into account the material flow rates in the process, the transaction study (Fig. 5.7) was made based on the annual production of finished fuel rods containing 200 MT of mixed oxide. Based on this study, the number of storage spaces required in the vault was determined to be 411. Details of the calculations involved in developing the transaction study are found in Appendix A.

5.2.4 *Storage containers*

The storage container (Fig. 5.8) is a 6-in.-diam by 18-in.-long can fitted with a screw cap. Its working capacity is:

PuO_2 powder	8.0 kg
Mixed oxide powder	12.5
Mixed oxide pellets	20.16

Calculations determining the above capacities are given in Appendix B.

5.2.5 *Transport and storage carrier*

The storage carrier is a 7-in.-ID by 7-ft-long cylinder (Fig. 5.9) which is suspended from the trolleys of the PFCS. The carrier is divided into four compartments, each of which is about 21 in. deep. The compartments are equipped with a door and latch and each will hold one storage container. Therefore, the capacity of the carrier for each of the materials to be handled is:

PuO_2 powder	32 kg
Mixed oxide powder	50
Mixed oxide pellets	80.6

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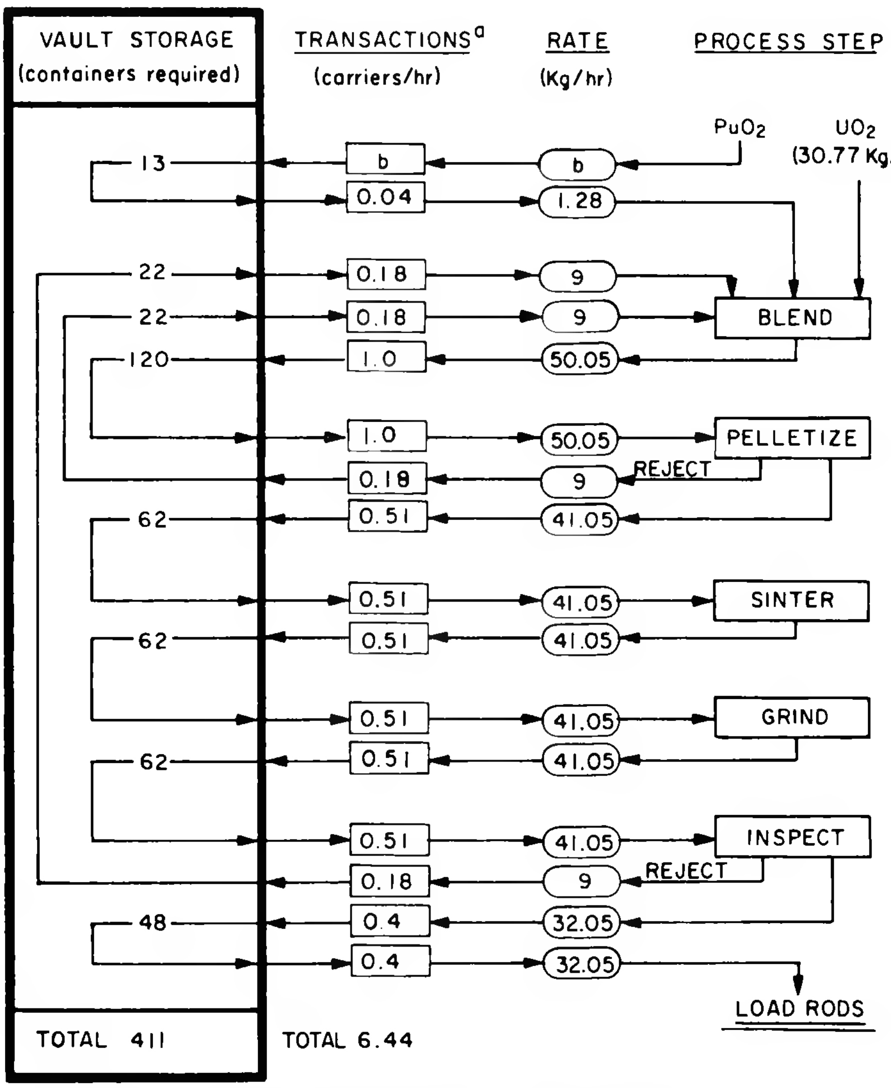

a. HANDLING A CARRIER CONSTITUTES A "TRANSACTION"
b. BIWEEKLY SHIPMENTS OF 39 CARRIERS, EACH CONTAINING 8 Kg PuO

Fig. 5.7 Transaction study: vault equipped with power and free conveyer system.

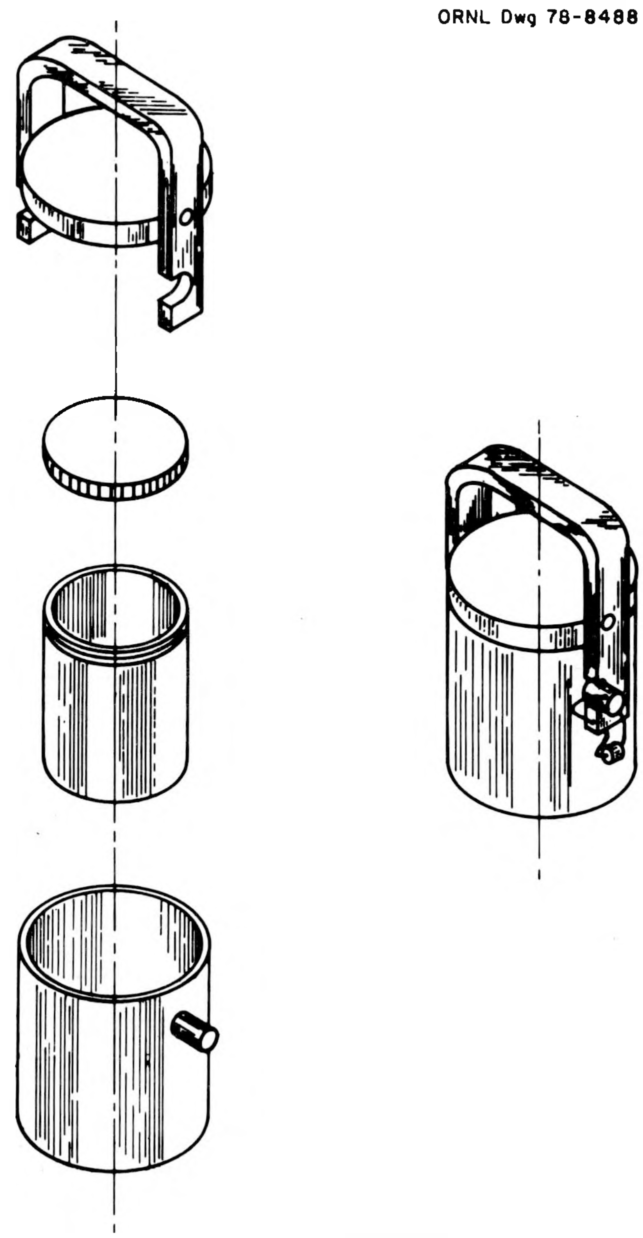

Fig. 5.8 Storage container.

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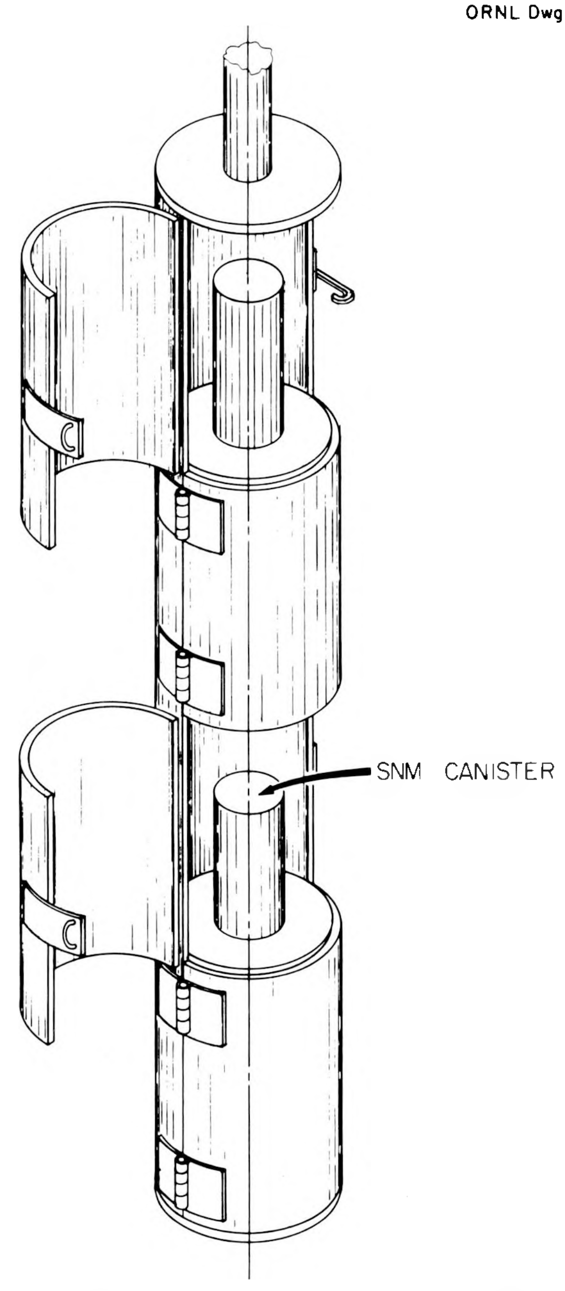

Fig. 5.9 Transport and storage carrier.

5.2.6 *Container handling system*

Containers of SNM are transported in the carriers suspended from the trolleys of the conveyer system. The containers are handled only at the I/O stations, each of which is served by a storage track (Fig. 5.5). A specified carrier is moved into position at a specified I/O station upon command of the supervisory computer when it recognizes the request of an authorized person to conduct an authorized process that it recognizes and identifies.

A carrier is loaded or unloaded at an I/O station as follows:

1. A specified carrier is called (by the operator).

2. The carrier is moved and indexed at the I/O station (Fig. 5.4).

3. The door of the specified compartment of the carrier is unlatched and opened with the remotely operated manipulator.

4. The container is removed from or transferred to the compartment using the remotely operated manipulator and placed on the load cell in the I/O station. It may also, if desired, be subjected to analyses for SNM content (NDA) in this area.

5. The container is weighed on the load cell and the result registered in the computer.

6. The container and its seal are identified and compared by the computer with inventory records.

7. When a container is to be transferred to the process, it is opened with the manipulator, and the SNM canister is removed and identified. In moving from the process to the vault, the canister is placed in the storage container; the top of the canister is then sealed and it is moved to the carrier in reverse to the sequence described above.

Results of the NDA are registered in the computer which converts the signal to weight units; this weight is retained and compared with that in the inventory records.

8. Canisters are transferred to or from the process via a rotating plug which contains a recessed cavity on one side (Fig. 5.4).

5.2.7 *Storage space requirements*

A total of 411 storage spaces are required in the vault (Appendix A). This number satisfies the process facility needs based on the mass flows shown in Fig. 5.2, the storage carrier capacities for each of the materials (Sect. 5.2.5) as they occur at each stage of the process, and takes into account the requirement that storage for a week's (120 hr) production of material at each step will be provided.

5.2.8 *Data management and equipment controls*

All SNM measurement data (weights and NDA) are acquired automatically and manipulated by the computer system. Inventory records are automatically updated by the computer, based on input which is also automatically acquired from the conveyer storage system; the computer is also programmed to accept receiving data and specified identification data from authorized personnel. Receiving data are identified as "temporary" in the computer until verified by measurement.

The conveyer storage system is controlled by the supervisory computer in the the AVSS.

In operation, the conveyer storage system will transfer any specific SNM item to any specified location upon a request which the supervisory computer is programmed to recognize as permissible. At the same time, the inventory records kept by the computer are automatically updated to reflect changes in location of SNM items in the storage vault.

The access door to the conveyer track room located in the upper level of the vault is supervised and monitored by the supervisory computer. When the door is opened, the computer automatically shuts off power to the conveyer drive and sounds an alarm in the AVSS control room. The alarm continues until it is acknowledged; after receipt of the identity of personnel authorized to enter the area, it can be reset manually. AVSS personnel will restore power to the PFCS when the authorized maintenance personnel leave the upper level (via the access door), identify themselves, and indicate that maintenance tasks are completed. Power to the detection and surveillance systems is not affected by this computer action.

5.2.9 *Safeguards system*

The safeguards system of the SNM vault system assumed for this example is described below.

5.2.9.1 *Physical protection.* Physical protection of the SNM contents of the conceptual vault is provided by the perimeter fence and the vault boundary walls and ceiling which are built to seismic and tornadic specifications. Entrances in the walls of the vault and the upper-level areas housing the PFCS are closed with vault-type heavy steel doors equipped with combination locks. Access to the combination of the lock is restricted to authorized personnel.

The design of the canisters, the storage container, and the carriers does not serve any function other than containment of the SNM.

5.2.9.2 *Surveillance.* The interior of the vault and the upper-level areas are continuously monitored by closed-circuit television (CCTV), which displays in Security Headquarters (SECHQ). These areas are also equipped with intrusion alarms (motion detectors) which sound in SECHQ.

Each of the doors to the vault, those to the upper level, and those leading to the operating areas of each of the I/O stations are under continuous CCTV surveillance, with displays at SECHQ; the vault access doors are also equipped with position indicators similarly displayed.

The position and identity of each storage carrier in the material handling system are continously monitored and retained in the memory of the supervisory computer in the Material Control Center (MCC), which is a section of the AVSS.

The interior of the MCC is continuously monitored by CCTV, which displays in SECHQ. Access to the MCC which houses the supervisory computers is under the visual surveillance of security guards manning the SECHQ.

5.2.9.3 *SNM inventory control.* All inventory records are kept in the computer. As SNM transactions occur, the computer automatically updates the inventory, activates alarms, and brings any transaction in progress to a halt when a deviation from programmed sequences occurs.

Cathode-ray-tube (CRT) units are provided at each of the I/O station areas to permit manual entry of identification data and operating commands to the computer(s) by operations personnel. Similar units are located in the MCC at the AVSS. A printer is also available in the I/O station area to provide hard copy of the inventory when needed. Similar equipment is located in the MCC.

Results of NDA and weight measurements are automatically acquired by the supervisory computer. Manual input is required for entering shipper's estimate of receipts and for identification of canisters and the associated security seals.

The supervisory computer is programmed to allow only authorized individuals, who must use coded numbers to gain access to the operation of the machine, to perform specified tasks in specified sequences within a specified time in transferring SNM to and from the vault. This computer monitors the operation and is programmed to provide detailed SNM inventory data upon command from the MCC. It is also programmed to locate and transfer any item of SNM in storage from one location to another and to update the inventory record.

5.2.9.4 *Personnel control.* Personnel access to the process area is controlled via a photoidentifier badge that also carries a coded signal recognized by the computer. An image of the person is called from the record by the computer and displayed in SECHQ against the image of the person presenting the badge.

Normally, personnel access to the vault interior is not required. In an abnormal situation requiring personnel entry into the vault—for example, to conduct inspections—additional surveillance is provided by security personnel (guards). Specified authorized maintenance personnel entering the upper level of the vault housing the PFCS is limited and controlled; all activities remain under continuous CCTV surveillance.

Personnel access to the AVSS (including the MCC) is limited to authorized personnel. A photoidentifier badge system similar to that described above is used.

5.2.10 *Reliability considerations*

The reliability, availability, and maintenance of the PFCS are important considerations in designing the material handling system in an SNM storage vault. Results reported by the FMC Corporation,[4] submitted under contract to develop reliability and cost information on PFCS based on a survey of industrial user experience, are summarized below.

1. Mean time between failures (MTBF) can be calculated from the equation:

$$\log(\text{MTBF}) = 2.864 - 0.2034 \log(\text{length}) - 0.729 \log(\text{complexity}) ,$$

where

MTBF = system operating time in hours,

Length = total length of system in feet,

Complexity = total number of divergent switches plus the number of chain-to-chain transfers in the system.

2. Mean time to repair (MTTR) ranged from 1 to 120 min, with an average of 9.4 min.

3. Availability in industrial systems was high, about 0.99.

The concensus of general comments by users and manufacturers who were interviewed are listed below.

1. Power and free conveyers are complex systems requiring frequent and continual maintenance. They are completely different in complexity and maintenance requirements from simple trolley conveyer systems.

2. Frequent stoppages due to jams of carriers hanging up at switches are common.

3. In many plants using PFCS, maintenance men walk the entire conveyer system once or twice a day to check the operation and to obtain an early warning of potential problems.

4. Power and free conveyers require maintenance men to be continually available for correcting jams, repairs, etc., whenever the conveyer system is operating. The conveyer systems cannot operate unattended.

5. Because conveyer stoppages may be corrected rapidly and do not cause much lost production, most commercial plants do not consider it worthwhile to spend additional funds to significantly increase the MTBF of these conveyer systems.

In the conceptual system chosen for this example the PFCS is located in the upper level of the vault system and is accessible for maintenance without requiring personnel to enter the SNM storage area. The MTBF of the conceptual vault system is estimated at 14.6 hr (minimum) to 29.2 hr (maximum).

A report submitted under contract with JBF Associates,[5] who conducted a parametric study of the unavailability of the power and free conveyer system envisioned in the conceptual vault of this example, is summarized in Figs. 5.10 through 5.12. Note that the nomenclature they use is slightly different, that is, MTTF is equivalent to MTBF. The base case identified in these figures is the conceptual system in the example given in this section, which, from Fig. 4.10, indicates an availability of 99.97.

5.2.11 *Safeguards effectiveness evaluation*

Table 5.1 gives performance standards and results of the evaluation of the conceptual automated vault system in this example for safeguards benefits (worth) using the methodology described in Sect. 3.2. The overall safeguards value of 6, shown on the last page of Table 5.1, indicates that the conceptual vault storage system of the example ranks high in safeguards benefits and, from the safeguards standpoint, is a viable candidate for the anticipated use.

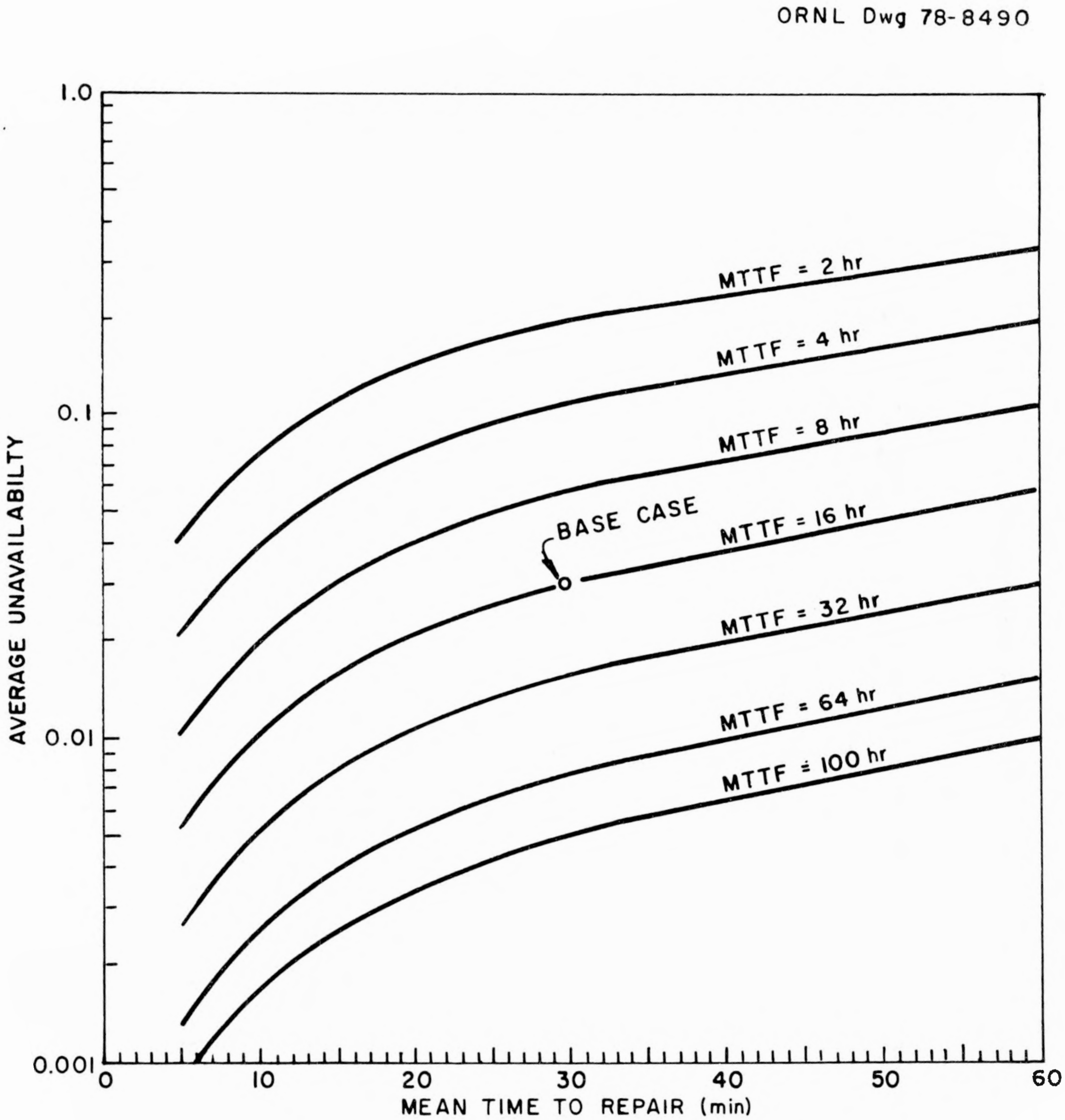

Fig. 5.10 Average unavailability as a function of the mean time to repair (MTTR).

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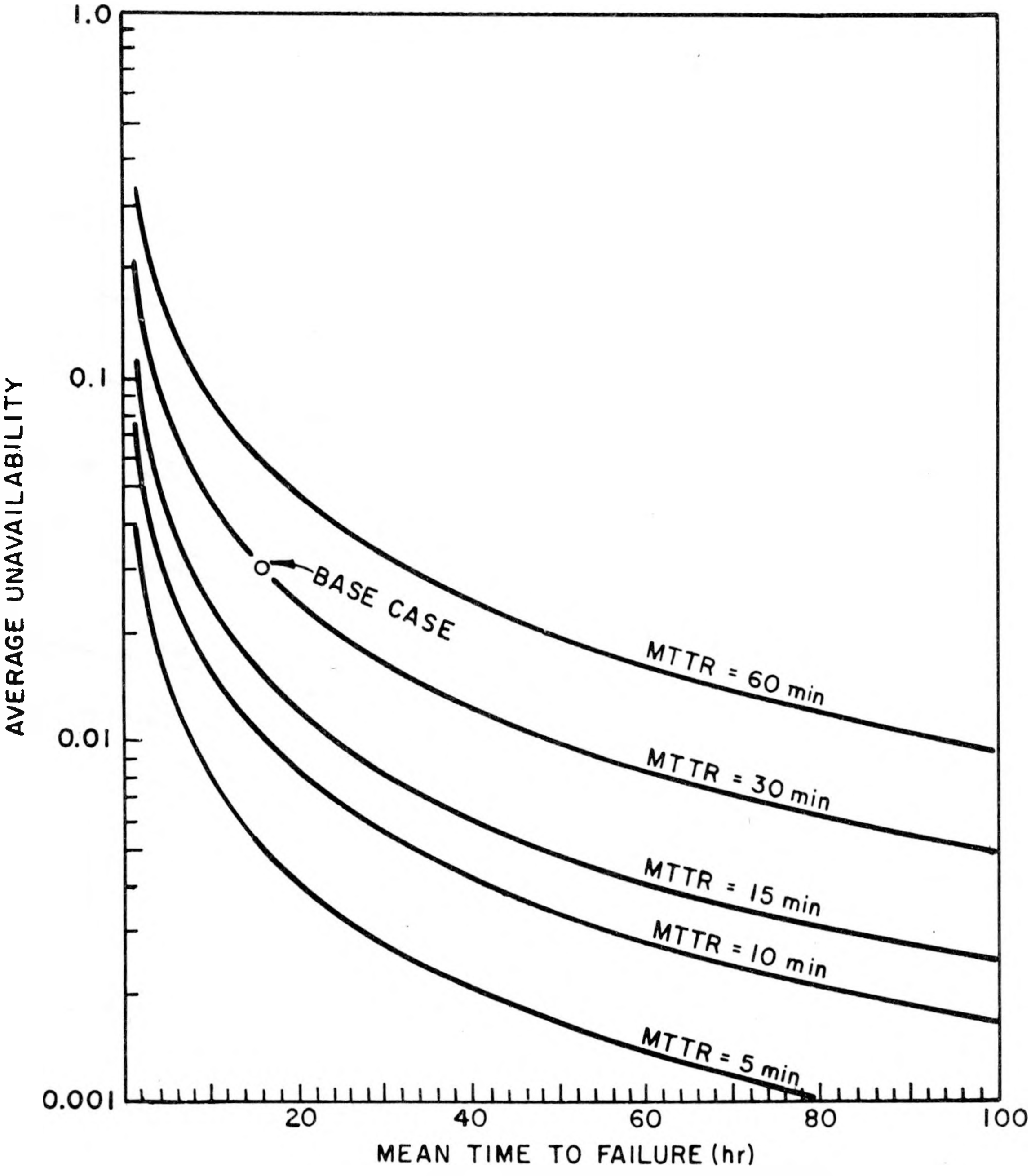

Fig. 5.11 Average unavailability as a function of mean time to failure (MTTF).

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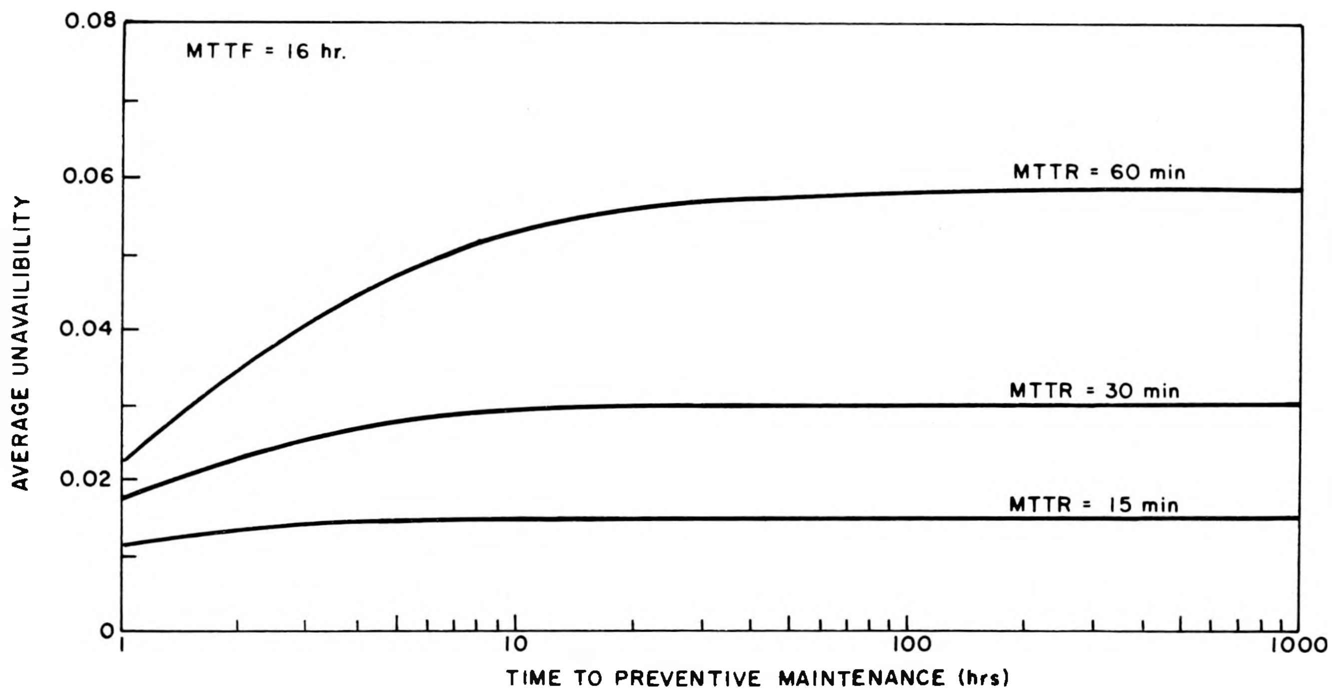

Fig. 5.12 Average unavailability as a function of time to preventive maintenance.

Table 5.1. Safeguards performance standards evaluation worksheet

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Conceptual vault system
1. DETECTION (SF_1)				
1.1 Vault inventory material balance discrepancies (PC_1, PF_{1i}; i=1,...4)	1.1 Vault inventory accuracy			
	(1) SNM measurement accuracy (PF_{11})	Measurement system comprised of conventional nondestructive assay, wet chemical analysis, and weighing with manual data acquisition. Process measurements >0.5% and laboratory measurements ≤0.4	Direct (e.g., nondestructive assay) measurement of all SNM flows and storage continuously to within 0.1%	Automated NDA system, computerized data Reduced reading and calculational errors
		Value[1] = 5	Value = 10	Value[a] = 8
	(2) Inventory data management (calculations) accuracy (PF_{12})	Human-based line entry accountancy with no computerization	Entirely computer-based with all physical data obtained from instrumentation electronically interfaced to the computer. Automatic calibration and verification of sensors	Computerized data management, record keeping, and reporting Reduced bookkeeping errors
		Value = 5	Value = 10	Value = 8
	1.2 Vault inventory timeliness			
	(1) SNM measurement frequency (PF_{13})	SNM measurements only performed in association with transactions at shipping, receiving, and transfer to process	Continuous SNM measurement during canister handling and storage	Automated inventory station: Direct inventory verification possible with automated NDA system
		Value = 2	Value = 10	Value = 7
	(2) Inventory data processing (PF_{14})	Manual (human-performed) vault item inventory requiring greater than two 8-hr shifts Physical inventory requiring a number of days from time of request	Vault item inventory based on direct verification of storage container integrity and all transactions initiated or completed Physical inventory within a few hours of request	Continuous dynamic inventory display
		Value = 1	Value = 10	Value = 9
$PC_1 = 1/4 \left(\sum_{i=1}^{4} PF_{1i} \right)$	Overall value	NA	NA	Value = 8

[a]Footnotes at end of each section of table.

Table 5.1. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Conceptual vault system
1. DETECTION (cont'd)				
1.2 Unauthorized personnel activities				
1.2.1 Unauthorized personnel in vital vault-related areas (PC_2, PF_{2i}; i=1,...4)	1.2.1 Surveillance effectiveness			
	(1) Vault interior (PF_{21})	No surveillance instrumentation utilized	Multiple (at least two) types of continuous volumetric intrusion monitors which scan 100% of sensitive area	Continuous intrusion monitoring during secure state (vault closed) includes continuous closed-circuit TV (CCTV)
		Value = 0	Value = 10	Value = 8
	(2) Vault input/output ports (PF_{22})	Same	Same	Personnel entry not required
		Value = 0	Value = 10	Value = 10
	(3) Vault system control room (PF_{23})	Same	Continuous identification (or discrimination of unauthorized) of authorized control room personnel	Required; integrity of computer-based data management and controls essential. Control room under continuous CCTV security surveillance
		Value = 0	Value = 10	Value = 5
	(4) Vault/process material transfer	Same	Same as (1) above	Vault physically integrated to process line; continuous surveillance feasible
		Value = 0	Value = 10	Value = 10
$PC_2 = 1/4\ (\sum_{i=1}^{4} PF_{2i})$	Overall value	NA	NA	Value = 8.3

Table 5.1. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Conceptual vault system
1. DETECTION (cont'd)				
1.2.2 Unauthorized use of system operational features (i.e., controls, computers, etc.) (PC_3, PF_{3i}; i=1,...3)	1.2.2 Operations surveillance effectiveness			
	(1) Container handling (PF_{31})	Total human operator container handling with essentially no additional administrative controls (e.g., operation which is totally at process operations integrity and convenience).	Container surveillance using independent and protected instrumentation of a system with automated container handling operations	Fully mechanized and computer-controlled continuous surveillance of all handling feasible (more sophisticated collusion required)
		Value = 0	Value = 10	Value = 9
	(2) Inventory data management (PF_{32})	No routine surveillance of inventory data bookkeeping functions	Continuous surveillance of secured on-line computer-based inventory system. Password control of all users (operators) and programmers	Computerized; continuous surveillance feasible. Inventory data base and software programs suitably secured
		Value = 0	Value = 10	Value = 10
	(3) Equipment maintenance (PF_{33})	No surveillance of a situation in which maintenance personnel require unencumbered access to complex equipment in vital areas and when key safeguards equipment is disabled 10% of the time	Situations which involve no equipment maintenance in vital areas	Virtually nonexistent
		Value = 0	Value = 10	Value = 9
$PC_3 = 1/3 \left(\sum_{i=1}^{3} PF_{3i}\right)$	Overall value	NA	NA	Value = 9.3

Table 5.1. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Conceptual vault system
1.3 Unauthorized SNM				
1.3.1 Location	1.3.1 SNM surveillance effectiveness			
	(1) SNM not containerized but within vault boundary[2] (anomalous condition in which SNM has been accidentally or purposely removed from a container at the wrong time) (PF_{41})	No surveillance instrumentation utilized Value = 0	Continuous radiation monitoring instrumentation which can discriminate uncontainerized (exposed to vault interior) SNM instantaneously Value = 10	Conventional radiation monitoring in some locations feasible (depends greatly on specific radiation characteristics and background) Value = 8
	(2) Containers in storage rack area (surveillance instrumentation built into storage rack) (PF_{42})	No passive locks, seals, or other methods utilized. Value = 0	Continuous SNM container assay for all storage rack container positions Value = 10	Continuous alarmed surveillance of storage rack; nuclear integrity surveillance feasible; also compatible with level of computerization Value = 7
	(3) Containers being handled within vault interior (surveillance instrumentation built into container handling system) (PF_{43})	Manual handling of containers by individual process operators without security guard present and no other surveillance instrumentation Value = 0	Mechanization of container handling such that human contact is not required and with continuous SNM container assay during time out of storage rack Value = 10	Continuous monitoring as integral part of mechanized handling system Value = 5
	(4) Containers in transfer (i.e., to/from process) (PF_{44})	Same as above Value = 0	Same as above Value = 10	Continuous surveillance feasible Value = 7
$PC_4 = 1/4\ (\sum_{i=1}^{4} PF_{4i})$	Overall value	NA	NA	Value = 6.8

Table 5.1. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Conceptual vault system
1.3 Unauthorized SNM (con't)				
1.3.2 Shielding materials (i.e., an amount which would compromise detectability)	1.3.2 Shielding surveillance[3]			
	(1) "Large" amounts of shielding crossing vault access ports (PF_{51})	No surveillance instrumentation utilized	Continuous surveillance of all vault access ports with instrumentation which will detect presence of significant quantities of materials with shielding properties which would defeat SNM portal monitors	Possible, but effect is minimized by use of the NDA stations to verify contents and comparison with results expected
		Value = 0	Value = 10	Value = 5
	(2) "Large" amount of shielding present during container transfer (PF_{52})	Same as above	Same as above except detection region is vicinity of handling equipment	Localized shielding not required Discrimination feasible
		Value = 0	Value = 10	Value = 5
$PC_5 = 1/2 \left(\sum_{i=1}^{2} PF_{5i} \right)$	Overall value	NA	NA	Value = 5
Detection Sumary				
1. Vault inventory material balance discrepancies	Weighted overall value W[4]=1	NA	NA	Value = 8
2. Unauthorized personnel activities	Weighted overall values			
• Unauthorized personnel in vital vault areas	W=1	NA	NA	Value = 8.3
• Unauthorized use of system operational features	W=0.8	NA	NA	Value = 7.4

Table 5.1. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Conceptual vault system
Detection Summary (cont'd)				
3. Unauthorized SNM presence	Weighted overall values			
• Location	W=0.8	NA	NA	Value = 5.4
• Shielding materials	W=0.8	NA	NA	Value = 4.0
Average overall weighted value	Overall value = A	—	—	Value = 6.6

Notes for detection:

(1) Value = subjective quantification of safeguards benefit on a scale of - to 10, 10 being most desirable.
(2) Vault boundary: storage area to process transfers.
(3) Shielding issue is intended as a relative argument; performance of heavy-metal detectors may be a major problem.
(4) Weighting factor.

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Conceptual vault system
2. DELAY (OF) (SF_2)				
(1) Adversary access to vault areas				
(2) Adversary use of vault systems functions (i.e., controls, equipment, etc.)				
(3) Adversary physical access to SNM (PC_2, PF_{2i}; i=1,...8)				

Table 5.1. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Conceptual vault system
	2.1 Active delay mechanisms			
	(1) Imposed adverse vault conditions (e.g., inert gas purge) (PF_{21})	Not utilized	Active system which is capable of rendering the vault environment to humanly debilitating conditions within minutes	None
		Value = 0	Value = 10	Value = 0
	(2) Normal vault entry access denial (e.g., automatic closure and securing of doors) (PF_{22})	No active denial mechanization utilized	Active system which is capable of securing within seconds all vault maintenance and normal entry points to a physical barrier delay effectiveness equivalent to that of the principal physical barrier. Reset function to require hours	Automatic deactivation and closure of access port(s) to the extent that special "reset" procedures required. This would permit the access ports to supply a delay time equivalent to the principal physical barrier
		Value = 0	Value = 10	Value = 7
	(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 (PF_{23})	Manually operated vault with no mechanization or control systems which could be deactivated for use denial	Completely automated vault storage system in which all equipment control features can be irreversibly deactivated (required hardware and software repair to reactivate)	Delay is equivalent to principal vault barrier
		Value = 0	Value = 10	Value = 7

Table 5.1. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Conceptual vault system
2. DELAY (OF) (SF_2) (cont'd)				
	2.2 Passive delay mechanisms			
	(1) Principal physical (structural) barrier (PF_{24})	Vault structure which can be easily compromised with conventional tactics (i.e., explosives, etc.)	Vault structure which encompasses all storage and transfer regions and requires hours to penetrate using conventional military tactics	Encloses entire vault boundary area (i.e., also encloses transfer region)
		Value = 0	Value = 10	Value = 5
	(2) Storage container design (PF_{25})	Container designed for human operation without special tools or machines	Container design requiring special machines for opening operation and handling (bulk weight > hundreds of pounds and which physically would require hours to penetrate using conventional military tactics	Mechanization of container filling/emptying feasible. Therefore, container design can preclude unassisted operation. Equivalent delay would be that of container destruction
		Value = 0	Value = 10	Value = 5
	(3) Container storage area design (PF_{26})	Storage area design for unassisted human direct container handling (neg. effect)	Storage area structural geometry which precludes human (of any conceivable size) entry and movement	Personnel access not required in normal operation
		Value = 2	Value = 10	Value = 5
	(4) Vault input/output port design (PF_{27})	Manually operated vault with normal human-entry access ports through principal physical barrier. Access door remains open for large fraction of day	Input/output structural geometry precludes human use and provides a delay effectiveness comparable to that of the principal physical barrier	Personnel access not required in normal operation
		Value = 2	Value = 10	Value = 5

Table 5.1. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Conceptual vault system
	2.2 Passive delay mechanisms (cont'd)			
	(5) Maintenance access ports (vault opening used for maintenance of internal equipment) (PF_{28})	Vault designs which require maintenance access accommodations which compromise the delay effectiveness of the principal physical barrier to minutes	Vault designs which require no maintenance access for internal equipment	Maintenance access to container storage area required
		Value = 0	Value = 10	Value = 5
Delay Summary $PC_2 = 1/8\ (\sum_{i=1}^{8} PF_{2i})$	Overall value = B	NA	NA	Value = 5
3. DETERRENCE (SF_3)				
(1) Potential overt adversary actions	3.1 Detection system effectiveness[1] (PF_{31})	Value = 0	Value = 10	Value = 6.6
(2) Potential overt adversary actions (PC_3, PF_{3i}; i=1,...7)	3.2 Delay system effectiveness[2] (PF_{32})	Value = 0	Value = 10	Value = 5
	3.3 Response system effectiveness	NA	NA	
	3.4 Intrinsic system characteristics			
	(1) Material access and isolation (during normal operation) (PF_{33})	Manually operated vault in which SNM containers are easily accessible when vault door is open	Material is completely isolated at all times in a vault system	Material is isolated at all times within the vault boundary
		Value = 1	Value = 10	Value = 6

Table 5.1. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Conceptual vault system
	3.4 Intrinsic system characteristics (cont'd)			
	(2) Material handling time (PF_{34})	Manually operated vault on which SNM containers are easily accessible when vault door is open	Material is completely isolated at all times in a vault system which requires no maintenance access	Handling time minimized. Virtually no direct handling within the vault boundary
		Value = 1	Value = 9	Value = 9
	(3) Collusion vulnerability	Manually operated vault	Fully automated vault	
	(a) Number and skills of people involved			
	• Number of operations people	High	<2 people/shift	Low
	• Number of maintenance people	Low	Maximum; high	High
	• Skill level	Operators and technicians	Engineers, computer programmers	Operators, technicians, material control, computer programmers, engineers (higher ratio of white collar types)
	(b) Mixture required[3] (PF_{35})	Crafts only	Maximum number of professionals/number of crafts	Operators, technicians, computer programmers, guards, and engineers
		Value = 3	Value = 6[3]	Value = 6
	(4) Functional system complexity (e.g., operating controls, computer security, surveillance) (PF_{36})	Manually operated vaults	Fully automated including material transfer to process	Complex
		Value = 2	Value = 7	Value = 7

Table 5.1. (continued)

Safeguards performance criteria	Vault safeguards performance factors	Lower bound	Upper bound	Conceptual vault system
	3.4 Intrinsic system characteristics (cont'd)			
	(5) Physical system complexity (barriers, vault internal structure, etc.)(PF_{37})	Conventional earthquake-proof construction	Internal geometry which precludes movement of average-size humans. Special barrier design to provide hours of delay when attacked with advanced weapons	Operators, technicians, guards, computer programmers, and engineers
		Value = 0	Value = 9	Value = 6
Deterrence Summary				
$PC_3 = 1/7\ (\sum_{i=1}^{7} PF_{3i})$	Average deterrence values = C	NA	NA	Value = 6.5

Notes for deterrence:

(1) Refer to Sect. 1, Dectection Summary.
(2) Refer to Sect. 2, Delay Summary.
(3) It is assumed that collusion requiring collaboration between individuals with varying societal characteristics (salary, education, etc.) is less likely to succeed compared with groups having common societal bases.

Overall safeguards summary				
1. Detection	A			Value = 6.6
2. Delay	B			Value = 4.9
3. Deterrence	C			Value = 6.5
Total safeguards relative value				Value = 6.0

Appendix A

TRANSACTION STUDY

A transaction study was done to establish the number of storage spaces required in the conceptual vault. The calculations are shown below.

The production rate of finished MO_2 is

$$(200{,}000 \text{ kg } MO_2/\text{year})(1 \text{ year}/260 \text{ days})(1 \text{ day}/24 \text{ hr})$$
$$= \mathit{32.05\ kg\ MO_2/hr}\ .$$

This requires the input of

$$(32.05 \text{ kg } MO_2/\text{hr})(4 \text{ kg } PuO_2/100 \text{ kg } MO_2) = \mathit{1.28\ kg\ MO_2/hr}\ ,$$

and

$$(32.05 \text{ kg } MO_2/\text{hr} - 1.28 \text{ kg } PuO_2/\text{hr}) = \mathit{30.77\ kg\ UO_2/hr}\ .$$

Working back from the product end of the process:

a. Assuming that 22% of the ground, sintered-pellet throughput is rejected on inspection, then the throughput at this stage is

(32.05 kg accepted pellets/hr)(100 pellets produced/78 pellets accepted)
= 41.05 kg MO_2 pellets/hr produced in the sintering-grinding steps.

Therefore, the reject-recycle rate is

$$41.05 - 32.05 = \mathit{9\ kg\ pellets/hr}\ .$$

b. Assuming that 18% of the green-pellet throughput is rejected, then the throughput at this stage is

(41.05 kg accepted green MO_2 pellets)(100 pellets produced/82 pellets accepted)
= 50.05 kg green MO_2 pellets produced/hr.

and the reject rate is

$$50.05 - 41.05 = \mathit{9\ kg\ green\ pellets/hr}\ .$$

Both of the above recycle streams are crushed and milled to obtain powder which is stored and later recycled to the blending step.

Appendix B

STORAGE CONTAINERS

The capacity of the storage container for PuO_2 powder is limited arbitrarily to 8 kg, the quantity normally in one canister when it is received from the processing plant. There will be one canister in each storage container to minimize handling the PuO_2 powder. The volume of the 6-in.-diam x 18-in.-long container is

$$(0.5 \text{ ft})(0.5 \text{ ft})(0.7854) \times 1.5 \text{ ft} = 0.2945 \text{ ft}^3 .$$

Assuming a density of 1.5 g/cc (42.5 kg/ft^3) for the MO_2 powder, the container holds

$$(0.2945 \text{ ft}^3)(42.5 \text{ kg/ft}^3) = \textit{12.5 kg } MO_2 \textit{ powder} .$$

The capacity of the storage container for the material in pellet form, assuming that the pellets are stacked in layers in the container that occupy 20% of the cross-sectional area is as follows. The pellets are assumed to be 0.5 in. in diameter x 0.5 in. long and weigh 0.02 kg. The area occupied by each layer of pellets is

$$(6 \text{ in.})^2(0.7854)(0.2) = 5.65 \text{ in.}^2 .$$

The area of the base of a pellet is

$$(0.5 \text{ in.})^2(0.7854) = 0.196 \text{ in.}^2 .$$

Therefore, the number of pellets in each layer is

$$(5.65 \text{ in.}^2)/(0.196 \text{ in.}^2) = 28 \text{ pellets} .$$

Assuming the pellets can be stacked to the full length of the container, then

$$(1.5 \text{ ft})(12 \text{ in./ft})(1 \text{ pellet layer}/0.5 \text{ in.}) = 36 \text{ layers} .$$

Then the total weight of pellets in a container will be

$$(36 \text{ layers})(28 \text{ pellets/layer})(0.02 \text{ kg } MO_2/\text{pellet}) = \textit{20.16 kg } MO_2 \textit{ pellets/container} .$$

REFERENCES

1. Hamel, W. R. and Shappert, L. B., *Desirability and Feasibility of Vault Automation in SNM Storage*, NUREG-0318 (Oct. 1977).

2. McDuffee, W. T. and Hamel, W. R., *Value Impact of Vault Automation in Special Nuclear Material Storage*, ORNL/NUREG-33 (in preparation).

3. Bain, E. E. et al., *Quantitative Evaluation of the Retimac System*, SAI-75-595-LJ (June 10, 1975).

4. FMC Corporation, *Power and Free Trolley Conveyor Reliability and Manitainability Study for Nuclear Storage Vault Use*, Document R-3675.

5. JBF Associates, *A Parametric Study of Power and Free Conveyor Unavailability*, Knoxville, Tennessee (September 1977).

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