Final Report

APPLICATION OF THE DECONTAMINATION AND DOSE CONTROL MODEL TO AN INDUSTRIAL COMPLEX

Prepared for:

OFFICE OF CIVIL DEFENSE
OFFICE OF THE SECRETARY OF THE ARMY
WASHINGTON D.C. 20310

CONTRACT DAHC20-70-C-0294
OCD Work Unit 3231D

STANFORD RESEARCH INSTITUTE
Menlo Park, California 94025 · U.S.A.

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Final Report *July 1970*

Detachable Summary

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By: W. LEIGH OWEN

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DETACHABLE SUMMARY

This study describes the application of a previously developed decontamination and dose control model to the problem of planning and scheduling the radiological recovery of a representative critical industrial installation, i.e., a steam power plant. The purpose of this study was to determine the magnitude of recovery operations and the related planning factors generated by the model under varied radiological conditions.

The model application has shown that the Hunters Point power plant can be successfully recovered and operated, when subjected to a broad range of fallout dose rates and fallout mass loadings, without exceeding the total number of men currently employed. Seventy men can decontaminate 13 acres of roofs and grounds in 4 to 6 hours. On completion of decontamination at the end of 14 days, all plant personnel are free to resume their regular duties--providing no more than about 6 hours per day are spent outside of the major structural complex the first month after attack. Without a decontamination effort, denial times would range from 1 month to over 3 months.

Although the power plant can stay on line with as few as 5 operators on duty, 10 times as many people are required to distribute the exposure dose and to man the minimum decontamination effort. Thus 50 men can operate and recover the plant if the standard dose rate does not go higher than 18,000 r/hr. A 70-man complement is required when standard dose rates reach 27,000 r/hr, and 100 men are needed for standard dose rates in excess of 30,000 r/hr. With this same number of men the plant can operate on a normal cycle of three 8-hour shifts until the standard dose rate exceeds 6000 r/hr.

In general, the pertinent model parameters tended to increase with standard dose rate. Exceptions include total dose D_T, conserved dose D_C, and the cost-to-effectiveness ratio D_C/D_T, which all remained relatively constant. The last value indicates that plant personnel would accumulate about 80 percent of the total dose allowed the first month after attack. Comparison of the various model parameters obtained in this study with those given in Ref. 2 shows that the unit costs for recovering the power plant are greater than those found for recovering the shopping center. Since this difference can be attributed to the fact that power plant recovery cannot be greatly improved through the use of mechanized methods, it is considered more difficult to recover than the shopping center.

It is recommended that the decontamination and dose control model be applied to still other essential sites and installations. For instance, the thin-shelled buildings characteristic of canneries, salt works, and sugar refineries would present a recovery problem very different from more heavily shielded structures like power plants. Such a study would provide additional information for determining the effects of target configuration and structural properties on recovery planning and scheduling.

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OCD REVIEW NOTICE

This report has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

ABSTRACT

The development by Stanford Research Institute of a Decontamination and Dose Control (D/DC) Model has provided a systematic method for planning and evaluating the radiological recovery of contaminated sites and facilities. The output of the D/DC model is highly dependent on prominent physical characteristics of the target complex. To obtain information on the effects of target configuration on recovery planning and scheduling, the D/DC model was applied to the recovery of a steam power plant.

The model application showed that this specific plant can be successfully recovered and operated when exposed to a wide range of fallout conditions without having to hire any additional help. A complement of 70 men can run the plant and participate in its decontamination if standard dose rates do not exceed 27,000 r/hr.

Comparison of the various model parameters derived in this study with those obtained from a similar application of the D/DC model to a shopping center indicates that the unit costs for recovering the power plant are consistently higher.

ACKNOWLEDGMENT

The author wishes to acknowledge the cooperation of Pacific Gas and Electric Company of California and, in particular, the Steam Generation Department. The drawings and information provided during the various visits to the Hunters Point power plant were essential to this research and are greatly appreciated.

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I INTRODUCTION

The development by Stanford Research Institute of a Decontamination and Dose Control (D/DC) Model[1,2†] has provided a systematic method for planning and evaluating the radiological recovery of essential contaminated facilities. The D/DC model system has been satisfactorily tested for the recovery of a regional shopping center exposed to specific fallout conditions.‡ The results are applicable to regional shopping centers in general, particularly to those considered useful as multiple staging areas.

The output of the D/DC model or comparable recovery planning methodology is highly dependent on prominent physical characteristics of the target complex itself, aside from the fallout effects. For instance, earlier radiological evaluations of a refinery complex and a housing complex subjected to similar fallout conditions resulted in very different estimated recovery requirements, plans, and procedures. Therefore, the findings from the shopping center example are considered to apply only to target complexes having structural configurations that resemble those usually exhibited by regional shopping centers.

To determine effects of target configurations on recovery planning and scheduling, it was necessary to exercise the D/DC model against a variety of target complexes. One class important to national survival includes complexes belonging to critical industrial sectors. This report describes the application of the model routines to a steam power plant.

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† Superscripts denote references listed at the end of the report.

‡ The detailed description of this sample application is given in Ref. 2.

Objective

The objective of this research is to determine the magnitude of the operational-recovery planning factors generated by the SRI D/DC Model when applied to a representative critical industrial complex under conditions requiring radiological decontamination.

Background and Approach

The D/DC model is a preplanning tool for estimating the cost and effectiveness of the recovery operations required for the removal of fallout from essential installations and sites. It takes into account physical and radiological conditions, as well as available resources and decontamination method performance, and schedules the allocation of people, equipment, exposure dose, and time required for the radiological recovery (Rad/Rec) of a given target complex. This is illustrated by the flow diagram in Figure 1.

The principal inputs furnish the operational and environmental starting conditions required by the procedural planning subsystem. Table 1 briefly outlines the principal inputs discussed previously in Ref. 1, which contains the bulk of the model's computational machinery for converting the input information into the desired model output forms. Figure 2 gives a more detailed description of the procedural planning subsystem in terms of the two submodels and 12 computational routines employed to obtain the central output, i.e., Rad/Rec plans and procedures.

The following sections of this report describe the application of the D/DC and its computational routines to the Rad/Rec of a power plant. The model inputs are defined, the computations are carried out, and, as indicated in Figure 1, the results are assessed in terms of pertinent cost and effectiveness measures. All the equations and curves required

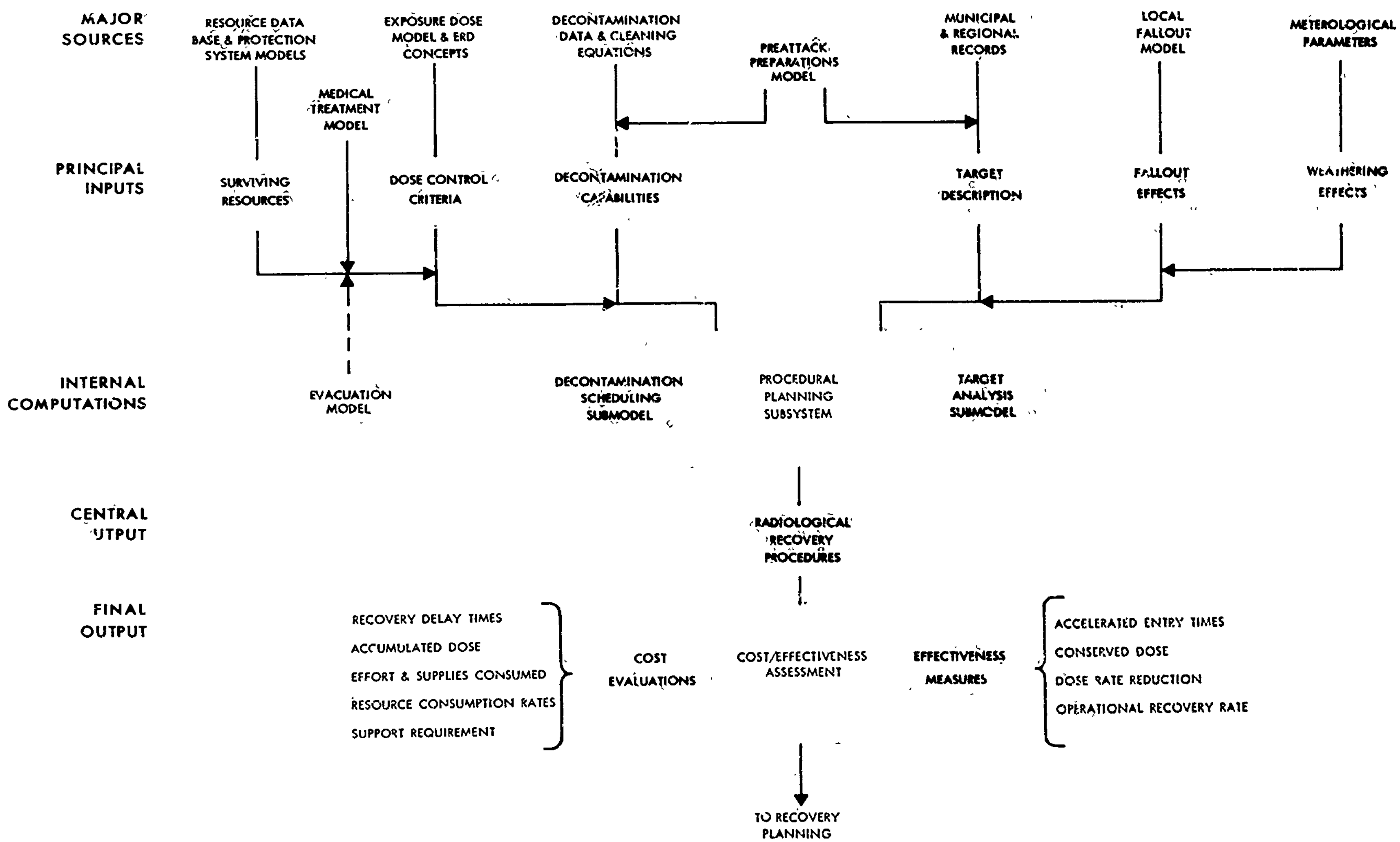

FIGURE 1 D/DC MODEL SYSTEM

Table 1

PRINCIPAL INPUTS TO THE PROCEDURAL PLANNING SUBSYSTEM

Environmental inputs

Target description--geometrical and structural

Fallout effects--parameters affecting the radiological situation

Weathering effects--redistribution of fallout particles

Operational inputs

Decontamination capabilities--recovery effectiveness versus effort requirements

Dose control criteria--ERD† concepts and dose limits

Surviving resources--human and material

Auxiliary inputs

Prettack preparations--as affecting both fallout environment and decontamination operations

Decontamination priorities for target complex units and selected sites

Shelter exit times or shelter stay time intervals

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† Equivalent Residual Dose.

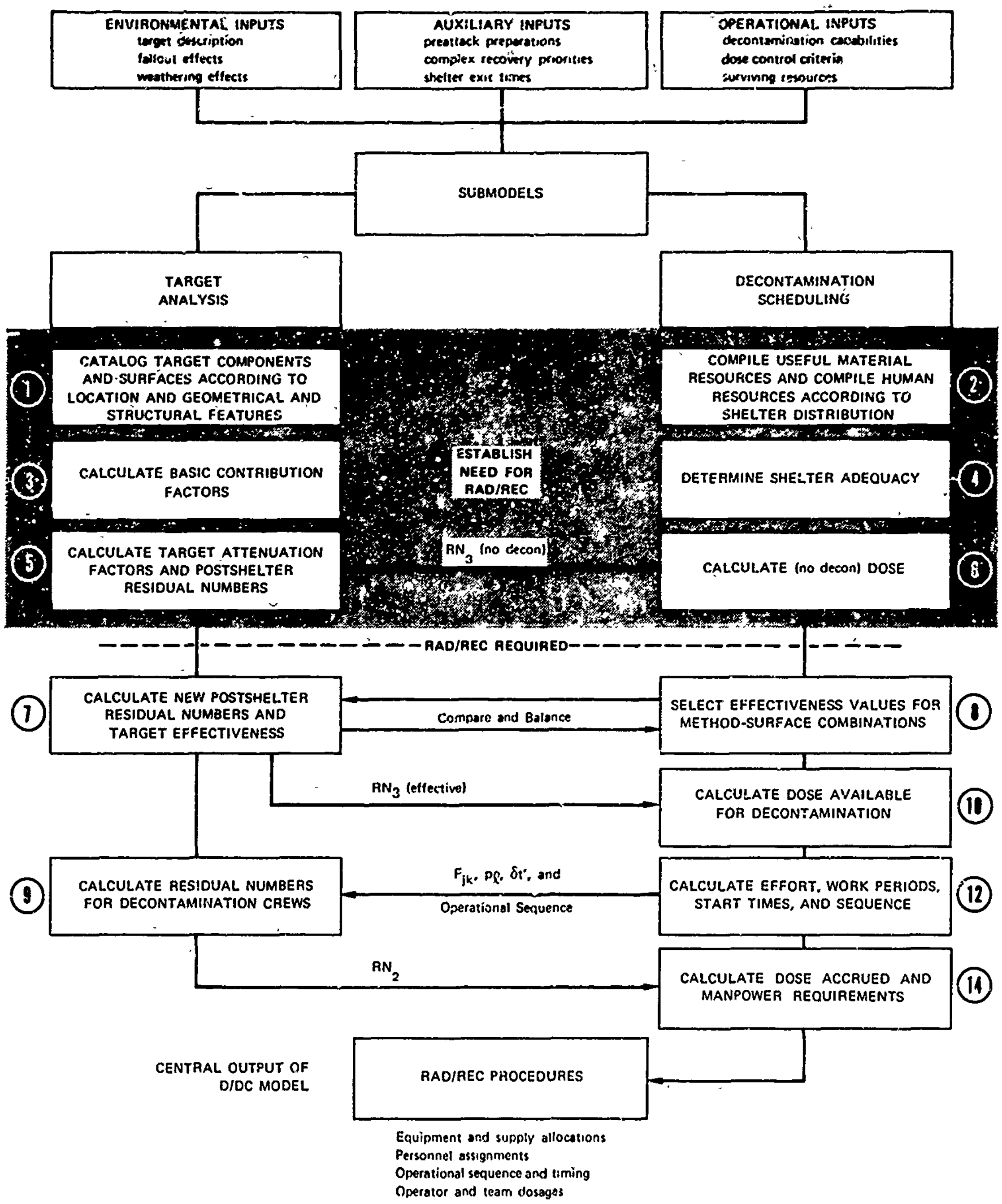

FIGURE 2 PROCEDURAL PLANNING SUBSYSTEM

to implement the model are contained in Ref. 2.† Because frequent reference will be made to these aids and associated techniques, it is recommended that the reader obtain a copy of that document. Thus, mathematical descriptions and explanations of model development are kept to a minimum in this report, although a list of the symbols used and a list of pertinent equations showing the relationships of the symbolized parameters are included in Appendixes A and B, respectively. To promote easier access, the original equation designation numbers of Ref. 2 are retained. The stepwise model application that follows is patterned as closely as possible after the format used in Section VI of Ref. 2.

† References 3, 4, and 5 are also recommended as sources of much of the concepts and techniques incorporated by the D/DC model.

II STARTING CONDITIONS

After a brief survey of candidate industrial installations in the greater San Francisco Bay Area, the Hunters Point Power Plant was selected for the model application. This plant belongs to the San Francisco Division of the Pacific Gas and Electric Company. Structurally, the Hunters Point Plant combines the two basic designs featured by power plants in the United States today. The original plant and the 1948 addition are of the enclosed type. The 1958 addition, however, has an exposed turbine and pedestal. Total output for all units is over 600,000 kva. Figures 3 and 4 show the plant as it exists today.

Principal Inputs

For the purpose of this application the following principal model inputs are designated in accordance with the outline given in Table 1. It is assumed that four 5-MT weapons have been detonated 80 to 90 miles upwind from the power plant. The prevailing wind velocity† during the fallout event is 20 mph.

Target Description

Drawings and tables showing locations, sizes, surface characteristics, mass thickness data for target components, and building elements are compiled in routine 1 (to follow).

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† No distinction is made between the velocity at ground surface and the velocities aloft. Twenty mph is an average effective value applied to all altitudes.

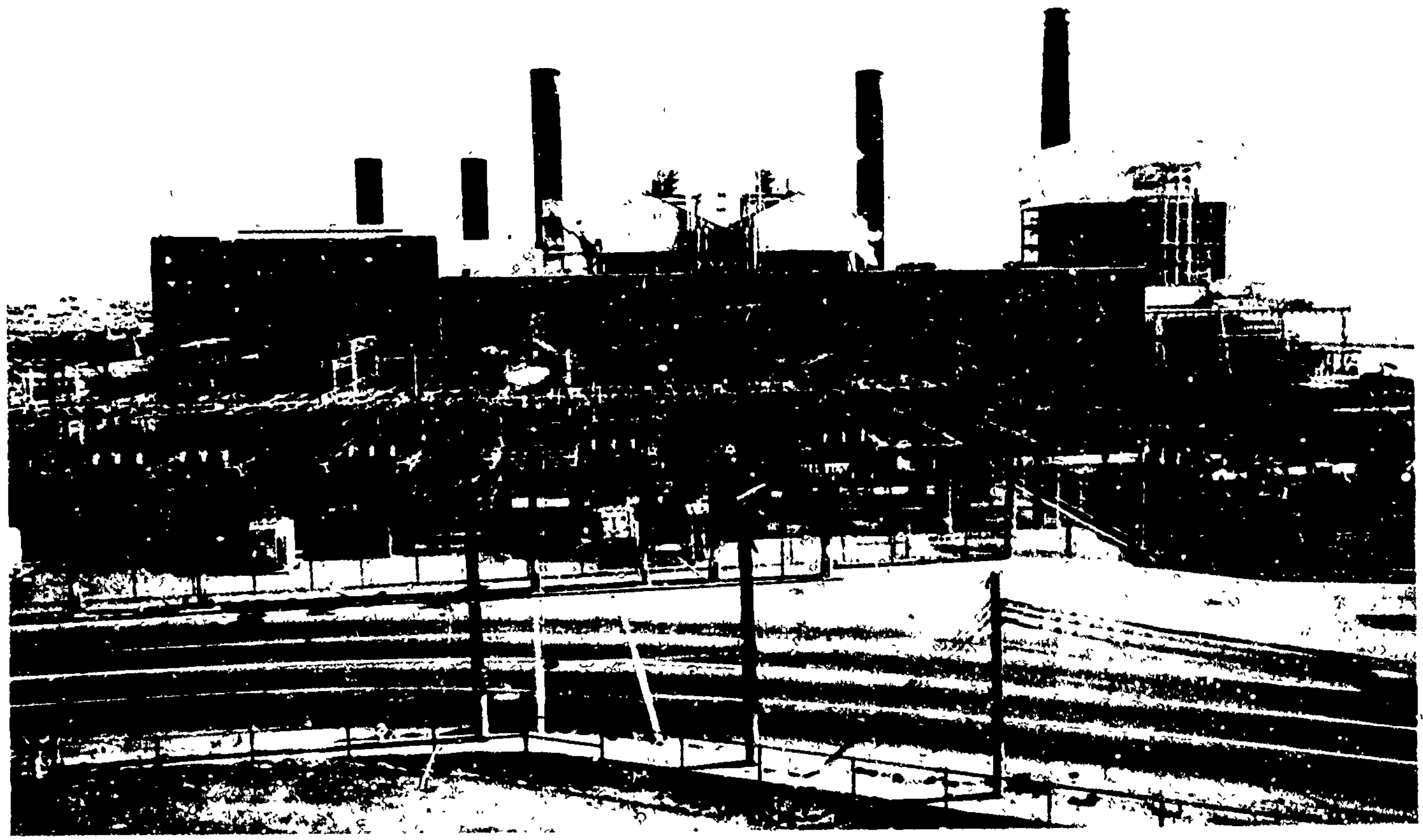

FIGURE 3 VIEW OF HUNTERS POINT POWER PLANT FROM EVANS AVENUE SHOWING THE SWITCH YARD IN THE FOREGROUND

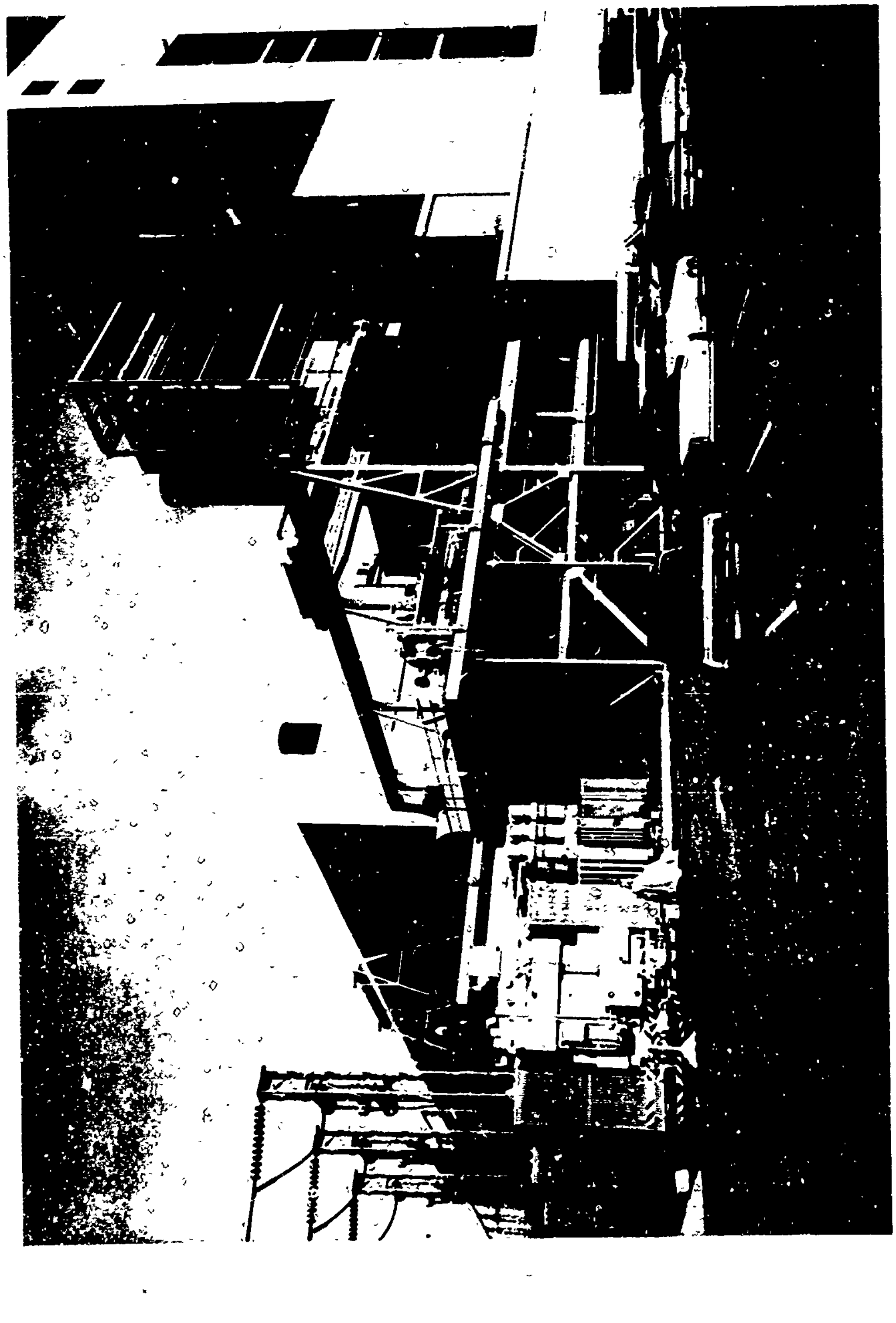

FIGURE 4 A CLOSE-UP OF THE NEWEST ADDITION (1958) TO THE HUNTERS POINT POWER PLANT

Surviving Resources

Shelter distributions and available skills, equipment, and supplies are compiled in routine 2 (to follow).

Fallout Effects

From the input generated by the local fallout model,† the radiological environment may be described for a 50-percent fission fraction in terms of the following parameters:

Standard dose rate I^o = 9000 r/hr.

Fallout mass loading M_o = 100 g/ft^2.

Particle size range (PSR) = 88 to 175 μ.

Arrival time t_a = 3.0 hr after detonation.

Cessation time t_c = 5.3 hr after detonation.

Weathering Effects

Because of the roughness of the graveled surfaces, the migration and redeposition of fallout on most of the roofs and much of the ground areas will be negligible. It is assumed that for some surfaces the 20-mph winds will remove a portion of the fallout. This weathering removal effectiveness is indicated by the fraction of fallout remaining, F_{jw}, which takes on the following values according to the surface:

Asphalt paved parking‡, F_{jw} = 0.40.

Bare ground surfaces‡, F_{jw} = 0.60.

Smooth sloping roofs over boiler house A and the warehouse

F_{jw} = 0.01.

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† Based on fallout history printout for Providence, R.I., generated by American Research Corporation for Five-City Study Data Bank.

‡ These refer to illustrations and tables in routine 1, to follow.

Dose Control Criteria

The allowable dose to any one person for all exposure periods will be limited to 200 r ERD.

Decontamination Capabilities

The expected performance and effectiveness of candidate fallout removal methods will be taken largely from Appendix A of Ref. 6.

Preattack Preparations

During the crisis buildup prior to attack, it is presumed that certain recommended precautions have been taken to improve the general success of the decontamination effort as follows:

1. Only enough vehicles to evacuate plant personnel are allowed to remain on the grounds. These are either placed inside buildings or provided with fitted covers to protect against fallout.

2. Necessary equipment and supplies have been stored indoors or under tarpaulins and plastic covers in readiness for the start of decontamination (and other recovery tasks). To reduce equipment set-up time further, fire hoses have been placed on building roofs.

3. Ladders or movable stairs have been placed at various locations to enable contamination crews to gain access to the roofs.

4. Loose gravel has been swept up and removed from all roofs to reduce the chance of plugging drains during the decontamination process.

Decontamination Priorities

The function of the power plant is highly essential to the survival of the community and therefore has a high priority for Rad/Rec wherever it is needed.

Shelter Exit Time

It is assumed that portions of the plant such as the control rooms and possibly the machine shop) will be manned at all times immediately following a nuclear attack. Therefore, personnel will spend some fraction of their time outside the primary basement shelter and in the aboveground part of the power plant, which may be considered a secondary shelter. Because there are no routine duties to be performed outside the main complex of adjoining buildings that cannot be postponed for many days, a nominal exit time of two weeks will be used for this example.

III THE NEED FOR RAD/REC

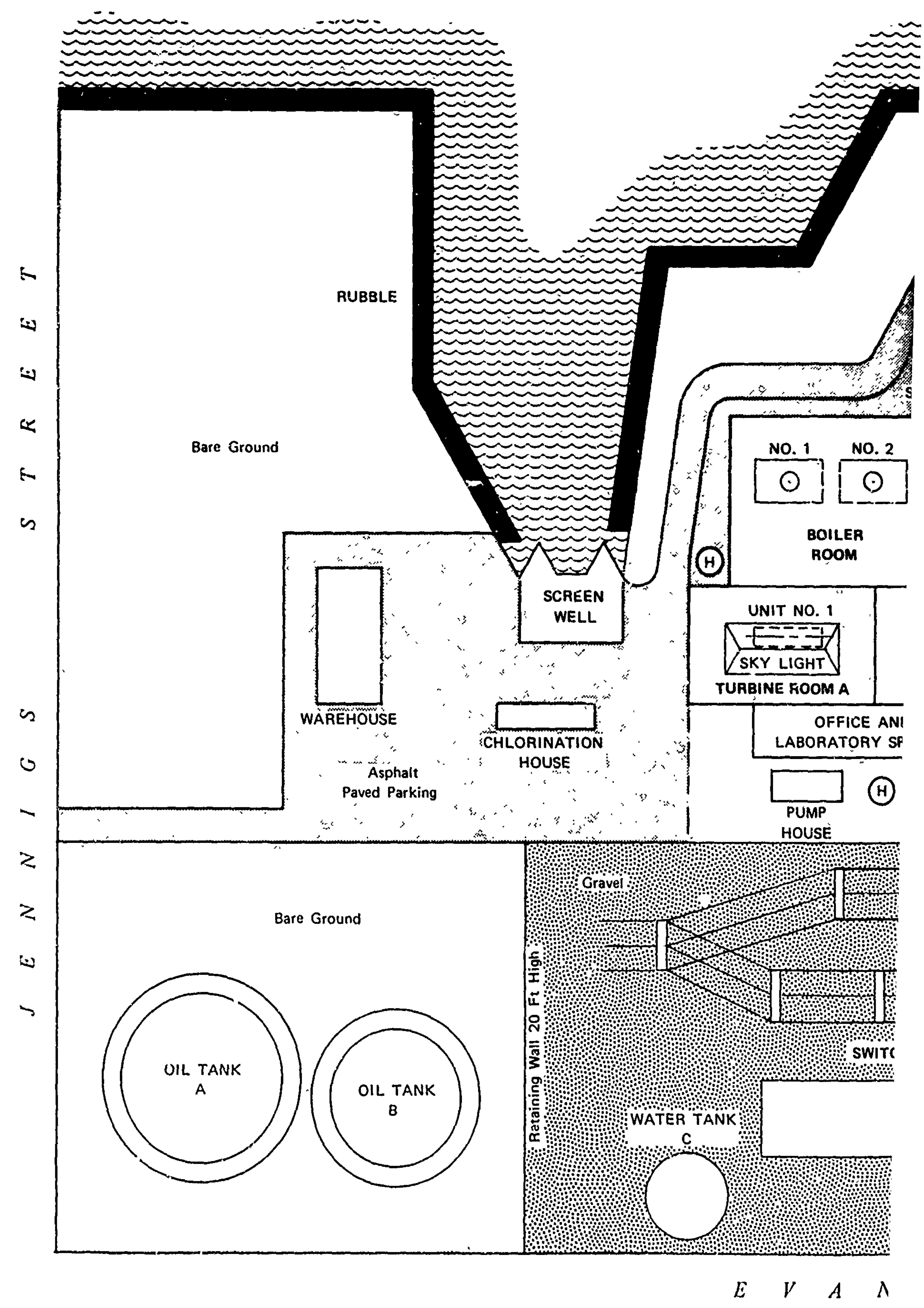
From the nine inputs and data sources described in Section II, the submodels and computational routines of the procedural planning subsystem are exercised as described in Ref. 2. The first six routines establish the need for Rad/Rec.

Routine 1: Target Description

A description of the power plant complex is presented in Figure 5 and Tables 2, 3, and 4. Briefly, the complex consists of three connecting plants including turbine rooms, control rooms, boiler houses, shops, and unloading areas. An office and laboratory building and a pump room adjoin the main structure. Minor buildings such as a warehouse, chlorination house, pump house, and oil house are located nearby. The immediate area connecting all these buildings is flat and paved with asphalt and concrete. Roof elevations in Table 2 are given with respect to this paved reference plane.

Between the plant proper and Evans Avenue is an unpaved area containing the switch yard and two large tanks of boiler fuel oil. The switch yard is covered with gravel and the remainder of the surface is bare ground. The total area shown in Figure 5, bounded by Jennings Street, Evans Avenue, and the bay shoreline, is 15.5 acres.

All surfaces (roof or ground level) are in good condition. With the exception of the roof on boiler house A, all surfaces are accessible to decontamination crews and their equipment. Nine fire hydrants are located around the perimeter of the main buildings, and eight vertical pipes with hose connections at each level service the building exterior. No drainage or waste disposal problems are expected.


JENNIGS STREET
RUBBLE
Bare Ground
SCREEN WELL
WAREHOUSE
CHLORINATION HOUSE
Asphalt Paved Parking
NO. 1
NO. 2
BOILER ROOM
UNIT NO. 1
SKY LIGHT
TURBINE ROOM A
OFFICE AN
LABORATORY SP
PUMP HOUSE
H
Bare Ground
Gravel
OIL TANK A
OIL TANK B
Retaining Wall 20 Ft High
WATER TANK C
SWIT
EVAN

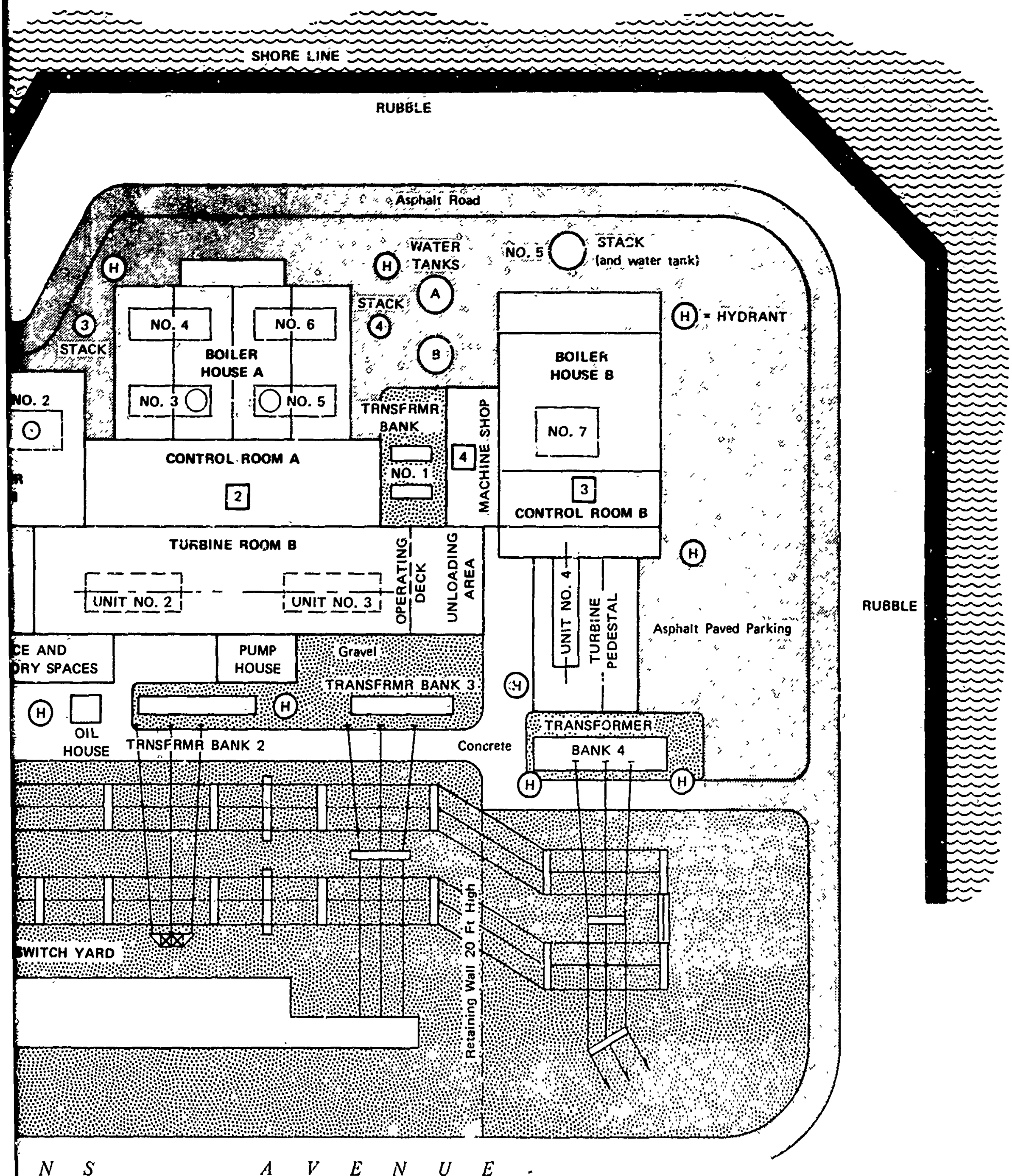


FIGURE 5 PLOT PLAN OF HUNTERS POINT POWER PLANT

B

Table 2

DESCRIPTION OF ROOF SURFACES

Components and Surfaces	Elevation† (feet)	Approximate Aerial Dimensions (W ft × L ft)	Surface Area (feet²)
	Major structures		102,370
Built-up tar and gravel (flat):			
Boiler room	90	100 × 125	12,500
Turbine room A	90	70 × 115	8,050
Control room A	55	55 × 200	11,000
Turbine room B	76	70 × 305	21,350
Laboratory	50	30 × 130	3,900
Pump room	22	30 × 55	1,650
Machine shop	31	35 × 90	3,150
Boiler houses	147	88 × 110	9,680
Control rooms	65	35 × 110	3,850
	40	20 × 110	2,200
		Subtotal	77,330
Concrete (flat):			
Turbine pedestal	26	70 × 100	7,000
Corrugated steel (gabled):			
Boiler house A	115	100 × 170	17,000
	40	16 × 65	1,040
		Subtotal	18,040
	Lesser structures		27,970
Built-up tar and gravel (flat):			
Pump house	12	18 × 45	800
Oil house	12	18 × 20	360
Chlorination house	12	15 × 60	900
		Subtotal	2,060
Sheet metal (gabled):			
Warehouse	13	40 × 80	3,200
Water tanks A and B	20	22 O.D.	800
Water tank C	35	50 O.D.	1,960
Oil tank A	15	120 O.D.	8,650
Oil tank B	45	105 O.D.	11,300
		Subtotal	25,910
	Total for all structures		130,340

† For built-up tar and gravel roofs, the height of the parapet is found by increasing the given elevation 4 feet for major structures and 1 foot for lesser structures.

Table 3

DESCRIPTION OF GROUND SURFACES

Components and Surfaces	Elevation (feet)	Approximate Aerial Dimensions (W ft X L ft)	Surface Area (ft^2)
Streets: asphalt		20 X 1570	31,400
Parking/working areas:			
asphalt		irregular	99,660†
Transformer tracks:			
Concrete		irregular	23,570
Miscellaneous exposed areas:			
Concrete‡			11,950
Subtotal			166,580
Transformer banks: gravel			
Bank No. 1		45 X 90	4,050
Bank No. 2		30 X 110	3,300
Bank No. 3		60 X 125	8,125
Bank No. 4		45 X 120	5,400
Subtotal			20,875
Switch yard: gravel	20	240 X 515	121,640†
	0	210 X 220	46,200
Subtotal			167,840
Oil storage: unpaved	20	240 X 290	49,650†
N.E. grounds: unpaved	0	irregular	79,400
Subtotal			129,050
Total			484,345
Shore line: rubble		60 X 1300	78,000

† Area of storage tanks, stacks, etc., has been subtracted.
‡ Located under boiler houses and turbine pedestal.

Table 4

STRUCTURAL COMPOSITION AND MASS THICKNESS OF BUILDING MEMBERS

Building Member Description	Mass Thickness (lb/ft^2)
Roofs	
Trussed concrete deck, tar and gravel	40 to 75
Reinforced concrete slab, tar and gravel	40 to 75
Trussed corrugated steel (boiler house A)	6
Floors	
Concrete slab, steel girders (operating deck)	150
Open steel grating (around all boilers)	15
Walls	
Reinforced concrete	
Major structures	100 to 150
Lesser structures	50 to 100
Corrugated cement asbestos (boiler houses)	6
Plate glass windows	4
Steel roll doors	8
Furnace shell, tubes, and fire brick	100

Routine 2: Surviving Resources

Except for the Naval shipyard nearby, the Hunters Point power plant is quite isolated insofar as expecting any immediate aid from the city disaster organizations. Ordinarily the plant requires only 100 men to keep it going around the clock. It is assumed that sufficient manpower for all three (8 hour) shifts has been required to report and stay in the basement shelter. This shelter space, which is located under the new unit, has a protection factor (PF) of about 10^4. All 100 plant personnel are considered able bodied and available to serve on the fallout decontamination teams as required.

Because of the small amount of paved surface surrounding the buildings, it is not anticipated that the use of mechanized street sweepers or street flushers will be made available to the power plant recovery operation. Therefore, firehosing will be used on all surfaces. The water system is more than ample, having two 1,000 gal/min pumps to boost the pressure. If the city mains fail during attack, water may be drawn from the bay. The preattack accumulation of sufficient fire hose and nozzles is not considered to be a problem. No other decontamination supplies or equipment are required other than a pickup truck and some spare fuel for hauling hose.

Routine 3: Contribution Factors

Following the stepwise computational sequence described in Section III of Ref. 2, dose rate contributions are calculated to selected receiver locations in the complex. Table 5 presents the total contribution factor C_j for each location and the fractional values attributed to roofs, grounds, and skyshine components. In Figure 5, location 1 is taken as a typical outdoor location and location 2 represents a central indoor reference point. The respective contribution factors for these two locations are reserved for application to routine 5.

Table 5

DOSE RATE CONTRIBUTION FACTORS FOR SELECTED RECEIVER LOCATIONS

Contributing Sources	Receiver Number and Location†					
	1 G North Parking	2 D Control Room A	3 D Control Room B	4 G Machine Shop	2 R Control Room A	3 R Control Room B
Roofs	0.00093	0.0370	0.0416	0.0021	0.609	0.435
Grounds	.714	--	--	.0388	--	.0508
Skyshine	.0197	.0022	0.0054	.00030	0.021	.0151
Total (C_j)	0.734	0.0392	0.0470	0.0412	0.630	0.501
Principal contributor						
66X66 ft square west of chlorination house	0.55	--	--	--	--	--
Roof, control room A	--	0.031	--	--	--	--
Roof, control room B	--	--	0.029	--	--	--
N.E. ground areas out to 100 feet	--	--	--	0.025	--	--
Roof, control room A	--	--	--	--	0.52	--
Roof, control room B	--	--	--	--	--	0.42

† G = ground level, D = operating deck, R = roof.

Routine 4: Shelter Adequacy

The foregoing model inputs and routines permit the determination of shelter adequacy. Before Eq. (25) of Ref. 2[+] is solved and the results are compared with the available PFs, two quantities must be found. According to Eq. (21) of Ref. 2, the effective (fallout) arrival time is

$$t_a' = 0.6\ (3.0) + 0.4\ (5.3) = 3.92\ \text{hr (after detonation)},$$

and the corresponding dose rate multiplier is $DRM_a' = 1.075$. Substituting into Eq. (25) of Ref. 2, the minimum PF required is

$$\overline{PF} \geq 0.007\ (9000)\ (3.03 - 1.075) = 123.$$

By cutting back on less important plant operations and utilizing supervisory, office, and laboratory personnel, the average work shift for essential jobs can be reduced to about six hours or less. This means that, in general, people spend about one-fourth of their time on the job and three-fourths in the primary shelter. Because the latter is a nearly perfect shelter with a PF of 10^4, the effective PF will be a function of the dose rate contribution factor existing in work areas. Taking C_j = 0.0392 from Table 5 for location 2 in control room A as the contribution factor for a typical indoor work area, the effective PF, according to Eq. (20) of Ref. 2, becomes

$$PF = \frac{1.33}{1/4\ (0.0392)} = 136.$$

Since this is greater than the above calculated minimum, the combined primary and secondary shelter system is adequate.

[+] Reference 2. equations are listed in Appendix B.

Routine 5: Postshelter Residual Number, RN_3

According to Eq. (27) of Ref. 2, the target attenuation factor equals the total contribution factor for the outdoor reference location. From Table 5 this is taken as equal to the value of C_j given for outdoor location 1. Thus, the target attenuation factor is

$$\bar{A}_j = 0.73$$

From Eq. (29) of Ref. 2, the average weathering effectiveness is

$$\bar{F}_{jw} = \frac{F_j C_j \text{ (roof)} + F_j C_j \text{ (ground)}}{C_j \text{ (location 1)}}$$

The roof contribution is negligible. The ground contribution is made up of two components, 0.65 from paved surfaces and 0.064 from bare ground surfaces. Therefore,

$$\bar{F}_{jw} = \frac{0.4\ (0.65) + 0.6\ (0.064)}{0.73}$$

$$= 0.41.$$

The postshelter residual number as defined by Eq. (28) of Ref. 2 is

$$RN_3 = F_{jw} \bar{A}_j$$

$$= 0.41\ (0.73)$$

$$= 0.30.$$

The facility attenuation factor is set equal to the ratio of the indoor to outdoor contribution factors [see Eq. (31) of Ref. 2], thus

$$A_f = 0.039/0.73$$

$$= 0.053$$

Finally, an effective residual number is obtained from an altered form of Eq. (32) of Ref. 2, where it is assumed that workers spend an average of about six hours a day or one quarter of their time outside and three quarters in secondary shelter.

$$EN_3' = \frac{0.30}{4}\left[3(0.053) + 1\right]$$

$$= 0.087.$$

Routine 6: Total Dose

The total dose to personnel in the absence of decontamination equals the sum of the shelter and postshelter doses. The latter dose is obtained from Eq. (33) of Ref. 2.

$$D_3 = EN_3' \, I^0 \, (\Delta DRM_3) \leq D^* - D_1$$

$$= 0.087 \, (9000) \, (3.424 - 3.242)$$

$$= 142 \text{ r.}$$

where 3.424 equals DRM^* at one month and 3.242 equals DRM_e at a shelter exit time of 14 days. The shelter dose as derived from Eq. (24) of Ref. 2 is

$$D_1 = \frac{1.33}{\overline{PF}} \, I^0 \, (DRM),$$

$$= \frac{1.33}{136} \, (9000) \, (3.242 - 1.675)$$

$$= 191 \text{ r,}$$

where

$$\Delta DRM_1 = DRM_e - DRM_a'$$

$$D_T = D_1 + D_2$$

$$= 353 \text{ r.}$$

For this same time period of one month, the allowable dose $D^* = 270$ r. Therefore, decontamination is required.

IV PLANNING AND SCHEDULING RAD/REC

Now that the need for decontamination is indicated, the remaining computational routines of the procedural planning subsystem must be performed to produce the desired model output. The sample calculations continue below.

Routine 7: New Postshelter Residual Number

The requirement for Rad/Rec implies that the postshelter residual number obtained in routine 5 was too large. Therefore, a trial estimate must be made by using Eqs. (37) and (42) of Ref. 2. Thus,

$$RN_3'(t) = \frac{270 - 220}{9000\ (3.424 - 3.242)}$$

$$= 0.030,$$

where the value of $D_e^* = 220$ and ΔDRM_3 is the same as in routine 6. Substituting this result into Eq. (42) gives:

$$F_j(t) = \frac{4\ (0.030)}{0.73\ [3\ (0.053) + 1]}$$

$$F_j(t) = 0.142,$$

where Eq. (42) has been altered to correspond to the changes made in Eq. (32) for routine 5.

Routine 8: Decontamination Effectiveness

Decontamination effectiveness values for firehosing different surfaces are selected from the advance solutions of cleaning equations tabulated in Appendix A of Ref. 6. The trial value $\bar{F}_j(t)$ found above is used as a guide in obtaining the effort required for the various method-surface combinations. For the physical and radiological environment indicated by routine 1 and the fallout effects input, the performance characteristics for decontaminating the power plant complex are shown in Table 6.

Because the removal due to weathering is so effective on smooth surfaces, no decontamination will be required on the metal roofs over the boiler houses and warehouse or on the tops of the various water tanks.

The graveled areas around transformer banks and in the switch yard will be sprayed with firehoses to soak the fallout particles and cause them to penetrate down into the gravel bed where much of the radiation effects will be shielded. In the switch yard, washing of the graveled surface will result indirectly from the hosing of the insulators and other parts of the equipment that are adversely affected by long exposure to dirt. Part of normal plant procedure is to wash down all these fixtures in the switch yard every month or so. Since the fallout will only aggravate this condition, it is important to plant performance that the switchyard be decontaminated.

The bare ground areas will be sprayed with firehoses to prevent the fallout from migrating to clean areas near the buildings.

The sum of the products of the individual effectiveness values, F_{jk}, and corresponding contribution factors (from routine 3) for outdoor location number 1 is computed from Eq. (26) of Ref. 2, as shown in Table 6. This is the new postshelter residual number that will result from

Table 6

FIREHOSING EFFECTIVENESS

Surface	Number of Men/Equipment Unit m_u	Specific Effort (Equipment-hr/1000 ft²)† $c_{j\ell}$	Number of Passes p_ℓ	Effectiveness (% remaining) F_{jk}	Contribution Factor‡ C_{jk}	Product $F_{jk}\ C_{jk}$
Pavement	3-4	0.054	1	7.1%	0.652	0.0462
Gravel	3-4	.16	1	20	.0058	.0012
Bare ground	3-4	.054	1	60 §	.072	.0043
Tar and gravel roofs	3-4	.185	1	10	.0040	.0004

$$RN_3 = \sum F_{jk}\ C_{jk} \approx 0.052$$

† Or team hour per 1000 sq ft

‡ Includes skyshine contribution

§ Effectiveness due to weathering only.

decontamination. An effective value is then calculated from Eq. (46), where the latter is altered in the same manner as Eqs. (32) and (42). Thus

$$RX_3' = \frac{0.052}{4}\left[3\,(0.053) + 1\right]$$

$$= 0.0154.$$

Since this result is smaller than the trial value estimated in routine 7, no extra decontamination passes will be required to improve effectiveness reduce $\bar{F}_j$, the fraction of fallout remaining). The methods selected are assumed to be adequate for the recovery task.

Routine 10: Available Dose

Because $RX_3' < RX_3'\,(t)$, Eq. (47) of Ref. 2 must be used to determine D_2, the dose available for decontamination. This obviates the need at this time for computing D_3, the postshelter dose.

$$D_2 \leq D_2\,(\max) = D_e^* - D_1$$

$$\leq 220 - 191$$

$$\leq 29 \text{ r}.$$

The product of D_2 and the number of men (100) give a reserve man dose of 2,900 man-r available for decontamination. The unit man dose equals the ratio of reserve man dose to the total surface area to be recovered, or

$$d_2\,(m) = \frac{D_2\, m_j}{S_j}$$

$$= \frac{2900}{469.2}$$

$$= 6.3\ \frac{\text{man-r}}{10^3\ \text{ft}^2}\,.$$

This estimate of the available unit man dose must be equal to or greater than the required unit man dose d_j. This quantity is expressed in Eq. (103) of Ref. 2 in the same way as d_2 (m), except that it is a function of actual decontamination dose required, D_2'. The calculation of D_2' is not made until routine 14. However, it is possible to make a reasonable estimate of d_j from the approximate expression

$$I^o \big/ 1700 = d_j \big/ \epsilon_j ,$$

where ϵ_j is the unit effort in man-hr/1000 ft^2. This simple relationship and the constant of proportionality were determined from the calculated results of the shopping center problem of Ref. 2, the residential recovery examples of Ref. 5, and an unpublished study of an oil refinery problem. Figure 6 contains a family of curves based on the above equation, showing d_j as a function of standard dose rate I^o for selected values of unit recovery effort ϵ_j. It is not likely that the unit effort required to recover the power plant will exceed that required for a residential area. The upper value of Figure 6 is about 1.2 man-hr/ 1000 ft^2. The curve for $\epsilon = 1.2$ intersects the 9000 r/hr dose rate line at a value of $d_j = 6.4$ man r/1000 ft^2. Because this value exceeds the above estimate of d_2 (m) by such a small amount, the decontamination dose reserve is considered to be adequate.

Routine 12: Decontamination Times

The elapsed decontamination time consumed by each method must be obtained by parts. The first part, operating time $\Delta t'_{j\ell}$, is given by Eq. (50) of Ref. 2. A solution to this expression is shown in Table 7, which lists in the last column $\Delta t'_{j\ell}$ values for various numbers of equipment units (nozzles). The second part, support time $\Delta t^o_{j\ell}$, is found from Eq. (54) of Ref. 2. Table 8 contains the solution to this equation for

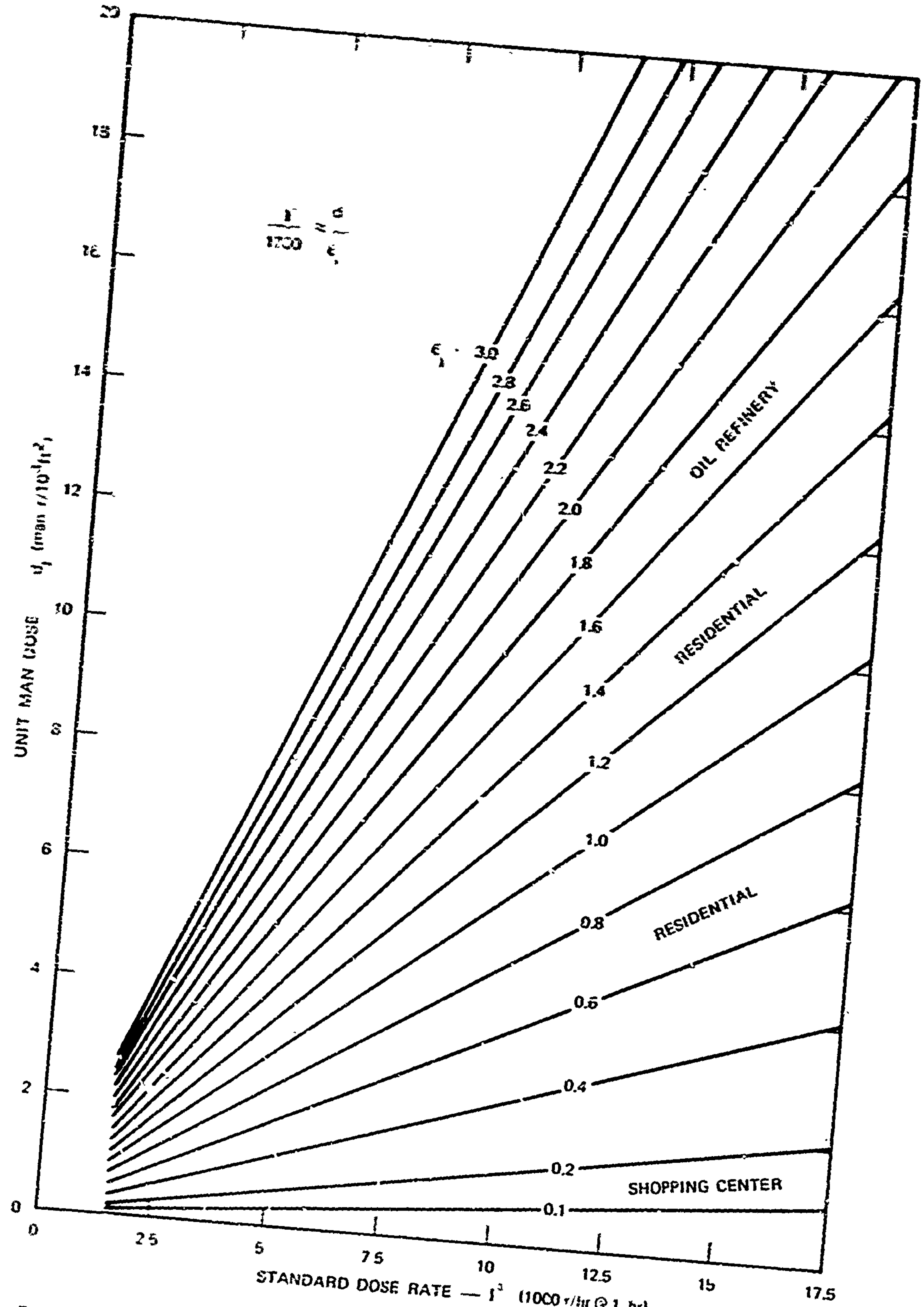


FIGURE 6 UNIT MAN DOSE VERSUS STANDARD DOSE RATE FOR SELECTED VALUES OF UNIT RECOVERY EFFORT

Table 7

FIREHOSING METHOD OPERATING TIME

Surface	Specific Effort (Equipment/ 10^3 ft^2) $e_{j\ell}$	Surface Area per Pass (10^3 ft^2) $S_{j\ell}$	Number of Passes p_ℓ	Total Operating Effort† (Equipment-hr) $E_{j\ell}$	Number of Equipment Units u_ℓ	Operating Time per Unit (hours) $\Delta t'_{j\ell}$
Pavement	0.054	166.6	1	11.25	2	5.6
					4	2.8
					6	1.9
Gravel	.16	188.7	1	37.8	2	18.8
					4	9.4
					6	6.3
					8	4.7
Bare ground	.054	129.0	1	8.7	2	4.3
					4	2.2
					6	1.4
Roofs	.185	79.4	1	18.3	2	9.2
					4	4.6
					6	3.0
					8	2.3

† Contains fatigue multiplier f_m = 1.25.

increasing numbers of nozzles. The last column of the table shows the totals for the decontamination time period, $\Delta t_{j\ell}$.

According to routine 2, the power plant has a fire system pumping capacity of 2000 gal/min. This will supply water to 20 nozzles at a recommended pressure of 75 lb per sq in. A comparison of the total decontamination times given in Table 8 indicates that the washing of the gravel surfaces requires the greatest effort. Assigning 8 nozzles to this task reduces the elapsed time to 5.2 hours. Eight more nozzles can complete the background and roof areas in a comparable time span. This leaves 4 nozzles to decontaminate the paved surfaces in less than 4 hours. Thus a total of 20 nozzles working concurrently can recover the contaminated facility and nearby surroundings in 5.3 hours. Therefore decontamination start time will be t_s = 331 hours [according to Eq. (61) of Ref. 2].

To prevent recontamination of paved surfaces, certain roofs and aboveground surfaces must be decontaminated at the beginning of the recovery period. These surfaces are:

- Unparapeted portion of roof over control room B.
- Turbine pedestal for unit No. 4.
- Roof of chlorination house.
- Roof of pump house.
- Roof of oil house.

Routine 9: Crew Residual Numbers, RN_2

All the information required for calculating RN_2 values is either available or readily derivable from previous routines and initial input information and data. If any new source contributions develop, all final values of RN_2 will contain the basic component (RN_2) as expressed by

Table 8

ELAPSED TIME FOR DECONTAMINATION

Surface	Number of Equipment Units† u_ℓ	Operating Time (hr.) $\Delta t'_{j\ell}$	Support Time (hr.) $\Delta t^{c}_{j\ell}$	Decontamination Time (hr.) $\Delta t_{j\ell}$
Pavement	2	5.6	2.0	7.6
	$\underline{4}$	2.8	1.0	$\underline{3.8}$
	6	1.9	0.7	2.6
Gravel	2	18.8	2.0	20.8
	4	9.4	1.0	10.4
	6	6.3	0.7	7.0
	$\underline{8}$	4.7	0.5	$\underline{5.2}$
Bare ground	$\underline{2}$	4.3	1.0	$\underline{5.3}$
	4	2.2	0.5	2.7
	6	1.4	0.5	1.9
Roofs	2	9.2	6.0	15.2
	4	4.6	3.0	7.6
	$\underline{6}$	3.0	2.0	$\underline{5.0}$
	8	2.3	1.5	3.8

† The underlined deployment of equipment units results in a minium elapsed decontamination time of 5.3 hours.

Eq. (67) of Ref. 2. Therefore, the first task is to solve this equation for each of the four surfaces listed in routine 8.

Because most methods operate simultaneously for long periods in large areas, the altered version of Eq. (67) applies. No method is scheduled for more than one pass so the equation will assume the simplified form.

$$(RN_2) = \sum C_x - (1-F)\, C_d/2 - (1-F)\, C_k/2 \; .$$

The various contribution factors are found from target analysis routine 3 and the appropriate equations. $\sum C_x$ is comparable to the contribution summations made earlier, except that the reference locations and the receiver heights are not necessarily the same.

The second task is to solve Eq. (69) of Ref. 2 for the depth of new source deposits. These deposits will be created only on the roof and paved surfaces. For these two cases the equation gives a new source depth of $X \approx 1/3$ cm. Since $X < 1.0$ cm, Eq. (68) of Ref. 2 will apply to the calculation of the new source contribution and a final RN_2 value. Table 9 shows the results of the various RN_2 calculations for the four basic surfaces to be decontaminated.

Table 9

DECONTAMINATION CREW RESIDUAL NUMBERS

Surface	Basic Component (RN_2)	New Source Contribution	Final Value of RN_2
Pavement	0.28	0.06	0.34
Gravel	.13	--	.43
Bare ground	.60	--	.60
Roofs	.34	.07	.41

Routine 14: Dose and Manpower

According to routine 12, recovery time $\Delta t_j \approx 5$ hours. Since this is less than 24 hours, the number of personnel changes, N_{pc}, equals the number of work shifts, N_{ws}.* Solving Eq. (77) of Ref. 2 first, the length of time that any one person can firehose is

$$\sum \delta t_{ws} \geq \frac{29 \text{ r}}{0.60\ (6.9)\ \text{r/hr}} = 6.85 \text{ hr}$$

where

D_2 = 29 r, available decontamination dose

I_r = 6.9 r/hr when the standard dose rate of 9000 r/hr is decayed to start time $t_{s\ell}$ = 331

RN_2 = 0.60 for firehosing bare ground.

Since the allowable time interval is longer than the required decontamination period, the dose D_2 will not be exceeded and time is not a critical factor. This will be true for all surfaces because the largest RN_2 value was used in the above solution of Eq. (77). Since $\Delta t_j < 8$ hr, only one work shift and one change of personnel will be required.

Equations (1), (24), (48), and (73) of Ref. 2 provide a complete history of the dose accrued by the decontamination teams. The dose charges for the various surfaces recovered are shown in the table below. It is evident from the table that all crew members receive practically the same dose. The average value for D_T indicates that the total dose is is about 44 r below the limiting value of $D^* = 270$ r/month. Thus the planned Rad/Rec procedure is acceptable as scheduled for a start time of 331 hours and a denial time of 336 hours.

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* $N_{pc} = N_{ws}-1$ is a more suitable notation, but since Ref. 2 uses $N_{pc} = N_{ws}$, it is repeated here. In this usage a personnel change is related to a work shift.

Table 10

DOSE CHARGES FOR VARIOUS SURFACES

Surface	Shelter Period		Decontamination Period		Post-Shelter Period		Total Exposure
	Radiation Exposure Dose (r)						
	D_1	+	D_2'	+	D_3	=	D_T
Pavement	191		5.0		25		221
Gravel	191		11.6		25		227.6
Bare ground	191		16.2		25		232.2
Roofs	191		9.2		25		225.2
Average dose							226.5

It is evident from the table that all crew members receive practically the same dose. The average value for D_T indicates that the total dose is about 44 r below the limiting value of $D^* = 270$ r/month. Thus the planned Rad/Rec procedure is acceptable as scheduled for a start time of 331 hours and a denial time of 336 hours.

Because dose has been shown to present no serious problems to the recovery of the power plant, a manpower allotment can be made up according to the decontamination times and tentative equipment allocation of routine 12. By using Eqs. (82) and (84) of Ref. 2, the allotment arrived at is shown in Table 11. The maximum number of workers required at any one time will also be 70 men since there is only one work shift. Inasmuch as the allowable decontamination time was found to be more than ample, the schedule could be relaxed. That is, fewer men could be used over longer periods, and this would free additional plant personnel for

Table 11

MANPOWER ALLOTMENT FOR DECONTAMINATION

Surface $\,$	Men/Equipment Unit or Team m_u	Number of Equipment Units/Method u_ℓ	Men/Shift m_ℓ	Number of Personnel Changes* N_{pc}	Total Men/Method $m_{j\ell}$
Pavement	3.5	4	14	1	14
Gravel	3.5	8	28	1	28
Bare ground	3.5	2	7	1	7
Roofs	3.5	6	21	1	21

Total manpower required $m_j = 70$

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* See footnote, p. 37

regular duty. Even with the short schedule, 30 men are available for regular plant chores and need not be considered for the recovery operation.

Fallout Effects

The D/DC model was applied to two additional fallout situations at increased standard dose rates of 18,000 and 27,000 r/hr. The 14-day shelter exit time used previously was retained. A summary of the results of these two cases, together with the case presented above, is shown in Table 12. In addition to the findings determined from the model inputs and computational routines, Table 12 includes the cost and effectiveness measures obtained from Eqs. (88) through (107) of Ref. 2.

It is evident from Table 12 that elapsed decontamination time Δt_j, available decontamination dose D_2, actual decontamination dose D_2', unit man dose d_j, unit effort ϵ_j, water consumption g_j, accelerated entry

Table 12

COMPARISON OF PERTINENT MODEL PARAMETERS FOR THREE FALLOUT CONDITIONS

Parameters	Symbol	Units	Case Number I	II	III
Standard dose rate	I^{o}	r/hr	9,000	18,000	27,000
Mass loading	M_{o}	g/ft²	100	150	200
Shelter adequacy	PF	for 1 week	123	246	369
	$\overline{PF}$	for decontamination	136	300	500
Available decontamination dose	D_{2}	r	29	47	65
Elapsed decontamination time	Δt_{j}	hr	3.8-5.3	4.8-6.4	4.8-6.4
Decontamination start time	t_{s}	hr	331	330	330
Manpower required	M_{j}	men	70	70	70
Decontamination dose	D_{2}'	r	5.0-16.2	10.1-32.4	15.2-48.6
Average total dose	D_{T}	r	226	220	222
Average conserved dose	D_{C}	r	44	50	48
Unit man dose	d_{j}	man-r/1000 ft²	1.24	2.98	1.48
Unit effort	ε_{j}	man-hr/1000 ft²	0.60	0.69	0.69
Water consumption	g_{j}	gal/ft²	1.05	1.2	1.2
Residual fraction	$\bar{F}$	- -	0.073	0.036	0.035
Recovery rate	R_{j}	1000 ft²/hr	106	88	88
Accelerated entry	Δt_{acc}	days	13	15	84
Effectiveness-to-cost ratio	$\Delta t_{acc}/t_{e}(max)$		0.48	0.76	0.86
Effectiveness-to-cost ratio	D_{C}/D_{T}		0.20	0.23	0.22

Δt_{acc}, and effectiveness-to-cost ratio $\Delta t_{acc}/t_e$ (max) all increased with standard dose rate I^o. Residual fraction $\bar{F}_j$ and recovery rate R_j decreased because of the increase in fallout mass loading. Decontamination start time moved up since exit time t_e was held constant and the elapsed decontamination time Δt_j increased. The increase in available decontamination dose D_2 with standard dose rate was caused by an increase in $\overline{PF}$. Had the ratio of $I^o/\overline{PF}$ increased with dose rate, then D_2 would have decreased (as it eventually must for higher and higher values of I^o).

Since it was possible to increase the effective protection factor $\overline{PF}$ by shortening the length of the work periods devoted to plant operations, the shelter dose actually decreased as I° increased. This decrease in D_1 was offset by an increase in decontamination dose D_2' and postshelter dose D_3. As a result, total dose D_T, conserved dose D_C, and effectiveness-to-cost ratio D_C/D_T remained essentially constant. Were it not for this capability to adjust $\overline{PF}$, D_T would have increased and the ratio D_C/D_T would have decreased. For higher values of I°, conserved dose D_C and the ratio D_C/D_T must eventually go to zero.

A comparison of the various parameters listed in Table 12 with those derived in Ref. 2 for the shopping center recovery problem indicates that the unit costs for recovering the power plant were higher (refer to values of d_j, ϵ_j, and g_j). This is true because decontamination was restricted to manual firehosing methods for the power plant whereas 85 percent of the shopping center was decontaminated by mechanized methods. There is little advantage to be gained by the introduction of street sweepers or street flushers (if available) into the power plant recovery operation, since only about one-fourth of the total surface area is accessible to such equipment. It is inferred, therefore, that by virtue of its physical characteristics, the power plant was more difficult to recover from the standpoint of higher unit costs. However, the overall decontamination effectiveness values (denoted by the average residual fraction $\bar{F}_j$) achieved on the power plant and the shopping center were comparable.

It was demonstrated earlier that the $\overline{PF}$ of 136 calculated for Case I was based on the stipulation that workers spend no more than 6 hours a day at their plant job outside of primary shelter. This reduced the numbers of jobs that could be manned around the clock from a peace-time level of 33 to a reduced level of 25. To conserve shelter dose in Case II so that D_2 would still be ample, the work period had to be decreased to 2.7 hours, which provided a $\overline{PF}$ of 300. This meant a further reduction in the number of jobs that could be performed to 11. Finally, in Case III a $\overline{PF}$ of 500 required that men work only about 1.6 hours a day, and the number of jobs performed dropped to 7.

Figure 7 relates these three radiological cases to four levels of plant operation as a function of the number of jobs performed versus the effective protection factor for different size work forces. The upper curves for 100 men indicate that Cases I and II do not impose any undue hardship on plant operations, but operating levels are below peacetime standards. In Case I, all 10 plant operators can function with some support. Case II coincides with operating level B--10 operators and no support. However, the plant can function with 5 operators (level C). Therefore, half of the 10 jobs could be assigned to support 5 operators. The absolute minimum level of operation for this plant is 2 men, 1 in each control room. This level is not recommended for protracted periods, even approaching 2 weeks. Level C, therefore, should be considered the minimum operating level for radiological situations demanding reduced operations for periods of 1 to 3 weeks. Case III is just above this limiting level.

Table 12 shows that the number of decontamination personnel remains constant at 70 men because 70 men with 20 nozzles use most of the fire system pumping capacity and no more than one work shift was required regardless of the standard dose rate. It is of interest to know whether the work force could be reduced from 100 to 70 men. Figure 7 contains

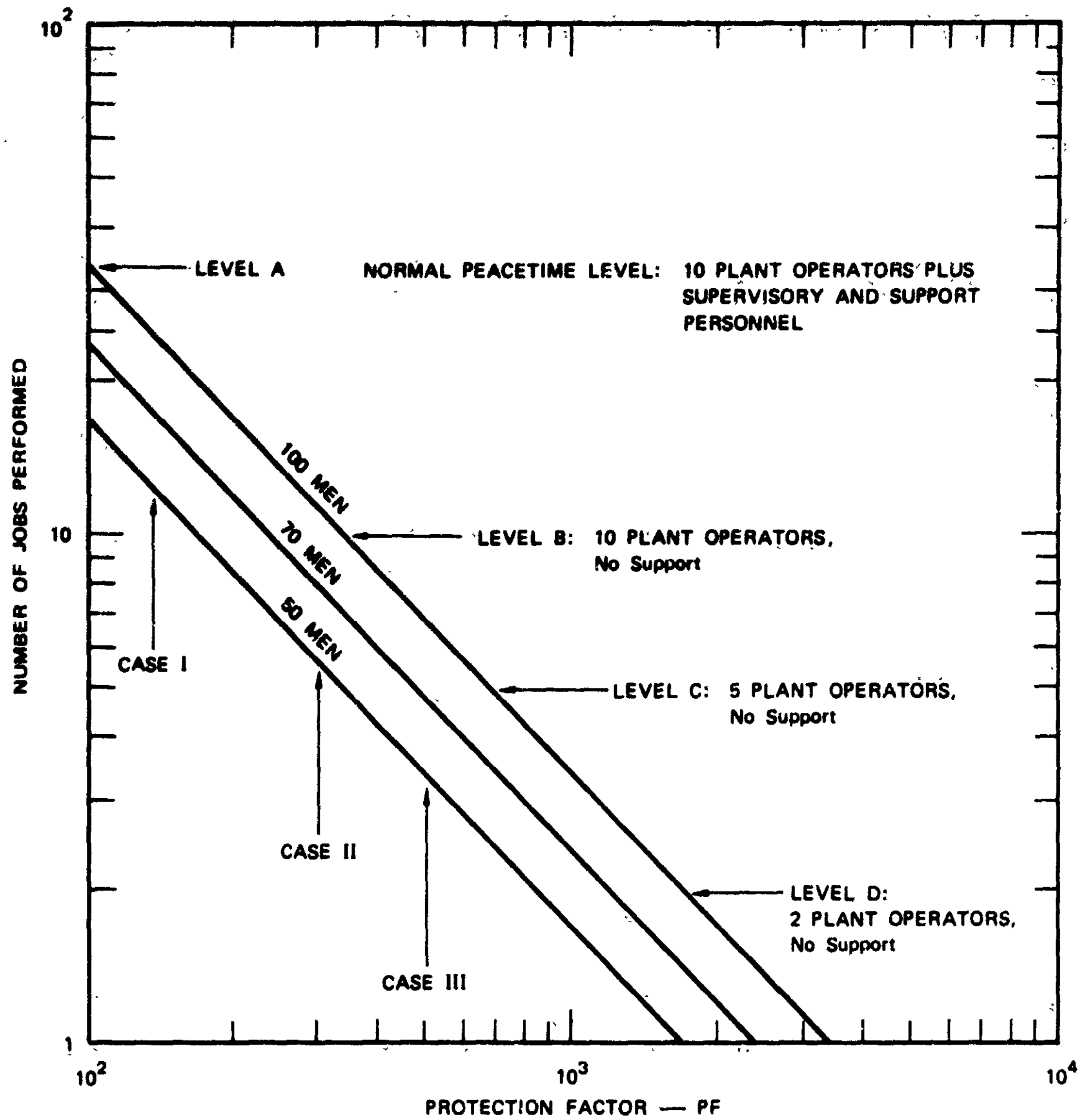

FIGURE 7 VARIOUS LEVELS OF POWER PLANT OPERATIONS IN TERMS OF JOBS PERFORMED VERSUS $\overline{PF}$, FOR A GIVEN SIZE WORK FORCE

a curve for a 70-man work force. The intersections of this curve with Cases I, II, and III show that plant operations would be reduced to 17, 8, and 5 jobs, respectively. Case I creates no hardships on operations. Case II allows for 5 operators with some support. Case III is border line since 70 men can barely furnish the job requirement of operating level C. Thus, if standard dose rates are not anticipated to exceed 27,000 r/hr, the plant could function and recover with a complement of 70 able-bodied men.

Aside from the capability to increase $\overline{PF}$ by reducing the level of plant operations, there are also alternatives open for reducing the number of men required for the decontamination effort. For example, the bare ground areas could be omitted from the recovery task because their contribution to the dose accrued by people engaged in plant operations in the post shelter period is extremely small.

It should be possible to roughen these bare ground surfaces as part of the preattack preparation. This could be achieved by scarifying with agricultural implements or by spreading the surface with the gravel removed from the roofs. The increased roughness would practically eliminate the migration of fallout particles from the ground areas to more sensitive locations near the buildings.

Because of the small radiation contribution from the switch yard, it may be desirable to reduce the effort expended in decontaminating that area. For instance, decreasing the number of nozzles from 8 to 4 (without changing the time interval $\Delta t_{j\ell}$) would free 14 men from the recovery operations. The remaining crews could still hose down the switch yard equipment, but the washing of the fallout into the gravel bed would not be so effective. Assuming that an additional 7 men are freed from hosing the bare ground surfaces, a total of 49 men would be needed for decontamination. The lower curve of Figure 7 shows that 50 men can manage the power plant for Cases I and II, although the latter is marginal at operating level C. Case III cannot be handled with so few men since it falls below the established minimum level of operation. The effects of these changes of recovery effort on the postshelter dose D_3, and hence total dose D_T, would not be significant.

V SUMMARY AND CONCLUSIONS

The foregoing describes the application of a previously developed decontamination and dose control model to the problem of planning and scheduling the radiological recovery of a representative critical industrial installation, i.e., a steam power plant. The purpose of this study was to determine the magnitude of recovery operations and the related planning factors generated by the model under varied radiological conditions.

The model application has shown that the Hunters Point power plant can be successfully recovered and operated, when subjected to a broad range of fallout dose rates and fallout mass loadings, without exceeding the total number of men currently employed. Seventy man can decontaminate 13 acres of roofs and grounds in 4 to 6 hours. On completion of decontamination at the end of 14 days, all plant personnel are free to resume their regular duties--providing no more than about 6 hours per day are spent outside of the major structural complex the first month after attack. Without a decontamination effort, denial times would range from 1 month to over 3 months.

Although the power plant can stay on line with as few as 5 operators on duty, 10 times as many people are required to distribute the exposure dose and to man the minimum decontamination effort. Thus 50 men can operate and recover the plant if the standard dose rate does not go higher than 18,000 r/hr. A 70-men complement is required when standard dose rates reach 27,000 r/hr, and 100 men are needed for standard dose rates in excess of 30,000 r/hr. With this same number of men the plant can operate on a normal cycle of three 8-hour shifts until the standard dose rate exceeds 6000 r/hr.

In general, the pertinent model parameters tended to increase with standard dose rate. Exceptions included total dose D_T, conserved dose D_C, and the cost-to-effectiveness ratio D_C/D_T, which all remained relatively constant. The last value indicates that plant personnel would accumulate about 80 percent of the total dose allowed the first month after attack. Comparison of the various model parameters obtained in this study with those given in Ref. 2 shows that the unit costs for recovering the power plant are greater than those found for recovering the shopping center. Since this difference can be attributed to the fact that power plant recovery cannot be greatly improved through the use of mechanized methods, it is considered more difficult to recover than the shopping center.

It is recommended that the decontamination and dose control model be applied to still other essential sites and installations. For instance, the thin-shelled buildings characteristic of canneries, salt works, and sugar refineries would present a recovery problem very different from more heavily shielded structures like power plants. Such a study would provide additional information for determining the effects of target configuration and structural properties on recovery planning and scheduling.

Appendix A

SYMBOL DEFINITIONS

Appendix A

SYMBOL DEFINITIONS

A_f	Facility attenuation factor
A_j	Target attenuation factor
C_d	Maximum decontamination contribution factor
C_j	Contribution factor to location j
C_k	Contribution factor for surface k
C_{jk}	Contribution factor of surface k to location j
C_x	Contribution factor for x^{th} surface
d_j	Required unit man dose (man r/1000 ft^2)
$d_2(m)$	Unit man dose (man r/1000 ft^2)
D^*	Allowable dose (r)
D_c	Average conserved dose (r)
D_e^*	Allowable dose at time of shelter emergence (r)
D_T	Total dose (r)
D_1	Shelter dose (r)
D_2	Available decontamination dose (r)
D_2'	Decontamination dose (r)
$D_2(max)$	Available decontamination dose (r)
D_3	Reoccupation dose (r)

DRM_a'	Dose rate multiplier at effective arrival time
DRM^*	Dose rate multiplier at one month
DRM_e	Dose rate multiplier at time of emergence
ΔDRM_1	Dose rate multiplier for shelter period
ΔDRM_3	Dose rate multiplier for reoccupation period
$e_{j\ell}$	Specific effort (equipment hours or team hours per 1000 ft^2)
$E_{j\ell}$	Operating effort (equipment hours)
ERD	Equivalent residual dose (r)
ϵ_j	Unit effort (man-hours/1000 ft^2)
f_m	Fatigue multiplier
F	Residual fraction
$\bar{F}$	Average residual fraction
F_j	Fraction of fallout remaining on surface j
$\bar{F}_j$	Average fraction remaining at j
F_{jk}	Removal effectiveness for surface k by method j
F_{jw}	Weather removal effectiveness at surface j
$\bar{F}_{jw}$	Average weathering effectiveness at surface j
$F_j(t)$	Trial estimate of recovery effectiveness at surface j
$\bar{F}_j(t)$	Average trial effectiveness at surface j
g_j	Water consumption (gal/ft^2)
I^0	Standard dose rate (r/hr at 1 hr)
I_r	Dose rate at decontamination start time
m_j	Number of men

m_{ℓ}	Men per shift
$m_{j\ell}$	Total men per method
m_u	Men per equipment or team
M_j	Manpower required
M_o	Fallout mass loading (g/ft^2)
N_{pc}	Number of personnel changes
N_{ws}	Number of work shifts
P_{ℓ}	Number of decontamination passes
PF	Effective protection factor
$\overline{PF}$	Minimum protection factor required
R_j	Recovery rate ($1000\ ft^2 \cdot hr$)
RN_2	Decontamination crew residual number
RN_3	Reoccupation residual number
RN_3'	Effective residual number (period 3)
$RN_3'(t)$	Trial estimate of RN_3
S_j	Total surface area
$S_{j\ell}$	Surface area per pass
t_a	Time of fallout arrival (hours after burst)
t_a'	Effective fallout arrival time (hours after burst)
t_c	Time of fallout cessation (hours after burst)
t_e	Shelter exit time (hours after burst)
$t_e(max)$	Maximum shelter exit time, no decontamination
t_s	Decontamination start time (hours after burst)

$t_{s\ell}$	Decontamination start time (hours after burst)
Δt_{acc}	Accelerated entry time (days)
Δt_j	Recovery time (hours)
$\Delta t_{j\ell}$	Decontamination time (hours)
$\Delta t'_{j\ell}$	Operating time (hours)
$\Delta t^o_{j\ell}$	Support time (hours)
δt_{ws}	Maximum work shift time (hours)
u_ℓ	Number of equipment units

Appendix B

LIST OF EQUATIONS FROM REFERENCE 2

Appendix B

LIST OF EQUATIONS FROM REFERENCE 2

$$D_1 = \frac{1.33}{PF} \; I^o \; \Delta DRM_1 \le D_1^* \; . \tag{20}$$

$$t_a' = 0.6 \; t_a + 0.4 \; t_c \; . \tag{21}$$

$$D_1 = \frac{1.33}{PF} \; I^o \; (3.03 - DRM_a') \le 190 \; r \; . \tag{24}$$

$$PF \ge 0.007 \; I^o \; (3.03 - DRM_a') \; . \tag{25}$$

$$RN_3 = \sum_{k=1}^{K} C_{jk} \; F_{jk} \; . \tag{26}$$

$$\sum_{k=1}^{K} C_{jk} = \bar{A}_j \; . \tag{27}$$

$$RN_3 = \bar{F}_{jw} \; \bar{A}_j \; . \tag{28}$$

$$\bar{F}_{jw} = \sum_{k=1}^{K} C_{jk} \; F_{jkw} \Bigg/ \sum_{k=1}^{K} C_{jk} \; . \tag{29}$$

$$A_f = \frac{I_i}{I_j} = \frac{\sum C_i}{\sum C_j} = \frac{\bar{A}_i}{\bar{A}_j} = \frac{PF_j}{PF_i} \; . \tag{31}$$

$$RN_3' = \frac{\bar{F}_{jw}\,\bar{A}_j}{3}\left(2A_f + 1\right) . \qquad (32)$$

$$RN_3'\ I^o\ \Delta DRM_3 + D_1 \leq D^* . \qquad (33)$$

$$RN_3'(t) = \frac{D^* - D_e^*}{I^o\ \Delta\ DRM_3} \qquad (37)$$

$$\bar{F}_j(t) = \frac{3\ RN_3'\ (t)}{\bar{A}_j\ (2A_f + 1)} \qquad (42)$$

$$RN_3' = \frac{\sum_{k=1}^{K} C_{jk}\ F_{jk}}{3}\ (2A_f + 1) . \qquad (46)$$

$$At_{j\ell}' = \frac{E_{j\ell}'}{u_\ell} = \frac{e_{j\ell}\ S_{j\ell}\ p_\ell}{u_\ell}\ \left(f_M\right) . \qquad (50)$$

$$At_{j\ell}^o = \left(\frac{N_{su}}{n_{su}}\right)\ \delta t^o . \qquad (54)$$

$$t_s = t_e - \Delta t_j . \qquad (61)$$

$$RN_2(p) = A(e)\sum_{x=1}^{q} C_x - A(e)\sum_{x=1}^{\ell-1}(1 - F_x)\ C_x$$

$$- \frac{A(e)}{2}\ (2 - F_{p-1} - F_p)_k\ C_k . \qquad (67)$$

$$RN_2\ (p) = Eq.(67) + \frac{\left(F_{p-1} - F_p\right)\ WL\ A_N^e}{2\ \delta^2\ 29} . \qquad (68)$$

$$x = 30.5 \, \frac{\left(F_{p-1} - F_p\right) WL}{wb\rho} \, m_o \; . \tag{69}$$

$$\sum \delta t_{ws} \geq \frac{D_2}{RN_2 \, I_s} \; . \tag{77}$$

$$m_\ell = u_\ell m_u \; . \tag{82}$$

$$m_j = \sum_{\ell=1}^{L} m_{j\ell} \; . \tag{84}$$

$$d_j = \sum_{\ell=1}^{L} D_2' \, m_{j\ell} \Big/ S_j \; . \tag{103}$$

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13. ABSTRACT

The development by Stanford Research Institute of a Decontamination and Dose Control (D/DC) Model has provided a systematic method for planning and evaluating the radiological recovery of contaminated sites and facilities. The output of the D/DC model is highly dependent on prominent physical characteristics of the target complex. To obtain information on the effects of target configuration on recovery planning and scheduling, the D/DC model was applied to the recovery of a steam power plant.

The model application showed that this specific plant can be successfully recovered and operated when exposed to a wide range of fallout conditions without having to hire any additional help. A complement of 70 men can run the plant and participate in its decontamination, if standard dose rates do not exceed 27,000 r/hr.

Comparison of the various model parameters derived in this study with those obtained from a similar application of the D/DC model to a shopping center indicates that the unit costs for recovering the power plant are consistently higher.

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