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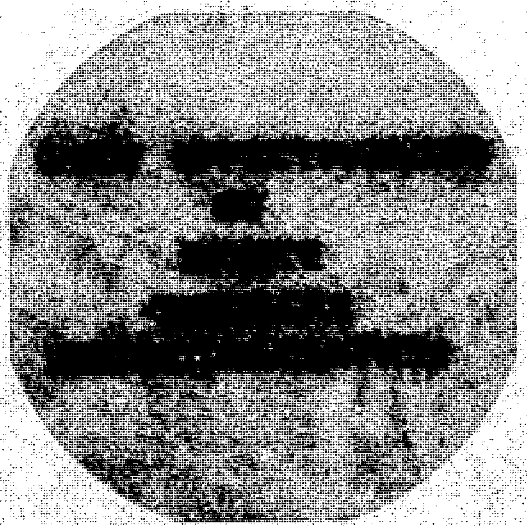

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COST EFFECTIVENESS OF DILUTE CHEMICAL DECONTAMINATION

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ABSTRACT

The basic principles of dilute chemical decontamination are described, as well as the method of application. Methods of computing savings in radiation dose and costs are presented, with results from actual experience and illustrative examples. It is concluded that dilute chemical decontamination is beneficial in many cases to:

- reduce radiation exposure of workers
- save money
- simplify the performance of the maintenance work

1. INTRODUCTION

Chemical decontamination has been used at nuclear establishments for many years. Traditional processes are based on the use of relatively concentrated (5 to 10 weight percent) solutions of alkalis and acids that possess oxidizing, reducing, or complexing characteristics. A large variety of techniques has been developed from which one or more methods may be selected with proven decontamination ability for almost any surface and almost any type of contaminant.

All of these concentrated solutions have one disadvantage in common; they produce relatively large amounts of noxious, radioactive waste, which is expensive to treat and dispose of in a safe and environmentally acceptable manner.

Other disadvantages presented by many of the concentrated chemical methods are their corrosivity towards materials of construction (notably carbon steel, aluminum, and plated surfaces) and their requirement for large investment in equipment (mixers, tanks, pumps, etc.) for process application and waste treatment. These problems may be effectively dealt with at centers where small components are brought for decontamination, but become much more serious for large systems that must be decontaminated in place.

Reactors cooled with heavy water (D_2O) present a further serious problem; namely, the loss and dilution of expensive heavy water, which would occur in the draining, flushing, and refilling of systems when using any concentrated chemical decontamination process.

To overcome these disadvantages, a technique was sought for the CANDU-PHW* design of reactor that would be relatively noncorrosive, would produce waste that could be easily managed, and particularly, would avoid the downgrading of reactor coolant (heavy water).

Such a process was devised in the early 1970s, and was given the name CAN-DECON™. The CAN-DECON™ concept gave rise to related studies under the generic title of Dilute Chemical Decontamination (DCD).

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*CANDU-PHW: CANada Deuterium Uranium Pressurized Heavy Water Reactor

2. THE CAN-DECON™ PROCESS

The CAN-DECON™ concept embraces the addition of chemicals directly to the coolant in the system to be decontaminated to give a dilute solution; removal of activity and regeneration of the reagent with cationic ion exchange resins; and finally, removal of the decontaminating reagent with mixed bed ion exchange resins. A photograph and a flow diagram of the equipment used to decontaminate the reactor water cleanup system at boiling water reactors (BWRs) are shown as Figures 1 and 2.

The actual application consists of the following steps:

(a) The reactor (or other process system to be decontaminated) is shut down, and mechanical isolations and connections made as appropriate.

(b) The water in the system is purified on ion exchange resins (e.g., in a pressurized water reactor (PWR) or CANDU-PHW, the Li^+ ions would be removed to reduce the alkalinity).

(c) Pretreatments are applied when appropriate (e.g., in a BWR a pretreatment to remove copper oxide may be required; in a PWR a pretreatment to further oxidize the surface oxide may be desirable).

(d) A suitable mixture of acidic complexing agents is added to give a total reagent concentration of less than 0.5 weight percent (typically, concentrations of 0.1 to 0.2 weight percent are used).

(e) The reagent is recirculated at moderate temperature (typically 90 to 130°C) through cationic ion exchange resin, which retains the metallic ions (including most of the radioactivity) and regenerates the reagent.

(f) When the process of activity transfer from the system surfaces to the cationic resin is complete (typically 24 hours), the reagent is removed on mixed bed ion exchange resins.

(g) System surfaces are passivated by producing a clean oxide film that inhibits recontamination in subsequent service.

(h) Normal system chemistry is restored (e.g., Li^+ is added to PWR systems).

Fuller accounts of the chemistry of the CAN-DECON™ process and oxide dissolution have been published elsewhere.[1 2]

Other DCD processes under development in several laboratories[3 4 5] utilize the same basic principles as those described. The main differences are in the natures of the chemical reagents used (e.g., oxidizing reagents and activity removal on anionic resins have been proposed instead of reducing reagents and cationic resins.)[4] Since this paper deals with the cost effectiveness of DCD as a generic concept, no further discussion of the chemistry of DCD will be made here.

3. DEGREE OF DECONTAMINATION ACHIEVABLE

A few years ago there was a general belief that concentrated chemical decontamination techniques would give decontamination factors (DF)* in the range 10 to 100, whereas dilute chemicals would achieve DFs of only 2 to 5.

Concentrated chemicals will certainly produce DFs of greater than 10 on components decontaminated in tanks. However, in large systems, redeposition of activity from concentrated solution tends to limit the effective DF to values between 5 and 10, unless several fill and drain applications are made, with a corresponding increase in the volume of waste generated.

Conversely, DCD processes are more effective when used in large systems consisting of pipe and heat exchanger tubes than when used in tanks. The relatively dilute concentration and the high velocity of circulation used tend to inhibit redeposition. The effectiveness of the decontamination depends upon process parameters (the reagent composition and concentration; the temperature of application; and the duration of exposure of the system to the reagent), and can be readily controlled. Developments in DCD technology have produced many results on actual reactor systems with DFs between 5 and 10, and also many above 10.

$$\text{*DF} = \frac{\text{activity present before decontamination}}{\text{activity present after decontamination}}$$

A DF of 5 represents 80 percent reduction in field, 10 corresponds to 90 percent, and 100 to 99 percent.

Thus for piping systems there is no real difference between the DF achievable with dilute or strong chemical decontamination processes.

4. DOSE SAVINGS

For a specific task the radiation dose saved (S_t) by a decontamination is the actual dose received (D_r) in performing the task after decontamination, multiplied by the DF at the component being worked on, minus the dose received in performing the task (D_r).* That is:

$$S_t = (D_r \times DF) - (D_r)$$

Usually many tasks are performed following decontamination of a system. Then the overall dose saving (ODS) is:

$$ODS = \sum_{t=1}^{t=n} S_t - (D_d + D_w)$$

where D_d = the dose expended in performing the decontamination
D_w = the dose received in disposing of the waste arising from the decontamination

For a dilute chemical decontamination, (D_d + D_w) is typically 5 to 10 rem, which is small compared with the overall dose savings generally achieved.

After performing the DCD, the system surfaces are passivated to inhibit recontamination. If the fuel surfaces in a complete reactor decontamination are also cleaned, the rate of recontamination will be further reduced below the rate before decontamination. At a subsequent system shutdown the radiation fields may

*This reasoning assumes that the task would have been performed in the same way had there been no decontamination. When very high doses are involved, an alternative way of performing the task, e.g., using robots or remote tooling, may have to be used if decontamination is not performed.

not have returned to their values prior to the decontamination. In this case, further dose savings for additional work performed in the second shutdown are attributable to the original decontamination.

Clearly, the benefit derived from a decontamination depends not only on the DF achieved, but also on the amount of work that has to be done on the system.

Some typical values of overall dose savings achieved by DCD are shown in Table 1.

The values for dose savings in Table 1 are very large. They may appear to be unreasonably large, considering that the average annual radiation exposure at light water reactors is around 500 rem,[11] although for individual stations annual values as high as 1000 and even 2000 are not uncommon.[12]

However, for each of the cases cited in Table 1, a large amount of repair work was anticipated in each of the systems decontaminated, which would have resulted in abnormally high radiation exposures. Examples of such repair work on a reactor water cleanup system at Peach Bottom[13] and the steam generators at Indian Point-1[14] have been documented. The effects of these exposures on station operating costs have been discussed elsewhere.[15]

The equations given in this paper to assess overall dose savings are simple to use, but may give an exaggerated estimation. In particular, no mathematical allowance is made for alternative ways in which the work may have to be performed if the fields are not reduced. Instead a "judgment factor" to allow for reduced time spent in very high fields was introduced by the station staff making the estimates used in Table 1. This consideration has been included in estimations made at the Hanford reactor site,[16] where the apparent reduction potential (ARP) of occupational radiation exposure (ORE) is calculated from:

$$ARP = \alpha .\ E.\ D^n$$

where α = an experience factor ranging from 0.8 to 1.2
E = the exposure (rem) accumulated during performance of the task
D = dose rate (rem/h) at the work site
n = an experience factor ranging from 0.2 to 0.4

TABLE 1

DOSE SAVINGS BY DILUTE CHEMICAL DECONTAMINATIONS

Station	Date	System Decontaminated	Approximate Dose Saved (rem)	Ref
Douglas Point	Aug. 75	full reactor	200	6
Vermont Yankee	Oct. 79	reactor water cleanup system	900*	7
Vermont Yankee	80		175**	7
Brunswick II	Mar. 80	reactor water cleanup system	500	8
Brunswick I	Mar. 81	reactor water cleanup system	900	8
Nine Mile Point	Apr. 81	five primary recirculation pumps	700	9
Vermont Yankee	Oct. 81	reactor water cleanup system	***	10

*This is the calculated savings that would have been achieved if the work for which the decontamination was performed had been carried out. The work was not done, for reasons unrelated to the decontamination.

**Savings during 1980 shutdown are due to residual benefit of decontamination.

***Work is in progress at time of writing.

This is a very desirable way to estimate the potential savings. However, the data from which to estimate the values of the experience factors, α and n, are not usually available at operating power reactors. Accumulation of relevant data to enable the foregoing calculation to be performed, as described by Demmitt et al,[16] is strongly recommended to all station health physics staff.

5. VALUE OF ONE REM

Performing work in a radiation field is more difficult and takes longer than performing the same work without radiation. Also, more people are usually required to do the work, plus additional people to monitor fields and doses, keep records, perform medical examinations, train artisans in the nature of radiation and approved working procedures, dispose of contaminated clothing, etc. Clearly, radiation has a cost associated with it, but the cost of one unit of exposure (the rem) is very difficult to compute accurately. This topic has been discussed in more detail elsewhere.[17] The value of one rem depends on many factors; a key consideration is the availability of skilled workers to perform the tasks required.[18]

The value assigned to one rem by a utility when assessing the costs of work to be performed during a maintenance outage is usually in the range $1000 to $10,000. Most commonly, values in the range $5000 to $7000 are used.

6. DOLLAR SAVINGS OF DILUTE CHEMICAL DECONTAMINATION

The dollar saving achieved by a decontamination is the value of the exposure saved minus the costs of the decontamination and disposal of the waste; that is:

$$\$ \text{ saved} = (\text{overall dose saving} \times \text{value of 1 rem}) - (\text{cost of DCD} + \text{cost of waste disposal})$$

As shown in Table 1, dose savings in excess of 500 rem are typically achieved by DCD. Assuming 500 rem are saved and $5000 as the value of one rem, the value of the dose saved would be $2,500,000.

The cost to perform the DCD depends on many factors that vary with the particular decontamination performed. Some of the factors to be considered are:

(a) size of the system to be decontaminated (and hence the decontamination equipment required)

(b) availability of suitable equipment

(c) whether the equipment is leased or purchased

(d) cost of chemicals

(e) cost of ion exchange resins and disposable filters

(f) contractor costs (specialist staff, licensing fees, royalties, travel, accommodation, etc.)

It is evident that a standard value cannot be given. In practice, the cost to a utility for decontaminating a subsystem (assuming equipment is leased, not purchased) is much less than $500,000. For a full reactor system, the application cost (excluding capital cost of equipment) should be less than $1,000,000. Both of these values include the cost of disposal of the waste, since the waste produced by a DCD is only ion exchange columns and filters of relatively small volume.

To illustrate the cost/benefit of performing a DCD, three cases will be taken. The results of the three cases are summarized on Figure 3.

Case 1

Work is required inside the channel head of a PWR steam generator for, for example, in-service inspection, tube plugging, tube sleeving, etc.

Assumptions are as follows:

Average initial field	10 R/h
Value of 1 rem	$5000
Cost of decontamination	$500,000

The value of 1 rem is taken as $5000 because highly skilled workers must be used, and a relatively large number of workers, because of the short exposure time permitted per person.

The cost of the decontamination ($500,000) includes shielding, waste disposal, and the cost of the dose expended in performing the decontamination and disposing of the waste.

	DF = 2		DF = 10	
Work Required (h)	Overall Dose Saving (rem)	Net (Cost) Benefit ($000)	Overall Dose Saving (rem)	Net (Cost) Benefit ($000)
0	0	(500)	0	(500)
1	5	(475)	9	(405)
10	50	(250)	90	(50)
20	100	0	180	400
30	150	250	270	850
100	500	2000	900	4000

Thus, the break-even point is at 20 hours' work for a DF of 2, and about 12 hours for a DF of 10.

If close to 100 hours of work are required, the net benefit of the DCD is $2,000,000 (for a DF of 2), or $4,000,000 (for a DF of 10).

Case 2

Major repairs are required to the heads of several heat exchangers in the cleanup system of a BWR.

Assumptions are as follows:

Average initial field	1 R/h
Value of 1 rem	$2000
Cost of decontamination	$200,000

The value of 1 rem is assumed to be $2000 in this case because more skilled workers are assumed to be available, and the allowable duration in the work area is longer than with case 1. Shielding and work around the decontamination equipment become easier. The overall cost of the decontamination is lower.

	DF = 2		DF = 10	
Work Required (h)	Overall Dose Saving (rem)	Net (Cost) Benefit ($000)	Overall Dose Saving (rem)	Net (Cost) Benefit ($000)
0	0	(200)	0	(200)
100	50	(100)	90	(20)
200	100	0	180	160
400	200	200	360	520
600	300	400	540	880
800	400	600	720	1240
1000	500	800	900	1600

In this case the costs break even at 200 hours' work (DF = 2) or approximately 100 hours' work (DF = 10), and a savings of $1,000,000 or more results if about 1000 hours of work are required.

Case 3

Large amounts of piping have to be replaced in a BWR subsystem because of incipient cracks in sensitized welds.

Assumptions are as follows:

Average initial field	0.2 R/h (200 mR/h)
Value of 1 rem	$1000
Cost of decontamination	$100,000

In this case the average value of 1 rem is taken as $1000 because relatively less skilled workers may be used to cut out and remove the contaminated (cracked) piping. The skilled workers required to replace the piping will be working on new, clean material, although there is likely to be a low background level of radiation from surrounding equipment.

The cost of the decontamination is even lower because the relatively low initial level of activity simplifies the operation and reduces the amount of activity in the waste for disposal.

Work Required (h)	DF = 2 Overall Dose Saving (rem)	DF = 2 Net (Cost) Benefit ($000)	DF = 10 Overall Dose Saving (rem)	DF = 10 Net (Cost) Benefit ($000)
0	0	(100)	0	(100)
500	50	(50)	90	(10)
1000	100	0	180	80
1500	150	50	290	190
2000	200	100	360	260

In this case where many hours of work are required, a net benefit of the DCD is achieved after 1000 hours (DF = 2) or 500 hours (DF = 10).

7. DISCUSSION

It is evident from the foregoing three examples that the net cost or benefit of a decontamination depends on many considerations, such as:

(a) the initial radiation field
(b) presence of hot spots
(c) radiation fields from surrounding equipment
(d) the amount of work to be performed
(e) the level of skill required by the workers
(f) the availability of skilled workers
(g) the DF achieved
(h) the value assigned to 1 rem
(i) the cost of the decontamination and waste disposal

For each of the three cases cited, dilute chemical decontamination would be cost beneficial considering the above factors. There are other examples where either a different method of decontamination (e.g., hydrolazing), or no decontamination, would be the preferable course of action.

For extremely high fields (50 R/h or greater), it may be impossible to perform repair work without some reduction in fields. The cost of a decontamination is easily justified in terms of reduced station downtime to carry out the repair work. With high fields (10 R/h or greater), decontamination shows a financial benefit after only a short working period of about 10 hours or less.

When the initial fields are lower, more working time has to be necessary to justify the decontamination in dollars on a once-off basis. However, actual experience shows that reducing the radiation fields around a system permits more work to be performed (improving the safety or operability of the system) than would have been attempted in the original fields. With the low recontamination rate experienced after DCDs, further benefit of the decontamination has occurred at subsequent shutdowns. Also, the requirement to meet the ALARA principle (to maintain radiation exposures As Low As Reasonably Achievable) is a strong driving force to apply DCD, since the exposure received in performing the decontamination and disposing of the waste is generally a small fraction of the dose saved by being able to work in a lower radiation field.

Thus at high, medium, or low fields, DCD can usually be justified by savings in exposure and costs, and because it is much easier to work in a low radiation field than in a higher one.

8. SUMMARY

The origin and basic principles of the DCD concept have been described and illustrated by reference to the CAN-DECON™ process. The estimated savings from the actual application of the process at several reactors have been presented and discussed. Two methods of performing a cost/benefit appraisal have been described and discussed. This methodology requires more study by the industry, including collection by station staff of relevant data on which future cost/benefit appraisals may be based.

Finally, three illustrative cases have been examined to show the breakeven point and potential savings achievable by DCD with different initial radiation fields and different amounts of work to be done.

The overall conclusion is that there are many cases in which DCD would be desirable to reduce radiation exposure of workers, to save costs to the station, and to ease the performance of maintenance and repair work on reactor systems.

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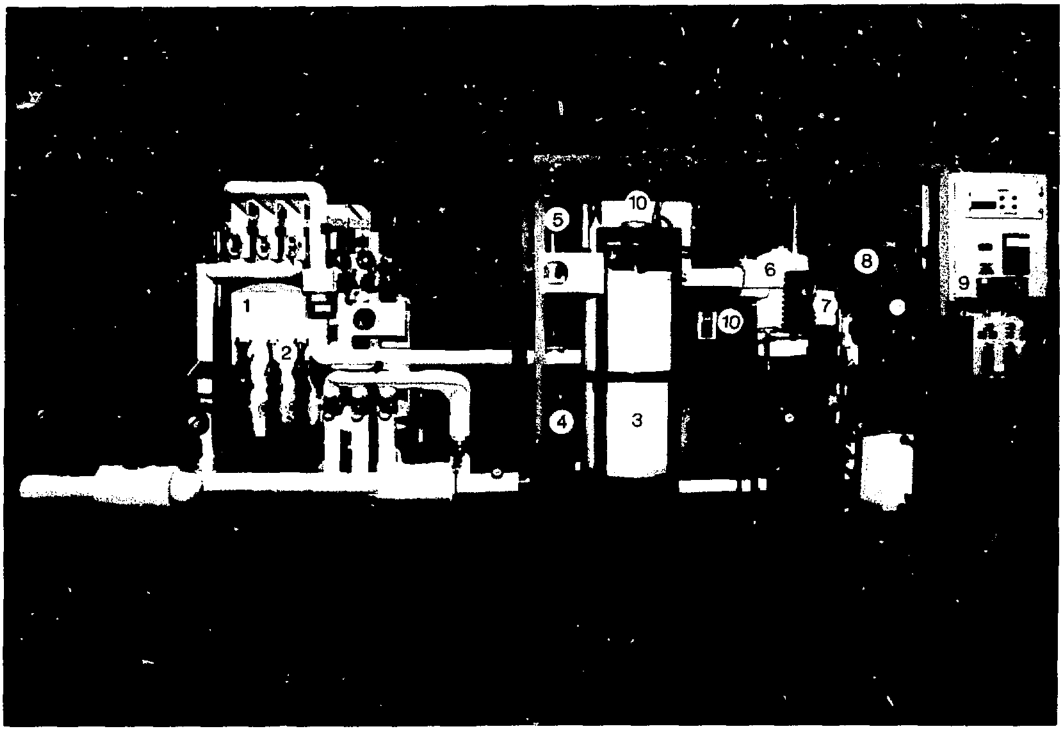
FIGURE 1

CAN-DECON DECONTAMINATION EQUIPMENT



ION EXCHANGE COLUMN SKID

1 Ion exchange columns
2 Resin slurry lines

ANCILLARY EQUIPMENT SKID

3 Reagent mixing tank
4 Chemical injection pump
5 Heater
6 Degasser
7 Sampling system
8 Surge tank
9 Control panel
10 Electrical supply panels

FIGURE 2

REACTOR WATER CLEANUP SYSTEM DECONTAMINATION LOOP

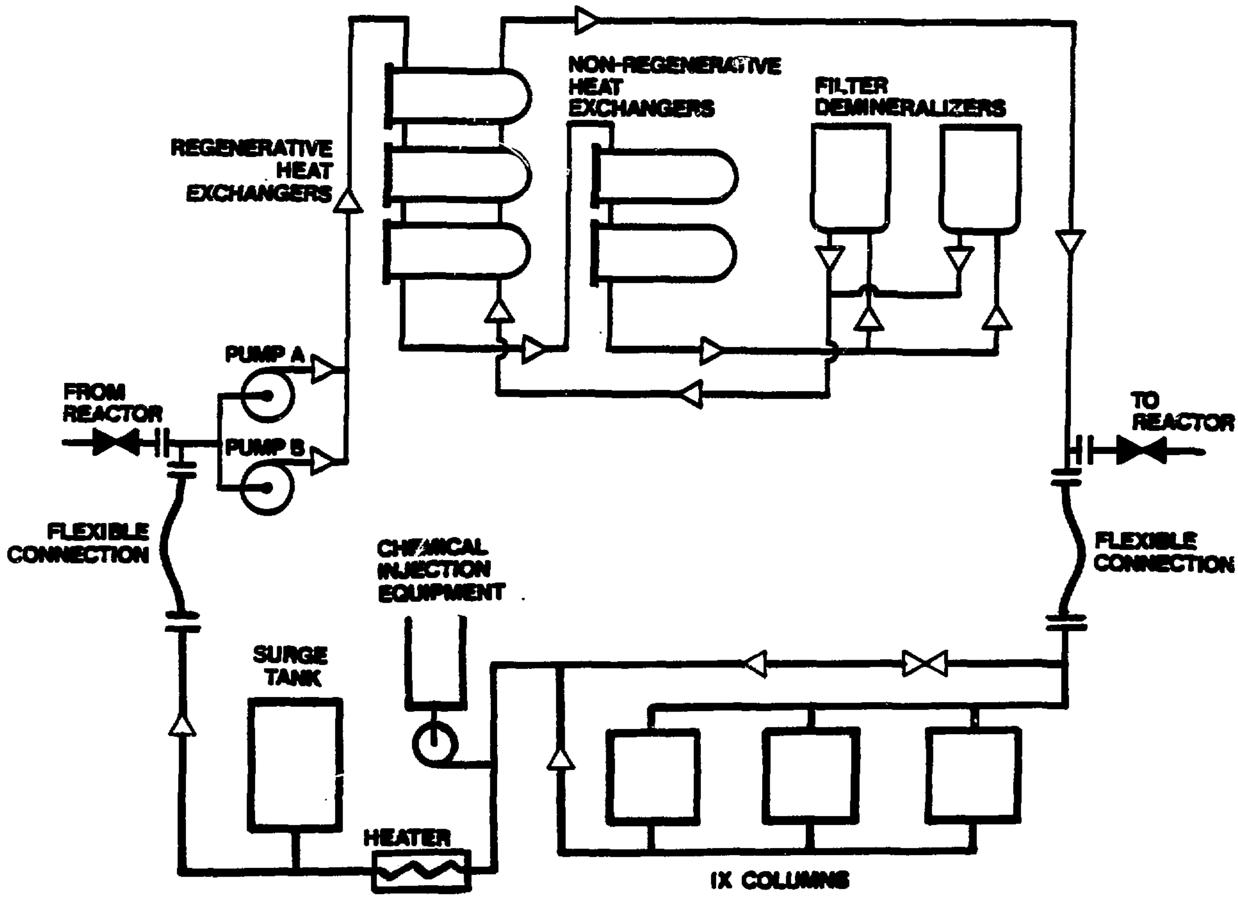
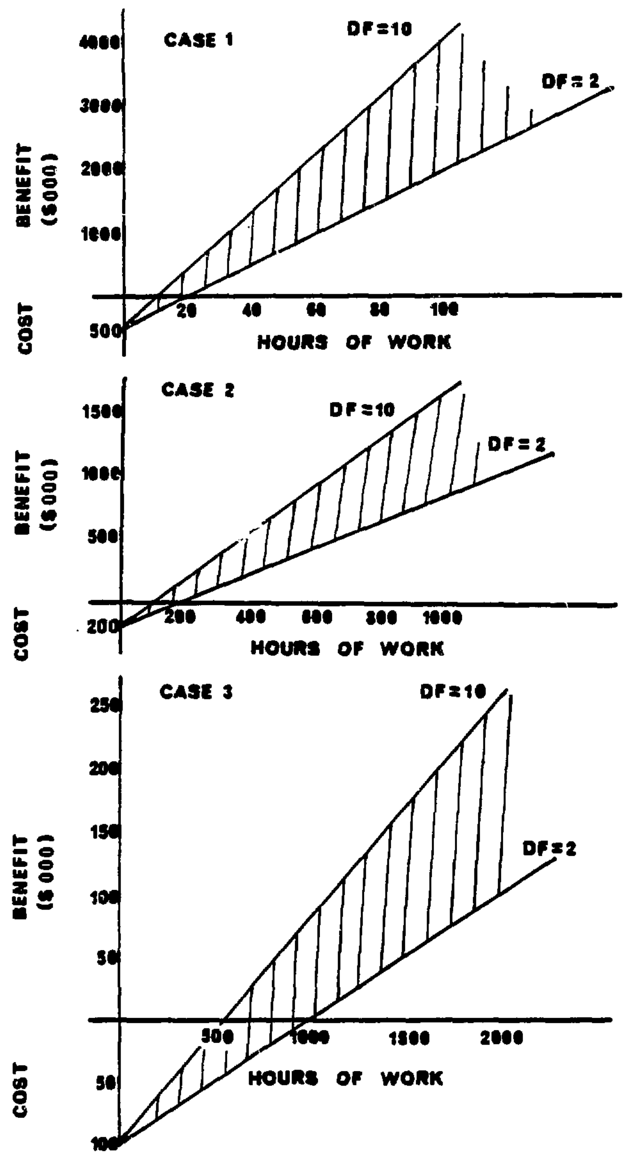


FIGURE 3

GRAPHICAL ILLUSTRATIONS OF THE COST EFFECTIVENESS OF DECONTAMINATION
(see text for details of each case)



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