OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

UNION CARBIDE

ORNL- TM- 153

COPY NO. - 41

DATE - March 7, 1962

DESIGN PHILOSOPHY FOR DIRECT-MAINTENANCE RADIOCHEMICAL PROCESSING PLANTS

by

J. C. Bresee and J. T. Long

ABSTRACT

The purpose of the paper is to describe the design philosophy of power reactor fuel processing plants using direct-maintenance techniques. In contrast to older comparisons between completely remote and contact-maintained plants, a spectrum of choices is presented within which the engineer may optimize the plant design. Optimum design depends to a considerable extent on a comparison of probable equipment and process life. An estimated probability function for trouble-free plant operation is presented as an example of the required design information. In a discussion of the influence of plant maintenance design on safety, containment criteria and calculation methods are emphasized which can provide acceptable plant safety independent of the maintenance method. Maintenance designs of two new radiochemical plants are discussed briefly.

Paper for Presentation at Nuclear Congress Session, "Radiochemical Processing of Irradiated Reactor Fuels," New York, New York, June 4-7, 1962.

DESIGN PHILOSOPHY FOR DIRECT-MAINTENANCE RADIOCHEMICAL PROCESSING PLANTS

by

J. C. Bresee and J. T. Long

Oak Ridge National Laboratory

This paper discusses the design philosophy for direct-maintenance radiochemical plants for power reactor fuel processing and presents the bases for determining the optimum maintenance technique in a direct-maintenance plant. Comparisons of direct-maintenance and remote-maintenance radiochemical processing plants have been made for many years. At the 1958 Geneva Conference on the Peaceful Uses of Atomic Energy, Schwennesen summarized the literature and the opinions of experienced American design engineers and plant operators.[1] He compared the large remote-maintenance production plants at Hanford and Savannah River with the small, direct-maintenance development-production plants at Arco and Oak Ridge. His comparisons, however, were between extremes, and he failed to point out that a spectrum of choices exists in which completely direct techniques (decontamination followed by contact maintenance) yield to more indirect methods until completely remote methods are reached (Fig. 1).

Examples of indirect equipment replacement or repair are the replacement of a filter cartridge through a small roof plug[2] and the use of a shielded cubicle like a lead telephone booth to lower a workman by crane into a radioactive cell for repairs, both done at the Idaho Chemical Processing Plant. At Marcoule the mixer-settlers were placed behind a shielding wall of stacked barytes blocks so that access was possible by removing a few blocks.[3] The chemical plant for the Homogeneous Reactor

UNCLASSIFIED
ORNL-LR-Dwg. 66771

EXHAUSTIVE DECON. FOR REPAIR OR SWITCH TO SPARE	PARTIAL DECON. FOLLOWED BY REMOVAL AND REPLACEMENT WITH REMOTE TOOLS (INCLUDING UNDERWATER)	PARTIAL DECON. FOLLOWED BY REPAIR WITH INSTALLED MANIPULATOR	PARTIAL DECON. FOLLOWED BY CRANE REMOVAL OF RACK-MOUNTED ASSEMBLIES	RINSING FOLLOWED BY REMOVAL AND REPLACEMENT OF ANY OR ALL VESSELS AND PIPING BY CRANE
NO FLANGES	SOME FLANGES OR DISCONNECTS		SEVERAL DISCONNECTS	MANY REMOTE CONNECTORS

Fig. 1. THE MAINTENANCE SPECTRUM

Experiment No. 2 at Oak Ridge National Laboratory was built in a pit that could be flooded with water so that workmen could carry out maintenance with long tools, using the water as a transparent shield. The same underwater technique will be combined with replacement performed with a manipulator and with removal of rack-mounted assemblies of components by a crane in the recovery of transuranium elements at Oak Ridge National Laboratory.

In the design of a modern radiochemical plant, a choice between direct and remote maintenance may not be as appropriate as the answer to two questions: (1) Does a choice of maintenance procedures exist? And, if so, (2) Where on the maintenance spectrum will the plant lie? Whether or not there is a choice depends largely on the feasibility of equipment decontamination. For example, since complete decontamination procedures are not available for the Oak Ridge National Laboratory Fluoride Volatility process, completely remote maintenance would probably be necessary for a plant using it. The equipment for a chop-leach head-end step probably could not be adequately decontaminated and would be too expensive to duplicate; hence remote replacement would have to be provided. For more conventional head-end treatments, particularly total dissolution, the second question becomes pertinent.

CHARACTERISTICS OF DIRECT-MAINTENANCE PLANTS

At least 17 plants with maintenance provisions nearer the direct than the remote end of the spectrum have been built or are under construction (Table 1), and many others have been designed. The most important common characteristic of these plants is the location of the heavy-duty crane outside the primary biological shielding. This feature results in as

Table 1. Western Direct-Maintenance Radiochemical Plants

Operating Plants

Plant Location and Name	Year in Operation	Present Status	Process	Maintenance Philosophy	Production Rate
ORNL, Bldg. 3503	1950	Standby	Interium 23	Contact	100 kg Th/day
ORNL, Bldg. 3019	1951 1956 1957	Dismantled Standby Operating	Purex Thorex Volatility	Contact Contact Contact	50 kg U/day 200 kg Th/day 10 kg U-235/ batch
ORNL, Bldg. 3505 (Metal Recovery)	1952	Standby	Purex	Contact	500 kg U/day
ORNL, FPDL	1958	Operating	F. P. Re-covery	Contact	Varies
ORNL, Bldg. 4507	1962	Operating	Purex, Ion Exchange	Contact	10 kg U/day
Dounreay, DMTR DFR	1957 1959	Operating Operating	TBP TBP	Contact Contact	> 75 kg U/yr
Marcoule	1958	Operating	TBP	Contact	Classified
Cherbourg	In const.		TBP	Contact	Less than Marcoule
Eurochemic	In const.		Purex	Contact	350 kg U/day
Italian Allis Chalmers AE Vitro Highly Enr. AE	In design study		ThO_2-UO_2 Amine Solv.	Contact Contact	1.5 kg/day unknown

Plant Location and Name	Year in Operation	Present Status	Process	Maintenance Philosophy	Production Rate
ORNL, HRT	1957	Standby	Solids separation H_2SO_4	Direct Underwater	90 gal/hr
Norway, Jener	1961	Operating	TBP	Contact	3 to 10 t/yr
Chalk River-"Trigly"	1949	Dismantled	trigly-hexone-TTA	Contact	Unknown
Chalk River-U Recovery	1952	Dismantled	TBP	Contact	200 lb U/day
Chalk River-Anion Exch.	1955	Standby	Anion Exch.	Contact	100 lb U/day
Chalk River-TBP Pilot Plant	Unknown	Dismantled	TBP	Contact	25 lb U/day
W. R. Grace and Co. Davison Chemical Division	In design		Chop-leach, Darex, Purex, Thorex	Contact and Remote	1 t/day
Japan	In design		Purex	Contact	1 t/day
India	In constr.		Purex	Contact	1 t/day
		DESIGN STUDIES			
DuPont, DP-566	Study		Purex Purex Purex	Remote Contact Remote	10 t/day 10 t/day 1 t/day
ORNL, Multipurpose	Study		Multiple	Remote	6 t/day
ORNL, Project Hope	Study		TBP	Contact	5.5 kg U-233/day
ORNL, Purex	Study		Purex	Contact	3 t/day
AEC reference plant	Study		Multiple	Contact	1 t/day
ICPP, Small Plant Design IDO-14521	Study		Mechanical Head-end, Purex	Contact	67.6 kg/day

much as 50% less shielded volume than when the crane is inside the shield for remote maintenance and also in easier repair of the crane which must itself be contact-maintained. The shielded volume is further decreased by stacking the equipment, since it does not have to be accessible to the crane from above.

Another characteristic of these direct-maintenance plants is the location of equipment in unit shields or blisters to decrease the amount of the plant that must be decontaminated when a breakdown occurs. This advantage is somewhat offset by an increase in the capital cost. A direct-maintenance plant has various levels of radioactivity segregated so that equipment in an area of low radioactivity can be worked on without decontamination of the high-activity areas.

Direct-maintenance plants have also been characterized by a minimum of flanges and moving parts. Flanges or disconnects are useful when equipment must be removed. However, the increased difficulty of plant decontamination that results from a leaking flange has led to the use of all-welded piping which is cut and re-welded when necessary. Avoidance of moving parts has led to the elimination of pumps, agitators, and centrifuges. Adoption of the concept of indirect replacement of selected equipment results in an increase in the use of disconnects and moving parts.

CONSIDERATIONS IN DETERMINING THE MAINTENANCE COURSE

In the design of a direct-maintenance radiochemical plant, provision can be made for one of three choices for the course to be followed in the event of failure of a piece of equipment within the shielding: (1) switching to duplicate equipment, (2) equipment replacement by indirect means, and (3) repair by contact maintenance after decontamination (Fig. 2). Provision of duplicate equipment can involve two alternates: (a) the duplicated equipment can be located in a common cell, in which case the first choice disappears after the initial failure and the second failure automatically requires a decontamination, or (b) the duplicated equipment can be in separate cells so that, as soon as operation is switched to the spare equipment, the original can be decontaminated, repaired, and placed on standby status. The choice among the several alternatives should be made on the basis of an economic analysis.

Probable Equipment Life. Performing an economic analysis requires a knowledge or estimate of the costs of the several maintenance alternatives, and of the probabilities of their being needed. Design engineers would be expected to understand readily the need for cost data and methods for estimating it, but they are less likely to be aware of the need for or the source of precise probability data. The probability function that is needed is for the useful life of processing equipment.

In principle, at least, an important decision tool can be obtained by comparing the expected life of the process equipment with the expected life of the process (Table 2). If the operating time that can be expected before the plant will have to be decontaminated anyway for process modification is less than the expected life of the equipment, maintenance will not be a problem. If the operating time is likely to exceed the trouble-free life of the equipment but not that of the equipment and an installed spare, then equipment duplication is suitable. However, if the operating time is expected to be several times the trouble-free life of the equipment, provision for equipment replacement is recommended. Equipment

UNCLASSIFIED
ORNL-LR-Dwg. 66772

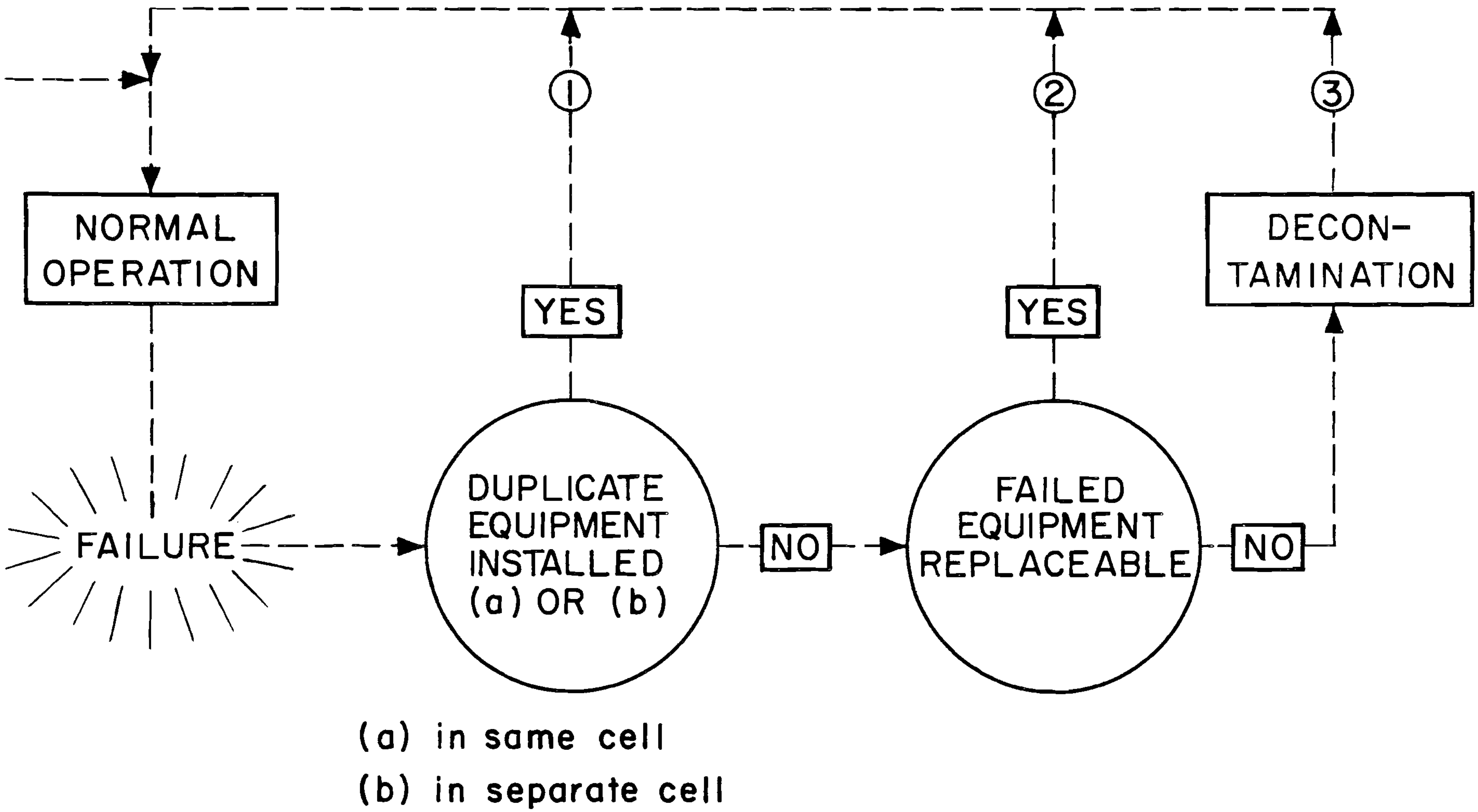


Fig. 2. CHOICE OF MAINTENANCE IN A DIRECT-MAINTENANCE RADIOCHEMICAL PLANT

Table 2. Effect of Number of Equipment Failures on Choice of Maintenance Course

No. of Major* Failures During Expected Life of Plant	Maintenance Course
0	Decontamination only
1	Equipment duplication
2	Limited replacement, or equipment duplication with facilities for decontamination and repair of standby line
3 or more	Provision for replacement, increasing with the probable number of major failures

*A major failure is any failure which, in the absence of equipment duplication or provision for replacement, would necessitate plant decontamination and cell entry for repair.

deemed most susceptible to failure would be made replaceable first, with more made so as the expected operating life becomes longer in relation to the expected equipment life.

Within the present decade, the operation that can be expected from any plant designed to process spent power-reactor fuels is limited by uncertainties in chemistry and in reactor development. Processes are still being developed for fuels containing zirconium and stainless steel, and proposed reactor designs entail changes in the expected fuel composition, burn-up, and processing load. Therefore early power reactor fuel processing plants may be shut down for plant modification or process improvement after a relatively short operating time.

Equipment life depends largely on the quality of the materials and workmanship that go into the plant and the type of equipment used. The difference between good welding procedure, for example, and the very best can mean a ten-fold difference in trouble-free service life, and specifications and inspections must be far more rigorous than in other process industries. Since direct-maintenance plants in the past have been developmental or pilot plant in nature, and were often built on an urgent-need basis, such quality may not always have been obtained.

For a direct-maintenance radiochemical processing plant there exists, for any given time, a probability that the plant will still be operating without the need for in-cell maintenance. Data are too few for accurate knowledge of this probability, but for this paper opinions were obtained from a small number of Oak Ridge National Laboratory engineers experienced in designing and operating radiochemical equipment, tempered with the few available plant data. Based on their predictions, the chances are 9 out of 10 that a well-built direct-maintenance solvent extraction plant for uranium-aluminum fuel elements could be run for 12 months before the high-activity cells would have to be entered for contact maintenance (Fig. 3). The chances are 3 out of 4 that this time interval is 20 months, and are even that it is 32 months. It was assumed for these estimates that the process had been carefully tested, the plant had been thoroughly shaken down in tracer runs, and mechanical pumps and pulse-column pulsers, if used, were housed in blisters that are accessible without cell entry. In the absence of established processes for and experience with zirconium- and stainless steel-containing fuel elements, the life expectancy of a plant for such fuel was estimated as half the figures given above.

Additional data are needed on the trouble-free life of direct-maintenance plants, as well as on the life expectancy for individual equipment items.

Equipment Duplication. The chief advantage of installing duplicate process vessels is minimizing of downtime (Table 3). This advantage may

Table 3. Installed Duplicate Equipment

Advantages	Disadvantages
Minimum downtime	High capital cost
All-welded system	Complication in connecting lines
If in separate cells, one line may be decontaminated and repaired while other is operating	

be offset by increased cost if the equipment is expensive or if additional shielded space is required. When the duplicate equipment is installed in a different cell from the first-line equipment, the original

UNCLASSIFIED
ORNL-LR-Dwg. 66773

R-1

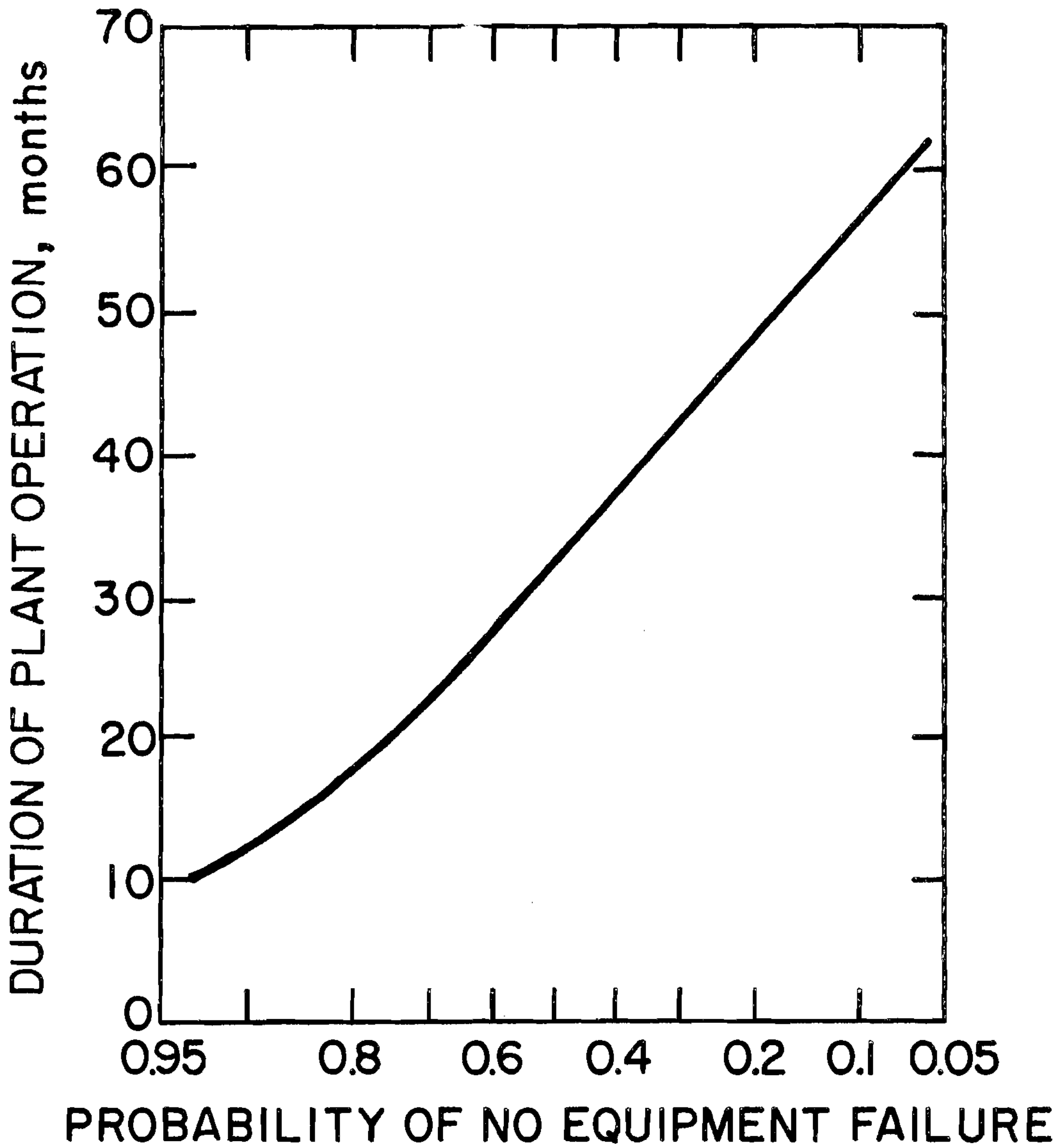


Fig. 3. ESTIMATED PROBABILITY OF NO EQUIPMENT FAILURE IN A DIRECT-MAINTENANCE PLANT

equipment can be decontaminated and repaired while the duplicate is in use. However, the shielding requirements may be somewhat greater than when the duplicates are installed in the same cell.

Indirect Replacement. Downtime losses are decreased by providing for indirect replacement of equipment, but the additional planning and specialized equipment needed may be costly (Table 4). Equipment replace-

Table 4. Replacement by Indirect Methods

Advantages	Disadvantages
Downtime less than for decontamination and repair	Extensive planning and design required
Low risk of personnel exposure	Inventory of spare vessels required
	Flanges or disconnects required
	Complexity of methods can surpass that for remote maintenance
	Larger in-cell space requirements for manipulative equipment

ment should receive more consideration now than in the past, since disconnects for transfer lines and methods for remotely cutting and sealing the lines have been extensively developed for reactor applications, and could be used also in processing plants. Also, manipulators for replacing equipment inside the shielding are now stronger, techniques have been developed that permit the use of manipulators in cells requiring complete containment of radioactivity.

As plant capacity decreases, the incorporation of replaceable equipment becomes easier since the equipment reaches a size that can be more readily handled by manipulators or in rack-mounted units. Within a given plant, the need of provision for equipment replacement is less at lower activity levels, since decontamination of low-activity areas is simply done and the equipment can be replaced by more or less conventional means.

Decontamination for Repair. Decontamination of radiochemical plants in the past has required from several months to a year, but recent research into the mechanisms involved has led to substantial improvements in the effectiveness possible. Laboratory studies indicate that a plant in which the vessels and piping can be completely flooded with decontaminating agents can now be decontaminated in as little as two weeks. Even if this prediction is optimistic by a factor of 2 or 3, the time lost might not be as costly as the capital costs incurred in providing for equipment duplication or replacement (Table 5).

Table 5. Decontamination and Repair in Place

Advantages	Disadvantages
Low capital costs	Time consuming
All-welded system	Implications of planned exposure
	Cost of treating and/or storing decontaminating solutions
	Possibility of low-activity waste treatment system being adversely affected by decontaminating agents
	Greater degree of compartmentalization required

Safety. No position on the maintenance spectrum is inherently safer than any other position, although there have been indications that improvement in previous design practice and operational control is needed more at the direct than at the remote end. Careful analysis of process and plant hazards and their consequences can lead to selection of appropriate control and containment methods to make the hazard as small as is desired. The danger from a radiochemical plant can be theoretically evaluated as the product of two probabilities: (1) that a physical, chemical, or nuclear accident will occur, and (2) that the consequences of the accident will spread beyond containment walls and injure people and property. Neither of these probabilities can be made zero, but their product can be made small relative to natural hazards.

Guidance for design decisions can be obtained from past experience with radiochemical plants of various maintenance types. Three serious accidents occurred in the United States in radiochemical processing plants in the six-month period October 1959 to April 1960, the first two in direct-maintenance plants and the third in a remote-maintenance plant with less serious consequences. The important difference was that the remote-maintenance plant had provisions for containing the results of the accident, but the direct-maintenance plants did not; however, these provisions could have been provided by relatively simple design changes. The three accidents were of similar severity, each could have been prevented by improved operating procedure, and recovery from each was carried out without further hazard to personnel and facilities.

These facts by no means indicate that the accidents occurred <u>because</u> a certain maintenance philosophy was used or that, once they occurred, the consequences were necessarily more severe in one case than another. They only suggest a greater need for improved design and operating criteria in direct-maintenance plants than in remote-maintenance ones. The requirement for design to contain the maximum credible accident is standard for reactors, and since "the hazards associated with operation of a chemical processing plant may be as great as or greater than those associated with a reactor, as measured either in terms of the total fission product inventory or the activity released in a nuclear excursion,"[8] such provisions should logically be included in a modern radiochemical processing plant.

The three accidents mentioned were: (1) A criticality incident on October 16, 1959, at the Idaho Chemical Processing Plant,[5] which allowed fission products to spread from a waste tank through vent lines and drain connections into operating areas of the building and outside the building through the unfiltered off-gas system. The building was evacuated, but seven persons were significantly exposed and one received 50 rem. (2) An explosion in an evaporator, November 20, 1959, in the Radiochemical Processing Pilot Plant at Oak Ridge National Laboratory,[6] which forced open a cell door and released 0.6 g of plutonium, contaminating both the Pilot Plant and nearby research facilities. There was no personnel exposure. (3) A fire in a dissolver, April 17-18, 1960, in the Redox Plant at Hanford,[7] in which no operating personnel were exposed and no activity was released, although the dissolver was lost and the cell was grossly contaminated.

Containment depends on how the normal effluents are handled and on whether new effluents streams appear during an emergency, the most important normal effluent being the ventilating gas. Air pressure differences control the direction of movement of contaminants and override the effect of gaseous release from an accident. Ventilation air, before release, must be treated to remove hazardous constituents by "absolute" filtration at a minimum.

For economy as well as safety, process and cell inleakage should be at the lower limit required for instrument air, heat removal, and flammable vapor dilution. Thus off-gas treatment facilities can be reduced in size and cost with no penalty in pressure difference. Direct-maintenance plants, with heavy hoisting equipment outside the biological shield, have suffered in past designs by having too many cell penetrations from areas with poorly controlled ventilation systems. Very high cell ventilation flows through regular inlets and leaks have been needed to keep contamination within the cells during normal operations. The use of the concept of primary and secondary containment regions[9] overcomes these weaknesses and allows design of a direct-maintenance plant with containment characteristics equal to those of a remote-maintenance plant.

In this concept, the heavily shielded cells and the building in which the cells are located are the primary and secondary containment barriers, respectively. Any small leakage of highly radioactive materials from process vessels is contained within the cells or released under controlled conditions. If the cell becomes pressurized under emergency conditions, accompanied by rapid release of energy as in a nuclear excursion or chemical explosion, radioactivity may be released to the cell surroundings. This will be contained by the building, e.g., by a penthouse containing a crane for access through roof plugs to the cell interior. If the building interior is below atmospheric pressure and has a sufficient volume to maintain its vacuum during cell pressurization, no radioactivity will be released outside. The analysis of air flow is complicated by the possibility of a region below atmospheric pressure on the lee side of the building during a wind storm. Additional working areas outside the secondary containment areas—control room, offices, change facilities, and lunch rooms—may be supplied with forced ventilation to raise the interior above atmospheric pressure for additional safety.

The most difficult containment problem facing the design engineer is the estimate of the magnitude and rate of energy release accompanying the maximum credible accident. Obviously, for any design there is an explosion of sufficient magnitude to rupture both the primary and secondary containment walls. Analysis indicates that the maximum credible accident of a modern radiochemical facility should not exceed the equivalent of 3 lb of TNT or a single nuclear burst of 10^{18} fissions.[9] Differential equations can be written describing the pressure transient accompanying such an energy release, and the equations solved for the particular facility. The solutions provide the criteria for combinations of normal vacuum, inleakage rate, and ventilation rate for the primary and secondary containment areas.

As is the practice for new reactors, new radiochemical facilities must be given containment tests before radioactive operations. Provisions of containment for a large radiochemical facility is an expensive and time consuming operation. Its cost must be included in any realistic estimate of the capital requirements for a processing plant. Once radioactive operations begin, periodic checks of building and cell leakage rates will still be required. Direct access to process areas during shutdown for maintenance should allow inspection and repair of ventilation seals and control systems. Thus minimum inleakage and controlled pressure difference should be attainable throughout the useful life of a direct-maintenance radiochemical plant.

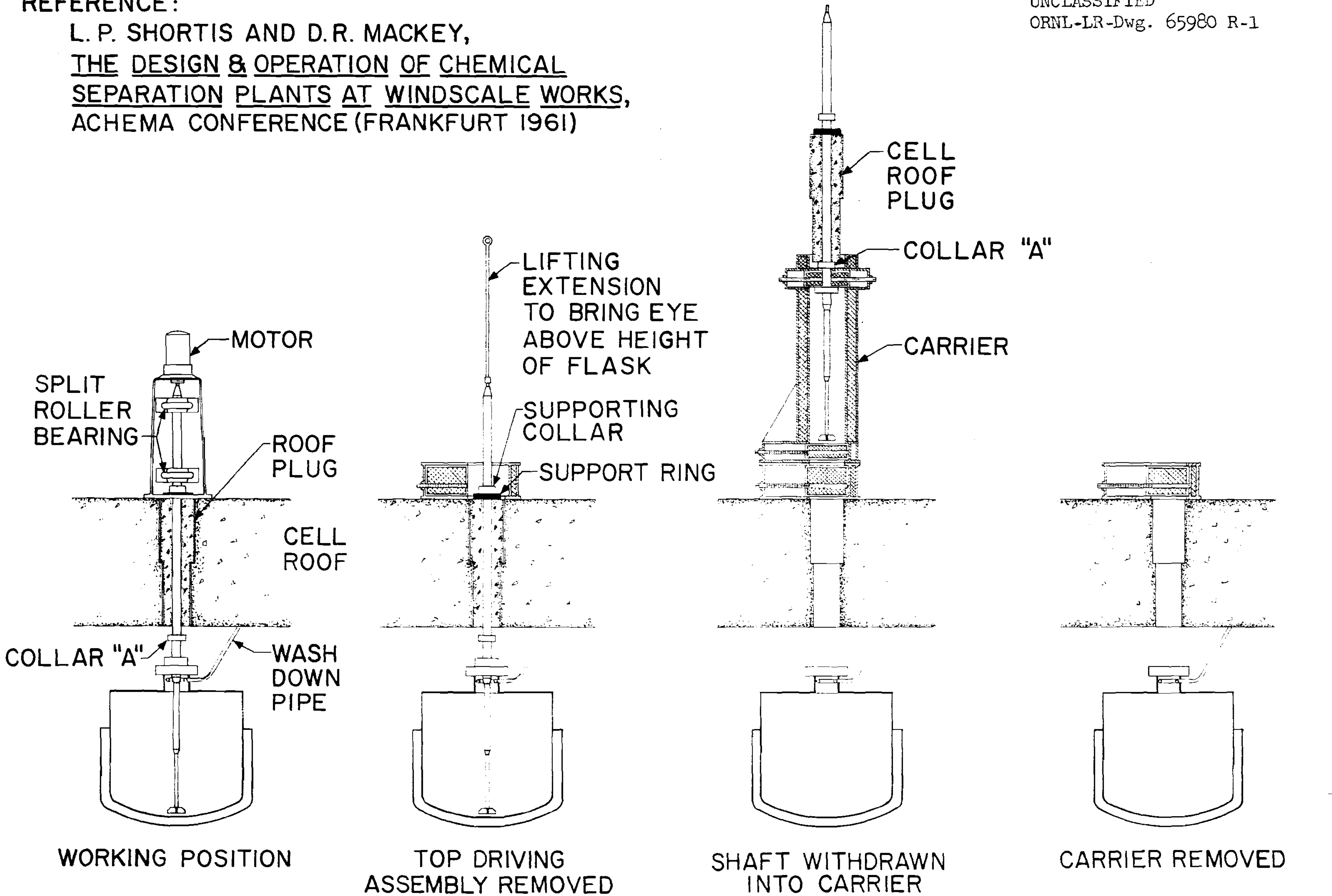
RECENT PLANT DESIGNS

Two radiochemical processing plants now being built at Windscale in Cumberland, England, and at Mol, Belgium, may be classed as direct-maintenance plants although they incorporate some indirect maintenance methods. The Windscale plant is an all-TBP plant for processing of natural uranium Magnox-clad fuel from the U. K. Civil Reactors.[10] The Mol plant is a small, multipurpose "development-production" facility being built by Eurochemic to process low-enrichment fuel from 10-15 European reactors.[11] The fuel cladding will range from aluminum to Zircaloy and stainless steel.

In the British plant, equipment with a short maintenance-free life expectancy, such as samplers, air and steam jets for liquid transfer, and mechanical agitator motors will be located outisde the biological shield, in shielded "bulges" when necessary. Figure 4 shows the replacement design for a mechanical agitator. Duplicate lines of the process form a central cell block, which is surrounded by a metal-framed building containing the control station and nonradioactive solution makeup areas. Ventilation flow is through the nonradioactive areas to the medium- and then high-activity cells, and thence to a stainless steel-lined stack. Cell equipment is in multiple layers, with gravity flow between process components wherever possible. Great stress is laid on extremely high fabrication standards for all vessels and pipes. Using such standards the first British Butex plant operated nine years with only one weld

UNCLASSIFIED
ORNL-LR-Dwg. 65980 R-1

REFERENCE:
L. P. SHORTIS AND D. R. MACKEY,
THE DESIGN & OPERATION OF CHEMICAL SEPARATION PLANTS AT WINDSCALE WORKS,
ACHEMA CONFERENCE (FRANKFURT 1961)



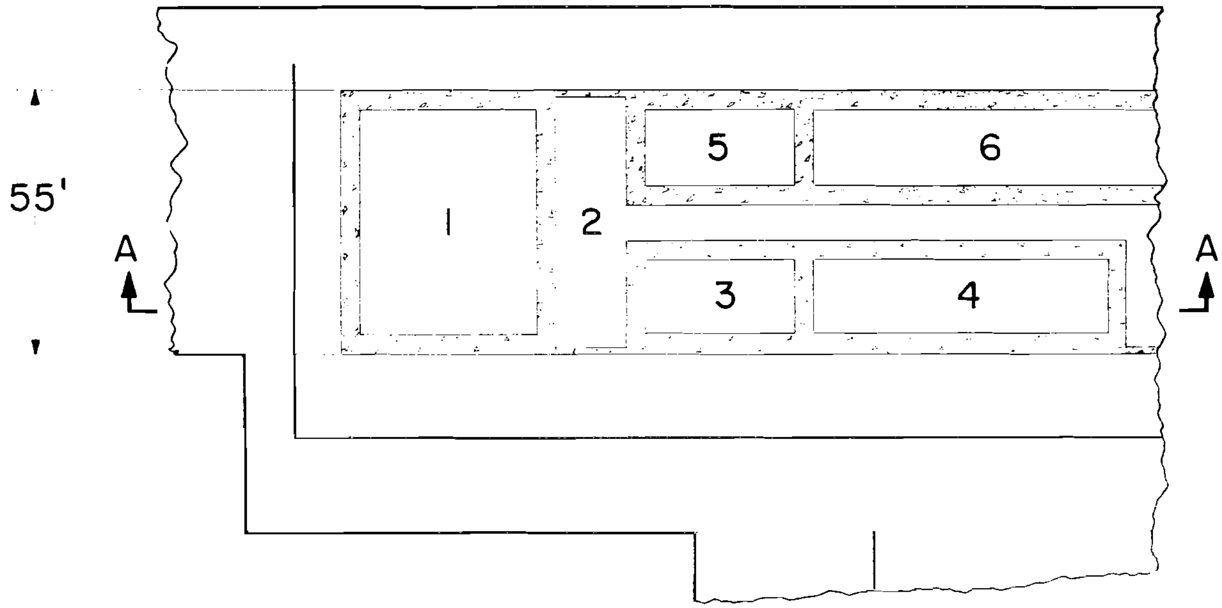
AGITATOR DRIVE AND REMOVAL THROUGH BIOLOGICAL SHIELD

?. 4

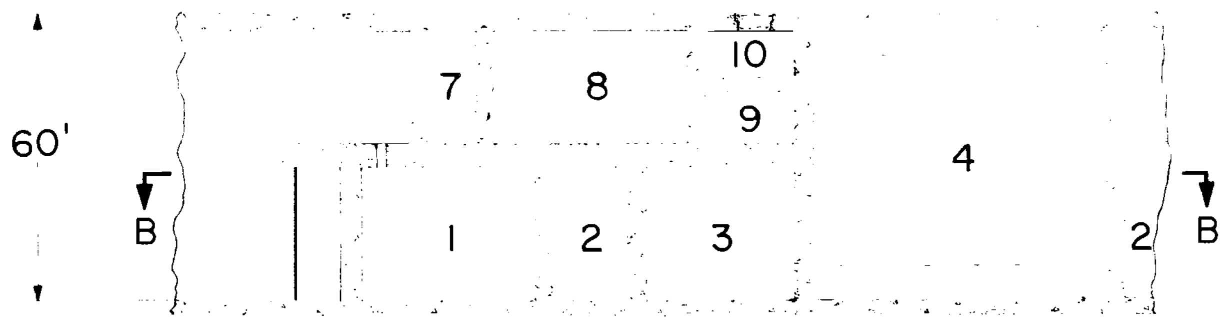
failure in the first cycle cells.

The Eurochemic cell block is divided into a large number of subcells (Fig. 5) to minimize the decontamination required with the expected frequent changes in process equipment. The three dissolvers are in the cell at the end of the block, with their off-gas system above. Storage tanks for decladding, fuel, and rinse solutions are on the cell upper level above a transverse access corridor. The drive motors of the two centrifuges are installed near the top of the cell block and are surrounded by shielding just below the cell top to provide easy access to the motors. The solvent extraction contactors, pulse columns, are mounted along one side of the longitudinal access corridor in the cell block, with evaporators in the other. This design is unique in a great amount of preplanning for entry into the cells in the highest activity area of the plant. Rapid and effective decontamination, already indicated to be feasible, is assumed.

UNCLASSIFIED
ORNL-LR-Dwg. 65981 R-1



PLAN "B-B"



SECTION "A-A" (ELEV)

1 DISSOLVERS
2 ACCESS CORRIDORS
3 FEED ADJUSTMENT
4 EXTRACTION COLUMNS
5 STORAGE
6 EVAPORATORS
7 OFF-GAS
8 INTERIM STORAGE
9 CENTRIFUGE
10 CENTRIFUGE MOTOR

REFERENCE:

1. NUCLEAR POWER, MAY, 1961.
2. PERSONAL COMMUNICATION, T. J. BARENDREGT, JAN. 1962.

PARTIAL PLAN AND ELEVATION OF EUROCHEMIC CELL-BLOCK

Fig. 5

REFERENCES

1. J. L. Schwennesen, "Nuclear Fuel Processing Plants - A Survey of Design and Operational Practices," Proceedings, Second Geneva Conference, Vol. 17, p. 514.

2. W. E. Unger, Auxiliary Radiochemical Equipment, in TID-7534, Symposium on the Reprocessing of Irradiated Fuels, Brussels, Belgium, May 20-25, 1957, pp. 936-9.

3. R. Galley, Problems of the Marcoule Plutonium Plant and Their Solutions, Energie Nucleaire 2, 2-20 (1958) (AEC-tr-3307).

4. J. W. Ullmann and J. P. Nichols, "Idaho Chemical Processing Plant Criticality Incident," Nuclear Safety, Vol. 1, No. 3, pp. 75-77, March, 1960.

5. H. N. Culver and W. B. Cottrell, "Plutonium Release from the Thorex Pilot Plant," Nuclear Safety, Vol. 1, No. 3, pp. 78-80, March, 1960.

6. J. C. Bresee, "Redox Multipurpose Dissolver Incident," Nuclear Safety, Vol. 2, No. 4, pp. 52-55, June, 1961.

7. E. D. Arnold and J. P. Nichols, "Hazards Analysis of Chemical Processing Facilities," Nuclear Safety, Vol. 3, No. 1, p. 56, September, 1961.

8. E. D. Arnold, A. T. Gresky, and J. P. Nichols, "The Evaluation of Radioactive Releases from Chemical Plants," ORNL-TM-19, October 3, 1961.

9. L. P. Shortis and D. R. Mackey, "The Design and Operation of Chemical Separation Plants," Achema Conference (Frankfurt 1961).

10. T. J. Barendregt, "Aspects of the Eurochemic Reprocessing Facility," Nuclear Power, May, 1961.

DISTRIBUTION

1. F. L. Culler, Jr.
2. R. E. Blanco
3-12. J. C. Bresee
13. K. B. Brown
14. D. E. Ferguson
15. H. E. Goeller
16. H. B. Graham
17. A. T. Gresky
18. E. Lamb
19. W. H. Lewis
20-30. J. T. Long
31. E. L. Nicholson
32-33. E. M. Shank
34. M. E. Whatley
35-36. Central Research Library
37. Document Reference Section
38-40. Laboratory Records
41. Laboratory Records - Record Copy
42-56. Division of Technical Information Extension
57. Research and Development Division