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CONCEPTUAL DESIGN STUDY FOR AN ACCIDENT RESPONSE EVAPORATOR

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ABSTRACT

This report documents the feasibility of designing, fabricating, and testing a mobile accident response evaporator (ARE) that could be quickly and easily placed into operation at a nuclear facility after an abnormal event or accident has generated liquid radioactive wastes. Design and development phases of the ARE, using the recommended climbing film design, are presented.

SUMMARY

The accident at Three Mile Island Unit 2 (TMI-2) in March 1979 has shown that cleanup and decontamination operations of a nuclear facility after an abnormal event or accident can generate large quantities of contaminated water and decontamination solutions. Since it may not be practical to dispose of some of the waste streams by ion exchange or direct solidification, it is necessary to be able to concentrate the radioactive contaminants by evaporation. These concentrates could then be solidified for long-term storage or burial.

The feasibility of designing, fabricating, and testing a mobile Accident Response Evaporator (ARE) that could be quickly and easily placed into operation at a nuclear facility as a decontamination support evaporator has been investigated. As a result of this investigation, an ARE could be designed, fabricated, and tested, using a climbing film evaporator concept. The climbing film evaporator concept, as described in this report, is recommended since it best meets the design and operational requirements. The ARE would be able to process nuclear facility building decontamination wastes and miscellaneous low and medium activity decontamination solutions. The feasibility of processing this waste would be ascertained when the waste streams had been better characterized and tests performed.

An ARE development would be implemented in two phases. The design phase, Phase I would cover development of a preliminary design and testing. The ARE equipment would be sized and selected, and the preliminary layout determined. A prototype, full-sized evaporator would then be fabricated and tested with selected solutions. The procurement phase, Phase II (final), would cover the fabrication of the evaporator and acceptance testing. Final design and layout of the ARE would be based on data obtained from the waste stream tests. The ARE would then be fabricated and cold acceptance tests run at the manufacturing plant.

The ARE would be operated at a nuclear facility by the facility's operating personnel. The operating data would be analyzed and any required modifications would be made to improve the ARE operation.

Design, fabrication, and testing of the ARE would take 2 years, beginning with the preparation of the initial design specification and concluding with the cold acceptance tests. Afterwards, the ARE would be ready for operation at a nuclear facility. The estimated cost, in 1983 dollars, is $1,490,000. A nuclear facility would require an estimated additional $440,000 for ARE site preparation and one year's operation.

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JUSTIFICATION FOR AN ACCIDENT RESPONSE EVAPORATOR

An accident or an unusual occurrence at a nuclear facility can generate a large quantity of radioactive liquid wastes that must be removed in order to return the facility to normal operation. The two preferred methods of removing radioactive contaminants from the waste streams are ion exchange and evaporation. Although both methods can satisfactorily remove the contaminants from most liquid waste streams, an evaporator is better suited for streams containing detergents or a high concentration of solids.

Most nuclear facilities have evaporators and demineralizers, but they are designed for normal plant operations and generally do not have the capability of handling the additional volumes of wastes that can be generated during an accident or an unusual occurrence. Under these circumstances, it would be desirable to have an additional evaporator available to the nuclear facility to clean the waste streams which contain detergents or have a high concentration of solids resulting from decontamination.

The Accident Response Evaporator (ARE) is a temporary evaporator that could process these radioactive liquid wastes. The ARE would have the advantage of being relatively mobile, self-sufficient, and easy to operate. By being relatively mobile, the ARE could be quickly and easily shipped to any nuclear facility requiring an evaporator on an emergency basis. If the ARE system was mounted on trailers, it would only be necessary to transport the system to its destination. The trailers could be placed at a convenient location at the facility and the equipment on them interconnected and electrical power supplied. The system would then be ready to be placed into service.

Having an ARE available would avoid the delay associated with the design and fabrication of a permanent facility since it would only require a concrete pad and electrical power. Since it would be a temporary facility, the expenses associated with seismic qualification would be minimized. Licensing delays would also be minimized since the ARE could be operated under a nuclear facility's operating license on a temporary basis under 10 CFR 50.59, "Changes, Tests, and Experiments."

A permanent evaporator would have to be assembled in a seismically qualified building at a fixed location at the facility and would require support facilities in addition to the electrical power necessary to operate the evaporator. Based on this and the fact that the need for the evaporator would be short lived, a permanent evaporator may not be cost-efficient.

A self-sufficient ARE could be easily set up at any nuclear facility with minimal interference in plant operations. The ARE would not require

supporting utilities such as steam, which might not be available or easily accessible. In addition, the evaporator could be set up at any convenient location at the plant, either inside or outside, so that it would not take up valuable space or be in the way of other operations. An ARE would also be self-regulating to the greatest extent possible, so that it would be easy to operate and would require little operator training.

Fabricating a unit would verify the system design and operation under actual operating conditions. The system capabilities would also be determined since a wide range of waste streams could be processed at the nuclear facility. The system's decontamination factor, volume reduction, and concentration capabilities could be tested by processing decontamination solutions and other waste streams. After processing the wastes and analyzing the data, the system would be modified, if necessary, to improve the ARE capabilities, and the ARE would then be available for immediate use at another nuclear facility. It would also be possible to fabricate additional ARE units based on the same design.

Study Criteria

In order to formulate a system design description for an ARE, it was necessary to investigate current industrial needs and contemplate future needs. The following is the result of that investigation and describes the capabilities, limitations, and requirements of an optimum ARE.

System Scope

The ARE would be designed to process radioactive waste solutions at a nuclear facility and reduce the volume requiring disposition. The ARE would have the equipment necessary to provide a complete evaporation system, including evaporator, separator, instrumentation, control panel, pumps, piping, and valves. In addition, there would be a distillate storage tank, a concentrates storage tank, a feed tank, and a station with the capability to fill containers with concentrates. Since the waste streams may come from a variety of locations, it is assumed that the streams would be either solid piped, or transported in drums or a tank truck to the feed tank. The ARE would also be designed so that the concentrates can be transferred directly to an adjacent solidification system if available. The system would be arranged on a minimum number of trailers that can be transported and rapidly set up at a nuclear facility.

Waste Stream Characterizations

For the purpose of this study, the Three Mile Island Unit 2 (TMI-2) waste streams were used as a basis for characterization. There are three categories of waste that can be considered for processing in an ARE. Although some of the wastes at TMI-2 have already been processed by EPICOR II and the Submerged Demineralizer System (SDS), the various sources identified can form a basis for the design of an ARE applicable for other situations as well.

The three categories of wastes that should be considered for processing by the ARE are (a) low-activity solutions such as building decontamination fluids (<10μ Ci/cm^3), (b) medium-activity solutions such as reactor coolant system (RCS) decontamination solutions (10 to 100μ Ci/cm^3), and (c) high-activity fluids (above 100μ Ci/cm^3). The liquid-waste sources and volumes can be broken down as indicated in Table 1.

In addition, there are other liquid wastes, such as anti-contamination laundry effluent streams, floor drains, and demineralizer regenerant solutions, that could be processed by the ARE. The activities and compositions of these streams would have to be analyzed prior to being processed by the ARE.

The wastes listed in Table 1 are very conservative estimates of sources that could potentially be processed by an ARE. It may not be necessary for the ARE to process all of the liquid wastes since alternative methods, such as a demineralizer system, may be used. The ARE could process the low activity building decontamination solutions since an evaporator is best suited for processing these waste streams, especially if they contain detergents or suspended dirt particles. The processing of high-activity waste streams with the ARE would not be recommended. However, when the bulk of the radioactivity is removed from high-activity waste sources in the Reactor Building sump, it should be possible to process the residual activity in chemical waste streams in the ARE.

The medium-activity RCS solutions could be processed through the ARE, however, they would need to be characterized further. In general, the ARE is not suited for processing large volumes of high-activity wastes or waste streams with appreciable amounts of fissile transuranic material.

For radiological shielding considerations, a limiting factor pertaining to the evaporation of liquid wastes is the concentration of the radioactive isotopes in the concentrates. Based upon conservative calculations, and using approximately 4 in. of lead shielding with 2 in. of steel plate, the radioactivity in the concentrates should not exceed approximately 500μ Ci/cm^3. Under this assumption, normal processing of low-activity wastes can be accomplished. The medium-activity wastes can be concentrated by a factor of approximately 10 before they begin to present a radiological problem. A definitive characterization of the wastes, equipment sizing, and detailed shielding calculations would provide a better basis for shielding design and allowable concentration factors for each waste stream.

TABLE 1. ESTIMATED LIQUID-WASTE SOURCES AND VOLUMES[a]

	Volume (gallon)	Curies	μ Ci/cc
Low activity			
Reactor Building decontamination solution			
Water-based	150,000	90	0.16
Chemical-based	40,000	10	0.07
Auxiliary and fuel handling building chemical decontamination solution	7,000	60	2.26
Medium activity			
RCS water	96,000	20,000	55
RCS decontamination solution			
Water-based	100,000	2,000-20,000	5.28-52.8
Chemical-based	500,000	2,000-20,000	1.06-10.6
RCS flush and drain	250,000	20,000-100,000	21.12-105.6
High activity			
Reactor Building sump water	700,000	500,000	188.6

a. Estimates are from the Three Mile Island Unit 2 Nuclear Plant.

System Requirements

The ARE would have to meet several criteria in order to provide optimum system design. Since some of these criteria conflict with each other, each requirement must be evaluated with respect to its significance. ARE requirements and their importance are as follows:

- Reasonably priced--It is desirable to minimize the capital investment in the design and fabrication of an ARE. A temporary evaporator such as the ARE should be efficiently designed with simple controls for satisfactory operation.

- Ability to process anticipated waste volumes and decontamination solutions--A wide range of chemical decontamination solutions may need to be processed in an ARE. There would also be a significant quantity of dirt particles in some of the solutions that must be considered in the system design. Many of the solutions would foam, and an ARE should be capable of handling the foaming. In addition, adequate shielding would have to be provided for the anticipated concentration of radioactive solutions. The system capacity would have to be such that it could process potential waste volumes within a reasonable time.

- High volume reduction capability--A high volume reduction would reduce the volume of concentrates that must be solidified. However, published reports have indicated that even evaporator/crystallizers, which can concentrate waste streams which contain as much as 50% solids, may have a design volume reduction FACTOR of only 20. Normal volume reduction factors vary from 15 to 400, depending upon the waste stream.

- Small size--A small ARE would reduce the number of trailers required, as well as minimize the space required at a nuclear facility. The ARE should be small so as not to exceed allowable trailer size and weight limitations. A tall evaporator vessel,

even if set upright after transport, would prove more difficult to shield than a short one, and would complicate the setup of the evaporator.

- Easy to assemble and start--The ARE should not require an extensive effort or a large amount of time to assemble. A small system with a minimum number of trailers and interfaces is preferable. Startup should not require any external utilities other than electrical and should be capable of being accomplished within a short time.

- Easy to operate--The ARE should be simple to operate. Once the ARE has been started, it should be self-regulating and require minimal attention.

- Easy to maintain--The ARE must be designed with radiological considerations in mind. The items containing highly radioactive solutions must be segregated from each other and from other noncontaminated equipment. The equipment must not be laid out so that maintenance is difficult to perform.

- Minimal number of interfaces--The ARE should be as self-sufficient as possible. An ARE that has numerous interfaces would be difficult to set up, due to added piping. Further, any given nuclear facility may not have a utility such as steam available, and cooling water may not be easy to obtain or dispose.

- Minimal solution volume--The amount of shielding required would be lessened by minimizing the volume of solution in the system, thereby decreasing the size and weight of the system. In addition, a small volume of radioactive solutions would minimize the spread of contamination in the event of an accident.

- Low system pressure--It would be preferable to have the ARE operate at a vacuum, so that any leakage would flow into the ARE and not spread contamination from the system out to the environment.

- Fabricated from suitable materials--Although the ARE would not be in continuous service, as would a permanent evaporator, the possibility of stress corrosion should be avoided. Therefore, materials such as Inconel 625 should be used wherever applicable.

- Must interface with a solidification system--Since the ARE would be a temporary facility that may not be located near a solidification system, the capability of providing for portable solidification to immobilize the evaporator concentrates should be considered.

- Should be capable of being easily licensed--In order to license an ARE, the United States Nuclear Regulatory Commission (NRC) would require evaporator operating data and site-specific radioactive release data. An evaporator design that is already in service at a nuclear plant may be easier to license than a new design requiring extensive testing or analysis.

- Should minimize the use of insulation--Insulation makes a system bulkier and maintenance more difficult. A vacuum evaporator that operates at 100 to 130°F does not require the insulation of a pressurized evaporator operating at elevated temperatures.

- Should use commercial parts when possible--Commercial parts would make field maintenance easier since it may not be feasible to store all the necessary special spare parts. Commercial parts that are easily available would minimize downtime for maintenance and avoid a costly spare parts inventory.

System Selection

System Design Selection

There are many types of evaporators on the market today which were evaluated for ARE use (see References 1 through 6). Many designs are used in nuclear plants, including wiped film, natural circulation, forced

circulation, and falling film evaporators. Of these, operating experience has shown that the forced circulation design has the best operating history. The climbing film evaporator, which has never been used in a nuclear application, was evaluated against the others.

Tests have shown that the climbing film evaporator has the real potential to provide a reliable system, and was, therefore, considered for the ARE. The solutions used in a test of the climbing film evaporator (see Appendix A) indicated that the evaporator would perform favorably in a nuclear radwaste application. The evaporator satisfactorily concentrated solids, boron, and other materials that would be encountered at a nuclear facility. Suspended solids could be filtered out upstream of the evaporator and would also be concentrated in the heater. Any solids collected in the heater could then be periodically recycled back to the concentrates tank.

Alternate evaporator designs have not performed well for a variety of reasons. Wiped film evaporators are compact and efficient but do not function well with streams containing suspended solids. They are also sensitive to stream rates and pressure which present control problems. Falling film evaporators are too tall to be feasible in a portable unit, would require more equipment and trailers than the climbing film evaporator, and occasionally have fouled nozzles. Wiped film and falling film evaporators also have a poor operating history in the nuclear industry. Based on these disadvantages, no further analysis or comparison was performed.

Both the forced circulation and the climbing film evaporator designs were evaluated with respect to the design requirements, and a summary of the preliminary evaluation is listed in Table 2. As can be seen by reviewing the table, each system meets some design requirements better than the other design. Certain design requirements, however, are more important than others, and this weighted evaluation indicates the climbing film evaporator should be selected for the ARE. The significant advantages of the climbing film design are that it is small and compact, is simple to operate, and would not require external utilities other than electricity.

This would allow the ARE to be placed almost anywhere at a nuclear facility, since running electrical cables would probably not be difficult. The climbing film evaporator would also take up little space, which is advantageous if there is limited available ground area. Minimum scaling is inherent in the design because of the low operating temperature. Due to its small size, the amount of shielding required would be minimized, and any leakage in the event of an accident would be minimized since the evaporator operates at a vacuum. Although the climbing film design has not been used in nuclear applications, preliminary test data indicate that it can handle the expected service. Test data for licensing approvals would be obtained to show that the design can be modified for nuclear service.

The forced circulation evaporator is an expensive, complex, and sophisticated system. The initial capital and setup costs would be high, because of the high headroom requirements of the evaporator. Since setup cost would be incurred each time the ARE is moved and placed in service, and since the ARE would not be in continuous use, it would be most cost efficient to procure an evaporator at the lowest possible capital and setup costs. For these reasons, it is recommended that the climbing film evaporator be selected for the ARE. The climbing film evaporator has a lower capital and setup costs, and would meet the system requirements.

<u>Processing Rate</u>

The ARE should have a design capacity of 3 to 5 gpm. This rate would enable the ARE to evaporate about 5,000 gal of contaminated water per day, while keeping the evaporator small enough for easy transport and setup. This capacity should be adequate for accidents such as that which occurred at TMI-2, even if the ARE does not operate at 100% capacity. Since the ARE would be temporary, it is intended only to process excess quantities of contaminated solutions.

A 3- to 5-gpm ARE would be small enough to be mobile and easy to transport. Larger capacity units would be correspondingly larger and not mobile. The smaller 3- to 5-gpm size would also lessen the shielding requirements.

TABLE 2. PRELIMINARY EVAPORATOR EVALUATION

Design Requirement	Evaporator Type	
	Forced Circulation	Climbing Film
Reasonably priced	Expensive owing to size, sophistication, and automation of system	Inexpensive, owing to simplicity of system design and operation
Easy to operate	Easy to operate, since automated	Easy to operate, owing to simple system design
Small	Large system, requires high overhead clearances and much equipment, and size presents decontamination problem	Small, compact system with low overhead clearance requirements
Easily set up and started	Large system, several trailers required; start up is easy	Small system, expect only two trailers required; start up easy
Minimally insulated	Insulation required owing to elevated temperatures	Minimal insulation required, owing to low operating temperatures
Easy to maintain	Although large, system has maintenance experience in nuclear operations	Small system, to be carefully designed for maintenance
Minimal utility interfaces	Requires electrical power and small amounts of cooling water	Requires electrical power only
Commercial parts	Several critical parts are specially designed	Commercial parts used to maximum extent possible
Capable of being licensed	Minimal difficulty owing to nuclear operating experience	Test data required before licensing can be obtained
Contain minimal solution volume	Large volume continuously recirculated	Small volume recirculated
Low system pressure	Operates slightly above atmospheric pressure	Operates at a vacuum

TABLE 2. (continued)

Design Requirement	Evaporator Type	
	Forced Circulation	Climbing Film
Ability to process waste streams	Proven experience in nuclear industry	Design successfully used on several solutions; preliminary tests with nonradioactive liquids containing detergents have shown that it could work with anticipated solutions
Interface with solidification system	Has experience transferring concentrates to a solidification system	Can be designed to interface with a solidification system
Effective concentration	Obtains a volume reduction of 15 to 400 in nuclear service	Has obtained high volume reduction as demonstrated in nonnuclear applications

Conceptual Design

The proposed conceptual design is a completely packaged system, mounted on trailers and ready for transport to an accident site. The proposed system is shown in Figure 1.

Major Components

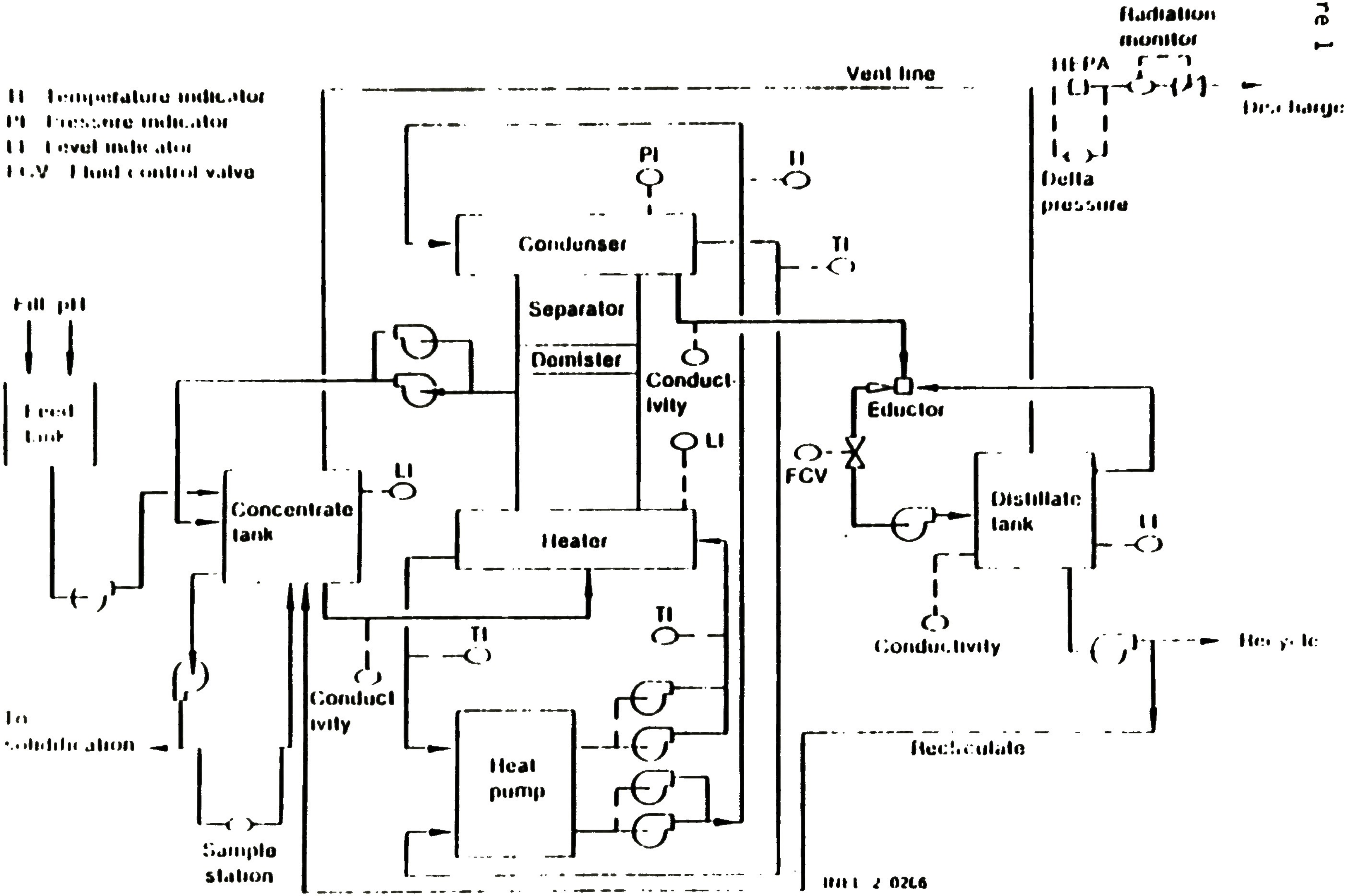
The major components of the system are the climbing film evaporator/separator, feed tank, concentrate tank, control panel, and distillate tank. These components would be positioned on trailers such that they can be moved to a nuclear facility and the system set up, checked out, and placed into service in minimial time. A typical arrangement of the equipment on the trailers is shown in Figure 2.

Operation

Radioactive wastes would be introduced into the system at the feed tank either by direct piping from a site source, by drums, or by tank trucks emptying into the feed tank. Properties of the feed would be monitored and the pH controlled as required.

The feed tank would be vented through a HEPA filter and a radioactivity monitor to ensure that gaseous effluents did not exceed predetermined limits. The feed would then be pumped to a concentrate tank.

The operator would maintain the level in the concentrate tank as required. Feed would be drawn by the evaporator vacuum from the concentrate tank and cycled through the climbing film evaporator loop. The evaporator bottoms would be pumped back into the concentrate tank, and the distillate drawn into the distillate tanks by an eductor. This eductor, located in a closed loop connected to the distillate tank, would maintain the vacuum within the evaporator. The vacuum would be monitored by a thermocouple connected to an alarm system, which would signal loss of vacuum. The concentrate tank would be monitored, and when the bottoms have



Radiation monitor
Vent line
HEPA
Discharge
Delta pressure
TI
PI
LI
FCV
Condenser
Separator
Demister
Conductivity
Eductor
Feed tank
Concentrate tank
Heater
Distillate tank
Heat pump
Recycle
Recirculate
To solidification
Sample station

Figure 1

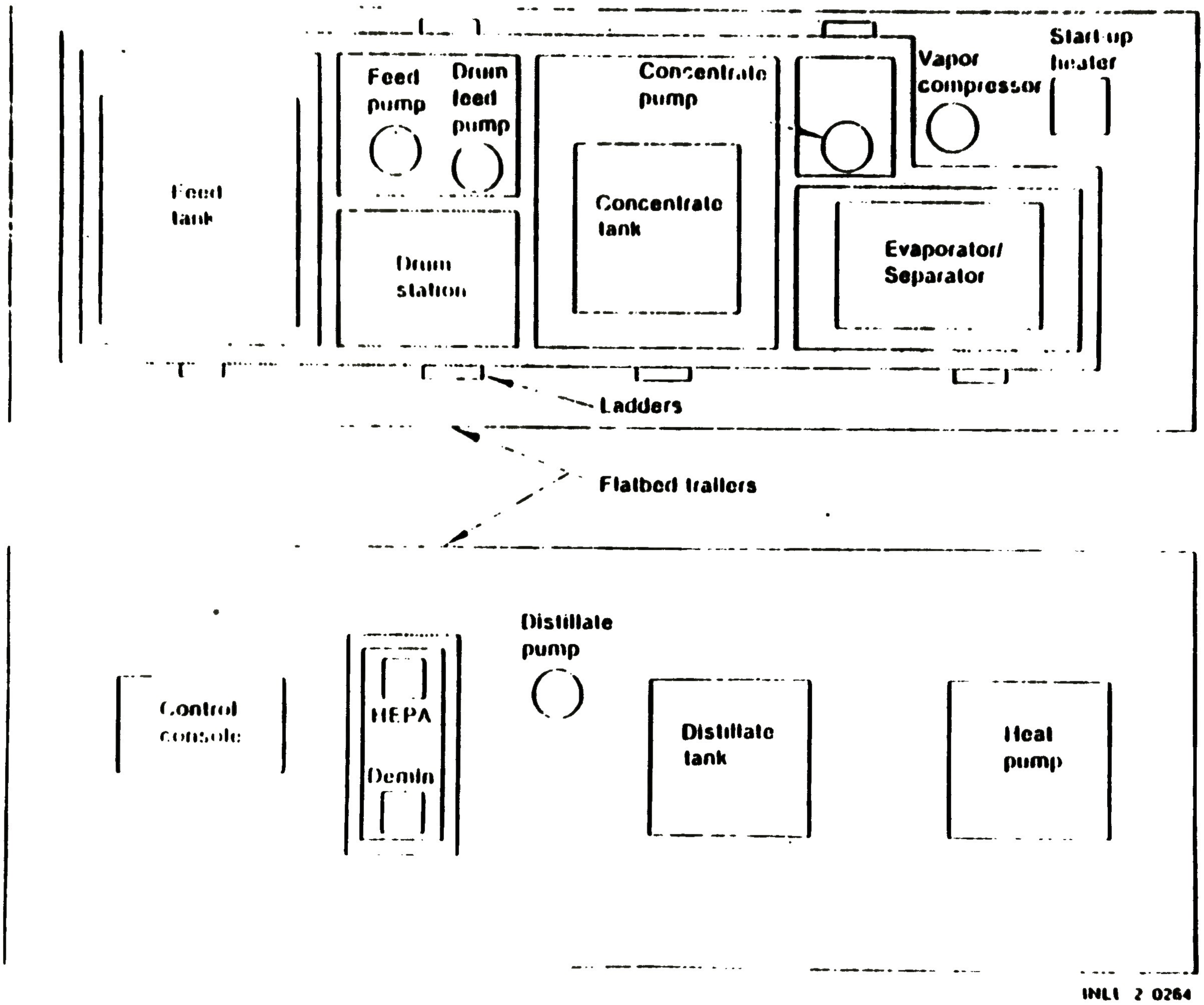

Feed tank
Feed pump
Drum feed pump
Drum station
Concentrate pump
Concentrate tank
Vapor compressor
Start-up heater
Evaporator/ Separator
Ladders
Flatbed trailers
Control console
HEPA
Demin
Distillate pump
Distillate tank
Heat pump
INEL 2 0264

Figure 2

been concentrated to the required level, they would be removed for solidification. It would be possible to load the evaporator bottoms directly into drums at an enclosed drumming station or to pump them directly to a solidification system located adjacent to the ARE.

The climbing film evaporator yields a pure distillate while operating at a low system temperature and pressure. This tends to reduce scaling and stress corrosion, which improves system reliability. The climbing film evaporator does not require the use of antifoam agents.

The distillate tank is also vented through the HEPA filter, where the gaseous effluents are monitored. A pump would be provided to transfer the distillate either into a monitor tank, 55-gal drums, or directly to a storage location provided by the site facility.

A control panel, separated from high-activity sources, would be located on one of the trailers. Startup and shutdown controls, as well as the instrumentation to monitor the system, would be at this panel.

When all wastes have been processed, and the system is no longer needed, the external and internal surfaces would be decontaminated to the extent necessary to meet appropriate transportation regulations, and the ARE would be prepared for transport.

System Interfaces

System interfaces would be minimal. The ARE would include a flanged piping connection for the feed input to the system and the concentrate and distillate discharges. The ARE would have a motor control center near the control panel for electrical power provided by the site facility. An adequate area with easy access would have to be provided by the facility for system setup and operation. A concrete pad would be required for the trailers and would serve as a backup to contain any radioactive spills.

System Mobility

The system would be contained on a minimum number of trailers and could be transported to any location in the country. Trailers would meet all state and federal regulations with regard to size and weight and be common so that commercial companies could transport them.

Utility Requirements

The only constant utility requirement of the system would be electricity. It is assumed that the nuclear facility would provide the necessary electrical power. A small volume of water would be needed for system startup.

PROGRAM PLAN

The design, testing, and fabrication of the ARE would occur in two phases. In Phase I, a design specification would call out the preliminary design and testing, in which (a) equipment would be selected, sized, and laid out, (b) a prototype, full-sized evaporator without auxiliaries, would be tested using specified solutions, and (c) the distillate and concentrate would be analyzed. In Phase II, a procurement specification would be released to fabricate and test a complete ARE. The specification would specify the final design, which would incorporate information obtained during testing of the evaporator in Phase I.

Following fabrication of the ARE, there would be an acceptance test at the manufacturer's plant, using nonradioactive sample solutions. The ARE would then be shipped to a nuclear facility, set up, and operated by the owners of the facility. Concurrent with the fabrication of the ARE, any necessary federal licensing documentation would be prepared and operational approval would be obtained.

Phase I Design Specification

The design specification would cover preliminary design and prototype testing of the ARE.

Design by Subcontractor

The subcontractor would design an ARE system in accordance with the requirements called out in the design specifications. He would size and select the equipment, controls, and instrumentation, and lay out the equipment on the trailers.

Concurrent with the design, the subcontractor would submit a prototype test plan, detailing the test plan and specifying the equipment to be used for the prototype.

Design Requirements

The design specification would include the design requirements discussed below.

Instrumentation and Control. An easily accessible control panel would be located on one of the system trailers, and it would be separated and shielded from areas of high-activity radiation. The control panel would have the necessary startup, operating, and shutdown capabilities, and it would be self-regulating to the greatest extent feasible. Instrumentation would be provided on the panel for complete system monitoring. It would be possible to take samples of the concentrate to monitor the system operations.

Capacity. The system capacity would be 3 to 5 gpm of distillate production. The design volume reduction factor would be a minimum of 10. Distillate carryover would be less than 1 ppm total dissolved solids and no suspended solids. The concentrate tank would be large enough to provide an adequate surge capacity, minimizing the frequency of the transfer of the concentrates.

Mobility. The system would be capable of being transported on a minimum number of trailers using interstate highways from storage locations to potential operation sites. State and federal regulations would be complied with regarding size and weight limitations. Trailers would be common so that they can be moved by commercial companies. The trailer design with system equipment in transport configuration would also comply with federal regulation 10 CFR 71, "Packaging of Radioactive Material for Transport," Subpart B.

Accessibility for Maintenance. Equipment would be located such that maintenance and repair could be accomplished with minimum obstruction and radiation hazard. Equipment that is expected to have a high radioactive content would be separated and shielded from other lower-activity items. Slurry lines would be provided with cleanouts.

Personnel Requirements. Personnel requirements would be kept to a minimum and defined as to number and special training. The nuclear facility would be responsible for supplying and training the required personnel.

Radiological Shielding. The system would be adequately shielded to minimize radioactive exposure to operating personnel. Shielding objectives would be in accordance with the objectives outlined in Table 3.

The heater, lower separator region, and feed tank would be designed for up to 4 in. of lead shielding. Feed piping and concentrate piping would have an allowance of 0.25 in. circumferentially for shielding. The sides of the concentrate tank would be designed with 4 in. of lead shielding and 1-in. steel plate on each side of the lead. An additional 4 in. of space would be allowed around the concentrate tank for additional shielding if activity warrants it. Actual shielding would be determined following final equipment sizing and system layout.

Valves. Ram-seal valves by Fetterolf or an approved equal would be specified at locations in the ARE where solids could collect. These valves would avoid the collection of solids in the valve seats.

Contamination Controls. The system design would maximize defenses against spread of contamination, and would minimize places where radioactive materials can collect. Sanitary finishes would be provided to reduce scale and improve cleaning and decontamination capabilities where appropriate. The system design would include provisions to purge lines when the system is shut down. Trailers would have a drip-pan that would collect radioactive contaminants that are inadvertently spilled or leaked. All piping connections would be flanged and located over the trailer drip-pan.

Materials of Construction. Materials of construction would be selected only after the material/solution studies were performed. This would maximize system reliability and longevity yet be readily obtainable

TABLE 3. DESIGN OBJECTIVES FOR SHIELDING FROM RADIOACTIVITY IN AN ACCIDENT RESPONSE EVAPORATOR

Criteria	Radiation Limit (mR/h)	Areas
Continuous occupancy	2.5	Areas outside the evaporator trailers; control console
Controlled occupancy (frequent nonroutine access)	25	Areas adjacent to highly contaminated equipment such as the pump areas
Controlled access (infrequent nonroutine access)	100	Highly contaminated equipment cubicles such as the feed tank

for spare parts and repair to the greatest extent possible. Industry experience has been to use Inconel 625 wherever the requirement exists, to reduce possibility of stress corrosion. Equipment such as the heater and concentrate piping would be Inconel 625. Stainless steel would be used at all locations not otherwise specified.

System Interfaces. Flanged piping would be provided at feed input and at concentrate and distillate discharges. Pumps would be provided for the concentrate and distillate discharge with a minimum capacity of 10 gpm and a head of 75 ft. A breaker box would be provided near the control panel for electrical power input.

Utility Requirements. Utility demands of the system would be limited to electrical power. System consumption would be noted in quotations.

Setup and Takedown Time. The system design would incorporate features to minimize setup and takedown times. Setup time would be 1 week maximum.

Federal Regulations and Industrial Codes and Standards. The following list of regulations, codes, and standards may apply and would be followed as applicable:

- Federal Regulations, Codes, Standards, and Guides

10 CFR 20	"Standards for Protection Against Radiation"
10 CFR 50	"Domestic Licensing of Production and Utilization Facilities"
10 CFR 190	"Environmental Radiation Protection Standards for Nuclear Power Operations"
10 CFR 71	"Packaging of Radioactive Materials for Transport"

Reg Guide 1.39	"Housekeeping Requirements for Water-Cooled Nuclear Power Plants"
Reg Guide 1.140	"Design, Testing, and Maintenance Criteria for Normal Ventilation Exhaust System Air Filtration and Absorption of Light Water Power Plants"
Reg Guide 1.143	"Design Guidance for Radioactive Waste Management System, Structures, and Components Installed in Light-Water-Cooled Nuclear Power Plants"
Reg Guide 8.8	"Information Relevant to Ensuring that Occupational Radiation Exposure at Nuclear Power Stations would be as Low as Reasonably Achievable"

o ANSI Standards

ANSI-N199	"Standard for Liquid Radioactive Waste Processing System for Pressurized Water Reactor Plants"
ANSI-N512	"Protective Coatings (paint) for the Nuclear Industry"
B 16.5	"Steel Pipe Flanges, Flanged Valves, and Fittings"
B 31.1.0	"Power Piping"

- American Society of Mechanical Engineers Boiler and Pressure Vessel Code

Section II	"Material Specifications"
Section IV	"Nondestructive Examination"
Section VIII	"Division 1 Pressure Vessels"
Section IX	"Welding and Brazing Qualifications"

- American Welding Society Standards
- Instrument Society of America Standards
- National Electrical Manufacturers Association Standards
- Tubular Exchanger Manufacturers Association Standards

Quality. The vendor's quality assurance program would meet the provisions of applicable federal and industrial codes.

Environment. The system would be designed to operate under environmental conditions as follows:

Temperature	+20°F to 100°F
Pressure	Atmospheric, from sea level to 6000-ft elevation
Humidity	0 to 100%.

Prototype Fabrication and Testing

A subcontractor would fabricate a prototype evaporator, which would be full-sized and used to test the evaporator configuration and size, using cold test solutions. Although the complete ARE system would not be tested at this time, the prototype would include the evaporator, concentrate, and distillate tanks, and enough instrumentation, controls, and auxiliaries to verify the evaporator design and operation.

Test solutions would be specified in the design specification and processed in the evaporator. The test solutions could include building decontamination solutions, RCS rinse solutions, and decontamination equipment effluent wastes or wet vacuum wastes. The distillate would be analyzed for purity and carryover, and the concentrate would be evaluated for concentration and volume reduction. The test results would be documented and used in the licensing application to show evidence of ARE efficiency.

Any design modifications indicated by the testing would be incorporated into the final design specification.

Identification of Test Waste Streams. There are several potential decontamination solutions that should be tested in the ARE. Table 4 lists lists decontamination solutions that could be used during decontamination of the primary system (see Table 4, Solutions 1 through 5). Solutions 6 and 7) could be used during decontamination of reactor building walls and equipment. In addition, a stream (Table 4, Solution 8) containing boron, dissolved solids, and other minerals could be tested as typical floor drain fluids.

Testing an ARE using decontamination solutions identified in Table 4 would indicate evaporator limitations, capabilities, and design modifications that should be incorporated prior to final assembly and operation of the ARE. These tests would also provide the data necessary for NRC licensing approval for ARE operation.

TABLE 4. POTENTIAL ARE TEST SOLUTIONS

Solution	Composition
1. Oxalic-citrate-peroxide	0.4 molar (M) oxalic acid 0.16 M ammonium citrate 0.34 M hydrogen peroxide Adjusted to pH 4.0 with ammonium hydroxide
2. Oxalic-peroxide-gluconic ($Na_2C_2O_4$)	0.025 M $H_2C_2O_4$ 0.5 M H_2O_2 0.013 M gluconic acid 0.045 M sodium gluconate Adjusted to a pH of 4.5
3. Alkaline permanganate-citrox process	Alkaline permanganate 10 wt% sodium hydroxide 4 wt% potassium permanganate Citrox 0.2 M oxalic acid 0.3 M citric acid 0.02 M corrosion inhibitors
4. Alkaline permanganate-ammonium citrate	10 wt% sodium hydroxide 4 wt% potassium permanganate Ammonium citrate 0.4 M ammonium citrate 0.01 M EDTA (ethylene-diamine-tetra-acetic acid)
5. Dow Chemical NS-1	Proprietary Solutions
6. Turco 4324	Proprietary Solutions
7. Radiac wash	Proprietary Solutions
8. Unnamed	2% sodium sulfate 4000 ppm boron 1000 ppm Na 200 mg/L dissolved calcium 40 mg/L suspended calcium 10 mg/L dissolved iron 200 mg/L suspended iron 8000 mg/L organic carbon 2000 mg/L dissolved phosphate 400 mg/L total suspended solids 40,000 mg/L total dissolved solids pH 7

Preliminary Operation and Maintenance Manual. Concurrent with the prototype, the subcontractor would prepare a preliminary operation and maintenance manual for the ARE. The manual would tell how to set up, start up, operate, and disassemble the ARE. Maintenance procedures would also be discussed. By reviewing these procedures, it would be possible to analyze the system operation and equipment layout to determine if improvements are desired or necessary.

Phase II Procurement Specification

A final procurement specification would be written following prototype testing of the ARE. The specification would be based on the preliminary design and on the information obtained during prototype testing. The procurement specification would cover the final design, fabrication of the ARE, and acceptance testing at the manufacturing plant.

The final design would establish final equipment selection, sizing, and placement. All of the instrumentation and controls would be specified and located in the system. The design requirements specified in the preliminary design would be followed. The necessary shielding would be determined and included in the design, and all electrical requirements would be specified.

The final design submitted by the subcontractor would include the subcontractor's schedule for fabrication, cold testing, and project completion.

Final Fabrication and Acceptance Testing

Acceptance testing would consist of operating the ARE (complete with all auxiliaries and instrumentation), and using the cold test solutions used during prototype testing. The test data would be analyzed for ARE efficiency and overall system operation.

Concurrent with the final design, a license application should be made to the Department of Transportation (DOT) in accordance with 10 CFR 71, so that the ARE can be transported before and after its use at a nuclear facility. This is necessary because it would not be possible to completely decontaminate the interior of the evaporator and its associated equipment, though it would be possible to decontaminate the exterior of the ARE.

The ARE could be operated at a nuclear facility under 10 CFR 50.59, "Changes, Tests, and Experiments."

Cost Estimate and Schedule/Deliverables

The cost estimate given in 1983 dollars is based on a 2-year period for design, testing, and fabrication of the evaporator. The evaporator would then be set up and tested at a nuclear facility, with the required subcontractor support. An additional 6-month period is assumed for initial hot testing (see Figure 3). A $960,000 estimated cost in 1983 dollars is believed reasonable for design, testing, and fabrication of an ARE by a subcontractor. Additional cost of approximately $528,000 would be incurred to provide project management, engineering, and contingency.

The estimated total cost for the project, starting with the preliminary design and continuing through the hot acceptance testing, is $1,490,000 (see Table 5 for detailed breakdown of the cost estimate). This is based on the ARE being designed, fabricated, and tested in FY-84 and FY-85. It is estimated that the site preparation and operating costs would be an additional $440,000 for the first year. This cost would be incurred by the owner of the nuclear facility where the ARE is to be used.

TABLE 5. ARE PROGRAM COST ESTIMATE

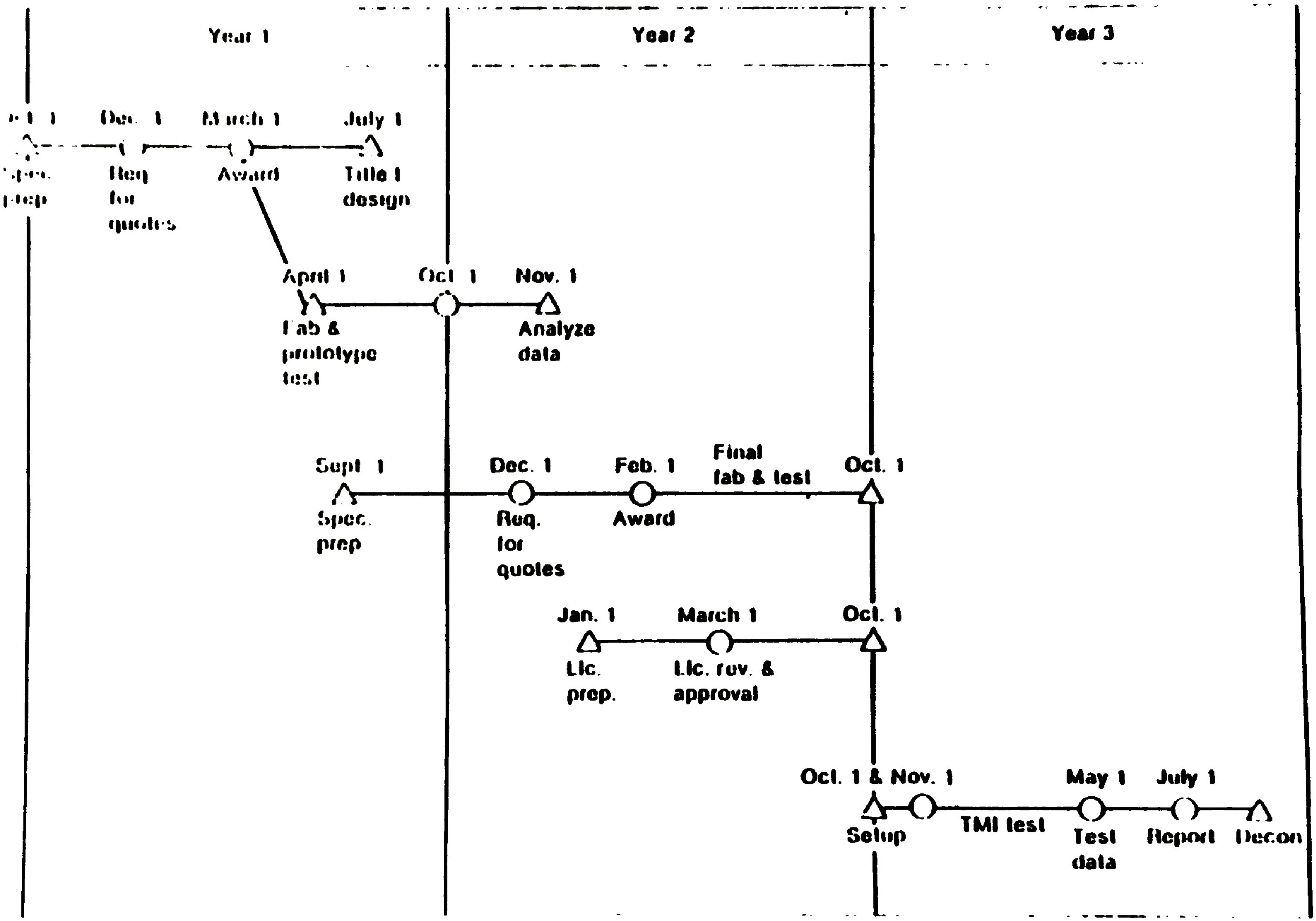
Preliminary design and prototype testing (FY-84)	Cost ($)
Engineering	
Prepare specification, 320 man-hours (MH) at $43/h	13,760
Review design, 580 MH at $43/h	24,940
Shielding analyses, 320 MH at $48/h	15,360
Criticality analyses, 280 MH at $46/h	12,880
Project management, 160 MH at $53/h	8,480
Analysis of solution, 320 MH at $48/h	15,360
Travel, six trips at $1800/trip	10,800
Computer	2,400
General and Administrative Expenses	33,270
	137,250
Subcontract	
Preliminary design	120,000
Fabrication	144,000
Testing	96,000
	497,250
Contingency at 15%	74,590
Total	571,840
Final design, fabrication, and acceptance testing (FY-85)	
Engineering	
Analyze prototype test data, 120 MH at $48/h	5,760
Prepare procurement specification and bid award, 160 MH at $48/h	7,680
Follow design and acceptance test, 140 MH at $48/h	6,720
Project management, 160 MH at $58/h	9,280
Three trips at $1,800/trip	5,400
Reproduction	2,400
DOT/NRC/PA[a] licensing support, 960 MH at 48/h	46,080
Reproduction/printing	4,800
One trip	1,800
	89,920
General and Administrative Expenses	78,983
Subcontract to design, fabricate, and test	600,000
	768,903
Contingency at 15%	115,335
Total	884,238

TABLE 5. (continued)

Project followup (FY-86)	
Engineering to analyze data, 80 MH at $54/h	4,320
Engineering to prepare report, 160 MH at $54/h	8,640
Typing/reproduction	3,600
Modifications to ARE	12,000
	28,560
Contingency at 15%	4,280
	32,840
Total project cost	1,488,918
Estimated utility costs	
Site preparation	9,600
Engineering, 960 MH at $48/h	46,080
Operation, one man 24 h/day at $36/h	315,360
Maintenance and support, 320 MH at $36/h	11,520
	382,560
Contingency at 15%	57,390
Total	439,950

a. Operation of the ARE in Pennsylvania is assumed for the purpose of the report.

Figure 3



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Attachment to Letter dated
July 7, 1980 TMI-II-R-40004

EVAPORATION TEST SOLUTION

Analysis	Sample					
	(feed:1) 66144	(dist:1) 66145	(conc:1) 66146	(feed:2) 66147	(dist:2) 66148	(conc:2) 66149
pH	6.30	5.69	6.22	7.58	10.16	6.85
conductivity (umho/cm)	21,200	7	27,200	30,700	184	48,100
total suspended solids (mg/l)	406	<1	438	92	1	1072
total dissolved solids (mg/l)	35,955	9	51,137	50,167	12	101.9
dissolved phosphate (mg/l P)	1760	<0.01	2440	2360	0.01	4900
boron (mg/l)	1926	0.60	2544	2500	3.93	4265
total organic carbon (mg/l)	7737	6.1	9958	9518	5.0	19.20
nitrogen as mg/l NH_3-N	<0.2	0.3	<0.2	700	115	1000
sodium (mg/l)	5080	<1	7600	7350	<1	14,960
dissolved calcium (mg/l)	178	<0.5	206	252	<0.5	454
suspended calcium (mg/l)	36	<0.5	52	6	<0.5	88
dissolved iron (mg/l)	9	<1	11	13	<1	28
suspended iron (mg/l)	287	<1	205	197	<1	522

Sample Identification

66144: batch #1, feed to LI-CON evaporator 5/28/80
66145: batch #1, distillate 5/28/80 @ 1824
66146: batch #1, concentrate at shutdown 5/28/80 @ 1914

66147: batch #2, feed to LI-CON evaporator 5/28/80 @ 1920
66148: batch # 2, distillate 5/28/80 @ 2048
66149: batch #2, concentrate 5/28/80 @ 2048

APPENDIX A
ANALYSIS OF EVAPORATOR TEST SOLUTIONS