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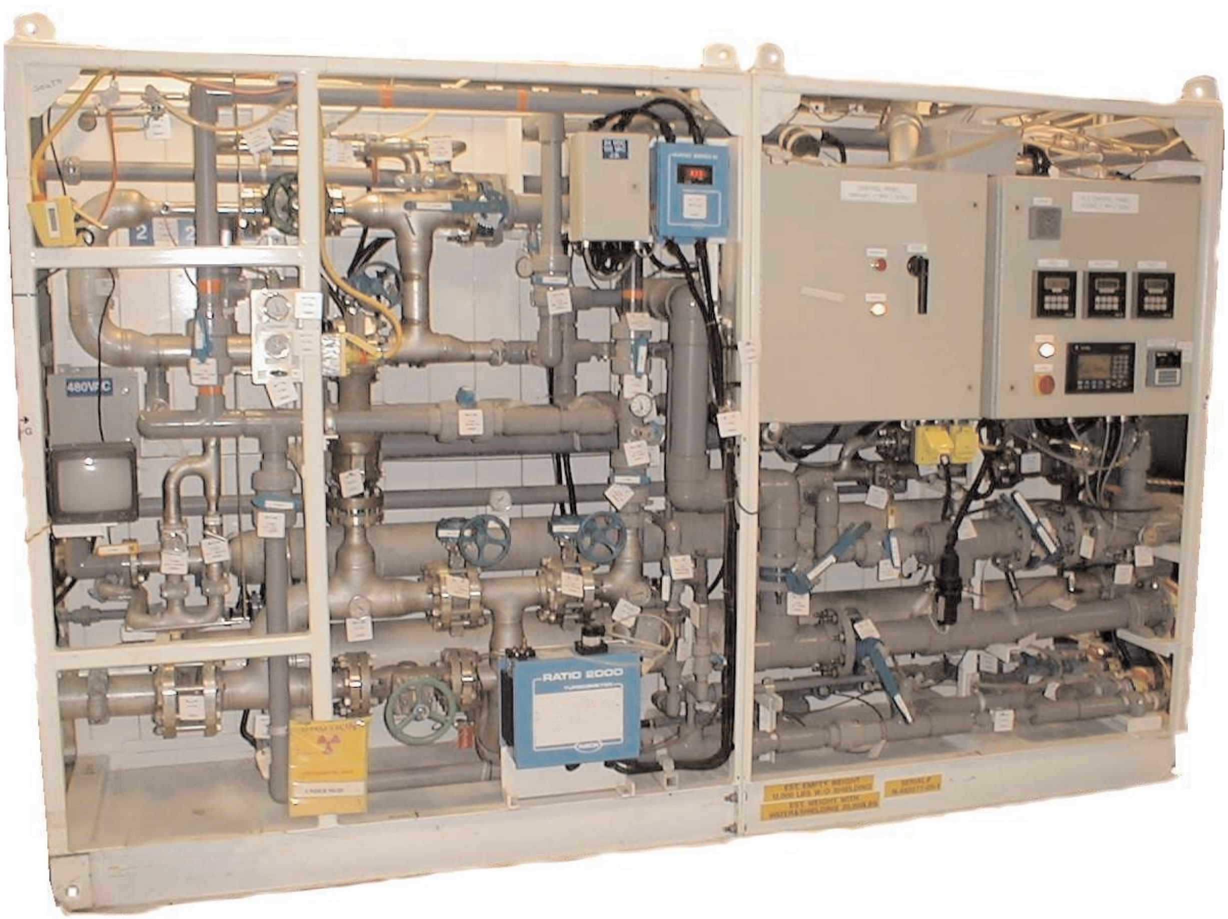
Performance Evaluation of Advanced LLW Liquid Processing Technology

Boiling Water Reactor Liquid Processing

Technical Report



Performance Evaluation of Advanced LLW Liquid Processing Technology

Boiling Water Reactor Liquid Processing

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Final Report, November 2001

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REPORT SUMMARY

This report provides condensed information on Boiling Water Reactor (BWR) membrane based liquid radwaste processing systems. The report presents specific details of the technology, including design, configuration, and performance. This information provides nuclear plant personnel with data useful in evaluating the merits of applying advanced processes at their plant.

Background

Membrane based processing of nuclear plant radioactive liquids is rapidly gaining acceptance within the industry. New membranes and anti-fouling techniques are now available making this technology viable for liquid radwaste processing. Recent experience with these improved systems has been quite favorable, and with proper application, the systems are dependable and possess a robust processing capability. The performance of these systems compares very favorably to conventional processing technologies.

Nuclear plant personnel have successfully applied membrane based processing to BWR liquid radwaste processing since 1994. The early systems experienced considerable difficulties with respect to hardware reliability and sustained performance. However, with the installation of the Thermex™ System at Nine Mile Point Unit 1 in 1994, nuclear plant operators have proven that membrane processing of liquid radwaste is cost effective with superior performance. This report addresses the design, operating experience and results being achieved at Pilgrim Nuclear Power Plant and at Nine Mile Point Units 1 and 2.

Objectives

To provide nuclear plant operators with meaningful information concerning the design, operating experience and data related to key performance parameters of advanced membrane systems in BWR plants.

Approach

The EPRI team visited each of the plants included in the review and discussed various aspects of their installation with plant operators and managers. They collected data on equipment design, component configuration and arrangement, process application, and performance. The project team also held detailed discussions with staff members familiar with the relevant vendors to gather information related to installation, operating performance, and plant and organizational impacts of the systems. Finally, the EPRI team made a comprehensive review of the publications and reports available to the public on these systems.

Results

The EPRI team found that the overall performance of these systems was superior to conventional technology, e.g., filtration and demineralization. In these specific installations, the conversion to

membrane based processing produced significantly improved water quality with less waste generation and lower operator radiation exposure. The report includes specific information detailing system performance, pre-treatment, reverse osmosis processing, post-treatment, waste processing and disposal.

EPRI Perspective

EPRI views this new technology for the processing of liquid radwaste as a very positive development. This report provides utility radwaste professionals with information on three BWR systems, covering design, configuration and performance. In addition, this report provides nuclear plant operators with a valuable tool for use in evaluating the merits of applying this technology at their plant.

Keywords

Radioactive waste processing
Radioactive liquid waste management
Low level waste liquid processing
LLW advanced processing technology
BWR liquid radwaste processing
Membrane based liquid processing

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We would like to express our appreciation for the comprehensive and timely support provided to this study by Mr. Rick Scala of Duratek, Inc.

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1 INTRODUCTION

1.1 Overview

The term “advanced processing systems” in the context of this report refers to the application of membrane based technology for the processing of radwaste liquids within a Boiling Water Reactor plant.

Early application of this technology to radwaste processing proved less than favorable. The root cause of these problems was related to such items as the variability of the waste stream, presence of high levels of particulate matter and excessive organic materials. Today, membrane processing of nuclear plant liquids is rapidly gaining acceptance within the industry. Experience gained in the early applications has focused attention to the pretreatment of the wastewater prior to membrane processing. Additionally, new membranes and anti-fouling techniques are now available making this technology viable for liquid radwaste processing. Recent experience with these improved systems has been quite favorable, showing that with proper application, they can be dependable and possess a robust processing capability. The performance of these current membrane systems compares very favorably to, and often exceeds, conventional processing technologies.

1.2 Background

Radwaste systems in Boiling Water Reactors (BWRs) have, as a design objective, to maximize the recycle of wastewater back to the main plant. This requires that the processing system consistently deliver a large volume of high purity effluent water. As a result, processing focuses on the removal of all ionic species (principal impurities include chloride, sulfate and sodium), organic matter (including such items as turbine and diesel oil, cleaning agents and lubricants) and particulate material (corrosion products and fractured processing media). Radioactivity of the process liquid is of secondary consideration for the recycle liquid. Early plant designs provided for the segregation of the wastewater based on their purity, i.e., high purity wastewater (Clean Waste – normally ~80%), medium to low impurity wastewater (Floor Drain Waste – normally 15 to 19%) and low purity (Chemical Waste or Miscellaneous Waste – normally 1 to 2%). The processing technology varied for each waste stream:

- *Clean Waste* – Filtration followed by deep bed ion exchange
- *Floor Drain Waste* – Filtration
- *Miscellaneous Waste* – Filtration

Note: 1. A major fraction of the plants were equipped with filter/demineralizers for filtration of the Floor Drain and Miscellaneous Wastes.

2. Nomenclature varies somewhat between plants, Clean Waste is often referred to as Equipment Drains, and Floor Drain Waste can be known as Chemical Waste. For clarity in this report, we have elected on the use of Clean Waste and Floor Drain Waste for the titles.

This report addresses the processing experience related to three systems located at, Pilgrim Nuclear Station, Nine Mile Point Unit 1 and Nine Mile Point Unit 2. All three are Thermex™ Systems provided by Duratek, Inc., a leader in the application of membrane technology to nuclear plant liquid wastes. *We believe this was appropriate, since the principal objective of this investigation was to assess membrane technology for the processing of BWR wastewater*. Therefore, these systems were selected for study based on period of operation and availability of detailed performance data.

2
PILGRIM NUCLEAR STATION

2.1 Plant Information

Pilgrim Nuclear Station is a 690 MWe Boiling Water Reactor located on Cape Cod Bay south of Plymouth Massachusetts. The plant was placed in commercial operation on December 1972.

2.2 Liquid Radwaste Processing Background Information

The original radwaste system was designed to segregate the liquid waste into three distinct streams, clean waste (high purity water from equipment drains), chemical waste (low purity water from floor drains), and miscellaneous wastes (consisting of a range of low quality water from such activities as laundry and decontamination activities).

Clean Waste Processing System Design

The original system design allowed for the collection of the Clean Waste in one of two 15,000 gallon (56,780 liters) receiver tanks. The Clean waste liquid was pumped at 50-100 gpm (189-379 L/min) to one of two Flatbed Filters for removal of particulate matter. These filters utilized a stainless steel 100 mesh belt with an effective filtration area of 60 ft^2 (6 m^2). Filter operation consisted of precoating the screen with diatomaceous earth media at approximately 0.1 lb/ ft^2 (42.1 kg/cm^2). At 25 pounds per square inch differential (psid) or 1.72 bars, the filter screen was washed and a new precoat was applied.

Following the Flatbed was a 30 ft^3 (0.8 m^3) deep bed Radwaste Demineralizer. Early operations called for a resin loading of 2:1 strong base anion resin to strong acid cation resin with a upper bed of 5 ft^3 (0.1 m^3) of activated carbon for removal of organic impurities. The demineralizer effluent is filtered through a metal screen post filter before entering one of four Treated Water Storage Tanks. The treated water can be routed back to the Condensate Storage Tank, recycled back to radwaste for further processing or discharged from the plant in the circulating water discharge header.

Chemical Waste Processing System Design

The original system design provided for the collection of the Chemical Waste in one of two 15,000 gallons (56,980 liters) receiver tanks. The Chemical waste liquid is pumped at 50-100 gpm (189-379 L/min) to one of two Flatbed Filters for removal of particulate matter, as described above. Originally, the plant was to chemically regenerate the Condensate Demineralizers. The original design defined the Radwaste Chemical Waste as a combination of the spent regenerate chemicals and the normal floor drain liquid wastes. This waste was to be processed by a concentrator and then stored in one of three 20,000 gallon (75,706 liters). Monitor Tanks for radioactive decay prior to being discharged from the plant.

Miscellaneous Waste Processing System Design

Miscellaneous waste consists principally of liquids containing high levels of detergents and chelating agents from cleaning and maintenance activities. These wastes are collected in a partitioned tank of 1,000 gallons (3,785 liters) total capacity. This water is filtered and discharged from the plant through the circulating cooling water header.

1992 Plant Processing Experience

In 1992, EPRI performed a detailed review of the operation of Pilgrim Station's liquid radwaste system as part of a comprehensive waste reduction project. Data taken from this earlier work provides a comprehensive benchmark of radwaste system's performance prior to Pilgrim's transition to membrane processing.

Table 2-1 shows the 1992 monthly average liquid input to the radwaste system to be 1,575,000 gallons (5,961,857 liters) per month (18,900,000 gallons per year or 71,540,000 liters per year). This volume translates to a high input of approximately 30 gpm (113.4 liters per min) from new waste input and recycled water to meet the recycle water chemical control limits.

Table 2-1
1992 Radwaste Liquid Clean and Chemical Waste Input

Month 1992	Gallons	Input gpm
January	1,766,000	33
February	1,380,000	26
March	1,534,000	27
April	1,220,000	23
May	1,743,000	32
June	1,810,000	35
Average	**1,575,000**	**29**

Note: 1 gallon = 3.79 liters

In 1992 waste from the Flatbed Filter dominated the radwaste operation. Table 2-2 provides operating data typical for this period. Data taken from May 20 to August 6, 1992 (79 days) shows the Flatbed Filter being precoated approximately 2.2 times per day with a projected waste disposal volume of approximately 2,000 cu. ft. per year (57 m^3/year).

Table 2-2
1992 Radwaste Flatbed Filter Operation

Item	Data
Period	May 20, 1992 – August 6, 1992
Total Precoats	170
Average Precoats per Day	2.2
Diatomaceous Earth Waste	11,000 ft^3 per year
Projected Burial Volume	2,050 ft^3 per year

Note: 1 ft^3 = 0.028 m^3

The benefits resulting from the Thermex™ System are very apparent as can be seen by the dramatic reduction in waste generation and disposal volumes. Much of this is the direct result of the elimination of Flatbed Filter operation.

Table 2-3 shows that during the first eight months of 1992, the Radwaste Demineralizer service run averaged 15 days between resin replacements. This represents an operating capacity of approximately 36,000 gallons per cu. ft. (4,811,829 liters per cu. m) of resin for this period.

Table 2-3
1992 Radwaste Demineralizer Operation

Item	Data
Period	January – August 1992
Total resin change outs	14
Average service run	15 days
Projected Resin Waste	630 ft^3 per year

Note: 1 ft^3 = 0.028 m^3

Finally, Table 2-4 presents a summary of chemistry data for the radwaste input and the treated wastewater. This data provides a general benchmark for assessing today's plant operations compared to that of 1992.

Table 2-4
1992 Radwaste Liquid Chemistry Data

Parameter	Radwaste Input	Treated Waste Tk.
Conductivity, µS/cm^2	22	0.55
Chloride, ppm	1.37	<1
Nitrite, ppm	1.2	<1
Nitrate, ppm	3.8	<1
T.O.C., ppm	1.0	0.09
Turbidity, NTU	8.4	0.18
Activity, cpm/ml	1,550	27

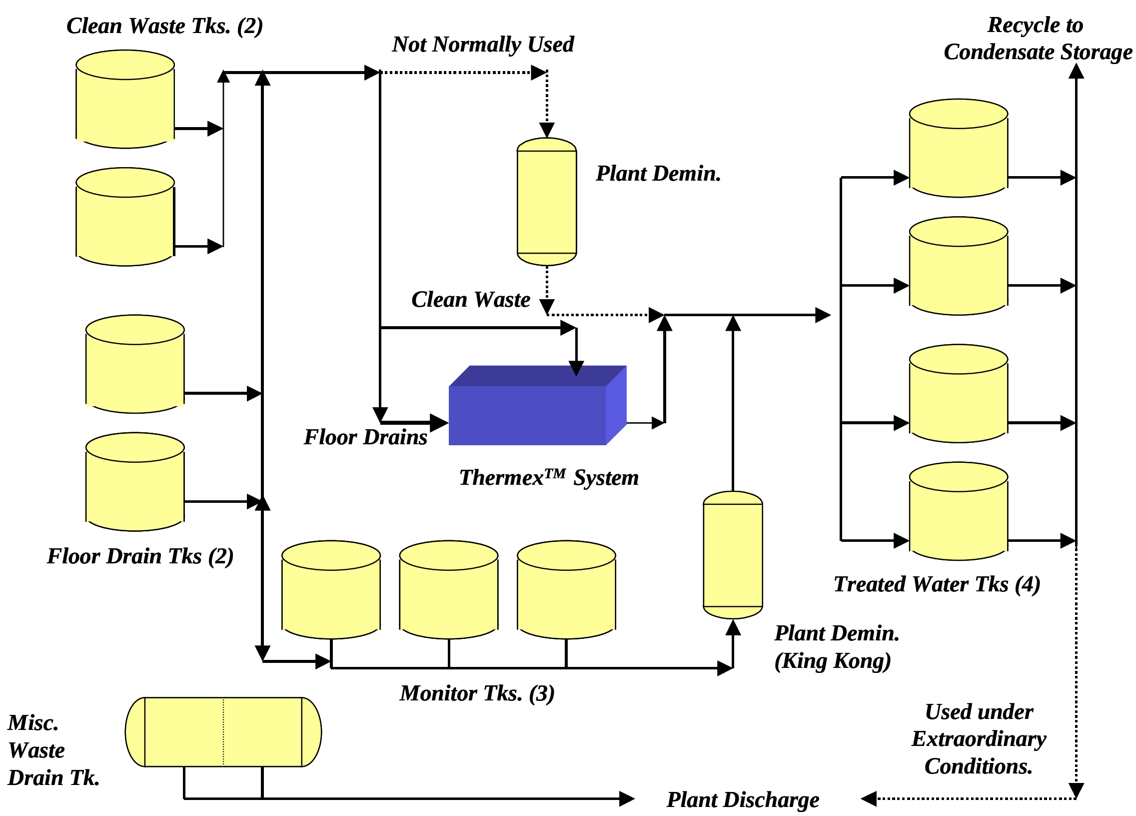

Figure 2-1
Pilgrim Radwaste System Schematic

2.3 Thermex™ Processing System Description

2.3.1 Overview

The Pilgrim Thermex™ Processing System was placed in service on July 11, 1997. This change in processing was directed at achieving the following:

Station Goals

- Reduce Radwaste Liquid processing and disposal costs
- Reduce personnel exposure related to radwaste operations
- Reduce waste disposal volume to meet INPO First Quartile rating
- Reduce plant equipment maintenance costs
- Improve TOC removal from Floor Drain wastes
- Improve quality of water recycled to the Condensate Storage Tank with respect to conductivity, TOC, chloride and sulfate parameters.

The new system was targeted for processing Floor Drain wastewater. It was not a completely independent system; rather it was integrated into the overall existing radwaste system and has the capability to process both Clean and Floor Drain waste. Additionally, this arrangement allows either of the systems to act as a backup to the other should such a need arise.

Refer to Figure 2-1 for a schematic of the Pilgrim Radwaste processing arrangement.

2.3.2 Thermex™ System

Each Thermex™ System is custom designed to the needs and constraints of the specific host plant. This has more to do with the arrangement of the hardware than with the underlying purification process. The Thermex™ System is custom designed in terms of components and configuration to meet the needs of individual plants. Specific impurities in the waste stream can impact the number and types of components selected for a given system. A system can be described as a number of sequential processes (pretreatment, reverse osmosis, and post treatment). Refer to Figure 2-2 for a schematic of the Thermex™ System. Note that Floor Drain Water is normally routed through the filters, the RO unit and Demineralizer. The Clean Waste is routed to the filters and then directly to the demineralizer bypassing the RO unit, which is a portion of the Thermex™ System. Clean waste is diverted to this flow path due to the thermal upper limit of the RO membranes.

Table 2-5 lists the various components of the Pilgrim Thermex™ System in terms of their overall footprint and floor loading.

Table 2-5
Thermex™ Component Weight and Dimensions

Component	Footprint W x L (in)	Height (in.)	Empty Weight (lb.)	Operating Weight (lb.)
Control Module (CM)	23 x 60	46	425	500
Suspended Solids Separator (SSS)[1]	42 Dia.	96	1,500	4,900
SSS Shielding	8 x 56.5	84	3,300	3,300
Suspended Solids Polisher (SSP)	26 x 38	61	1,650	1,870
Process Feed Tank (DSS-PFT)	73 x 80	140	2,200	11,400
DSS Prefilter (F-2)	24 x 30	67	2,355	2,800
Dissolved Solids Separator (DSS)	60 x 144	78	18,000	20,900
Dissolved Solids Polisher (DSP)	40 x 110	84	3,500	4,700
Demineralizer (DEMIN)	42 Dia.	96	1,500	4,900

Note: 1 in = 2.54 cm
1 lb. = 0.454 kg

<u>Preconditioning</u>

Oil and particulate material is removed by means of graded charcoal followed by a bag filter. Two vessels (Suspended Solids Separators) containing graded charcoal are arranged for parallel operation. This is followed by a 1 micron bag filter (Suspended Solids Polisher) for removing any fines in the charcoal filter effluent prior to delivery of the waste to the reverse osmosis (RO) portion of the system.

<u>Thermex™ Reverse Osmosis System</u>

The preconditioned liquid enters the Thermex™ System at the RO Process Feed Tank (PFT). This tank serves as a front-end supply tank to the process. Water is withdrawn from the tank by the main recirculation pump and is then routed through a second bag filter. The pressure is then increased by a Booster Pump and delivered to the Reverse Osmosis (RO) unit. The RO unit was assembled as two modules to accommodate equipment installation. Under this arrangement, permeate from the first section (Dissolved Solids Separator) flows to the next stage (Dissolved Solids Polisher). The final concentrate is recirculated back to the PFT for reprocessing through the RO system. The purified liquid permeate from each stage is collected and delivered to the post treatment section of the system.

Polisher

The RO permeate flows through a deep bed demineralizer (Polisher) containing custom blended ion exchange resin. The effluent of this portion of the system is directed to one of the Treated Water Tanks for analysis and disposition.

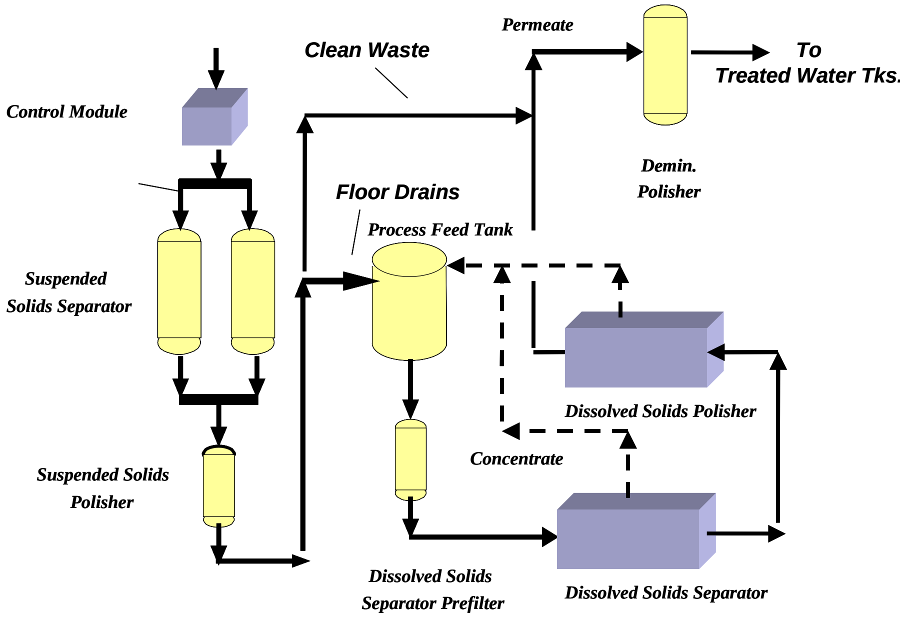

Figure 2-2
Pilgrim Thermex™ System Schematic

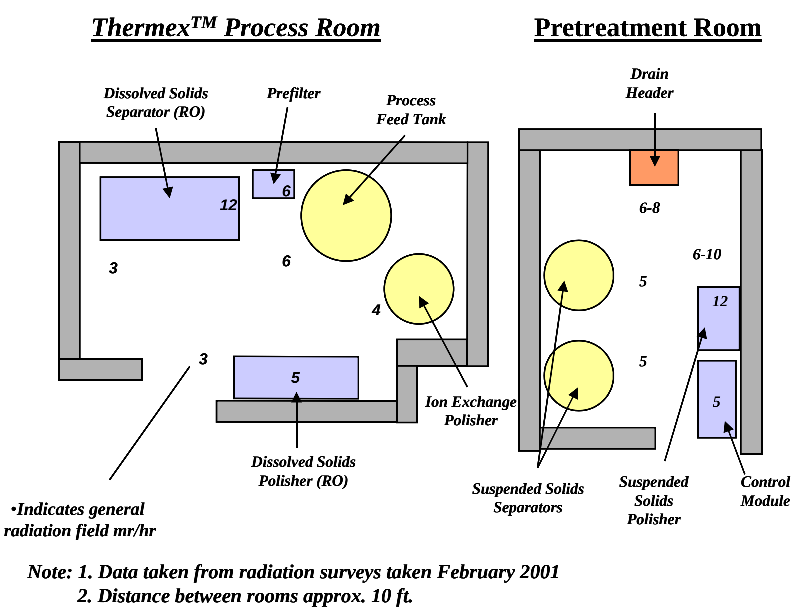

Figure 2-3
Pilgrim Thermex™ General Arrangement and Radiation Fields

2.4 Component Information

2.4.1 System Controls

Pilgrim Station's Thermex™ System is designed for manual operation with continuous monitoring of key parameters and is capable of automatic shutdown should pre-selected set points be exceeded. Manual operation is used to reduce the complexity of the system operation. Process flow is fixed and changes within the process can be made as identified by the performance monitoring program. Connections between major components are made by means of reinforced hoses. The design allows for all routine operations to be accomplished without disconnecting and reconnecting any of these hoses.

A Data Acquisition System (DAS) captures data from key process parameters including, process variables such as; flow, temperature, tank level, pressure, and chemical conditions such as; pH, conductivity, and turbidity. This system is capable of alarming operators to off-normal conditions and initiating system shutdown upon exceeding operating control limits. Additionally, the system is capable of retrieving alarm sequences and values. Finally, the DAS is used to log operator selected parameters that are used to track and assess system performance. Figure 2-4 shows a screen shot of Pilgrim's DAS schematic.

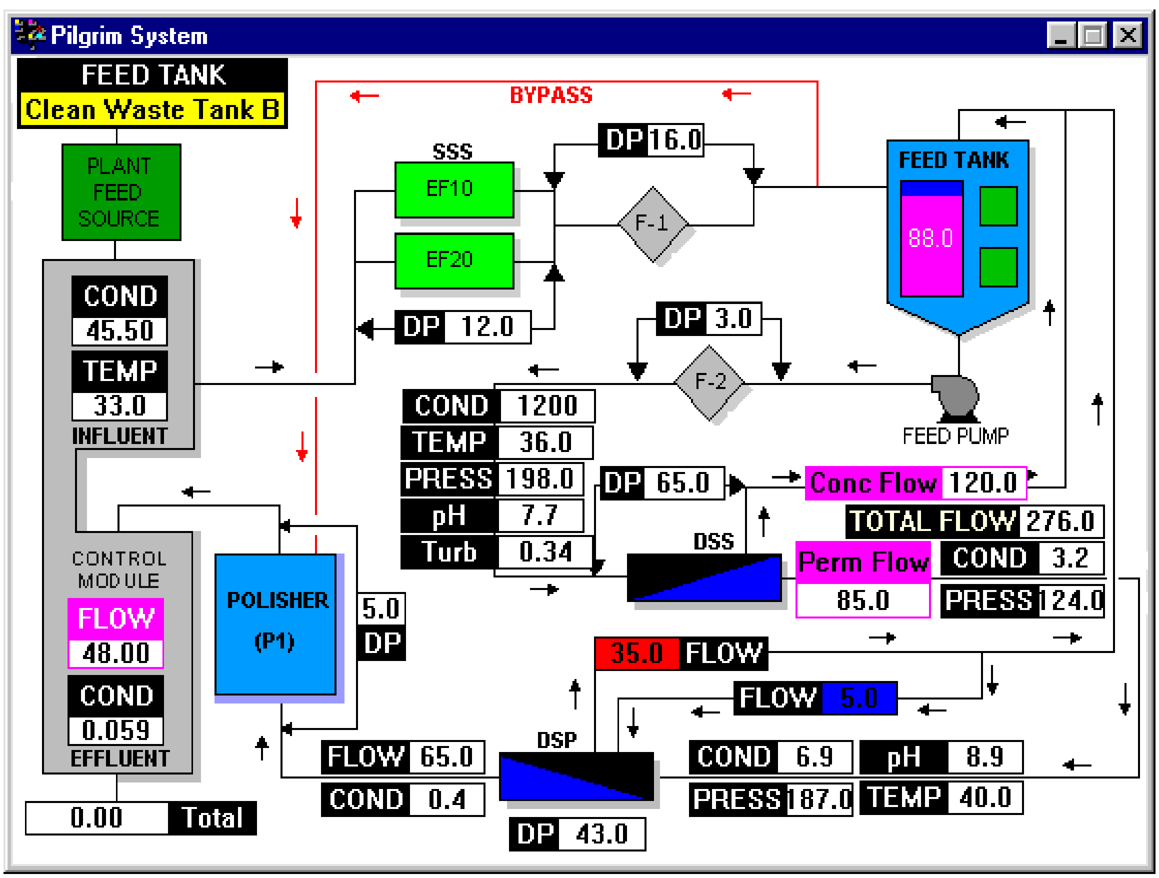

Figure 2-4
Pilgrim DAS Schematic

2.4.2 Control Module

The Control Module provides a common control and monitoring point for the Thermex™ System influent and effluent waste liquid. The Module is equipped with instrumentation for continuous measurement of the flow, temperature and conductivity. The plant laboratory provides system feed turbidity, TOC and pH analyses.

2.4.3 Pretreatment Vessels

The pretreatment system utilizes the Advanced Liquid Processing System (ALPS) vessel design developed by Duratek for portable liquid processing. The vessel design allows the vessel to be back-flushed, top-flushed or top-sluiced to reduce high differential pressure, excessive radiation fields or removal of fouled media.

2.4.4 Pre-Filter

The pre-filter is a bag filter with a 1 μm rating designed to remove small particulate matter from flushing or transfer operations, that may have migrated through the pretreatment system. This unit is located upstream of the PFT and protects the RO system from particulate fouling.

2.4.5 Process Feed Tank

The PFT is an 1100-gallon (4164 liter) tank for receipt of the input waste stream and that of the recirculating concentrate from the RO system. Once the liquid within the tank reaches a limiting chemical concentration, the contents of the tank can be routed to the Spent Resin Storage Tank or High Integrity Container (HIC) for transport to an off-site processing facility.

2.4.6 Reverse Osmosis Pre-Filter

The RO Prefilter is a four bag filter designed to prevent fouling of the RO membranes by removing particulate matter from the recirculating waste stream prior to its entering the reverse osmosis membranes.

2.4.7 Thermex™ Dissolved Solids Separator and Polisher

The Pilgrim Thermex™ System has been configured into two distinct modules. The unit is designed to operate at <113 ^{0}F (<45^{0}C) with a sustained permeate flow of approximately 45 gpm (170.4 liters per min) (this flow is presently limited by plant input pump capacity). Both the Dissolved Solids Separator and Dissolved Solids Polisher are two-stage units (4X3 and 2X2X1X1X1 membrane arrangement). Permeate from this portion of the system is sent to the Post Demineralizers for polishing. The rejected concentrated liquid is returned to the PFT for recirculation through the membranes.

2.4.8 Post-Treatment Vessels

The post-treatment system utilizes a pressure vessel design. The vessel contains a custom mix of ion exchange resins for polishing of the water prior to its entering the Treated Water Tanks.

2.5 Plant Support Information

2.5.1 System Category

Pilgrim Station presently contracts for the use of the Thermex™ System. However, the equipment is treated as a permanently installed plant system. As such, system changes are carried out under existing plant engineering procedures. This involves the use of Request for Engineering Services and Engineering Change Orders for plant modifications. This process requires complete review; approval and documentation paralleling that used for plant equipment.

2.5.2 System Operating Documents

Similarly, operating procedures and equipment configurations are treated as plant documents and subject to plant review and approval prior to implementation. Process and Instrument Drawings (P&IDs) consists of basic system drawings (plant documents) and the vendor maintains a second set of detailed drawings.

2.5.3 Operating Staff

The Pilgrim Station personnel assigned to Radwaste operations are certified for Thermex™ operation. Supervision of the day-to-day operation and on-site engineering review of the system performance is the prime responsibility of the vendor's representative.

2.5.4 Maintenance

The vendor's site representative performs all system maintenance on the Thermex™ system.

2.6 Liquid Processing System Performance

2.6.1 Overall performance

Table 2-6 presents key data from pre-Thermex™ operation and for the period of 1998 – 2000. Several conclusions can be drawn from a review of the Thermex™ performance period. These include:

1. The Thermex™'s excellent performance is evidenced by Pilgrim's increased utilization of this system.

2. The total waste is dramatically lower than that experienced prior to the Thermex™ installation.

3. The personnel exposure associated with the radwaste operation is significantly lower that that seen during Flatbed operation.

4. The performance seen in 2000 met all of the goals established by the plant for radwaste processing.

Table 2-6
Thermex™ Annual Overall Performance Data 1998-2000

	Pre –Thermex 1992 Estimate	1998	1999	2000
Total Wastewater Processed gal.	18,900,000 Total RW input	8,692,229	15,574,576	17,741,107
Total Waste Generated cu. ft.	2,700	561	537	470
Average Effluent Conductivity, µS/cm[2]	0.55	0.06	0.06	0.09
Average Effluent TOC, ppb[1]	90	51	50	54
Total Personnel Exposure, mRem	15,000	1,148	919	1,340[2]

Note: 1. Plant routine analytical limit of detection for TOC is 50 ppb.
2. The annual dose for 2000 included 633 mRem directly related to operator training.
3. 1 cu. ft. = 0.028 cu. m.

2.6.2 Input Wastewater Volume

Data obtained in the 1992 EPRI assessment showed the average wastewater to be 1,575,000 gallons/mo (5,961,857 L/mo). Figure 2-5 shows that in the year 2000 the wastewater input has remained essentially the same. Floor Drain wastewater represents approximately 20% of the total radwaste input.

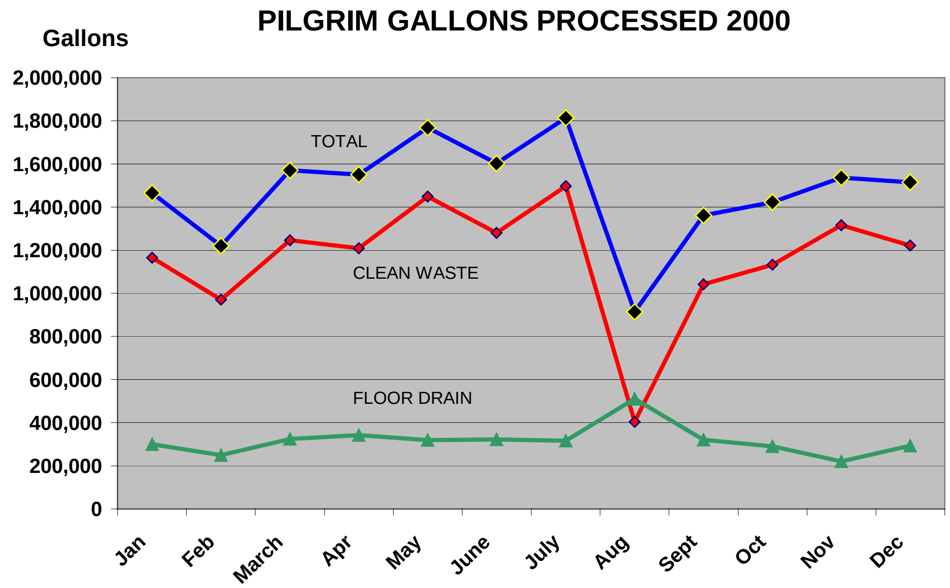

Figure 2-5
Pilgrim Station Wastewater Influent

2.6.3 Influent Wastewater Impurities

Pilgrim Station has a history doing an excellent job of limiting waste impurities in the radwaste input liquid. Figure 2-6 shows the influent and effluent conductivity values for the year 2000. Overall these values are approximately 50% lower than the 22 $\mu S/cm^2$ reported in the EPRI 1992 radwaste assessment.   This figure clearly shows that a major impurity intrusion event was experienced during June and July. This was traced to Closed Cooling Water System leakage based on a significant increase in the nitrate concentration present in the waste input stream. The impact of this event can be seen in Figure 2-6 as a significant spike in the radwaste system effluent conductivity. This intrusion caused a major increase in waste generation due to the demand placed on the plant demineralizer resin; refer to Figure 2-7.

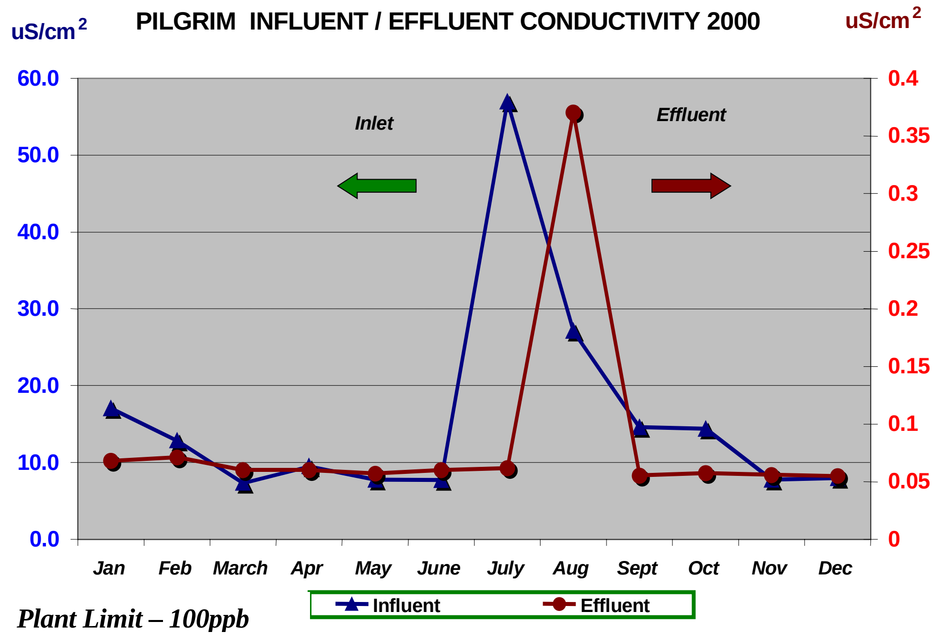

Figure 2-6
Thermex™ Wastewater Influent and Effluent Conductivity

2.6.4 Waste Generation

Thermex™ processing has produced a major reduction in the radwaste system waste generation. In 1996 Pilgrim Station reported the waste generation from radwaste operation to be 1,350 cu. ft. (38 cu. m) of resin and 660 cu. ft. (19 cu. m) of diatomaceous earth media. The values are slightly different from those reported for 1992. However, the waste values in both of these years generally correlate and show pre- Thermex™ operation as producing an excessive quantity of waste. Figure 2-7 presents the monthly waste generation for the year 2000. As mentioned earlier, the July figure reflects the effect of the Reactor Building Closed Cooling Waste intrusion event.

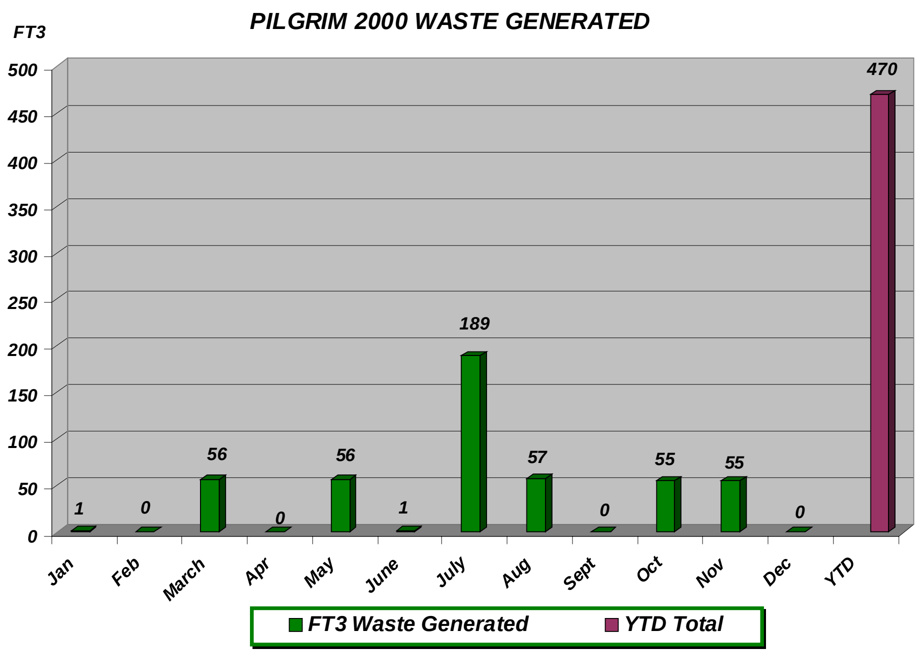

Figure 2-7
Radwaste Waste Generation 2000 with Thermex™ Processing

2.6.5 Removal of Total Organic Carbon (TOC)

BWRs recycle a major fraction of the wastewater entering their radwaste system. The goal is to maintain the processed liquid as free of chemical impurities as practicable. Ingress of organic contaminants to the primary power system, particularly those containing halogens or sulfur, can elevate reactor water concentrations to an undesirable level. For this reason, EPRI's "BWR Water Chemistry Guidelines – 2000" designates TOC as a diagnostic parameter and recommends a limit of <200 ppb. However, the Guidelines do point out that using this value with present measurement techniques may not provide adequate protection from significant chemistry excursions. For this reason, Pilgrim's goal is to reduce the TOC level present in the radwaste recycle to an absolute minimum value (presently the plant achievable limit is <100 ppb and a goal has been set at <50 ppb, which is the plant's lower limit of detection).

Figure 2-8 shows the typical values being achieved with radwaste processing.

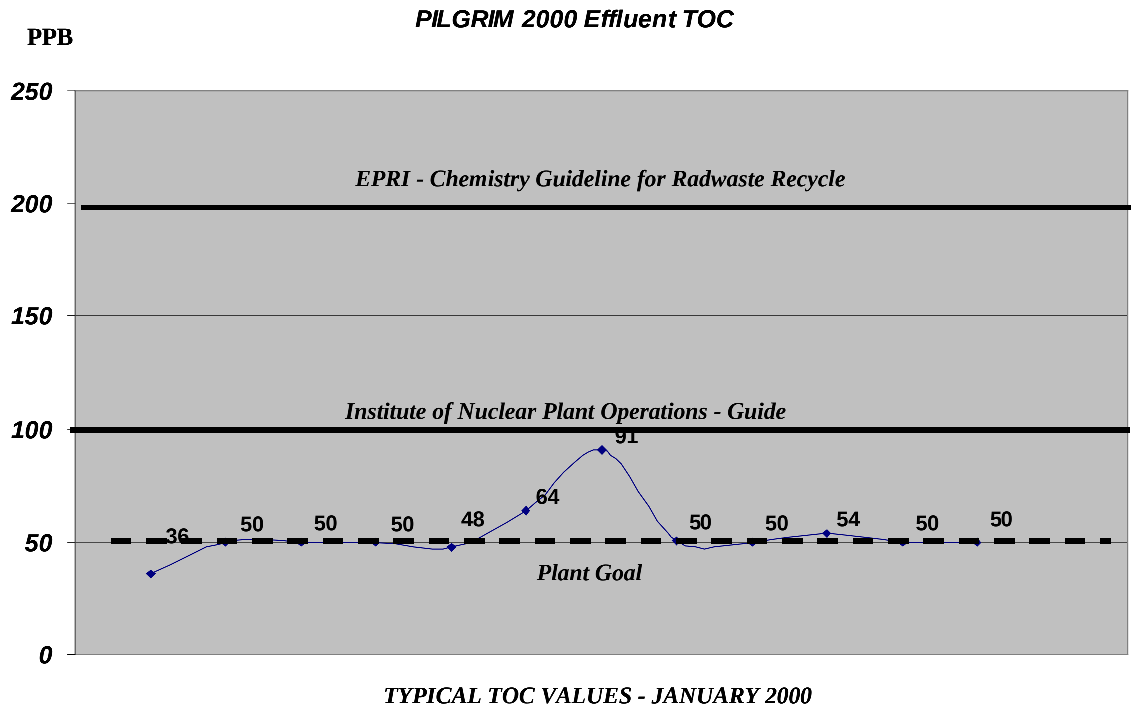

Figure 2-8
Removal of TOC with Thermex™ Processing

2.6.6 Removal of Radioactivity with Thermex™ Processing

Pilgrim Station, like a number of boiling water reactors, operates with essentially zero liquid discharge. During normal operation, both the Clean and Chemical waste streams are purified to a level that will allow it to be recycled to the Condensate Storage Tank for reuse. Only under abnormal conditions, e.g., major impurity intrusions, major component replacement or refurbishment, etc. would the plant consider liquid discharge.

Under this mode of operation, the primary radwaste consideration is the purity of the liquid being recycled to the plant. Radioactivity content is of only secondary importance since the liquid is not being released to the environment. Figure 2-9 presents a typical Thermex™ removal efficiency for key nuclides; this data provides a general reference for radioactivity removal. This parameter will vary with waste stream impurities. However, this figure does provide basic removal figures which allow for comparison of the Thermex™ technology to the industry's standard ion exchange processing.

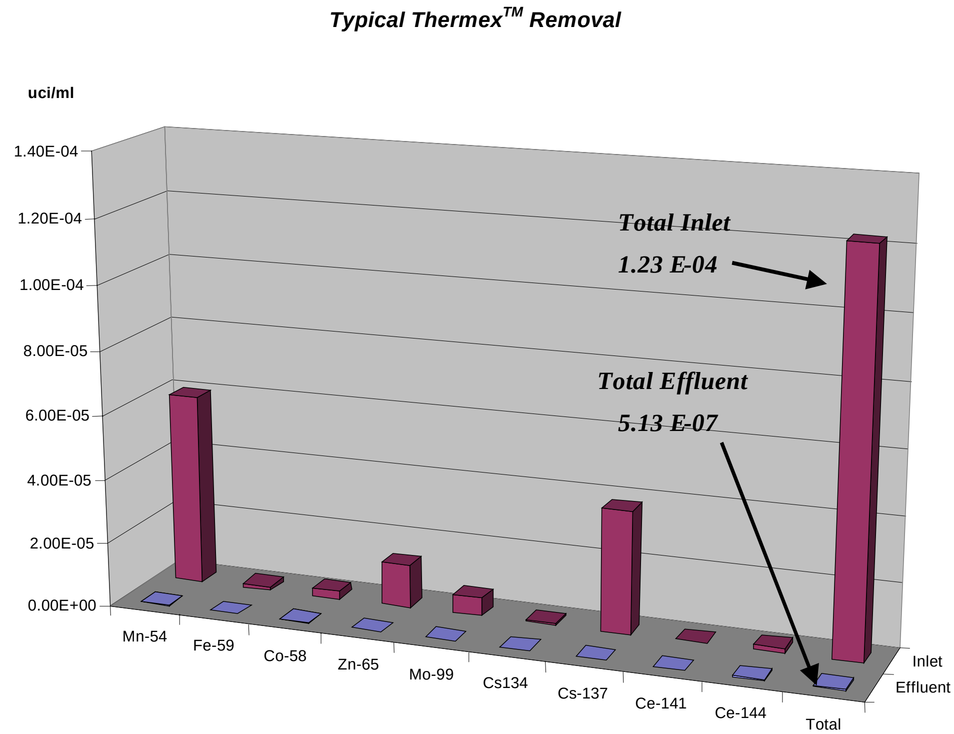

Figure 2-9
Removal of Radioactivity with Thermex™ Processing

2.6.7 Personnel Exposure Related to Operation of the Thermex™ System

Thermex™ operation has produced a significant reduction in the personnel exposure associated with the operation of the radwaste system. Much of this reduction is the direct result of elimination of the Flatbed Filters. Plant personnel estimate that these two filters represented an annual exposure of 15 Rem to plant operators and maintenance personnel. Operation of these filters required repeated adjustment or replacement of the screen filter and calibration of the waste monitoring equipment.

Figure 2-10 shows the monthly personnel exposure experienced during the year 2000. This figure breaks down the exposure into routine operations and training. Routine operations consist of operator actions, daily maintenance duties and scheduled maintenance tasks. During this period, the operating staff was undergoing a transition from a dedicated radwaste position to a rotating assignment within the Operating Department. This change in job function greatly expanded the number of operators needing to be qualified on the system. The result was a significant increase in the training activity. A major fraction of the operators' training was spent on hands operations requiring considerable more time in the area of the Thermex™ System than would be required for normal operation. In 2000 Routine Operation Exposure was 707 mRem and Training Special Project was 633 mRem with a Total Annual Radwaste Exposure of 1,340 mRem.

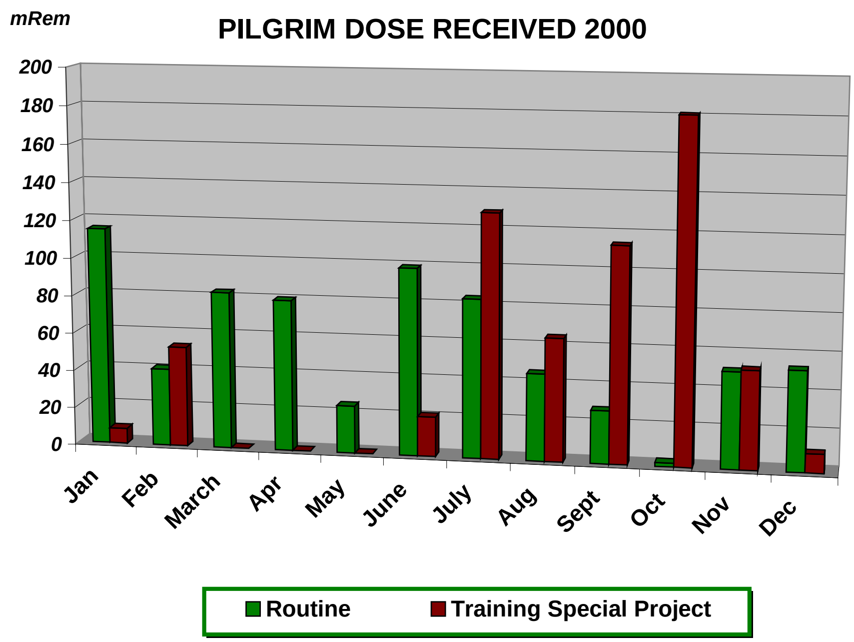

Figure 2-10
Personnel Exposure with Thermex™ Processing

2.6.8 Membrane Cleaning and Projected Service Life

Successful application of a membrane technology for the processing of liquid radwaste depends on the prevention of membrane fouling. Chemical cleaning of membrane is a standard practice in other industries. However, in a nuclear plant the waste chemicals are viewed as contributing to the generation of radioactive waste. For this reason, the membrane cleaning process receives considerable attention beyond that given in other applications.

During most of the year 2000, chemical cleaning of the Thermex™ membranes was performed approximately monthly. A new cleaning process was first applied in December 2000. This technique has been applied three times and the results suggest a major reduction (in excess of 50%) in the cleaning frequency, refer to Figure 2-11.

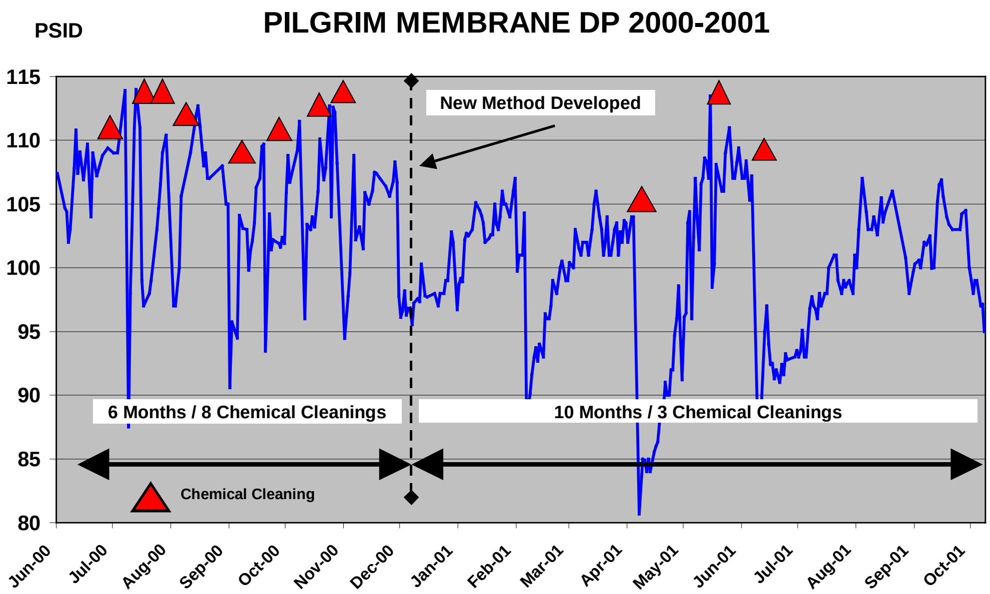

Figure 2-11
Membrane Cleaning of the Thermex™ System

2.6.9 Thermex™ Concentrate Processing

Processing of the concentrate from a membrane based system is viewed within the industry as a major hurdle to applying this technology to a nuclear plant's radwaste system. Plant personnel and Duratek worked together to develop a unique approach to the disposal of the membrane concentrate. The concentrate is routed from the Process Feed Tank to the plant Spent Resin Storage Tank where it is brought in contact with spent resin from the condensate demineralizer system. At the time of removal, this resin still possesses a major fraction of its ion exchange capacity, which is available for removal of the concentrate contaminants.

To this point, the availability of spent resin has been adequate to remove the concentrated impurities avoiding off-site shipments, processing and disposal of the Thermex™ concentrate. To date no concentrate has been shipped off-site for processing. This approach results in major savings to the plant.

Other plants seeking to use this approach will need to evaluate the availability of spent resin verses the projected ionic loading resulting from the process. It is possible that other plants will find that meeting their needs for concentrate processing will require a combination of the use of spent resin and off-site processing.

2.7 Reference

1. "Low Level Characterization at Pilgrim Nuclear Station"; John Kelly, Mike Naughton TARAwest, Internal EPRI report.

3
NINE MILE POINT UNIT I

3.1 Plant Information

Nine Mile Point Station Unit I (NMP-1) is a 610 MWe Boiling Water Reactor located on Lake Ontario east of Oswego, New York. The plant was placed in commercial operation in 1969.

3.2 Liquid Radwaste Processing Background Information

It is important to note, that NMP-1 has elected to operate under a "zero discharge" philosophy. This plant has sustained normal plant operation without a liquid discharge for a period of more than 10 years. Only once did the plant have to discharge liquid and this was related to overall plant inventory control.

The original radwaste system design was similar to that described for Pilgrim Station. Liquid waste was segregated into two major streams; Clean Waste (high purity water from equipment drains) and Floor Drain Waste (low purity water from floor drains). Refer to Figure 3-1 for a schematic of the Nine Mile I Radwaste System.

Clean Drain Processing System Design

The original system design provided for the collection of the Clean Drain in the receiver tank. The Clean waste liquid was pumped to precoat filters arranged for parallel operation (a flatbed filter was decommissioned early in plant life) for removal of particulate matter. A deep bed Radwaste Demineralizer followed this filter. The demineralizer effluent was routed to either one of two Waste Sample Tanks for return to the main plant Condensate Storage Tank.

Floor Drain Processing System Design

From plant startup until 1992 the floor drains were processed by means of a forced circulation evaporator. Experience showed that this approach was costly, produced less than desired product water quality and involved a high degree of labor and associated personnel exposure. Much of the operating cost was related to the electric boiler associated with the evaporator system.

1992 Plant Conversion to a Portable Filtration/Demineralization System

In 1992, a ChemNuclear (Duratek) installed an Advanced Liquid Processing System (ALPS) consisting of Charcoal, Cation, Anion and Mixed Bed vessels, to replace the evaporator/electric boiler system. This change resulted in the following:

- Reduced the radwaste waste volume.
- Improve the quality of the final recycle water.
- Reduced operator and maintenance exposure.
- Lowered operating cost

By eliminating the operation of the electric boiler from the processing system, NMP-1 increased the plant's power delivery to the electric grid by 48 MWe per day. This increase allowed the plant to set a new station generation record with the added benefit of an estimated annual cost avoidance of 1.4 million dollars. Additionally, switching from evaporation to ALPS demineralization resulted in a waste reduction assessed at 1600 cu. ft. per year (45 cu. m per year). This waste reduction translated into an additional $720,000 cost savings. It is important to note that these figures reflect 1992 costs and would produce significantly higher savings in today's market.

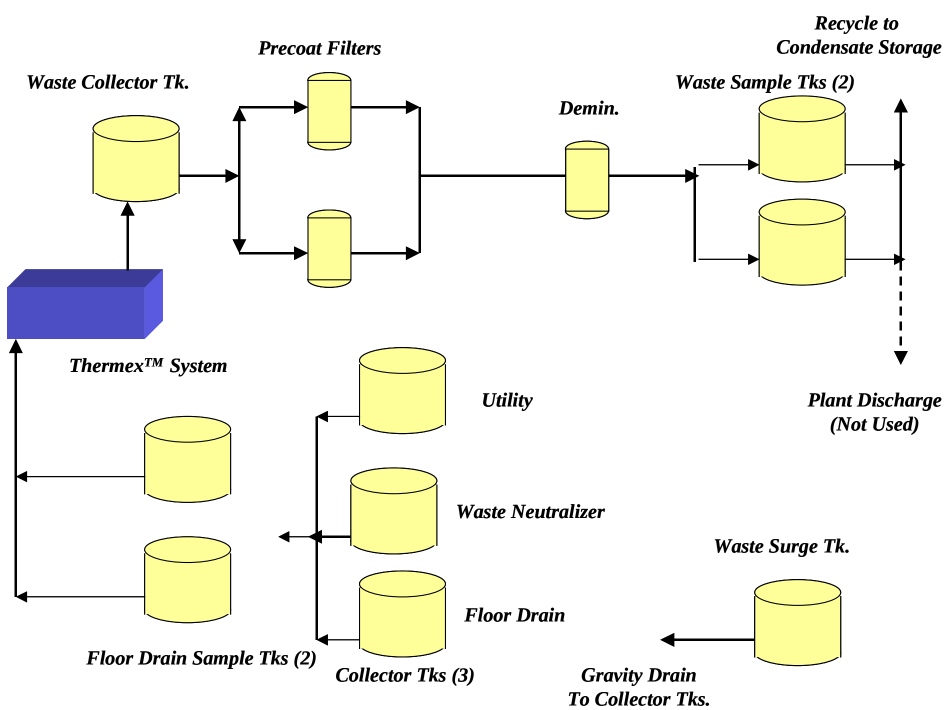

Figure 3-1
NMP-1 Radwaste System Schematic

3.3 Thermex™ Processing System Description

3.3.1 Overview

The NMP-1 Thermex™ Processing System was placed in service in January 1995 for the processing of floor drain wastewater. This installation was the first full size Thermex™ System specifically designed for application in a nuclear plant radwaste system. A comprehensive off-site pilot testing program was conducted with a 1/25th scale unit as part of the development program.

The information generated under the test program provided the basis for performance projections and component sizing for the NMP-1 system.

Refer to Figure 3-1 for a schematic of the NMP-1 Radwaste processing arrangement.

The change to Thermex™ processing was directed at achieving the following:

<u>Station Goals</u>

- Reduce liquid processing waste by 80% to extend the storage life of the on-site solid radwaste storage facilities.
- Allow processing wastewater with varying concentrations of impurity while maintaining ultra-pure product quality standards.
- Reduce the concentration of organo-anions present in the radwaste recycle to the Condensate Storage Tank.

The transition to the ALPS processing did result in a significant reduction in the radwaste waste generation. However, plant personnel continued to view the waste generation as unacceptable in view of the uncertainty surrounding disposal of low-level waste. Pilot plant testing projected a major waste reduction was possible with the Thermex™ System. A very aggressive goal of 80% waste reduction was established based on the pilot plant data.

Operating under a zero release philosophy, NMP-1 had in the past faced numerous processing challenges tied to periodic wastewater transients. The root cause of these events included such items as lake water and sanitary waste in-leakage, and a range of chemical intrusions (oils, ice melt products, etc.). A goal was established to select a robust technology that could meet the diverse impurities found in wastewater entering radwaste

Finally, plant personnel had a strong desire to provide a radwaste processing technology capable of removing organo-anions from the wastewater. Industry research had shown that reducing anions entering the reactor increases fuel integrity and minimizes corrosion, thereby reducing plant life cycle costs.

3.3.2 Thermex™ System

NMP-1 had ample space for the Thermex™ System. This allowed for the development of an optimum arrangement of the components for effective operation and maintenance activities. Refer to Figure 3-2 for a schematic of the Thermex™ System and Figure 3-3 for its general arrangement.

The NMP-1 Thermex™ System has a 40 -45 gpm (151-170 L/min) normal operating capacity. The RO portion of the system is configured as a 2X2 unit. Preconditioning consists of two deep bed filters configured for parallel operation followed by a bag filter. The final permeate polishing is accomplished by two deep bed ion exchangers configured for series operation. Flexible hoses are used throughout the system. Every two years, the hoses either are re-certified for continued use by means of hydraulic testing or are simply replaced. The piping design allows all routing operations to be performed without uncoupling of any hoses. The only exception is sluicing of expended media (charcoal or resin) from Thermex^{TM} vessels.

Table 3-1 lists the various components of the NMP-1 Thermex^{TM} System in terms of their overall foot print and floor loading.

Table 3-1
ThermexTM Component Weight and Dimensions

Component	Footprint W x L (in)	Height (in.)	Empty Weight (lb.)	Operating Weight (lb.)
Control Module (CM)	60 x 42	48	900	1,066
Suspended Solids Separator (SSS)	42 Dia.	98	900	5,725
SSS Shielding	52 x 11	85	3,500	3,500
SSS Shielding End Panel	56 x 11	85	3,900	3,900
Suspended Solids Polisher (SSP)	21 x 21	78	225	265
SSS Shielding for Polisher	16 x 16	46	1,000	1,000
Process Feed Tank (DSS-PFT)	60 x 60	144	1,500	6,620
Dissolved Solids Separator (DSS)	217 x 54	96	8,000	8,830
SSS Shielding on Skid	NA	NA	11,000	11,000
Dissolved Solids Polisher (DSP)	42 Dia.	96	900	5,725
Demineralizer (DEMIN)	42 Dia.	96	900	5,725

Note: 1 in = 2.54 cm
1 lb. = 0.454 kg

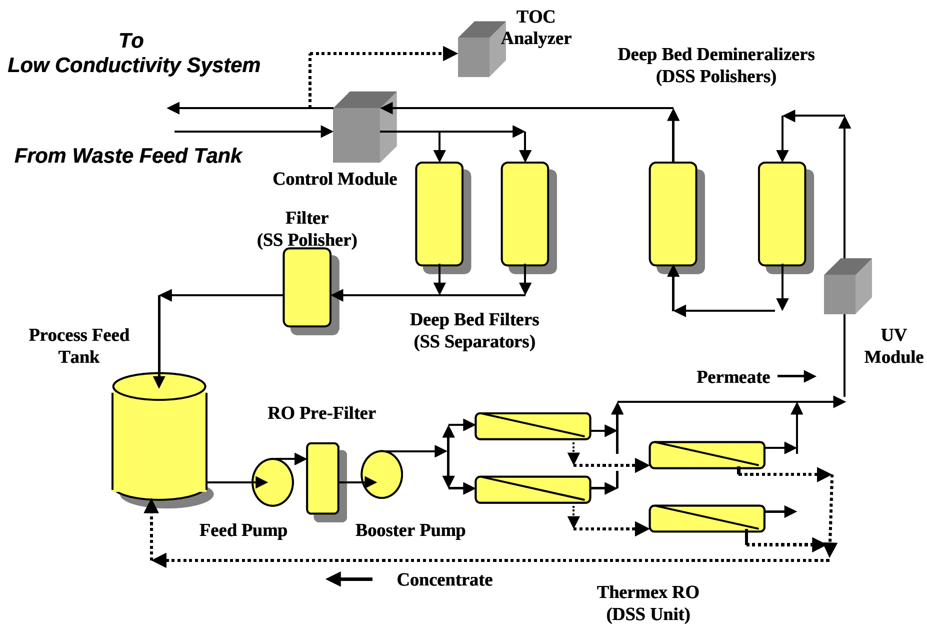

Figure 3-2
NMP-1 Thermex™ System Schematic

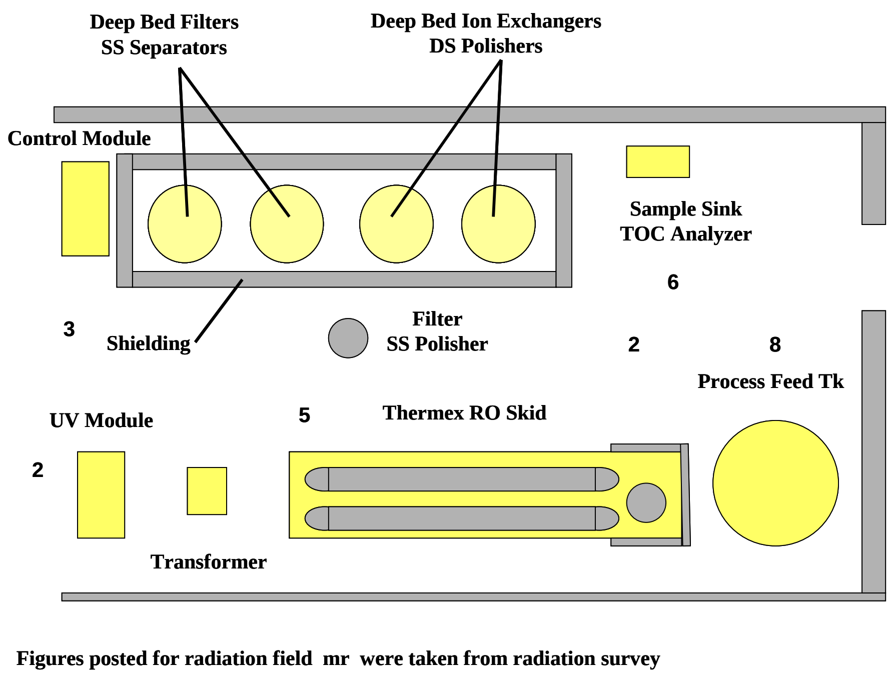

Figure 3-3
NMP-1 Thermex™ System General Arrangement

3.4 Component Information

3.4.1 System Controls

NMP-1 Station's Thermex™ System is designed for manual operation with continuous monitoring of key parameters capable of automatic shutdown should pre-selected set points be exceeded. Manual operation is used to reduce the complexity of system operation where the process flow is fixed and changes within the process can be made as identified by the performance monitoring program. Connections between major components are made by means of reinforced hoses. The design allows for all routine operations to be accomplished without disconnecting and reconnecting any of these hoses.

A Data Acquisition System (DAS) captures data from key process parameters including, process variables such as; flow, temperature, tank level, pressure, and chemical conditions such as; pH, conductivity, turbidity and silica. This system is capable of alarming operators to off-normal conditions and initiating system shutdown upon exceeding operating control limits. Additionally, the system is capable of retrieving alarm sequences and values. Finally, the DAS is used to log operator selected parameters that are needed to track and assess system performance.

3.4.2 Control Module

The Control Module provides a common control and monitoring point for the Thermex™ System influent and effluent waste liquid. The Module is equipped with instrumentation for continuous measurement of the flow, temperature, and TOC. The plant chemistry laboratory provides plant information on pH, conductivity and turbidity.

3.4.3 Pretreatment Vessels

The pretreatment system utilizes the ALPS vessel design developed for portable liquid processing. The vessel design allows the vessel to be back-flushed, top-flushed or top-sluiced to reduce high differential pressure, excessive radiation fields, or removal of fouled media.

3.4.4 Pre-Filter

The pre-filter is a bag filter designed to remove small particulate matter from flushing or transfer operations, which may have migrated through the pretreatment system. This unit is located upstream of the PFT and protects the RO system from particulate fouling.

3.4.5 Process Feed Tank

The PFT is a 750-gallon (2839 L) tank for receipt of the input waste stream and the recirculating concentrate from the RO system. Once the liquid within the tank reaches a limiting chemical concentration, the contents of the tank can be routed to the Spent Resin Storage Tank or High Integrity Container (HIC) for transport off-site for final processing.

3.4.6 Reverse Osmosis Pre-Filter

The RO Prefilter is a single bag filter designed to prevent fouling of the RO membranes by removing particulate matter from the recirculating waste stream prior to its entering the reverse osmosis membranes.

3.4.7 Thermex™ Dissolved Solids Separator and Polisher

The NMP-1 Thermex™ System has been assembled as a single module. The unit is designed to operate at <113 ^{0}F (45^{0}C) with a sustained permeate flow of approximately 40-45 gpm normal operating capacity. The RO membranes are arranged in a 2X2 configuration. Permeate from this portion of the system is sent to the Post Demineralizer for polishing. The rejected concentrated liquid is returned to the PFT for recirculation through the membranes. Upon reaching a predetermined upper control limit the concentrate is drained from the PFT for processing.

3.4.8 Post-Treatment Vessels

The post-treatment system again utilizes the ALPS vessel design. The vessel contains a custom mix of ion exchange resins for polishing of the water prior to its entering the Waste Collector Tanks.

3.5 Plant Support Information

3.5.1 System Category

NMP-1 presently contracts for the use of the Thermex™ System. However, the equipment is treated as a permanently installed plant system. As such, system changes are carried out under existing plant engineering procedures. This involves the use of Request for Engineering Services and Engineering Change Orders for plant modifications. This process requires complete review; approval and documentation paralleling that used for plant equipment.

3.5.2 System Operating Documents

Similarly, operating procedures and equipment operating configurations are treated as plant documents and subject to plant review and approval prior to implementation. Process and Instrument Drawings (P&IDs) consists of system drawings (plant documents) and a second set of detailed drawings maintained by the vendor.

3.5.3 Operating Staff

The NMP-1 personnel assigned to Radwaste operations are certified for Thermex^{TM} operation. Supervision of the day-to-day operation and on-site engineering review of the system performance is the prime responsibility of the vendor's representative.

3.5.4 Maintenance

The vendor's site representative performs all system maintenance on the Thermex^{TM} System. The plant may provide additional support to this activity if required.

3.6 Liquid Processing System Performance

3.6.1 Overall performance

Several conclusions can be drawn from a review of the Thermex^{TM} performance during the period of 1998 –2000, refer to Table 3-2. These include:

1. Increasing trend to utilize the Thermex^{TM} Unit based on its excellent performance.

2. Total waste is dramatically lower than that experienced with other processing equipment prior to the Thermex^{TM} installation.

3. The personnel exposure associated with the radwaste operation is significantly lower than that seen during evaporator operation.

4. The performance seen in 2000 met all of the goals established by the plant for radwaste processing with the Thermex^{TM} System.

Table 3-2
ThermexTM Annual Overall Performance Data 1998-2000

	1998	1999	2000
Total Wastewater Processed gal.	4,712,707	5,318,946	7,038,356
Total Waste Generated cu. ft.	202	331	205
Average Effluent Conductivity, µS/cm	0.06	0.05	0.06
Average Effluent TOC, ppb	28	22	28
Personnel Exposure (routine ops.), mRem	219	362	288

3.6.2 Input Wastewater Volume

Table 3-2 shows that over a three-year period, Floor Drain wastewater averaged approximately 475,000 gallons per month (1,798,020 liters per month). Figure 3-4 summarizes Floor Drain input for the year 2000. Note that for the first 9 months of the year this waste stream was relatively constant. The increase seen in the final months of the year is the result of a change in the ultrasonic cleaning procedure used in processing condensate demineralizer resin.

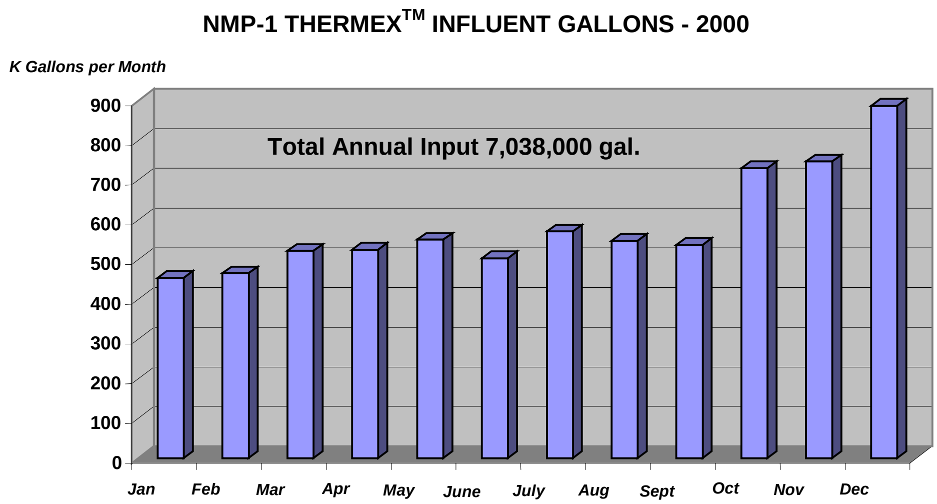

Figure 3-4
NMP-1 Station Wastewater Influent Gallons

3.6.3 Influent Wastewater Impurities

An earlier report by NMP-1 for the period 1995-1997 showed the “average” influent conductivity to range from 30 to 48 $\mu S/cm^2$. During that period conductivity spikes were experienced; 1995 – 172 $\mu S/ cm^2$, 1996 – 1200 $\mu S/ cm^2$ and 1997 – 192 $\mu S/cm^2$. Figure 3-5 shows the radwaste monthly influent conductivity values for the year 2000.

Figure 3-6 presents monthly average values for the Thermex™ influent and effluent conductivity. Overall these values are comparable to those seen at Pilgrim Station and NMP-2.

Finally, Table 3-3 presents a typical conductivity profile across the entire processing system.

Nine Mile Point Unit I

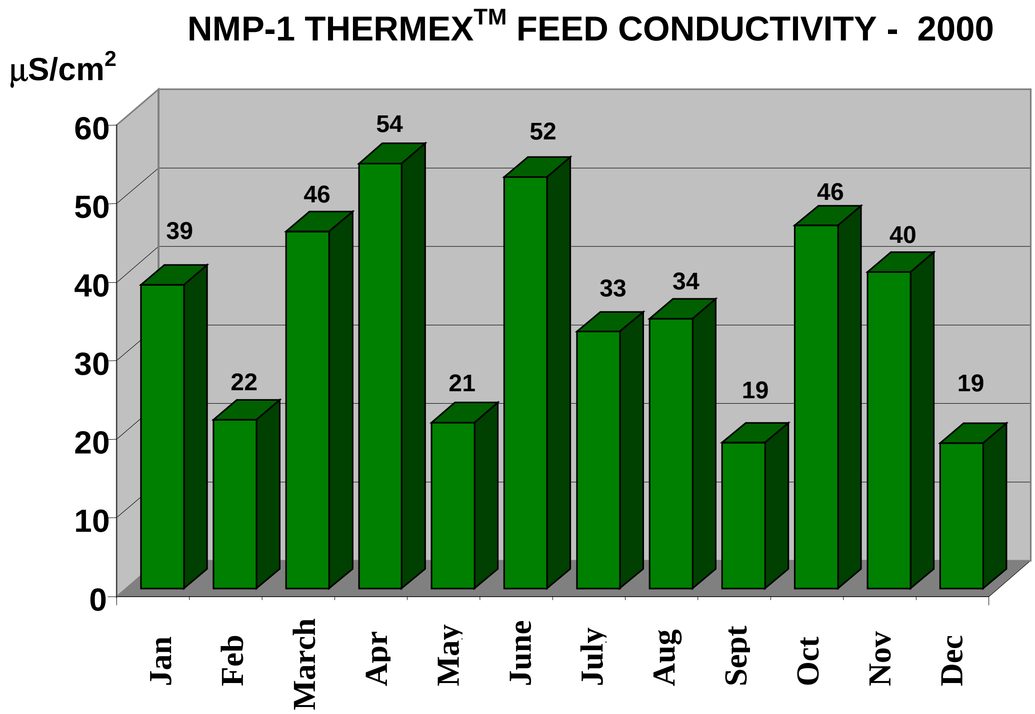

Figure 3-5
Radwaste Wastewater Influent Conductivity

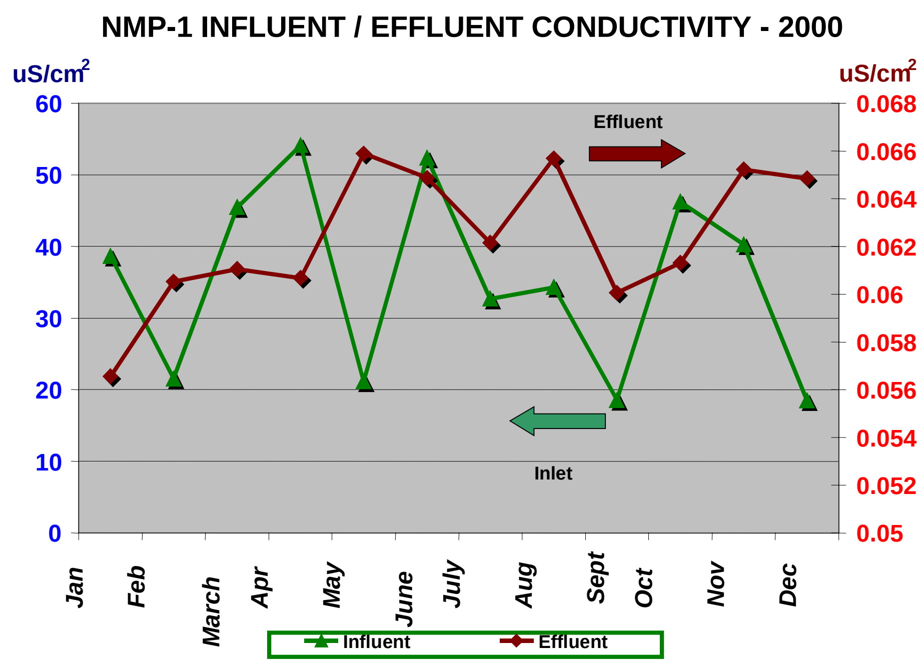

Figure 3-6
Thermex™ Influent and Effluent Conductivity

Table 3-3
ThermexTM System Average Conductivity Profile - 2000

	$\mu S/cm^2$
System Influent	35
RO Concentrate	504
Permeate	6.5
System Effluent	0.062

3.6.4 Waste Generation

Thermex™ processing has produced a major reduction in the radwaste system waste generation. After placing the ALPS in service in 1993, NMP-1 reported the waste generation from radwaste operation to be 188 cu. ft. (5 cu. m) for a 6 month period. Operation of the plant's evaporator for a similar period was estimated to produce 1,000 cu. ft. (28 cu. m) of waste.

Figure 3-7 presents the monthly waste generation for the year 2000. This figure shows a relatively constant volume of waste reflecting equilibrium system operation. Total waste for the Thermex™ System is comparable to that achieved with ALPS processing. However, the quality of the final product water is significantly improved from the filter demineralizer system. This is reflected in the Product Water Quality Requirements established at NMP-1 for each of these systems, shown below in Table 3-4.

Finally, Table 3-5 presents data on waste generation and overall performance given in gallons of processed water per cubic foot of waste generated. This Table clearly illustrates the major reduction in waste generation and improved radwaste performance resulting from the implementation of ALPS processing. This was followed by a similar improvement resulting from the change to Thermex™ processing.

Table 3-4
Product Water Quality Requirements

NMP 1 Product Water Quality Requirements		
Parameter	**ALPS (1992)**	**Thermex (1995)**
Conductivity, µS/cm²	<1.00	<0.08
Chloride, ppb	<10.00	<1.00
Sulfate, ppb	<10.00	<1.00
Silica, ppb	<20.00	<1.00
Sodium, ppb	Not Specified	<1.00
Calcium, ppb	Not Specified	<1.00
Magnesium, ppb	Not Specified	<1.00
Total Organic Carbon, ppb	<400	<50

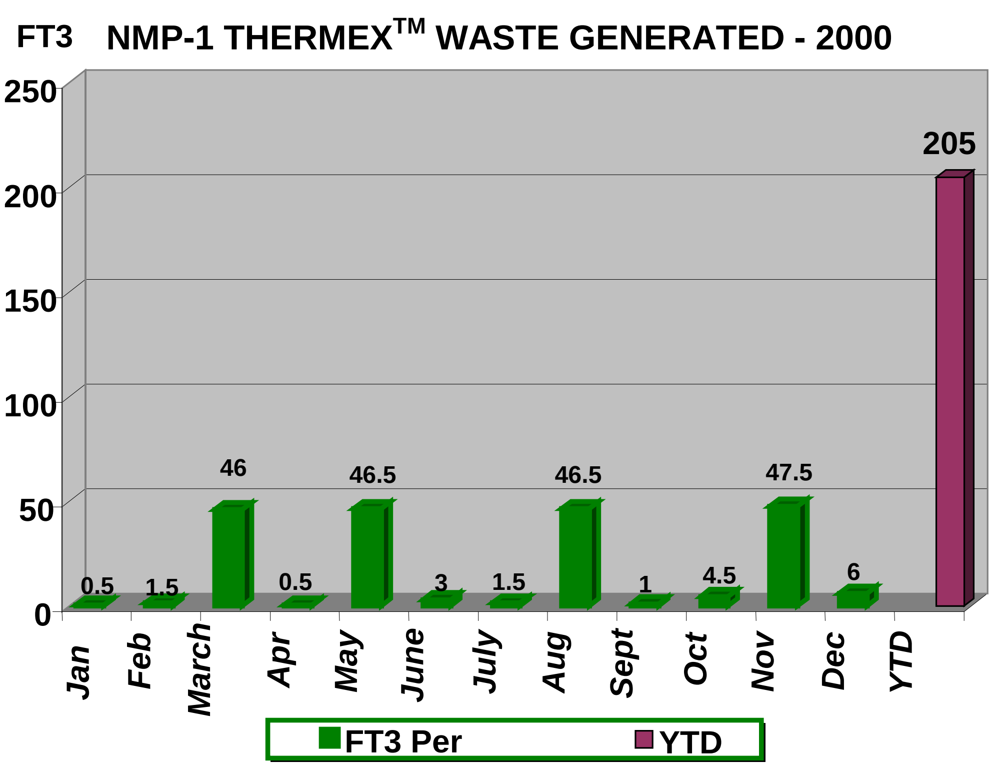

Figure 3-7
2000 Radwaste Waste Generation with Thermex™ Processing

Table 3-5
Analysis of Total Plant Annual Waste Generated 1988-2000

	Evaporator Pre-1992	ALPS 1992-1995	Thermex™ 1998-2000
Total Media Waste cu. ft.	1600 (estimated)	400 (estimated)	246
Gal. Recovered/Waste cu. ft.[1]	3,562	14,250	23,170

Note: 1. Based on an average annual Floor Drain input of 5,700,000 gallons.

3.6.5 Removal of Total Organic Carbon (TOC)

Personnel at NMP-1 are keenly aware of the need to control organic material present in the radwaste recycle water. In the early operation of the radwaste evaporator, significant levels (up to 1000 ppb) of organic material were carried over in the distillate. The problem was that this organic material proved to be extremely difficult to remove with existing radwaste processing equipment. The move to ALPS processing did improve the situation, but did not meet the ultimate plant goal of removal of TOC. This was a major consideration in the implementation of Thermex™ processing. Figure 3-8 shows the average monthly effluent TOC values achieved in 2000. Table 3-6 shows the effectiveness of the membrane technology and its continued improvement with operating experience over the period of 1998-2000 compared to earlier 1993 data.

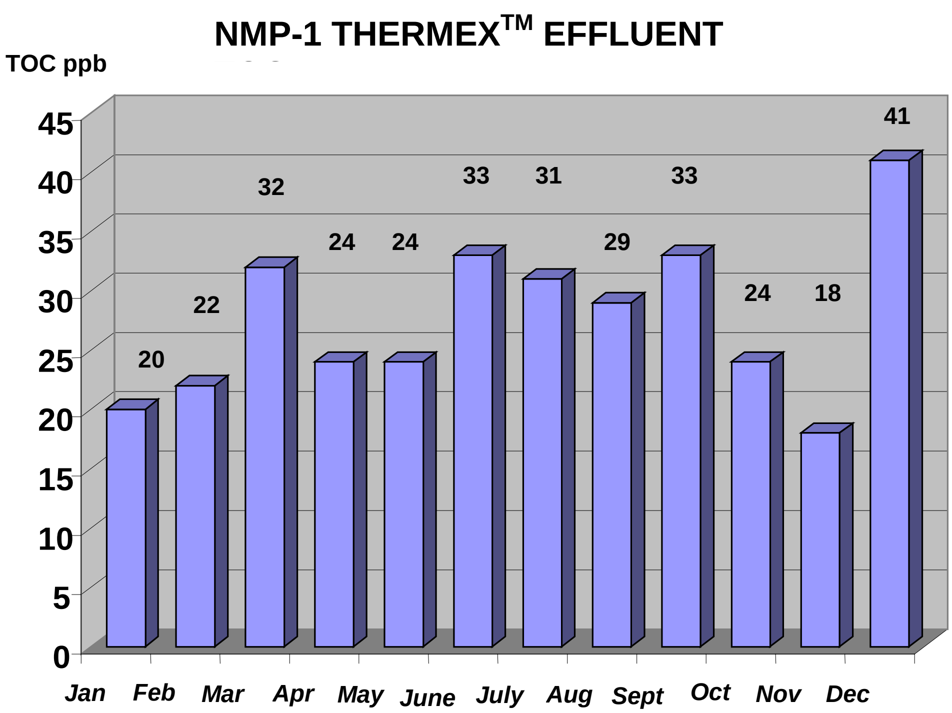

Figure 3-8
Removal of TOC with Thermex™ Processing

Table 3-6
Annual Average ThermexTM System TOC ppb Values

	1993[1]	1998	1999	2000
Influent TOC	5,130	NA	NA	7,490
Effluent TOC	167	28	22	28

Note: Data was taken from a 1993 plant report for the period of April-September, 1993.

3.6.6 Removal of Radioactivity with Thermex™ Processing

Nine Mile I Station operates as a "zero release" plant making radioactivity removal an item of secondary importance. The plant does continue to monitor the decontamination values achieved by the Thermex™ System as part of the routine surveillance program. Table 3-7 shows typical radioactivity removal performance for the Thermex™ System.

Table 3-7
Typical Thermex™ System Radioisotope Removal Performance

Radioisotope	Typical Input Concentration µCi/ml	Typical Effluent Concentration µCi/ml
Co-60	1.5 E-04	<LLD[1]
Cs-134	2.0 E-05	<LLD
Cs-137	2.0 E-04	<LLD
Mg-54	4.0 E-05	<LLD

Note: 1. Lower Level of Detection (LLD) is approximately 9.9 E-07 µCi/ml.

3.6.7 Personnel Exposure Related to Operation of the Thermex™ System

NMP-1, like the industry in general found that evaporator operation and maintenance was a high personnel exposure item. Table 3-8 shows the major reduction in personnel exposure resulting from the move to ALPS and continuing with the Thermex™ operation. Figure 3-9 shows the monthly personnel exposure experienced during the year 2000.

Table 3-8
Analysis of Annual Personnel Exposure for Radwaste Operations

	Evaporator Pre-1992	ALPS 1992-1995	Thermex™ 1998-2000
Average Annual Total Personnel Exposure mRem	2,560	300	290

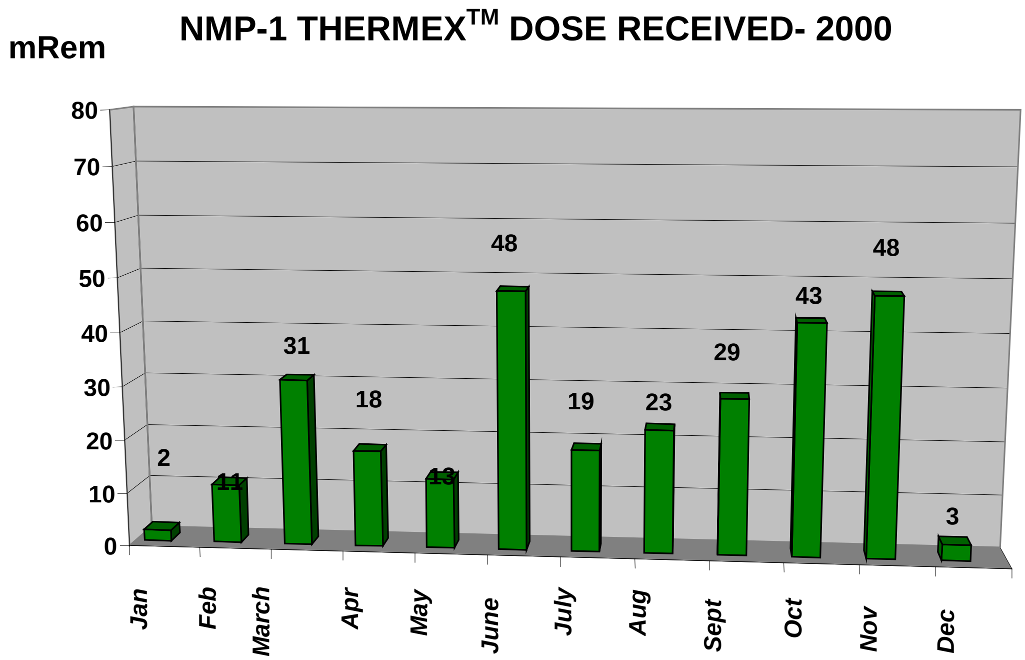

Figure 3-9
Personnel Exposure with Thermex™ Processing

3.6.8 Membrane Cleaning and Replacement

During the past 5 years membrane performance has been excellent. Cleaning is performed at a frequency of approximately twice per year refer to Figure 3-10.

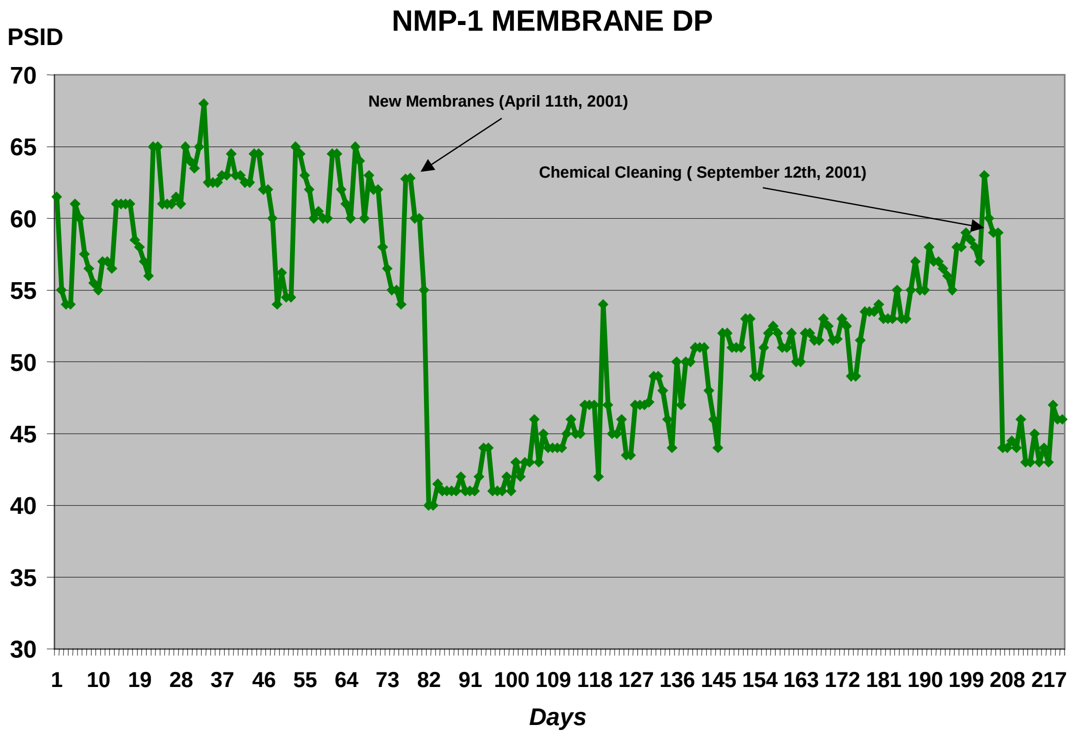

Figure 3-10
Membrane DP and Cleaning Frequency

3.6.9 Thermex™ Concentrate Processing

Like Pilgrim Station, the concentrate is transferred to the Spent Resin Storage Tank and brought in contact with spent resin from the condensate demineralizer system. The remaining ion exchange capacity on this resin is used to remove the concentrate contaminants.

As a result of implementing this technique, processing of waste concentrate has not resulted in the generation of additional radioactive waste.

3.7 Reference

1. "Advanced Treatment of Liquid Radwaste at the Nine Mile Point Station", Jack Torbitt and Ron Cole, Niagara Mohawk.

4
NINE MILE POINT UNIT II

4.1 Plant Information

Nine Mile Point Station Unit II (NMP-2) is a 1225 MWe Boiling Water Reactor located on Lake Ontario east of Oswego, New York. The plant was placed in commercial operation in 1988.

4.2 Liquid Radwaste Processing Background Information

The original radwaste system design was similar to that described for Pilgrim Station. Liquid waste was segregated into two major streams; clean waste (high purity water from equipment drains) and floor drain waste (low purity water from floor drains). Refer to Figure 4-1 for a schematic of the NMP-2 Radwaste System.

Clean Drain Processing System Design

The original system design provided for the collection of the Clean Drain in one of two receiver tanks. This liquid was pumped to an etched disc filter for removal of particulate matter. Following this filter is a deep bed Radwaste Demineralizer containing spent condensate demineralizer resin. The demineralizer effluent was routed to either one of two Recovery Sample Tanks for return to the main plant’s Condensate Storage Tank or discharged from the plant.

Floor Drain Processing System Design

The original Floor Drain processing system design was a duplicate of the Clean Drain system.

Like other early BWRs, the original design called for chemical regeneration of the condensate demineralizer resin. Spent regenerate chemicals were to be fed from one of two Regenerant Waste Tanks to an evaporator with a steam supply from an electric boiler. The evaporator is used for processing miscellaneous liquid wastes and concentrate from the Thermex™ System.

1992 Plant Conversion to a Portable Filtration/Demineralization System

In 1992, the ChemNuclear (Duratek) Fluidized Transfer Demineralizer System (FTDS) consisting of Charcoal, Cation, Anion and Mixed Bed vessels was installed to improve the quality of the final recycle water and minimize radwaste waste generation.

It should be noted that Clean Drains have continued to be processed through the plant radwaste demineralizer.

Nine Mile Point Unit II

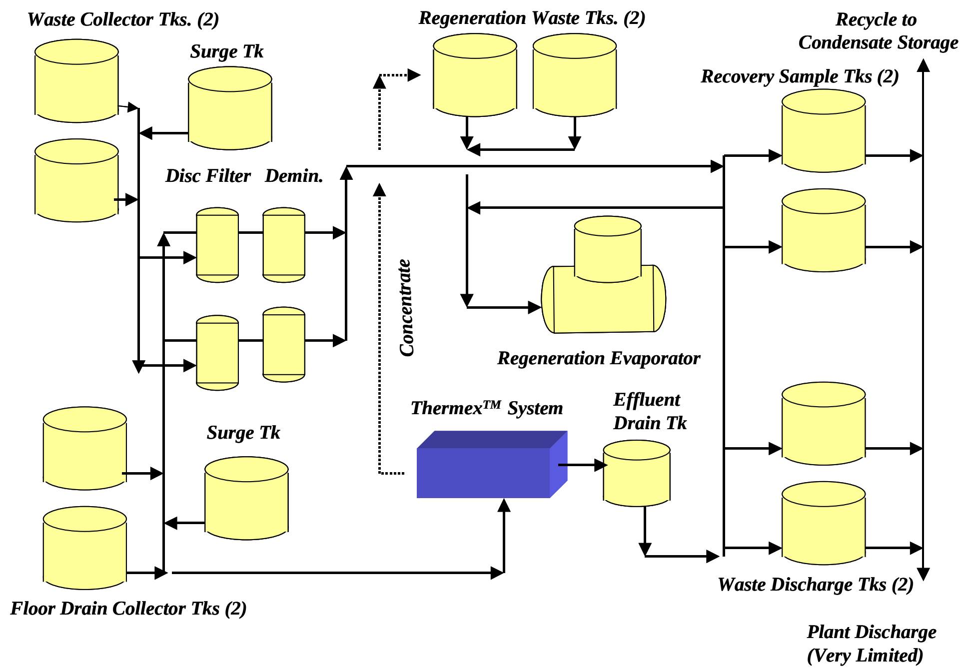

Figure 4-1
NMP-2 Radwaste System Schematic

4.3 Thermex™ Processing System Description

4.3.1 Overview

The NMP-2 Thermex™ System was placed in service in April 1996. It was not a completely independent system; rather it was integrated into the overall existing radwaste system.

Refer to Figure 4-1 for a schematic of the NMP-2 Radwaste processing arrangement.

This change to Thermex™ processing was directed at achieving the following:

<u>Station Expectations</u>

- Extend the service life of the on-site solid radwaste storage facilities by reducing radwaste processing waste generation.
- Reduce TOC concentration of radwaste process water.
- Continue to recycle high quality water to the Condensate Storage Tank with respect to conductivity, TOC, chloride, and sulfate impurities.

The new membrane system was projected to continue the high performance achieved with the portable FTDS unit previously installed at the site. This was based on the results already achieved with the operation of a similar system at NMP-1. Movement to a reverse osmosis based system was seen as providing additional protection from intrusion of TOC into the main power system. This aspect of the conversion was an integral part of the overall cost benefit evaluation.

Thermex™ System processing was projected to extend the service life of the existing on-site low level waste storage facilities from the design value of 5 years to 25 years.

4.3.2 Thermex™ System

Due to the limited space available in Unit II, the Thermex™ System component arrangement was customized to meet the plant needs and constraints. These changes did not affect the Thermex™ design and hardware developed for Unit I. Refer to Figure 4-2 for a schematic of the Thermex™ System.

Table 4-1 lists the various components of the NMP-2 Thermex™ System in terms of their overall foot print and floor loading.

Table 4-1
ThermexTM Component Weight and Dimensions

Component	Footprint W x L (in)	Height (in.)	Empty Weight (lb.)	Operating Weight (lb.)
Control Module (CM)	16 x 120	60	660	700
Suspended Solids Separator (SSS)	42 Dia.	98	900	5,725
SSS Shielding	52 x 11	85	3,500	3,500
SSS Shielding End Panel	56 x 11	85	3,900	3,900
Suspended Solids Polisher (SSP)	21 x 21	78	225	265
SSS Shielding for Polisher	16 x 16	46	1,000	1,000
Process Feed Tank (DSS-PFT)	60 x 60	144	1,500	6,620
Dissolved Solids Separator (DSS)	217 x 54	96	8,000	8,830
SSS Shielding on Skid	NA	NA	11,000	11,000
Dissolved Solids Polisher (DSP)	42 Dia.	96	900	5,725
Demineralizer (DEMIN)	42 Dia.	96	900	5,725

Note: 1 in = 2.54 cm
1 lb. = 0.454 kg

System Overview

The NMP-2 Thermex™ System has a 40-45 gpm normal operating capacity. The RO portion of the system is in a 2X2 configuration. Similar to Unit 1, preconditioning consists of two deep bed filters configured for parallel operation followed by a bag filter. The final permeate polishing is accomplished by two deep bed ion exchangers configured for series operation.

Flexible hoses are used throughout the system. Every two years, the hoses either are re-certified for continued use by means of hydraulic testing or are simply replaced. Piping design allows all routing operations to be performed without uncoupling of any hoses. The only exception is sluicing of expended media (charcoal or resin) from Thermex™ vessels. A plant modification is presently being prepared which will allow all operations to proceed without uncoupling any of the piping.

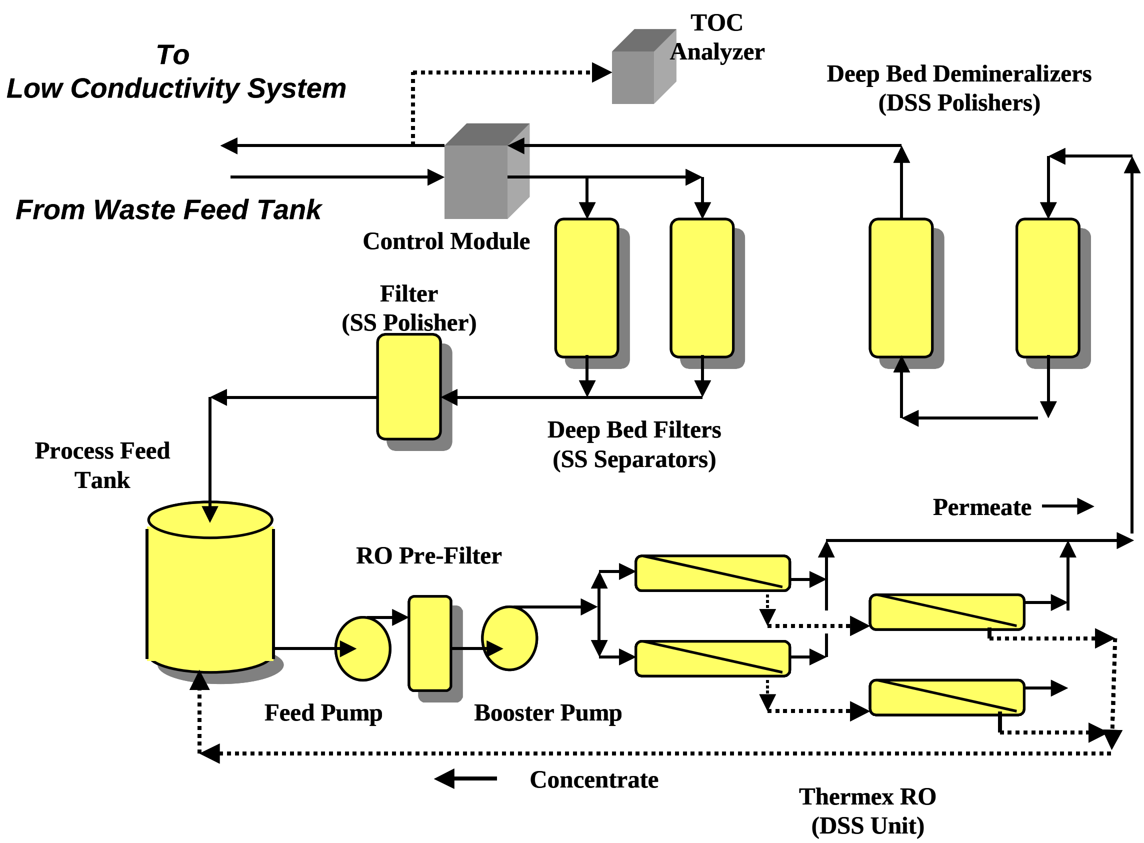

Figure 4-2
NMP-2 Thermex™ System Schematic

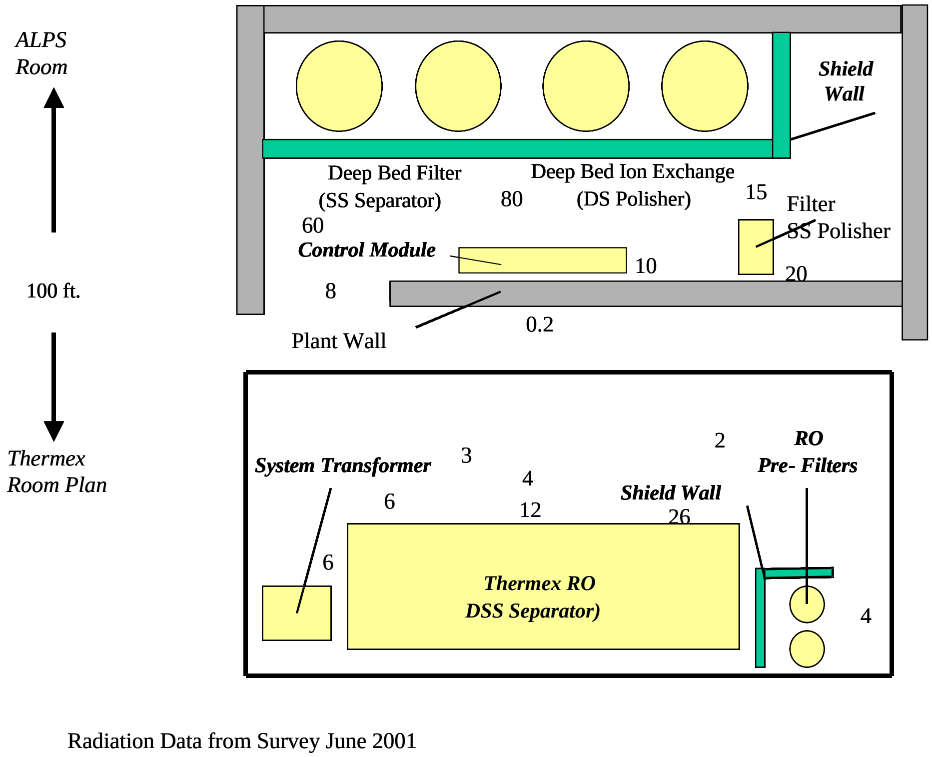

Figure 4-3
NMP-2 Thermex™ System General Arrangement

4.4 Component Information

Refer to Section 3-3 for component details

4.5 Plant Support Information

4.5.1 System Category

NMP-2 presently contracts for the use of the Thermex™ System. However, the equipment is treated as a permanently installed plant system. As such, system changes are carried out under existing plant engineering procedures. This involves the use of Request for Engineering Services and Engineering Change Orders for plant modifications. This process requires complete review; approval and documentation paralleling that used for plant equipment.

4.5.2 System Operating Documents

Similarly, operating procedures and equipment operating configurations are treated as plant documents and subject to plant review and approval prior to implementation. Process and Instrument Drawings (P&IDs) consists of system drawings (plant documents) and a second set of detailed drawings maintained by the vendor.

4.5.3 Operating Staff

The NMP-2 Station personnel assigned to Radwaste operations are certified for Thermex^{TM} operation. Supervision of the day-to-day operation and on-site engineering review of the system performance is the prime responsibility of the vendor's representative.

4.5.4 Maintenance

The vendor's site representative performs all system maintenance on the Thermex^{TM} System. The plant provides additional support to this activity if required.

4.6 Liquid Processing System Performance

4.6.1 Overall performance

Table 4-2 summarizes key radwaste operating parameters for the period of 1198-2000. Several conclusions can be drawn from a review of the Thermex^{TM} performance during this period. These include:

1. Total waste is dramatically lower than that experienced with other processing equipment prior to the Thermex^{TM} installation.
2. The personnel exposure associated with the radwaste operation is significantly lower that that seen during earlier operation.
3. The performance seen in 2000 met all of the goals established by the plant for radwaste processing.

Table 4-2
ThermexTM Annual Overall Performance Data 1998-2000

	1998	**1999**	**2000**
Total Wastewater Processed gal.	10,837,210	7,700,000	9,612,730
Total Waste Generated cu. ft.	350	394	384
Average Effluent Conductivity, $\mu S/cm^2$	0.05	0.06	0.07
Average Effluent TOC, ppb	41	38	38

4.6.2 Influent Wastewater Volume

The Floor Drain input represents approximately 50% of the total radwaste influent. Figure 4-4 shows that over a four-year period, Floor Drain wastewater averaged approximately 800,000 gallons per month (3,028,245 liters per month). A slight downward trend (~15%) is apparent in this data.

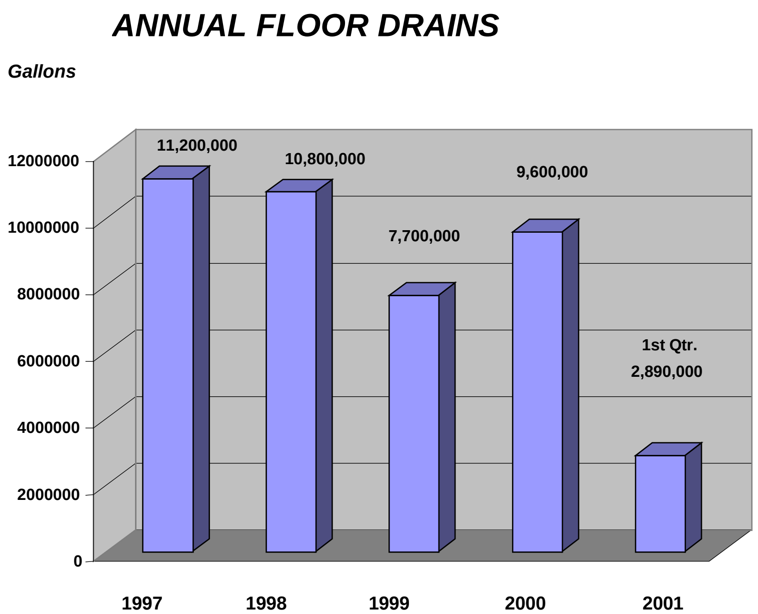

Figure 4-4
NMP-2 Station Wastewater Input

4.6.3 Influent Wastewater Impurities

NMP-2 has a history of controlling waste impurities entering the radwaste system. Much of this is attributed to the effectiveness of the plant Chemical Control Program and the institution of routine cleaning of plant waste sumps. Figure 4-4 shows the monthly influent conductivity values for the year 2000. This figure shows the major impact of a service water intrusion event experienced during Refueling Outage 7. This event can also be seen in Figure 4-6 as a spike in the radwaste system effluent conductivity. However, effects of this intrusion are not apparent in waste generation.

Figure 4-6 presents monthly average values for the Thermex™ influent and effluent conductivity and Table 4-3 gives annual values for these parameters. Overall these values are comparable to those seen at Pilgrim Station and NMP-1.

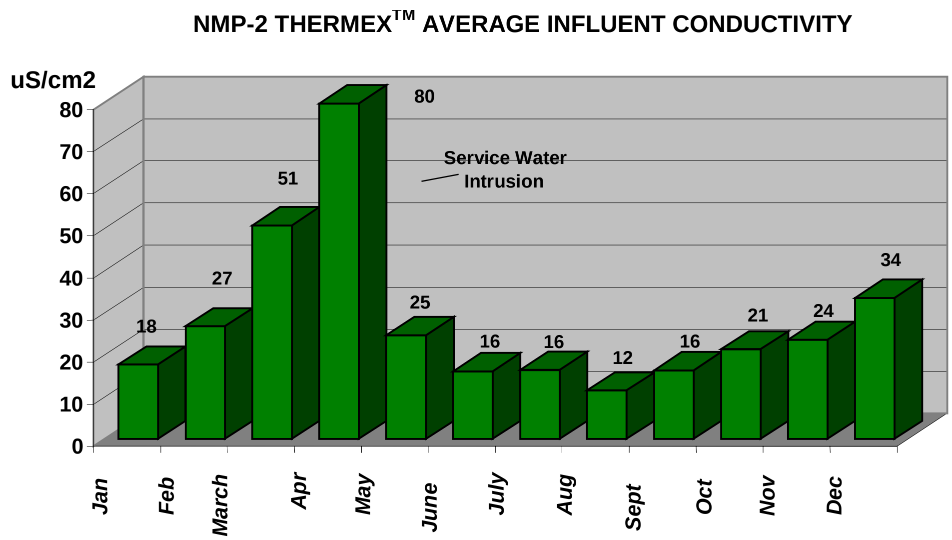

Figure 4-5
Radwaste Wastewater Influent Conductivity

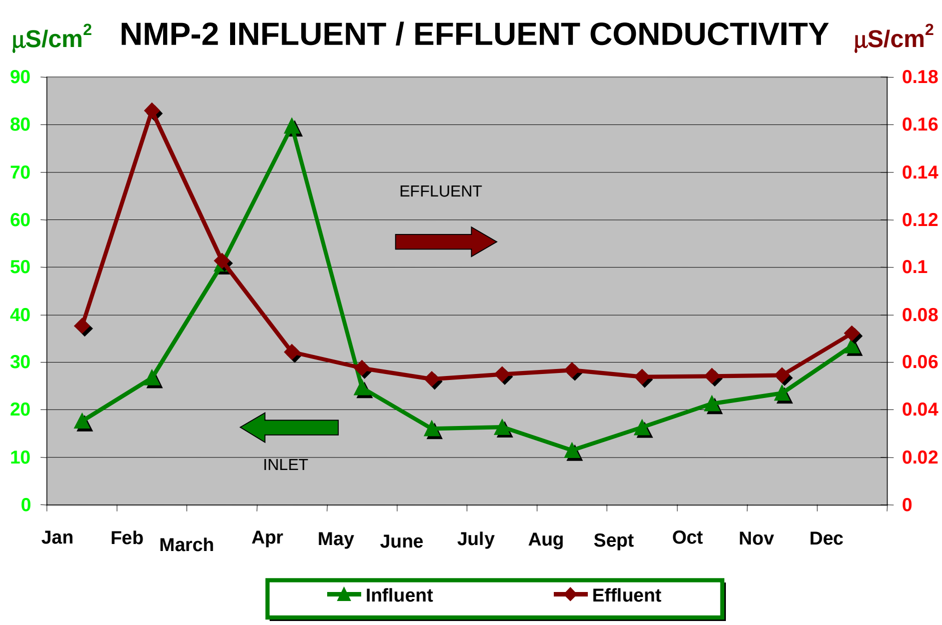

Figure 4-6
Thermex™ Influent and Effluent Conductivity

Table 4-3
Annual Thermex™ Average Influent and Effluent Conductivity

	1997	1998	1999	2000
Influent µS/cm²	41	38	39	28
Effluent µS/cm²	0.26	0.065	0.066	0.072

4.6.4 Waste Generation

Early in 2001, NMP-2 personnel preformed a comprehensive analysis of radwaste operations over the period of 1988 through 2000. During this period three distinct processing methods were used:

- 1988-1991 Original Plant Equipment
- 1992-1995 Portable FTDS
- 1996-2000 Thermex™ System.

The variable used to assess the performance of each method was the gallons of water recovered (returned to the Condensate Storage Tank) per cubic foot of expended processing media. Table 4-4 presents that basic data and results of this evaluation. Note that the waste figure includes the total condensate demineralizer resin. This can be misleading in evaluating the waste related to radwaste operations, since only a fraction of this spent resin is used in radwaste. A review of resin replacement records (using spent condensate demineralizer resin) in the Clean Waste System for the period of July 1998 to July 1999 showed a requirement of 440 cu. ft. (13 cu. m) of resin. Therefore, adding this figure to the waste generated by the Thermex™ System produces an estimated *total annual radwaste volume* of approximately 850 cu. ft.(24 cu. m) (Thermex™ ~400 cu. ft (11 cu. m) and Clean Waste Demineralization ~450 cu.ft (13 cu. m)). This does not include evaporator concentrate waste, which is estimated to be <200-400 pounds, refer to the discussion in Section 5.3.

The analysis unmistakably shows that major radwaste improvement accompanied each processing upgrade. The change to FTDS reduced the waste volume by ~50% and improved the performance in terms of recovered gallons/cu. ft. by ~100%. Conversion to Thermex™ processing resulted in a similar improvement over the FTDS, waste volume reduction ~45% and recovered gallons/cu. ft. improvement of ~30%.

Figure 4-7 presents the monthly waste generation for the year 2000 and shows a relatively constant volume of waste reflecting equilibrium system operation.

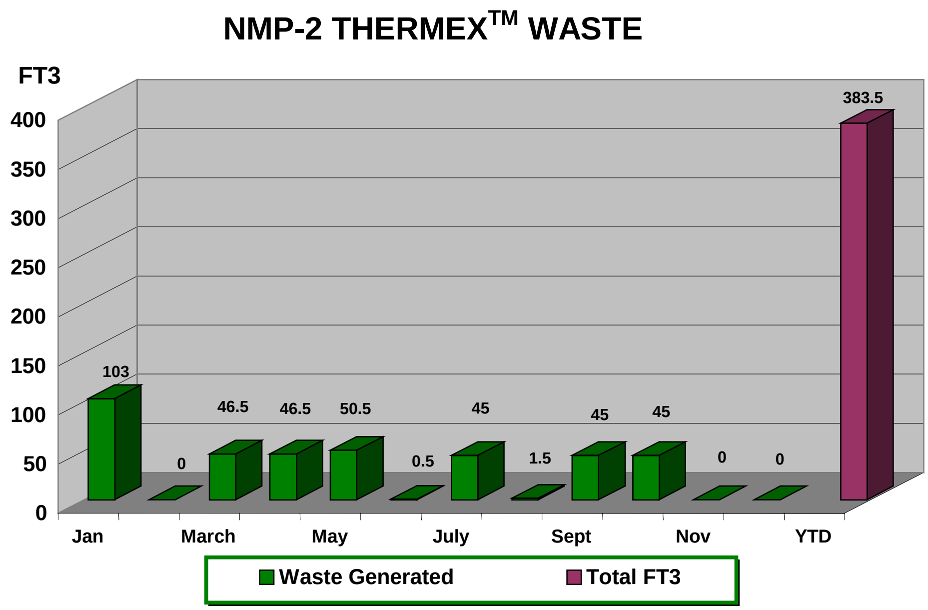

Figure 4-7
Removal of TOC with Thermex™ Processing

Table 4-4
Analysis of Total Plant Annual Waste Generated 1988-2000

	1988-1991	1992-1995	1996-2000
Total Recovered Water, gallons	21,400,00	20,900,000	17,500,000
Processing Technology Clean Floor	Evaporator Filters, Demin.	Evaporator FTDS	Evaporator Thermex
Total Media Waste cu. ft.[1]	9,154	4,365	2,807 (Thermex™ 380)
Gal. Recovered/Waste cu. ft.	2,340	4,802	6,230

Note: 1. Total waste figures include spent condensate resin and radwaste processing media used in the Clean and Floor Drain Systems.

4.6.5 Removal of Total Organic Carbon (TOC)

Refer to Section 3.6.6 for Nine Mile Point's (Unit 1 and 2) perspective on the importance of TOC in the radwaste recycle water. Figure 4-8 shows the monthly effluent TOC concentration for 2000.

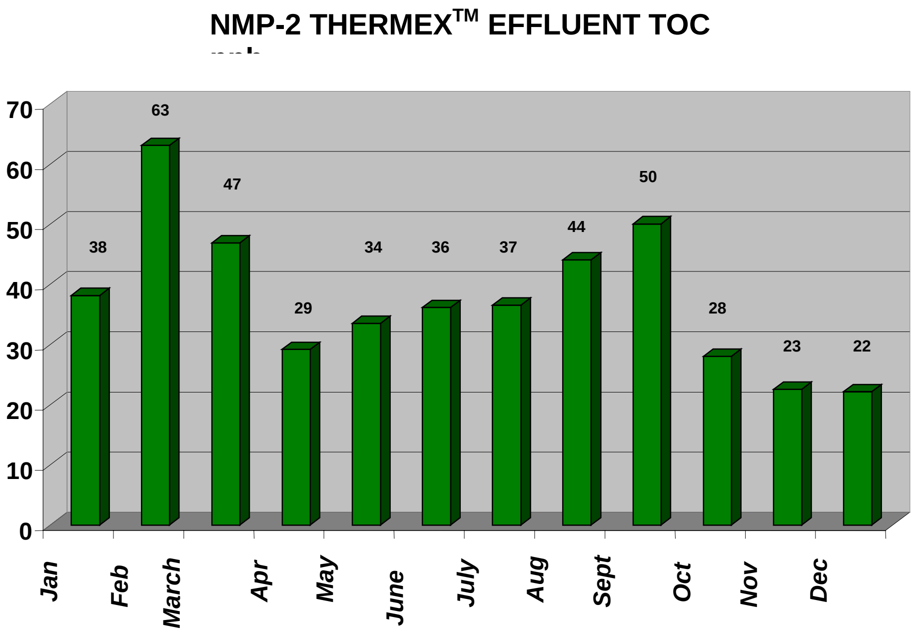

Figure 4-8
Removal of TOC with Thermex™ Processing

Table 4-5
Annual Average ThermexTM System TOC ppb Values

	1997	1998	1999	2000
Influent TOC	892	822	659	790
Effluent TOC	49	41	41	38

4.6.6 Removal of Radioactivity with Thermex™ Processing

NMP-2, like a number of BWRs, operates with minimal liquid discharge. During normal operation both the Clean and Chemical waste streams are purified to a level that will allow recycle to the Condensate Storage Tank for reuse. Liquid was discharged for Unit-2 to maintain water balance within the plant. This was caused by makeup required due to bleed and feed operations required for chemical control in closed cooling water system. The gallons discharged in 2000 represented approximately 15% of the wastewater input to the radwaste system.

Under this mode of operation, the primary radwaste consideration is the purity of the liquid being recycled to the plant. Provided the discharge liquid is properly processed, radioactivity content is of only secondary importance.

4.6.7 Personnel Exposure Related to Operation of the Thermex™ System

Thermex™ operation has been conducted with minimum exposure to the operating and maintenance personnel. Figure 4-9 shows the monthly personnel exposure experienced during the year 2000. This figure breaks down the exposure into routine operations, daily, and scheduled maintenance, including the special task of membrane replacement.

NMP-2 has implemented a number of system changes and improvements directed at reducing personnel exposure. These include:

- Relocation of data acquisition system from the process area to the control room.
- Installation of video cameras at critical locations in the Thermex™ area.
- Relocation of valves to a low exposure area.
- Institution of a comprehensive training program to improve operator skills.

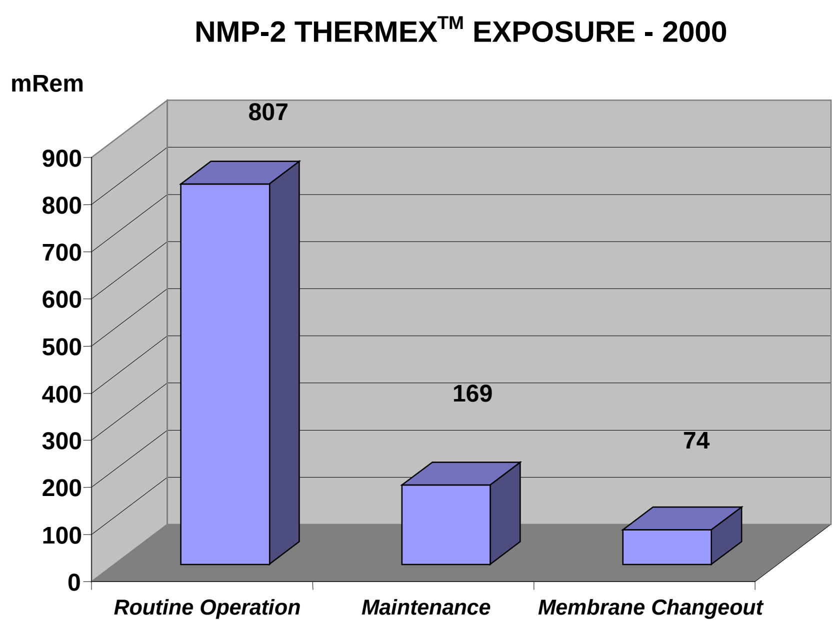

Figure 4-9
Personnel Exposure with Thermex™ Processing

4.6.8 Membrane Cleaning and Replacement

Figure 4-10 presents the differential pressure (DP) seen in 2000 across the RO membranes. In January 2000, it was determined that the membrane DP had reached an undesirable level following 4 years of operation. The membranes had a radiation field at contact of 800 to1,500 mr/hr at the time of the change out. Their removal was performed by 4 workers in a period of 5 hours at a total exposure of ~100 mRem. Each membrane represents ~1 cu. ft. (3 E-02 cu. m) of radioactive waste. Spent membranes are packaged along with other dry waste and sent for off-site processing either by supercompaction or incineration.

Following membrane replacement, the DP dropped from ~110 psid (7.58 bars) to 30 psid (2.07 bars) and the Thermex™ performances returned to normal. Chemical cleanings were performed 3 times at a frequency of approximately once every 6 months.

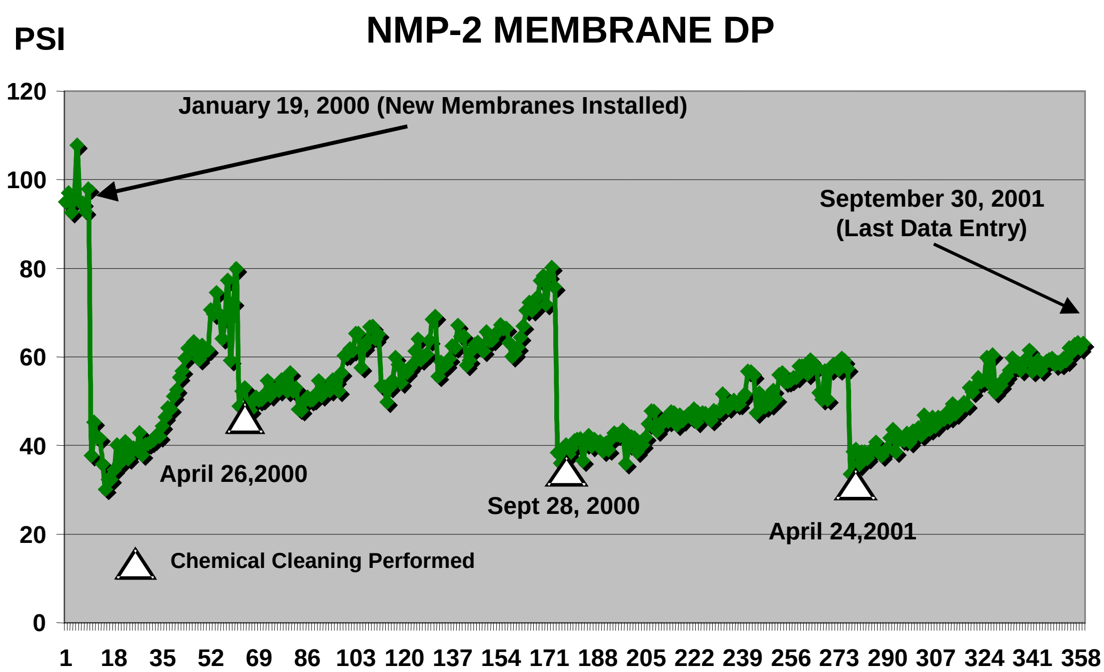

Figure 4-10
Thermex™ RO Membrane Cleaning and Replacement

4.6.9 Thermex™ Concentrate Processing

Concentrate is continuously withdrawn from the Process Feed Tank during operation of the Thermex™ RO unit. This stream is routed to one of the 25,000 gallon (94,633 liters) Regeneration Waste Tanks. This produces a tank of concentrated waste (~500 $\mu S/cm^2$) approximately once a quarter. The concentrated waste is then processed along with miscellaneous waste by the evaporator for disposal. Presently, the quantity of resulting waste is not assigned to the Thermex™ operation.

Radwaste design does not allow for the transfer of the concentrate to the Spent Resin Storage Tank as is being done at Pilgrim and Nine Mile I. There is considerable economic incentive to correct this deficiency and plant modification options are presently under consideration. These options include routing the concentrate to either the Spent Resin Tank or the Sludge Tank.

4.7 Reference

1. "Liquid Waste Processing at Nine Mile Point II Utilizing Reverse Osmosis Membrane Technology"; Tom Paeno, Niagara Mohawk, Rick Scala, Duratek Inc., EPRI LLW International Conference 2001.

5 CONCLUSIONS AND OBSERVATIONS

5.1 Principal Finding

Membrane purification is an established reliable technology for the processing of liquid radwaste. This is borne out by the experience of the three plants reviewed in this study, i.e., Pilgrim Station, Nine Mile Point Unit 1 and Nine Mile Point Unit 2, where Thermex^{TM} Systems have operated for a combined period of over 17 years. During that period, they have combined to process over 155 million gallons (587 million liters) of wastewater; Pilgrim –60.3 million gallons (228 million liters), NMP-1 36.7 million gallons (139 million liters) and NMP-2 60.3 million gallons (228 million liters). The Thermex^{TM} System can be characterized for these three plants as producing excellent quality water, with significantly lower waste generation and low operator radiation exposure.

5.2 Processing System Performance

There are a number of indices that can be used to measure the performance of a BWR radwaste processing system. They include:

1. Conductivity – a measure of ionic impurities
2. Total Organic Carbon – a measure of organic contaminants
3. Media Operating Life – a measure of the efficiency of the process
4. Membrane Cleaning and Replacement – a measure of efficient and stable operation

The following sections provide operating data for 1998-2000 for each of the above key parameters.

5.2.1 Conductivity

The effluent conductivity for the three plants studied approached theoretical purity of pure water. The overall average conductivity was 0.063 $\mu S/cm^2$ for these plants for 9 years of operation, refer to Table 5-1 below. Performance with respect to the removal of ionic impurities was excellent.

Table 5-1
Effluent Conductivity for the Study Plants – 1998-2000

Plant	Period	Average µS/cm²
Pilgrim Station	1998-2000	0.07
Nine Mile Point Unit 1	1998-2000	0.06
Nine Mile Point Unit 2	1998-2000	0.06

5.2.2 Total Organic Carbon

TOC is viewed as an important diagnostic parameter, since the presence of organic material has the potential to deliver undesired ions (sulfate, chloride, fluoride, etc.) to the reactor. The effluent TOC levels for the three plants studied were significantly below levels previously achieved with their original processing system, refer to Table 5-2. The overall average TOC was 39 ppb for these plants for 9 years of operation. Performance with respect to the removal of TOC was excellent.

Table 5-2
Effluent TOC for the Study Plants – 1998-2000

Plant	Period	Average ppb
Pilgrim Station*	1998-2000	52
Nine Mile Point Unit 1	1998-2000	26
Nine Mile Point Unit 2	1998-2000	39

* Present TOC instrumentation at Pilgrim has a LLD of 50 ppb.

5.2.3 Media Operating Life

The basic media used in the Thermex™ System is charcoal (deep bed filtration) and resin (deep bed ion exchange). The operating efficiency experienced by the three plants for these two media is shown in Table 5-3. Additionally, the underlying data shows a robust technology with relatively predictable performance. Overall, the media performance appears to be superior to that seen in many BWRs.

Table 5-3
Media Performance for the Study Plants – 1998-2000

Plant	Deep Bed Charcoal Pretreatment Gallons/cu.ft.	Deep Bed Ion Exchange Final Polishing Gallons/cu.ft.
Pilgrim Station	297,000[1]	41,000 (7)[2]
Nine Mile Point Unit 1	221,000	26,000 (4)
Nine Mile Point Unit 2	257,000[3]	33,000 (6)

Notes: 1. This charcoal bed is still in service, presently has 15 months of operation.
2. This charcoal bed is still in service, presently has 27 months of operation.
3. ( ) designates the number of resin replacements.

5.2.4 Membrane Cleaning and Replacement

Table 5-4 summarizes the experience of the three plants with respect to membrane chemical cleaning and replacement. Overall, the membrane performance appears to be quite acceptable.

Table 5-4
Membrane Cleaning and Removal

Plant	Cleaning Frequency	Membrane Replacements
Pilgrim Station	6 months	Never changed since 1997
Nine Mile Point Unit 1	5 months	3 times since 1995
Nine Mile Point Unit 2	6 months	Once since 1996

5.3 Processing System Waste Generation

The three plants studied all had a history of excessive waste generation, which was related to the original radwaste plant processing systems. In each case, the move to membrane processing technology resulted in a major reduction in waste generation. Many BWRs produce lower waste from existing radwaste processing, in these cases the waste reduction would be less dramatic. The waste figures for the three plants do represent excellent operation, refer to Table 5-5. As noted earlier, two of the plants utilize spent condensate resin for processing of the RO concentrate, which results in no additional waste from this stream. The remaining plant uses an existing evaporator and does not quantify the waste generated from concentrate processing. Overall, the waste generation appears to be excellent.

Table 5-5
Waste Generation for the Study Plants – 1998-2000

Plant	Period	Total Waste Generated cu.ft./yr	Gallons Processed per cu.ft. Waste
Pilgrim Station	1998-2000	520	27,000
Nine Mile Point Unit 1	1998-2000	246	23,000
Nine Mile Point Unit 2	1998-2000	380	24,000

Note: 1. Concentrate processing is being performed by spent condensate demineralizer resin at Pilgrim and Nine Mile Point 1.

2. Concentrate processing is being performed with the plant evaporator at Nine Mile Point Unit 2. However, the waste associated with the concentrate is not debited in the plant records back to the Thermex™ System. The waste from this stream is estimated to represent approximately 200 – 400 pounds of material and would not represent a significant addition to the waste volume.

5.4 Personnel Exposure Related to Thermex™ Operation

Personnel radiation exposure appears to be comparable for BWR radwaste processing. For these plants, the reduction in personnel exposure was significant due to the replacement of high maintenance/high exposure equipment. Overall the personnel exposure appears to be well controlled, refer to Table 5-6.

Table 5-6
Personnel Exposure for the Study Plants – 1998-2000

Plant	Period	Total Exposure Related to Thermex Operation mRem/yr	mRem per Million Gallons Processed/yr
Pilgrim Station	1998-2000	1,135	80
Nine Mile Point Unit 1	1998-2000	290	51
Nine Mile Point Unit 2	1998-2000	1,050	112

5.5 Personnel Training and Technical Support

A critical element in the implementation of an advanced technology is the training and support of the operating staff. The three plants reviewed use essentially a common training program customized to their individual systems. Operator certification requires successful completion of the training program involving a comprehensive review of the system components, valving sequences, and hands-on operation of system components. Vendor on-site representatives must successfully complete a 3-month training involving a comprehensive curriculum including theoretical review of the technology and hands-on operation and routine maintenance of system components.

The systems reviewed were all provided by the same vendor, this allowed an integration of the data into a common database of key parameters. This has allowed a real time in-depth analysis of the performance of each system. Additionally, this common thread has allowed the leveraging of operating and component improvements across all of the systems.

5.6 Considerations in Applying Membrane Based Processing to a BWR

Discussions with plant and Duratek personnel identified a number of items that need to be considered in moving ahead with a membrane system to replace the existing plant process. The following lists those aspects seen as being most significant to this modification:

1. Pretreatment is critical to reliable and high performance membrane processing. Therefore, characterizing the impurities present in the input stream is a key to designing an effective pretreatment system required by a membrane based processing system. Particular attention needs to be given to such items as:
   - Suspended solids, normal concentration and spikes from such processes as ultrasonic resin cleaning, use of powdered resin demineralization in the condensate demineralizers and radwaste systems, resin transfers and such activities as major desludging operations.
   - Presence of organic materials such as light oils, treatment polymers, and biofouling agents.
   - Presence of significant levels of silica, calcium and magnesium from plant ground water and cooling water inleakage.
2. Concentrate processing and disposal needs to be carefully evaluated. This requires such considerations as:
   - Is there sufficient spent resin for the condensate demineralizer operation needed for processing of the RO concentrate? Does the plant have evaporator processing capability or will off-site services be required?
   - Does the existing radwaste piping allow transfer of the concentrate to processing and shipping locations?
3. Today’s RO membranes typically have an upper temperature limit of 113^0 F (45^0C). Clean drains can approach or exceed this limit, both Pilgrim Station and Nine Mile Unit 2 were forced to divert this stream from the RO portion of the Thermex™ System due to the temperature of the wastewater.
4. Wastewater radioactivity needs to be evaluated for shielding required for sustained operation due to exposure considerations related to RO operation.

Target:
Nuclear Power

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