NUREG/CR-2731

# An Evaluation of the Safety Aspects of the Design and Operation of Temporary/Mobile Radioactive Waste Solidification Systems

Prepared by F. N. McDonald, L. W. McClure

**Exxon Nuclear Idaho Company, Inc.**

**Prepared for**
**U.S. Nuclear Regulatory Commission**

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Springfield, Virginia 22161

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# An Evaluation of the Safety Aspects of the Design and Operation of Temporary/Mobile Radioactive Waste Solidification Systems

Manuscript Completed: February 1982
Date Published: May 1982

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**Prepared for**
**Division of Systems Integration**
**Office of Nuclear Reactor Regulation**
**U.S. Nuclear Regulatory Commission**
**Washington, D.C. 20555**
**NRC FIN A6159**

## ABSTRACT

An evaluation of the safety aspects of the design and operation of temporary/mobile radioactive waste solidification systems in use at commercial nuclear power reactors was completed. The study was undertaken in response to a General Accounting Office report issued in August, 1978 calling for "more regulatory oversight of commercial low-level radioactive waste treatment." After reviewing the design and operation of three different vendor-operated waste solidification systems, it is clear that there are areas in which the vendors can improve their services. However, the vendors generally do a good job of solidifying waste in a manner that is well controlled and safe.

## SUMMARY

An evaluation of the safety aspects of the design and operation of temporary/mobile radioactive waste solidification systems in use at commercial nuclear power reactors was completed. The study was undertaken in response to a General Accounting Office report issued in August, 1978 calling for "more regulatory oversight of commercial low-level radioactive waste treatment." Systems are currently being operated by at least three vendors.

Information to complete this report was gathered through interviews of vendor and licensee personnel and through visits to observe operating waste solidification units. The vendors' systems were compared to the criteria and guidelines for installed systems described in Regulatory Guides 1.143 and 8.8 and in Standard Review Plan 11.4. Specifically, the criteria and guidelines cover system design, ALARA considerations, instrument and alarm configurations, quality control and assurance of system construction, and quality control and assurance of the final solidified product. The major conclusions are: (1) there is no direct method to prove that a waste has been successfully solidified; process control programs are currently relied upon to provide assurance of proper solidification, (2) the vendors are constantly updating their equipment and operating procedures, and (3) safe work areas (areas that meet ALARA criteria) are not always provided for the vendor to do the work.

Even though this study concludes that NRC criteria are generally satisfied, several areas that are candidates for improved practices were identified. Therefore, even though no formal NRC regulation or criteria exist in these areas, the major recommendations are: (1) vendors should explore cost-effective non-invasive techniques to assure that wastes are completely solidified, (2) vendors should continue to update their equipment and operating procedures through their respective development programs, and (3) vendors should insist that safe work areas be provided by the licensee, such that liquid spills can easily be contained and routed back to the licensee's radwaste system, even though this is the licensee's responsibility.

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# 1. INTRODUCTION

## 1.1 Background

Within the last ten years, temporary/mobile waste solidification systems have been developed to service the nuclear industry. Equipment failures and operational difficulties at many nuclear power plants have caused the amount of waste generated to surpass the capacities of the installed waste handling systems. In addition, many nuclear power plants have opted for use of mobile solidification systems as a means of switching to a preferred solidification agent or of updating the technology used in waste solidification. Liquid waste must be solidified since burial sites accept waste with only trace quantities of water. Two burial sites require that solid waste contain no more than 0.5 volume percent liquid. Because temporary/mobile waste systems currently in use were not approved by the NRC, the NRC requested Exxon Nuclear Idaho Co., Inc (ENICO) to perform this evaluation as part of the EG&G Idaho technical assistance contract with the NRC. In particular, this report focuses on the safety aspects of such systems as they affect nuclear industry workers and the general public.

In August of 1978, the GAO asked the NRC to assure that there were no unanswered safety questions concerning contractor temporary/mobile waste solidification systems. The GAO concluded that such systems were increasing the potential of worker exposure to unnecessary radiation and were causing unplanned releases of radioactivity to the environment. In addition, the GAO charged that some systems were ineffectively solidifying waste. The GAO suspected that these solidification systems were not reviewed by the NRC with sufficient scrutiny and frequency. The NRC's position was that the waste treatment systems did not affect public health and safety significantly, and should therefore be authorized and controlled under facility operating licenses. The requirements of 10 CFR Part 50.59 permit a licensee to make changes in the facility design and operating procedures as described in the Safety Analysis Report without prior NRC approval, provided the change does not involve modifications to the technical specifications or involve an unreviewed safety question. Thus, the NRC asserted that a licensee must have enough flexibility to adapt to actual operating conditions.

## 1.2 Scope of Work

The scope of work for this task was to review the safety aspects of temporary/mobile waste solidification systems with respect to design criteria, spill prevention, occupational exposure, and accident potential. Three vendors currently operating such systems were investigated. This involved visits to the facilities of the vendors and three reactor facilities to discuss and observe the major solidification methods currently in use. General conclusions were drawn regarding the major methods used to solidify waste, and conclusions were made on how closely the temporary/mobile waste solidification systems compare with the NRC's Regulatory Guides 1.143 and 8.8 and Standard Review Plan 11.4. Although these systems are not required to meet the provisions of these documents, the documents provided guidelines for this evaluation.

These Regulatory Guides and the Standard Review Plan apply most directly to permanently installed systems, though some of the guidance could easily apply to temporary/mobile systems also. Though Regulatory Guides and the Standard Review Plan are not legally binding requirements, criteria in these documents are intended as a methodology acceptable to the NRC for implementing the regulations themselves. Thus, in general, either the guidance in Regulatory Guides or an alternative acceptable to the NRC is followed by applicants and licensees.

## 2. VENDOR DESCRIPTIONS

The systems operated by three major vendors of temporary/mobile waste solidification systems were evaluated. These vendors are Delaware Custom Materiel, Incorporated (DCM); Hittman Nuclear and Development Corporation (HNDC); and Chem-Nuclear Systems, Incorporated (CNSI). Each vendor guarantees its process will solidify a customer's liquid (or wet particulate) waste into a free standing monolith that meets burial ground requirements. Table 1 lists the waste forms handled by these vendors and their respective radiation levels. CNSI does not solidify organics (that is oil-like mixtures), and neither DCM or CNSI claims to solidify charcoal filters. The radiation levels are defined for the purposes of this report as: low (less than 0.2 R/hr on contact *), medium (0.2 R/hr to 10 R/hr on contact), and high (greater than 10 R/hr, but less than 800 R/hr on contact). Even though "high" level wastes can be up to 800 R/hr on contact, they generally are less than 200 R/hr on contact. The following three sections describe the waste solidification equipment operated by the above vendors.

Table 1.

Liquid Waste Forms and Their Respective Radiation Levels Generally Handled by Temporary/Mobile Waste Solidification Systems

| Waste Form | Activity Level |
|---|---|
| Evaporator Bottoms | Low |
| Bead Resins | Medium to High |
| Powdered Resins | Medium to High |
| Decontamination Solutions | Low |
| Charcoal Filter Media | Low |
| Boric Acid | Low to Medium |
| Organics | Low |
| Sand Blasting Grit Solutions | Medium |

* "On contact" refers to the radiation level existing at the surface of a container (or liner) filled with solidified waste.

## 2.1 Delaware Custom Materiel, Inc.

Delaware Custom Materiel's (DCM) waste solidification systems, as described by DCM, utilize reactions between soluble silicates and silicate setting agents to produce a solid matrix. The matrix is based on tetrahedrically coordinated silicon atoms reacting with oxygen atoms along the backbone of a linear chain. The charged side group oxygens, when reacted with polyvalent metal ions, result in strong bonding between adjacent chains to form a loose-linked, three dimensional, polymer matrix that is similar in its low solubility to naturally occurring iron-magnesium silicates. This type of structure displays properties of high stability. The matrix can also be made to have an affinity for monovalent cesium ions by adding a proprietary mineral in small amounts. It is also possible to entrain organics (e.g. oils) into the matrix by adding appropriate chemical agents. Figure 1 shows one of DCM's manual waste solidification systems that consists of a 55 gallon drum, a lid with bung holes for agent addition, and a mixer driven at turbulent Reynold's numbers.

If the waste is deemed to be of very low activity (less than 0.2 R/hr on contact) such that spillage does not present significant radiological hazards to workers, then the solidification is done as in Figure 2 where no lid is required, and solidification agents are added after the drum has first been loaded with waste. DCM should have no trouble with splashing from agent addition or from mixing in this mode if care is taken. However, splashing has been observed. Simplicity adds to speed so that several drums of waste can be solidified in succession. The mixer is lifted out of a drum once homogeniety has been attained, allowed to finish dripping, and then placed in the next drum to be solidified.

If the waste is deemed to be of high enough activity (greater than 0.2 R/hr on contact) to require a lid (DCM personnel always verify with survey instruments), then the solidification agents are added before waste addition and the stirrer remains in the solidified matrix for burial. Thus, radiological problems for workers are minimized when utilizing this method. At present, DCM has available a prototype automatic solidification system. Its automatic nature will allow DCM to solidify higher activity wastes than it has previously undertaken. As yet, no customer has ordered this system.

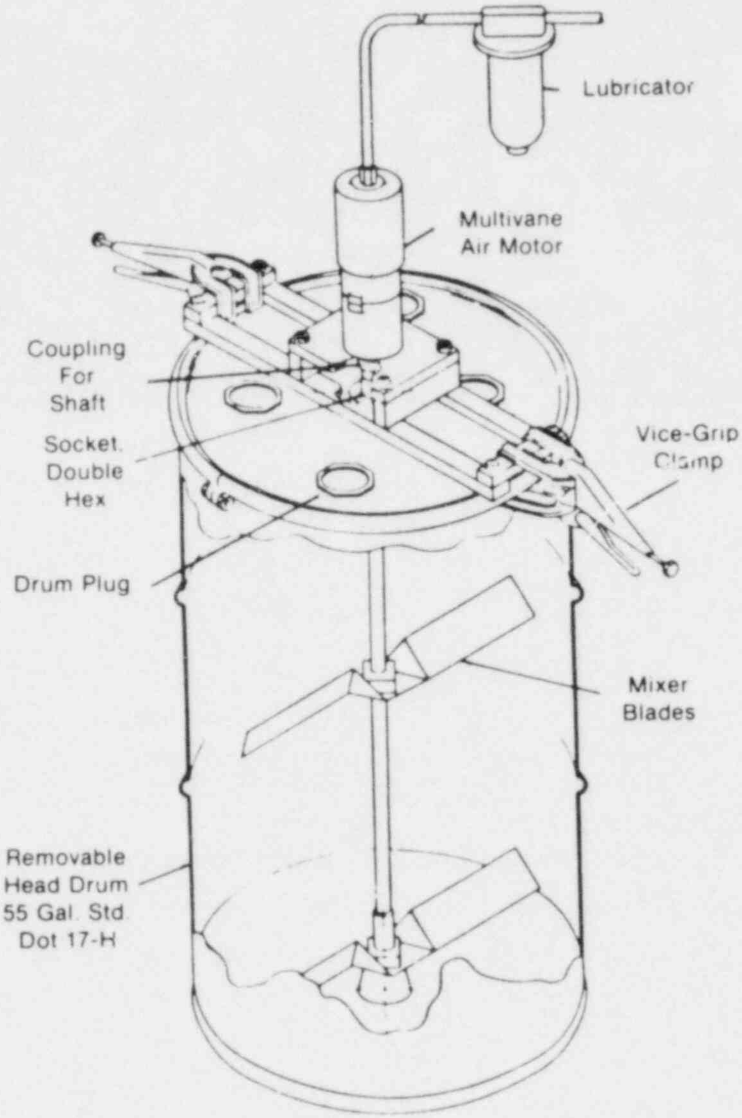


Figure 1. DCM Manual Waste Solidification System

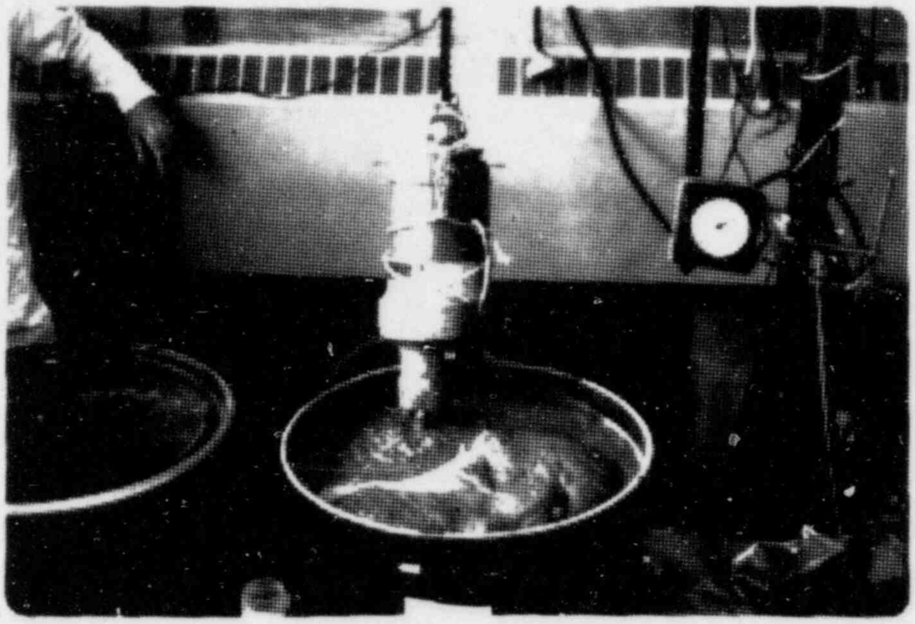

Figure 2. DCM Solidification Drum Showing Solidification of Low Specific Activity Waste

In general, DCM handles the lowest activity waste (less than 5 R/hr at contact) and the most chemically intractable wastes of all the vendors. Table 2 lists DCM's current customers and the specific sites where the work is periodically conducted.

Table 2.

Current Customers of Delaware Custom Materiel

| Customer | Site |
|---|---|
| Carolina Power & Light | Brunswick I & II Reactors |
| Consumer Power Company | Palisades Nuclear Reactor |
| Iowa Electric Light & Power Co. | Duane Arnold Reactor |
| Northern States Power Co. | Monticello Nuclear Reactor |
| North East Utilities | Haddam Neck Reactor (Test) |
| Philadelphia Electric Co. | Peachbottom II and III |
| Public Service Electric & Gas Co. | Salem I Reactor |
| Union Electrica | Jose Cabrera Reactor-Spain |
| Virginia Electric Power Co. | North Anna and Surry Reactors |

## 2.2 Hittman Nuclear and Development Corporation

Hittman Nuclear and Development Corporation's (HNDC) waste solidification system utilizes cement, an alumina-silicate material that will chemically combine with most of the polyvalent metal ions found in commercial liquid wastes. Sodium metasilicate is added to the cement to hasten the solidification process. Table 3 lists HNDC's current customers.

Table 3.

Current Customers of Hittman Nuclear Development Corporation

| Customer | Site |
|---|---|
| Indiana & Michigan Electric Co. | Donald C. Cook |
| Arkansas Power & Light Co. | Arkansas Nuclear One |
| Commonwealth Edison Co. | Zion |
| Virginia Electric & Power Co. | Surry, North Anna |
| Baltimore Gas & Electric Co. | Calvert Cliffs |
| Consolidated Edison Co. | Indian Point, Unit 2 |
| Metropolitan Edison Co. | Three Mile Island, Unit 1 |
| Alabama Power Co. | J. M. Farley |
| Public Service Electric & Gas Co. | Salem |
| Iowa Electric Light & Power Co. | Duane Arnold |
| Northern States Power Co. | Prairie Island |
| Georgia Power Co. | Hatch |
| Jersey Central Power & Light Co. | Oyster Creek |
| Westinghouse Electric Corp (Florida Power & Light Co.) | Turkey Point |

HNDC's waste solidification equipment is shown in Figures 3, 4, and 5. It consists of: 1) a control panel with indicators, 2) a liner, with internal mixing blades, to receive waste, 3) a fill-head with a dewater line and mixing motor, 4) a cement addition hopper and screw feed conveyor, 5) a dewatering pump skid (for processing resins, filter media, and grit), and 6) an off-gas line connected to a bag filter that collects cement dust. Waste is first pumped by the customer into the liner through the fill-head. The dewatering (for resin solidification) and addition of solidification agents then take place. For other than the lowest activity waste (less than 0.2 R/hr on contact), all solidifications are performed with the liner inserted into a shipping cask or some other comparable radiation process shield.

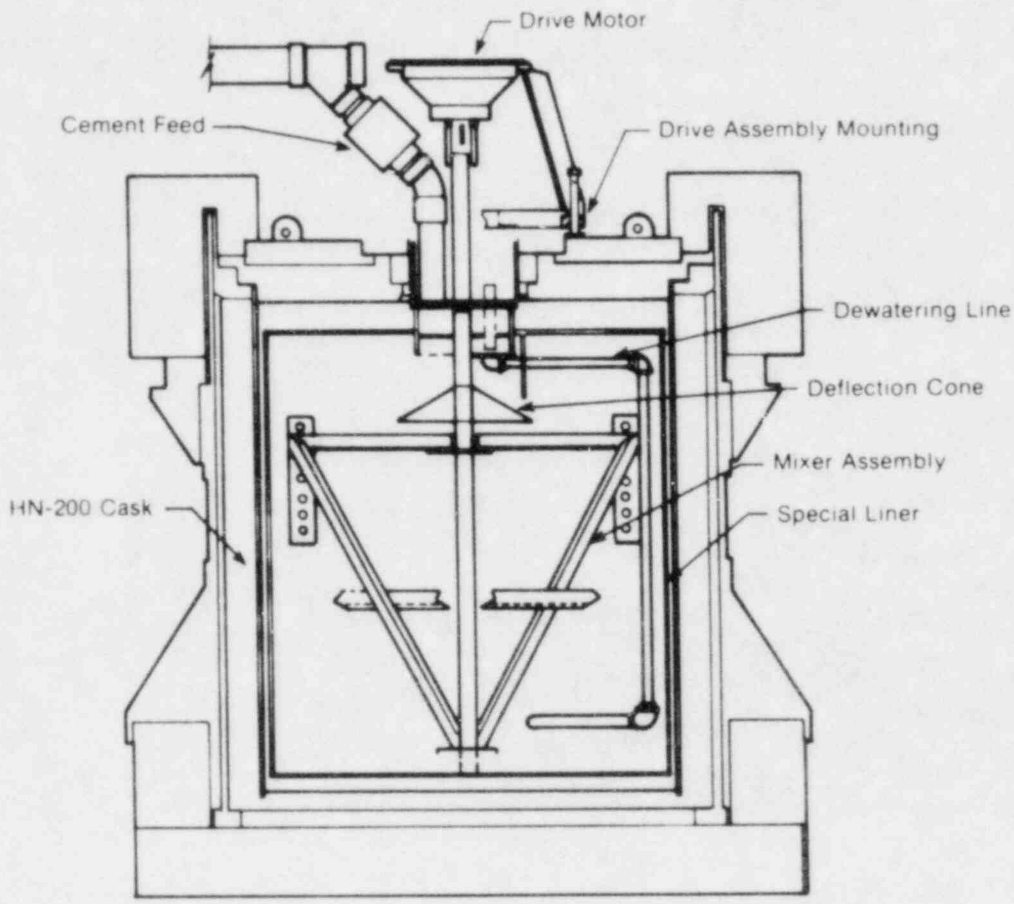


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Figure 3. HNDC Waste Solidification System

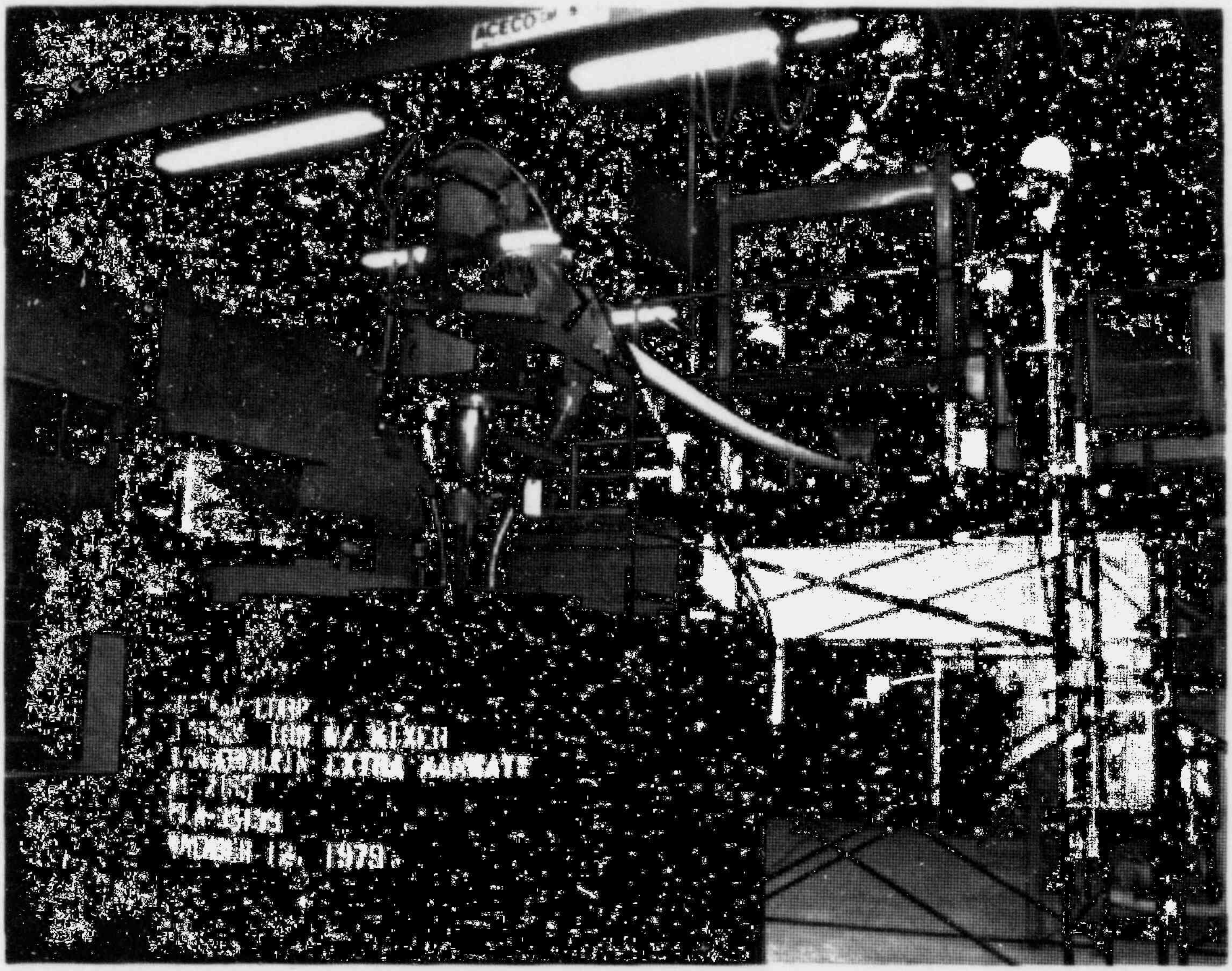


Figure 4. HNDC Waste Solidification Liner and Fill-Head

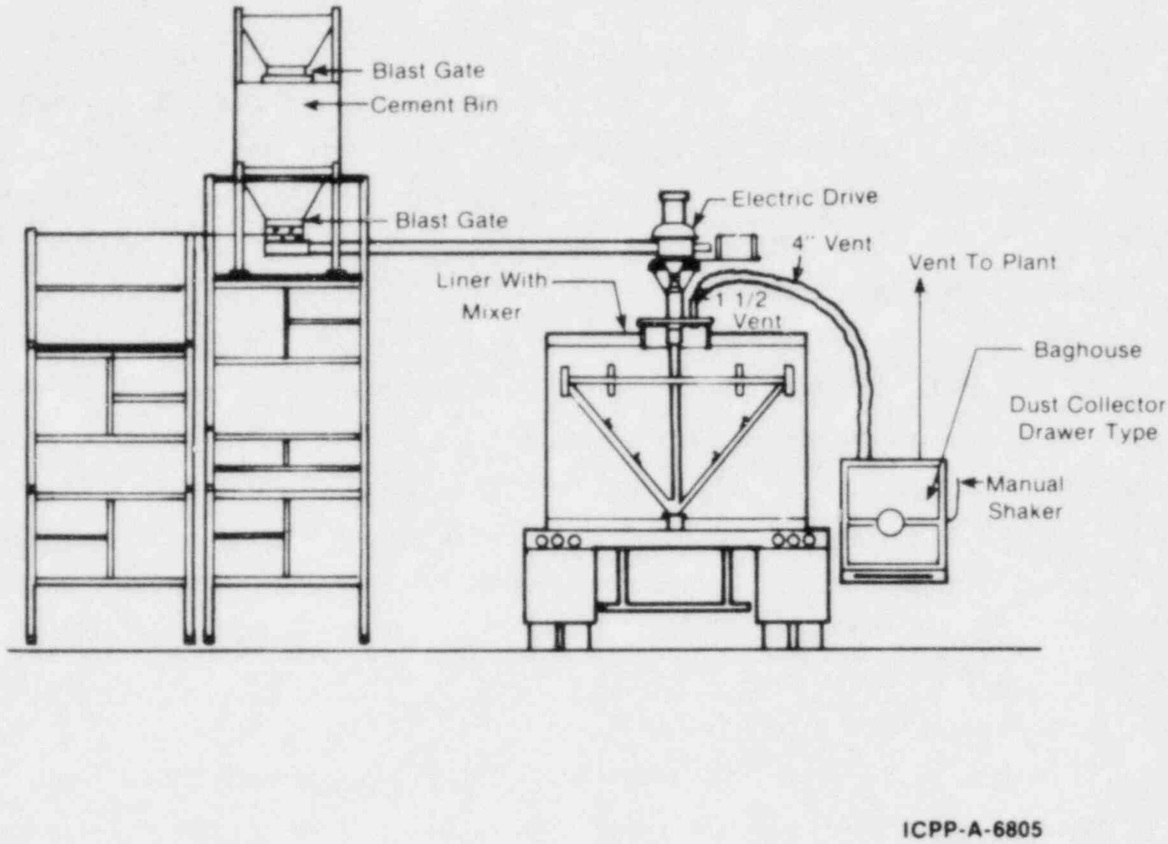


Figure 5. HNDC Waste Solidification System Schematic

## 2.3 Chem-Nuclear Systems, Inc.

Chem-Nuclear Systems, Inc. (CNSI) uses a cement and a Dow process to solidify liquid wastes. The former is the major process in use by CNSI. However, urea-formaldehyde (UF) was the major process utilized until October 1, 1981. It consists of adding urea-formaldehyde and an acid catalyst to the waste to be solidified. As a condensation polymer, urea-formaldehyde loses water concurrent with cross-linking of the polymer. This requires the resulting product to be dewatered. The UF equipment consists of a control panel with indicators, a urea-formaldehyde storage container, an acid container, a fill-head, and a pump skid. The fill-head has several lines connected to it: a dewater line routed to the next liner to be used in solidifying waste, a urea-formaldehyde addition line, a sparge air line for mixing, an acid addition line, a vent line that returns to the plant off-gas system, and a TV instrument line. A camera mounted inside the fill-head monitors the progress of waste solidification. Solidifications are performed with the liner inserted into a shipping cask if the radiation level is high (greater than 10 R/hr on contact).

The equipment used in the cement and Dow process is very similar to that used in the urea-formaldehyde process. A hydraulic mixer is used for the cement and Dow processes while sparge air is used with the UF process to stir the liner contents. Figures 6, 7, and 8 depict a typical cement fill-head, a standard instrument panel with TV monitor, and a cement addition hopper. Waste is always added to a liner prior to the solidification agents for the cement and urea-formaldehyde processes. Conversely, the Dow process requires solidification agents to be added first. The cement process uses several additives, but it does not require sodium-silicate or any other agent that hastens solidification. The Dow process uses a modified vinyl ester resin, a catalyst, and a promoter to produce an addition polymer (therefore no water is produced). The polymer agents and the waste are mixed thoroughly so that the final product consists of finely dispersed waste droplets within a matrix. This process works best on wastes with high solids contents, such as resins. Table 4 list NSI's current customers.

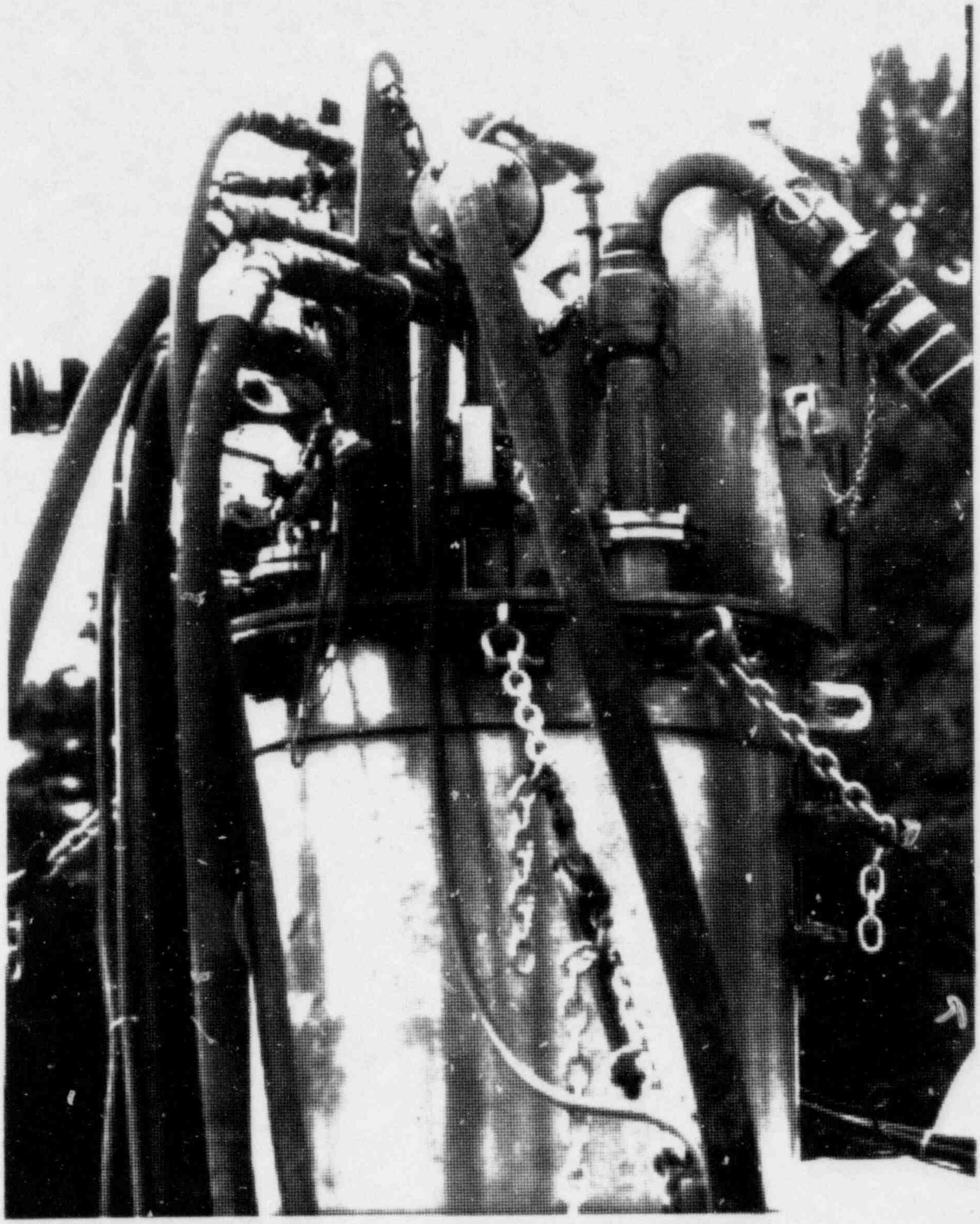

Figure 6. CNSI Cement Fill-Head

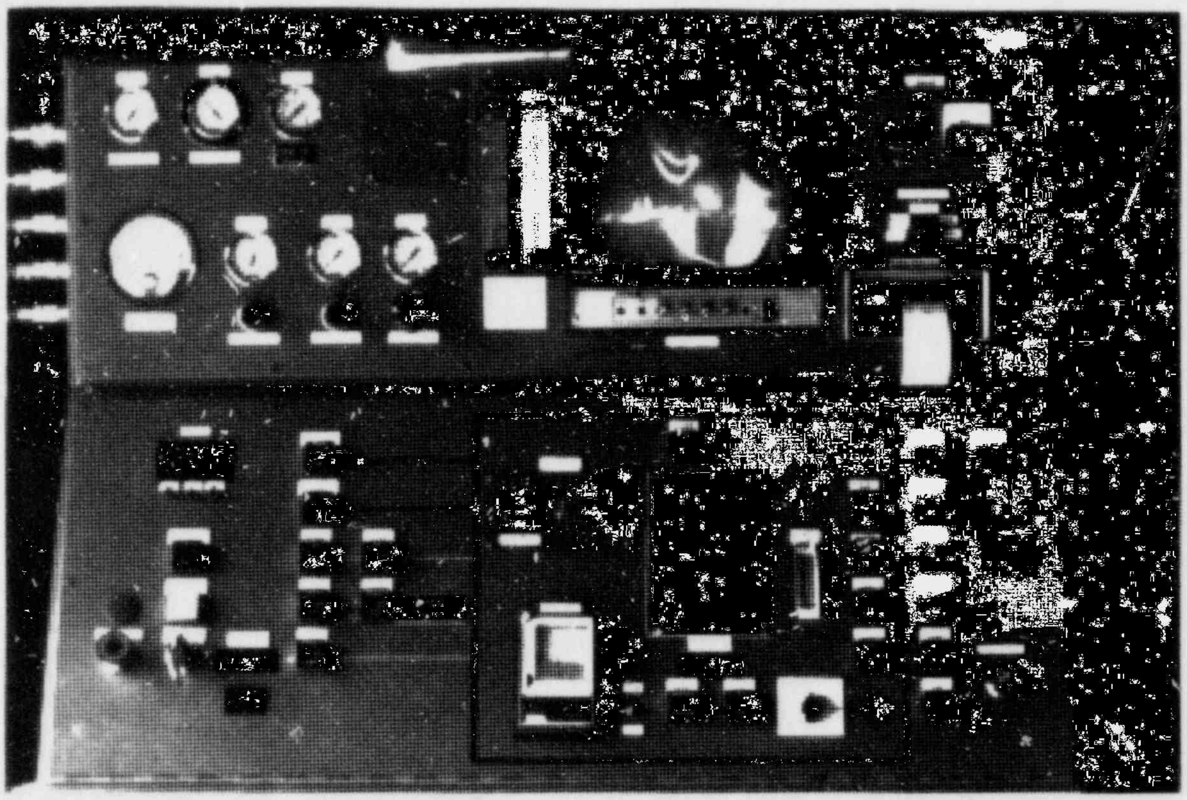

Figure 7. CNSI Instrument Panel with TV Monitor

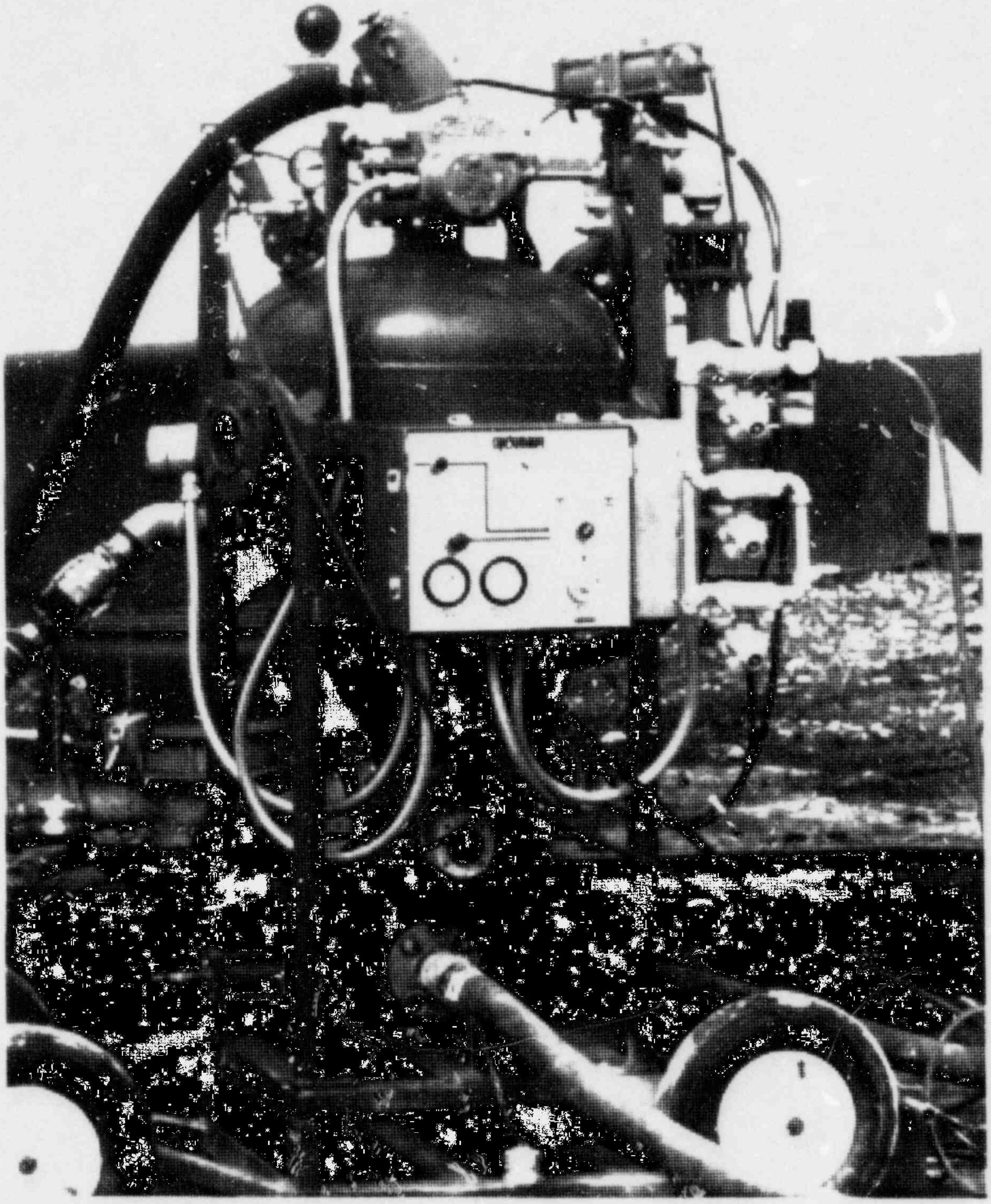

Figure 8. CNSI Cement Batch Feed Tank

Table 4.

Current Customers of Chem-Nuclear Systems, Inc.

| Customer | Site | System Type |
|---|---|---|
| Florida Power & Light Co. | Crystal River | Cement |
| Northeast Nuclear | Millstone | Dow Process |
| Duke Power Co. | Oconee | Cement |
| Northern States Power Co. | Monticello | Cement |
| Power Authority of New York | James FitzPatrick | Cement |
| Portland General Electric Co. | Trojan | Cement |
| Southern California Edison Co. | San Onofre | Dow Process |
| Commonwealth Edison Co. | Quad Cities | Dow Process |
| Duke Power Co. | William-McGuire | Dow Process |

## 3. EVALUATION OF THE THREE VENDORS' SOLIDIFICATION SYSTEMS

### 3.1 System Criteria

To evaluate the temporary/mobile waste solidification systems, their design and operation were evaluated based on the criteria and guidelines for installed waste solidification systems. These criteria are defined in Regulatory Guides 1.143 (Design Guidance For Radioactive Waste Management Systems, Structures, And Components Installed In Light-Water-Cooled Nuclear Power Plants) and 8.8 (Information Relevant To Ensuring That Occupational Radiation Exposures At Nuclear Power Stations Will Be As-Low-As-Reasonably-Achievable) and in Standard Review Plan 11.4 (Solid Waste Management Systems). These documents are only guides and do not set forth any specific requirements that must be met by either the licencee or the vendor. The following section defines the criteria used. Later sections compare temporary/mobile waste solidification systems to these criteria.

#### 3.1.1 Design Criteria

Systems should be designed and tested in accordance with ASME Code Sections II, III (class 3), VIII (Div. 1), and IX and with ANSI B 31.1. Pressure-retaining components of these systems should use welded construction to the maximum practical extent (where it makes sense to do so). Vessels and piping systems that are to retain pressure should be hydrostatically tested for 30 minutes without leakage prior to initial operation. Process lines should be equal to or greater than 3/4-inch (nominal) diameter and they should not be connected in such a manner that radioactive particles will collect in low spots or crevices. Materials of construction should be compatible with the chemical, physical, and radioactive environments that exist under normal operating conditions.

#### 3.1.2 ALARA Criteria

In order to maintain radiation exposures to operating and maintenance personnel as low as reasonably achievable (ALARA), the system should have features that control leakage and facilitate access, operation, inspection, testing, and maintenance (including decontamination). Potential spills due to overfilling should be controlled by utilizing curbs, drains to plant waste systems, or any other suitable arrangements that route overflowed waste to a safe container.

3.1.3 Instrument and Alarm Criteria

The system should have a liquid monitor that alarms whenever overfilling is imminent. Automatic process shutdown upon reaching a set-point is a desirable feature.

3.1.4 Quality Control and Assurance Criteria of System Construction

The design, procurement, fabrication, and construction activities should conform to the quality control provisions of ANSI N199-1976/ANS-55.2 "Liquid Radioactive Waste Processing System for Pressurized Water Reactor Plants".

3.1.5 Quality Control and Assurance Criteria of the Final Solidified Product

The solidified product should be quality controlled and assured throughout its production. This includes the storage of solidification agents in a noncorrosive and non-radioactive environment, the periodic sampling of solidification agents if necessary, the establishment of solidification procedures for different types and activities of waste, the periodic sampling of liquid waste to monitor its characteristics for necessary changes in solidification procedures, and (if practical) the testing of the final product to see that it meets "free liquid" burial requirements. The quality control and assurance criteria of the final solidified product is always described in a vendor's "Process Control Program". This is a necessary document described in SRP 11.4. It has been the position of the NRC that implementation of this document - particularly those sections delineating solidification procedures - is an acceptable alternate to a direct verification of solidification. That is, it is not necessary to open every solidified container to confirm the absence of free water since the Process Control Programs should be the result of extensive laboratory and full-scale testing.*

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* Despite the usage of Process Control Programs to assure solidification, the State of South Carolina had to issue civil penalties of one thousand dollars to each of five power companies on September 28, 1981 for five shipments of solidified waste received at the Barnwell burial site that did not meet the state limit of one-half percent liquid per container or one-percent liquid per high-integrity container. Three of the shipments were from temporary/mobile waste solidification systems (high-integrity containers) and two were from installed systems (standard containers). Therefore, non-invasive direct verification techniques should be explored.

## 3.2 Comparison of DCM's Temporary/Mobile Waste Solidification Systems to Criteria

### 3.2.1 Design Criteria

DCM states that its systems (manual and automatic models) are designed, constructed, and tested in accordance with the applicable provisions of ASME Code Sections II, III (class 3), VIII (Div 1), IX, and ANSI B 31.1 Welding conforms to the ASME Pressure Vessel Code applicable to air pressure vessels only. Since the radioactive waste handling portion of the systems are not pressurized, they do not meet any codes for welding pressure vessels. However, the automatic model will be leak tested in accordance with the applicable codes after the final assembly and prior to initial operation. The only pressurized components in the automatic model are the hydraulic system (1800 psi, schedule 160 pipe and high pressure hose) and the catalyst injection system (75 psi, schedule 40 pipe and 125 psi rated hose). All of the actuating (hydraulic, air) lines and the catalyst feed lines are screw connected. The plant waste feed line (owned, operated, and connected by the customer) is connected to the processor head by a quick coupling. Thus, both of DCM's systems meet the design criteria as stated in Section 3.1.

### 3.2.2 ALARA Criteria

The manually operated system is generally used to solidify waste of such low level that additional shielding is not necessary. Often no drum head is required (spills of low level waste do not present significant radiological hazards to workers) and mixing is done by moving the stirrer and motor from one drum to the next. To avoid receiving higher than expected activity waste and to avoid unexpected exposure, DCM operators carry GM radiation detectors. If the activity is high enough to warrant precautions against spilling (greater than 0.2 R/hr on contact), then a drum with a permanently installed stirrer and head are used. Further shielding can also be provided. In any event, DCM operators follow NRC regulations and customer policy on allowable exposure, which is always less than 1.25 rem per quarter. In addition, the customers have responsibility under NRC regulations to assure adequate health physics services are provided. If remote control is required to process waste of sufficient specific activity, then the automatic system can be employed. According to DCM, the automatic system is in compliance with Regulatory Guide 8.8 and is designed and constructed to observe ALARA requirements for all types of commercial liquid waste. The equipment controls are located external to the areas of highest dose rate. All system performance and maintenance checks, as well as necessary adjustments, are performed externally.

The processor head and support assembly is constructed of commercially available materials (ASTM A 331, grade 4130 or 4140) and is mechanically oversized to several hundred percent over the actual pressure requirements. The processor head and support require no maintenance, and there are no lines to decontaminate (as the customer supplies flexible fill lines). Contamination on the inside of the processor head is removed by water flushes and subsequent wire brushing. Other components likely to become contaminated are bolted or screwed parts allowing rapid removal, and disposal.

Decontamination solutions can be solidified or transferred into the customer's radwaste system. For both systems, in the unlikely event of a spill or overflow condition, the customer's radwaste drain piping is expected to handle the waste. However, DCM does not require the customers to have a radwaste drain system. NRC Regulatory Guides 8.8 and 1.143 urge the licensee to provide curbing and a radwaste drainage system to contain potential spills. Process upsets are not expected to result in personnel exposure because standard operational procedures written by DCM require the nature of the waste to be determined before full-scale solidification. A power failure to either system will not result in any additional personnel exposure. Thus, neither of DCM's systems meets every ALARA criterion, but they do meet the general intent of the criteria.

### 3.2.3 Instrument and Alarm Criteria

DCM's manual system has no liquid level indicators or alarms. When the drum lid is off, the liquid level can be determined visually. When the lid has been secured prior to waste addition, the liquid level is determined by adding a known volume of solidification agents to a measured amount of waste within the drums. Liquid level monitoring in the automatic system is provided by an ultrasonic device with adjustable level trip switches. The device is equipped with its own safeguards against lost echo and spurious reflectance. It controls the filling of the containers when the system is operated in an automatic mode.

Overfilling is guarded against by two back-up sensors. The primary protective sensor is a contact type conductivity probe adjusted to denote an alarm point slightly above the process control level. Both this and the main level sensor activate two fail-closed air-operated flow control valves installed in series. The other back-up sensor is a float control valve at the maximum level of the waste container. The float operates through a mechanical multiplier linkage, thereby achieving full valve closure at minimum activation. Thus, the automatic system meets the instrument and alarm criteria. However, the manual system need not meet the criteria, because visual inspection during solidification is possible and appears to be an acceptable alternative.

### 3.2.4 Quality Control and Assurance Criteria of System Construction

The design, procurement, and construction activities of DCM are carried out according to the provisions of DCM's Quality Assurance Manual. The Manual delineates, in detail, the responsibilities of quality assurance personnel and the various documentation requirements. According to the manual, DCM's quality assurance program is in full compliance with ANSI N199-1976/ANS-55.2, and therefore meets the quality control and assurances criteria of system construction.

### 3.2.5 Quality Control and Assurance Criteria of the Final Solidified Product

The solidification agents used in DCM's process are common industrial chemicals of known character posessing long shelf lives. Consequently, they are stored in non-radioactive areas and do not require sampling. DCM has developed a standard process to ensure a homogeneous and completely solidified final product. In general, the sampling and test solidification procedure, as derived from DCM's Process Control Program, is as follows:

(a) The type of waste to be solidified is characterized as lab waste, decontamination solution, evaporator bottoms, etc. By knowing the waste type, DCM can choose an overall solidification recipe that it will modify based on results from the following steps.

(b) An appropriate amount of waste is sampled.

(c) The pH is determined.

(d) If the waste contains oil, it must be emulsified with detergent.

(e) The pH is adjusted to the appropriate value to ensure solidification.

(f) The required amounts of cement and sodium silicate for complete solidification are determined and added.

(g) After an appropriate amount of time, the degree of solidification is checked to see if it conforms to accepted standards. If not, then the test solidification is repeated.

In general, the full-scale solidification procedure, as derived from DCM's Process Control Program (with exceptions noted for the manual system), is as follows:

(a) A predetermined amount of waste is added to the container (unless the manual system with lid is being used, in which case the solidification agents are added first).

(b) Oil waste and emulsifier are added (that is, if oil is to be solidified).

(c) The pH is adjusted.

(d) Mixing is started and a predetermined amount of cement (from test procedure) is added.

(e) A predetermined amount of sodium silicate (from test procedure) is added.

(f) Stirring ends and the mixer is removed to allow the matrix to set.

(g) The matrix is visually checked for solidification. If any liquid remains, then dry cement is added to absorb it. Although the matrix usually sets up shortly after stirring ends, complete solidification on the molecular level will not be chemically complete for approximately 30 days.

Thus, both of DCM's systems (manual and automatic) meet the quality control and assurance criteria of the final solidified product when direct verification is possible. However, should DCM begin solidifying medium or high level waste, it will not be able to use direct verification techniques. Non-solidification will be possible at some small frequency because of variabilities in both waste content and batch chemistry. Therefore, development of non-invasive verification techniques could potentially improve DCM's solidification quality control program and would benefit both DCM and its customers.

## 3.3 Comparison of HNDC's Temporary/Mobile Waste Solidification System to Criteria

### 3.3.1 Design Criteria

HNDC reports that its system is constructed of good commercial quality materials. Piping, valves, and pumps are specified to be equal to ASTM Material Specifications for Type 304 stainless steel. Material selection is based on expected normal operating conditions and on potential operational upsets, including pressure increases due to valve closures. The pressure-retaining components include a three-way solenoid-operated feed and recirculating valve, interconnect piping and/or hoses between the piping and the solenoid valve, and a dewatering pump connected to the facility piping through a discharge hose. All other equipment that contains or transports radioactive waste operates at atmospheric pressure or slightly less, and is, therefore, not classified as pressure-retaining. None of the pressure-retaining connections are welded. Instead, they consist of threaded pipe joints that are easier to disconnect and to decontaminate (therefore less exposure) than flanged joints. However, threaded pipe joints have a greater potential for leakage than flanged joints. Process lines are nominally two inches for liquid waste and one inch for dewatering. They consist of hoses made of neoprene rubber (rated 300 psig at 180$^{\circ}$F) with quick connect fittings and stainless steel pipes with threaded fittings. All quick connects are bagged with polyethylene plastic and absorbent rags. Thus, the HNDC system does not specifically meet the design criteria, but it generally meets the intentions of the criteria.

### 3.3.2 ALARA Criteria

Operators depend on plant health physics personnel for monitoring exposure (e.g. personnel dosimetry, constant air monitors etc.); HNDC also supplies its workers with its own TLD's as an added precaution. Worker exposure is kept to a minimum by normally performing solidifications in a liner within a shipping cask or within some other comparable radiation process shield. HNDC reports that its operators receive less than 1.25 rem per quarter.

The system is hydrostatically tested for leaks and system operability before going into service at a customer's facility. A system may also be hydrostatically leak tested just prior to handling high-activity waste. Decontamination of the system to reduce radiation fields is done by flushing with water. Additional manual decontamination of system equipment, using appropriate cleaning solutions, is performed as necessary.

Since HNDC's system is portable and customers merely provide convenient locations for HNDC to solidify waste, curbs and waste drains are not always provided by the customer. Thus, HNDC's system does not meet all of the ALARA criteria. However, it does meet the general intent of the criteria.

### 3.3.3 Instrument and Alarm Criteria

HNDC's system has a high-high level alarm that provides visual/audible indication of an impending overfill condition and that provides a signal which can be used to operate an automatic waste feed system isolation or three-way recirculation valve to secure waste flow to the liner. This isolation or recirculation system is supplied by HNDC only after the need for it is established by the customer based on the waste stream being processed, as well as on the specific configuration of the plant system with which the HNDC system interfaces (i.e., the high-high level signal may be used to operate a plant valve so as to secure flow). The HNDC fill head also has a provision for directing an over-flow line to a separate waste container as an added backup protection against spills if deemed necessary by the specific processing application.

During processing operations, waste level within the liner is often determined visually or calculated from known fill rates. For processing certain waste types, probes that sense levels lower than the high-high level are used to control operating level within the HNDC liner. Thus, the HNDC system meets the instrument and alarm criteria.

### 3.3.4 Quality Control and Assurance Criteria of System Construction

If specifically required by a client, HNDC's quality assurance program, normally employed in supplying engineered systems for permanent in-plant installation, can be applied to the temporary/mobile waste solidification systems. According to HNDC, the usual practice is to apply the design control provisions of this program to mobile system equipment. HNDC mobile systems undergo thorough functional testing prior to delivery to the plant site. Quality of solidification liners is controlled through the use of HNDC QA-approved specifications. These specifications call for specific manufacturing controls such as use of welders and weld procedures in accordance with ASME Code Section IX. Thus, the HNDC system does not specifically meet the quality control and assurance criteria of system construction, but it generally meets its intent.

3.3.5 Quality Control and Assurance Criteria of the Final Solidified Product

HNDC does not store its solidification agents in a radioactive environment, and there are no provisions for sampling, as none are required for chemicals of long shelf lives. HNDC has developed standard solidification procedures that call for periodic sampling and test solidifications (every one to ten batches*) of the waste liquid. In general, the sampling and test solidification procedures, as derived from HNDC's Process Control Program, are as follows:

(a) The type of waste to be solidified is characterized as lab waste, decon solution, evaporator bottoms, etc. By knowing the waste type, HNDC can choose an overall solidification recipe that it will modify based on results from the following steps.

(b) An approp·iate volume of waste is sampled.

(c) The pH, boric acid content, sulfate content, detergent content, oil content, and solids content are determined.

(d) The pH is adjusted.

(e) Anti-foaming agents are added if detergent is present.

(f) If oil is present in amounts greater than 1% by volume, then emulsifying agents are added. However, the Barnwell burial site will not accept oil greater than 1% by volume. In this case, it is the customer's responsibility to separate the aqueous waste from the oil before solidification can be done.

* A batch is usually defined as one full liner of waste.

(g) The required amounts of cement and sodium silicate are added for complete solidification.

(h) After an appropriate amount of time, the degree of solidification is checked to see if it conforms to accepted standards.

The solidification recipe is changed only if the chemical characteristics of the waste change significantly from sample to sample. The general full-scale procedure, as derived from HNDC's Process Control Program, is then performed as follows:

(a) The appropriate amount of waste from the test procedure is pumped into a liner by the customer through the fill-head. A cask already surrounds the liner unless the specific activity of the waste is so low that no shielding is required.

(b) The waste is dewatered if it is required (as in resins).

(c) The pH is adjusted if required.

(d) The appropriate amount of water (from test procedure) is pumped in (for resin solidification), and the mixer started.

(e) The approprate amount of dry cement (from test procedure) is fed in.

(f) The appropriate amount of sodium metasilicate (from test procedure) is fed in.

(g) During mixing of liners with dewatering underdrains, the dewatering pump is used to maintain suction on the underdrain during the cement addition process in order to fill the underdrain with cement, thereby immobilizing it.

(h) Mixing is stopped when all materials are added to the liner in accordance with the Process Control Plan, and when the mixer has been run an additional period of time in accordance with the HNDC operating procedure.

(i) The solidified matrix is probed with a stick to check for solidification if the specific activity is low enough to permit it. This is a qualitative test to see if any pockets of free flowing liquid are present near the surface of the matrix.

Thus, HNDC's system meets the quality control and assurance criteria of the final solidified product. However, because of the variability of the waste to be solidified and the variability inherent to batch chemistry, non-solidification is possible at some small frequency. Therefore, development of non-invasive verification techniques could significantly improve HNDC's solidification quality control program and would benefit both HNDC and its customers.

## 3.4. Comparison of CNSI's Temporary/Mobile Waste Solidification Systems to Criteria

### 3.4.1 Design Criteria

CNSI reports that its systems are designed, constructed, and tested in accordance with ASME Code IX. Process piping is pressure rated to a minimum of 150 psi. The systems are always tested to 150% of rated pressure for 30 minutes prior to installation at a plant according to ANSI B 31.1. CNSI is in the process of changing exclusively to stainless steel pipes and stainless steel jacketed teflon hoses. This will save money and reduce personnel exposure since stainless steel and teflon last longer and decontaminate easier than plastic or rubber. The fill-head and dewater pump are of stainless steel construction. All structural welding of pipes meets AWS standards (socket welds for potentially contaminated process lines), all pressurized lines are flanged, and all process lines are 1-1/2 inch (nominal). Thus, CNSI's systems generally meet the design criteria.

### 3.4.2 ALARA Criteria

CNSI uses ALARA to protect its workers from unnecessary radiation exposure in the spirit of Regulatory Guide 8.8. It is the utility's responsibility to monitor worker exposure through badging with TLD's, but CNSI very often does its own area monitoring. In addition, CNSI keeps records of its worker exposure, so that no one receives more exposure than that allowed by Federal regulations or more than 1.25 rem per quarter. However, the customer will often set lower worker exposure limits while CNSI is on the job.

CNSI's equipment is well designed to protect workers from exposure. To keep contamination from the floor space, drip trays are provided for the pump and control skids, polysleeves (and sometimes lead blankets) are placed around process lines, and a swinging drip basket is normally attached to the fill-head. Air is vented from the liner to the customer's off-gas system. An isolation valve will close if the liner begins to overfill or if the fill-head is improperly positioned. A radiation monitor located near the plant isolation valve will also sound an alarm in CNSI's control module should higher than expected activity in the liquid waste be detected.

This same monitor will also tell the operator how well the system has been decontaminated when flushing the process lines after each operation. Final decontamination is done when the unit is shipped back to CNSI for repairs or modification. Process upsets are generally not expected because standard operational procedures are followed, and power failures should not result in any additional personnel exposure. Curbs to contain spills and drains to route spillage to the plant radwaste system should be supplied by the customer. However, the customer does not always follow the intent of NRC guidelines that are established for permanently installed systems.

Temporary/mobile solidification system vendors often perform solidifications in areas convenient for the customer. For example, in July 1980 the NRC documented the following incident at a nuclear power plant. CNSI was to solidify plant liquid waste by its cement process for one of its customers. The customer did not provide a suitable place for this solidification, as no curbs or drains to the plant radwaste system were provided. A plant technician used an inadequate hose and clamp combination to transfer condensate storage tank water to CNSI's equipment. Leakage from this temporary connection flowed out of the building into a storm sewer and eventually into a river. It was estimated that approximately 2000 gallons of condensate were released from the radwaste shipping building, most of which was absorbed in the ground before reaching the storm sewer, and about 100 gallons were discharged into the river. An analysis of samples of the liquid in the storm sewer indicated dilution reduced concentrations of radioactive material to below applicable 10 CFR Part 20 limits almost instantly.

Thus, CNSI's system does not meet all of the ALARA criteria, but it does meet the general intent of the criteria.

### 3.4.3 Instrument and Alarm Criteria

In the discontinued urea-formaldehyde process, liquid level monitoring was provided by conductivity probes placed at predetermined positions within the liner. In the Dow and cement systems, level indication is provided by bubbler probes. All three systems have a float switch in the fill-head to provide a high-high level alarm in the control room. In the case of a high-high level condition the waste solidification equipment will automatically shut down. All processes are remotely controlled and, as mentioned before, the incoming waste can be monitored for activity. A TV camera is used to monitor the progress of solidification within the liner. Thus, the CNSI systems meet the instrument and alarm criteria.

### 3.4.4 Quality Control and Assurance Criteria of System Construction

CNSI's quality assurance program, as described by CNSI, is very complete. It assures that drawings are correct, that supplied items conform to company requirements, that items assembled or repaired in-house meet company specifications, that modifications to older equipment are made, and that equipment used in testing solidification equipment is calibrated in accordance with Mil-C-4562 (or that an alternate calibration is documented). Thus, CNSI's systems meet the quality control and assurance criteria of system construction.

### 3.4.5 Quality Control and Assurance of the Final Solidified Product

Sampling is not required for the Dow polymer and the cement soldidification agents. In general, waste to be solidified is sampled every 10th batch* to ensure that the solidification requirements of the batches remain constant. The general sampling and test solidification procedure** for the cement process as derived from CNSI's Process Control Program is as follows:

(a) An appropriate amount of waste is sampled.

(b) An analysis for pH, oil, boron, etc. is run. Waste with greater than 1% oil is not accepted for solidification due to burial ground requirements.

(c) The pH is adjusted.

(d) The waste is added to and mixed with an appropriate amount of cement and any required agents. For powdex and bead resin solidifications, the solidification agents are added to the waste.

(e) The sample may be cured in an oven to simulate temperatures that result in full scale solidifications.

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* A batch is usually defined as one full liner of waste.

** The sampling and test solidification procedures for the Dow process were not available.

(f) The solidified sample is visually inspected and probed with a stick. If the solidification is deemed inadequate, then the chemical agent proportions are altered in another test solidification.

The general full-scale field procedure* for the cement process is as follows:

(a) The waste is transferred to the liner, followed by a flushing of the waste transfer line. Resins can be dewatered after this step.
(b) The mixer is turned on and the solidification agents are added to the liner in a predetermined amount (from the test procedure.)
(c) After attaining a homogeneous mixture (or upon experiencing increasing viscosity with resins), the stirring is stopped.
(d) After allowing for curing, the matrix is checked for solidification by probing it with a stick, if the waste is of low specific activity.

Thus, CNSI's systems meet the quality control and assurance criteria of the final solidified product. However, because of the variability of the waste to be solidified and the variability inherent to batch chemistry, non-solidification is possible at some small frequency. Therefore, development of non-invasive verification techniques could significantly improve CNSI's solidification quality control program and would benefit CNSI and its customers.

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* The full-scale field solidification procedures for the Dow process were not available. However, it is known that solidification by the Dow polymer process can be followed by monitoring the matrix temperature. The process has a distinct heat-generation curve that will indicate if proper solidification has occurred.

## 4. CONCLUSIONS

1. Although the licensee is always legally responsible for the waste during solidification and transportation, vendors assume a de facto responsibility at some point during solidification. The vendors differ on where this responsibility begins in the waste handling process. DCM and HNDC assume responsibility for the waste only when it is physically in their drums or liners. Whereas, CNSI takes responsibility of the waste once it enters their fill lines directly out of the customer's storage tank. This gives CNSI greater control over waste transfer, but this does not prevent unplanned incidents, as evidenced by the previously mentioned release of contaminated liquid to the storm sewer at a nuclear power plant.

2. The Dow polymer and the urea-formaldehyde processes are unable to solidify any significant amount of oil.

3. Evaporator bottoms, decontamination solutions, charcoal filters, organics, and boric acid waste constitute the lowest activity waste solidified by the vendors, while bead and powdered resins constitute the highest activity waste solidified by the vendors.

4. The special precautions taken with "medium" or "high" level wastes are not taken with "low" level wastes. The former are usually solidified in remote or automated shielded (cask) systems.

5. Remote or automatic systems often have back-up sensors that will alarm and shut down a process. They may also have radiation monitors on the waste fill lines. However, these features may sometimes be treated as options by the customer.

6. Remote or automatic systems in current use are always leak tested prior to operation.

7. Quick couplings are often seen as superior to fl ıged fittings in reducing worker exposure during maintenance.

8. The more complicated or sophisticated a system is for the purpose of handling higher level wastes, the more applicable the criteria in Regulatory Guide 1.143 are and the more often they are met. However, all of the evaluated systems meet the intent of the criteria.

9. The DCM system has a potential for generating air-borne activity, as it does not have a line that vents back through its customer's waste off-gas system. The HNDC system can be equipped with a vent line that connects to the customer's waste off-gas system, but it is not always utilized. An off-gas filter utilized in the system is often deemed sufficient by the customer.

10. The vendors don't always rely on the customer to provide high quality health physics services. For example, DCM's operators carry their own GM counters and HNDC's carry their own TLD's, even though they require their customers to provide all health physics services.

11. Even though all three vendors guarantee their solidification processes and even though the NRC position in SRP 11.4 is that a Process Control Program is an acceptable alternative to direct inspection of solidified wastes, there is nothing that directly verifies liquid waste solidification. Due to radiological health considerations, only low level waste can be directly inspected.

12. The vendors are always updating their equipment in response to improvements made in their development programs.

13. Nuclear power plant operators who have contracts with vendors for radwaste solidification services often fail to provide adequate facilities (design features equivalent to criteria in Regulatory Guide 1.143) for the proper operation of the temporary/mobile solidification systems, i.e., adequate floor drains, curbing to retain spills, etc. These design features are always taken into consideration in a permanent radwaste solidification facility. In spite of the fact that it is possible to design and operate a temporary/mobile solidification system as safely as an installed system, it appears that the 10 CFR 50.59 reviews that should have been performed by operating nuclear power

plant licensees prior to using temporary/mobile solidification systems have in many cases been insufficient to assure that suitable facilities are provided to house the temporary/mobile system operations. Recognizing this situation, the commission issued IE circular 80-18, 10 CFR 50.59 Safety Evaluations for Changes to Radioactive Waste Treatment Systems, on August 22, 1980. It appears that guidance in IE Circular 80-18 may not have always been followed and that in such cases a decision to utilize temporary/mobile radwaste solidification equipment may result in an overall system that is inferior to an installed system.

## 5. RECOMMENDATIONS

1. Nuclear power plant licensees should provide adequate facilities for the temporary/mobile solidification system operations. That is, they should make sure that curbs to contain spills and waste drains are provided that route spills back to the customer's radwaste system. They should make sure health physics personnel are present when their operators are working and that TLD's, constant air monitors, and survey monitors are available and being utilized. The guidance in IE Circular 80-18 should be followed more closely by nuclear power plant licensees planning to use temporary/mobile solidification systems.

2. Remote or automatic solidification systems, handling anything but the lowest activity waste, should have their off-gas routed back to the customer's off-gas system.

3. Back-up sensors, alarms, three-way diversion valves, and automatic shutdown capabilities should not be optional on remote or automatic systems, but should be standard.

4. Vendors should continue to develop new equipment and procedures and to update old equipment and procedures. This will help to ensure a quality solidified product and to assure worker safety.

5. Improved techniques to ensure that solidified wastes meet burial ground requirements for free water and degree of solidification should be explored by the vendors, preferably non-invasive ones that pose no radiological hazards to the personnel involved.

| NRC FORM 335 (11-81) U.S. NUCLEAR REGULATORY COMMISSION **BIBLIOGRAPHIC DATA SHEET** | | 1. REPORT NUMBER (Assigned by DDC) NUREG/CR-2731 | |
|---|---|---|---|
| 4. TITLE AND SUBTITLE (Add Volume No., if appropriate) An Evaluation of the Safety Aspects of the Design and Operation of Temporary/Mobile Radioactive Waste Solidification Systems | | 2. (Leave blank) | |
| | | 3. RECIPIENT'S ACCESSION NO. | |
| 7. AUTHOR(S) F. N. McDonald, L. W. McClure | | 5. DATE REPORT COMPLETED MONTH: February YEAR: 1982 | |
| 9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code) Exxon Nuclear Idaho Company, Inc. Idaho Falls, Idaho 83401 | | DATE REPORT ISSUED MONTH: August YEAR: 1982 | |
| | | 6. (Leave blank) | |
| | | 8. (Leave blank) | |
| 12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code) Office of Nuclear Reactor Regulation, Division of Systems Integration, U.S. Nuclear Regulatory Commission, Washington, DC 20555 | | 10. PROJECT/TASK/WORK UNIT NO. | |
| | | 11. FIN NO. FIN A6159 | |
| 13. TYPE OF REPORT Formal - Technical | PERIOD COVERED (Inclusive dates) 1980-1982 | | |
| 15. SUPPLEMENTARY NOTES | | 14. (Leave blank) | |

16. ABSTRACT (200 words or less)

An evaluation of the safety aspects of the design and operation of temporary/mobile radioactive waste solidification systems in use at commercial nuclear power reactors was completed. The study was undertaken in response to a General Accounting Office report issued in August 1978, calling for "more regulatory oversight of commercial low-level radioactive waste treatment". After reviewing the design and operation of three different vendor-operated waste solidification systems, it is clear that there are areas in which the vendors can improve their services. However, the vendors generally do a good job of solidifying waste in a manner that is well controlled and safe.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

mobile radwaste solidification
temporary radwaste solidification

17b. IDENTIFIERS/OPEN-ENDED TERMS

| 18. AVAILABILITY STATEMENT | 19. SECURITY CLASS (This report) | 21. NO. OF PAGES |
|---|---|---|
| Unlimited | Unclassified | |
| | 20. SECURITY CLASS (This page) Unclassified | 22. PRICE $ |

NRC FORM 335 (11-81)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
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