RADIOACTIVE WASTE SYSTEMS AND RADIOACTIVE EFFLUENTS

BY

Thomas H. Row

Reactor Division
Oak Ridge National Laboratory*

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Thomas H. Row
Reactor Division
Oak Ridge National Laboratory*
Oak Ridge, Tennessee 37830

The operation of nuclear power plants results in the generation of gaseous and liquid radioactive wastes. These wastes must be treated to bring about a significant reduction in concentration before release to the environment can be considered. This treatment requires complex chemical processing equipment in most cases.

The predominate type of nuclear generating station currently being purchased by utilities is the Light Water Reactor (LWR). The Boiling Water Reactor (BWR) generates steam which flows directly to the turbine generator, the Pressurized Water Reactor (PWR) transfers heat to a secondary loop where the steam is produced that drives the turbine generator.

There are three processes, common to both systems, that result in radioactive wastes: (1) fission products which have been released from the fuel matrix leak from defective fuel elements into the primary coolant; (2) fission products which originate in the primary coolant as a result of the fissioning of "tramp" uranium on fuel surfaces; and (3) activation of corrosion products, chemical additives, and the coolant itself. Three types of radioactive effluents must be considered in process design: gases, liquids, and solids. The gaseous effluents consist of the fission product noble gases (krypton and xenon) and halogens (primarily iodine), tritium (in water vapor form), and particulate matter (fission products, their daughters, and activated corrosion products). Experience has indicated that some fifty fission and activation products need to be considered in the liquid effluents. Solid wastes result from processing liquid wastes (e.g., spent demineralizer resins, evaporator bottoms, sludge tank residues, filters, etc.) and the ordinary contaminated solids such as contaminated rags, clothing, paper, laboratory material, and small tools.

GASEOUS WASTES

Boiling Water Reactors

The gaseous radwaste system of a typical boiling water reactor is shown schematically in Fig. 1. The major source of gaseous radioactive waste during normal plant operation is the off-gas resulting from the steam powered

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Figure 1 Gaseous-Waste and Ventilation Systems for a Recent Representative BWR Nuclear Plant

air ejectors (or occasionally a mechanical vacuum pump) pulling a "vacuum" on the main steam turbine condenser. These off-gases consist mainly of hydrogen and oxygen from the radiolytic decomposition of water in the reactor.

All treatment systems of the gaseous effluent from the air ejectors are based upon hold-up so that the gases decay to acceptable values prior to release. Initially this hold-up was accomplished using a large pipe where a half-hour decay was followed by release from a 100 meter stack. Newer systems apply catalytic recombination where the resulting water vapor is condensed and removed, carrying with it most of the radioactivity. Additional gas decay time plus complete halogen removal can then be obtained by passing the dried gas stream through large, cooled charcoal beds. The most advanced concept used in a few plants is the cryogenic distillation column. In this system the separated noble gases are compressed for long-term (years) storage in cylinders.

During startups, a mechanical vacuum pump will pull the vacuum on the condenser until enough steam is generated so that the steam jet air ejector can take over. The discharge from the pump is discharged through a line with a nominal hold-up of the order of two minutes before being discharged through the plant stack. The turbine packing gland seal system steam is condensed and the non-condensable gases sent through the two minute hold-up line.

Leakage could occur in the reactor building, radwaste building, and turbine building. The ventilation systems in these buildings are generally once-through, with air passing from relatively clean areas to those areas of higher potential radioactivity. In most plants the ventilation air is discharged through building vents without treatment. However, if the activity level exceeds a pre-set level, the air can be directed through the "Standby Gas Treatment" (SGT) prior to discharge. The radwaste building exhaust is filtered before release to the stack, the turbine building often is exhausted directly to the atmosphere through roll-type filters.

Pressurized Water Reactors

The gaseous radwaste system of a typical pressurized water reactor is shown schematically in Fig. 2. The major source of gaseous radwaste arises

Figure 2 Gaseous Waste Disposal and Ventilation System for a Recent Representative PWR Nuclear Plant

from the "stripping" of (1) the letdown stream in the "Chemical and Volume Control System" (CVCS) and of (2) the shim bleed in the boron control system.

Hydrogen purge, nitrogen purge, or vacuum stripping, is used in the CVCS to strip entrained gases from the letdown stream. Care is taken to keep the hydrogen concentration below the explosive limit in the gaseous waste processing system. Similar means can be used in the degassification of the shim bleed, but degassification may also be accomplished via the evaporators used to concentrate the boric acid in the boron control system. In addition, the primary coolant is completely degassified whenever the reactor is shutdown prior to opening the reactor to the atmosphere.

The degassification wastes are compressed and stored for 30 to 180 days prior to release through the plant vent. Advanced plants frequently remove hydrogen with catalytic recombiners, the water is removed, and after decay, the gas recycled as cover gas for many of the tanks in the various process streams. Frequently the effluent from the storage tanks is filtered by charcoal filters before being discharged.

Leaks develop in steam generator tubes, allowing radioactive primary coolant to leak into the secondary side of the steam generator. This results in radioactive effluents in relatively low concentrations. The effluent from the turbine condenser is passed through filters prior to discharge, in the modern plants.

In some of the plants the steam generators have a small "blowdown" stream as part of the secondary water treatment process. This is directed to a "blow-down flash tank" where some of the high pressure water flashes to steam. The gaseous effluent is discharged either through a roof vent or to the main turbine condenser.

Leakage into auxiliary and containment buildings can occur as in BWRs. PWR containments are sealed during operation and some plants contain an "Internal Recirculating System" which is used to reduce the radioactivity, mainly airborne iodine, prior to containment purge. The purge exhaust air may or may not be treated by filtering with a charcoal filter prior to release.

The ventilation air from the fuel handling and potentially contaminated areas of the auxiliary building is frequently filtered by HEPA and charcoal

filters prior to exhaust, although some plants have no treatment. The ventilation air from other areas of the auxiliary building is usually not treated. Ventilation air from the turbine building is usually discharged untreated through roof vents.

LIQUID WASTES

Boiling Water Reactors

Radioactive liquid wastes from BWR systems are characterized as clean (low conductivity), dirty (moderate conductivity), chemical (high conductivity), and laundry wastes. The various treatment systems employed are illustrated schematically in Fig. 3.

Reactor coolant leakage to the drywell, wastes from the equipment drains in the reactor building, radioactive waste building, and the turbine building are collected in the clean waste collector tank. These wastes are filtered and passed through a mixed-bed demineralizer, monitored, and normally returned to the condensate storage tank. Some backwash liquid and evaporator distillate are also collected in the clean waste collector tank.

Liquids accumulated in sumps in the reactor building, radioactive waste building, and the turbine building are collected in the floor drain waste collector tank. These wastes are also filtered, demineralized, and some is recycled.

Wastes from resin regeneration facilities, laboratory drains, decontamination areas, and certain shop floor drains go to the chemical waste tanks. At stations using deep-bed and regenerable condensate demineralizers, the regenerant chemical wastes are the greatest routine source of radioactive and chemical liquid wastes. These wastes are evaporated and the distillate discharged or sent to clean or dirty waste collection tanks for further processing.

Laundry and shower wastes are collected in detergent drain tank, filtered, monitored and discharged or recycled to the chemical or dirty waste system for further processing.

Pressurized Water Reactors

Radioactive liquid wastes from PWR systems are characterized as clean (deaerated or tritiated), miscellaneous dirty (aerated or nontritiated), blowdown and detergent wastes. Treatment systems for liquid waste processing are shown schematically in Fig. 4.

The primary coolant quality is maintained by a sidestream treatment system that takes a 50 to 100 gpm letdown stream, passes it through a mixed-bed demineralizer, adds chemicals for pH control and oxygen content, and partially degasses before returning to the primary loop. A small portion of the sidestream is bled off to adjust boron concentration (shim bleed). The reactor coolant leakage, shim bleed, and system drain and expansion and expansion liquid (when necessary) are processed through a demineralizer and a degasifier-evaporator package in the boron recovery system. The recovered boron, in the form of a basic acid concentrate, and the treated liquid are recycled or portions are discarded, depending on plant operating philosophy.

Reactor coolant leakage into the containment building is collected from equipment drain lines entering the reactor coolant drain tank, where it is normally pumped to the chemical and volume control system (CVCS) boron recycle holdup tanks. The containment sump wastes can be sent to the aerated dirty waste holdup tank, which may be a floor drain tank or a separate miscellaneous aerated-waste tank. Most plants follow procedures to prevent mixing of deaerated wastes with aerated wastes.

Other miscellaneous wastes such as leakage in the auxiliary building and liquid from laboratory drains, decontamination areas, steam generator blowdown or quench tank, certain floor drains, demineralizer resin regenerates, and detergent wastes are segregated and processed in batches as either clean, dirty, or miscellaneous wastes. The processing of the liquids removes entrained gases and isolates radionuclides in resins, filters, and semisolid evaporator concentrates. The treated liquids can be recycled for further plant use or discharged under monitored conditions to the environment.

Many reactors plan treatment of steam generator blowdown through the use of either mixed bed demineralizers, anion bed units, or evaporator-demineralizer systems. Reverse osmosis also appears to be a future alternative.

Laundry and hot shower wastes are treated in much the same manner as in BWRs.

SOLID WASTES

The solid wastes from PWR and BWR plants are similar, including evaporator bottoms, spent resins, filter sludge, filters, miscellaneous

paper, and rags. While other methods exist, one of the more popular ways of disposing of sludges, resins, and evaporator concentrates is to add cement and package in 55-gallon drums which are shipped, after appropriate decay time, to a licensed burial facility.

ANALYSIS OF SYSTEM OPERATION

The AEC has developed an analytical technique over the last two years that results in a very thorough evaluation of the operation of a radwaste processing system. This evaluation generates radioactive source-terms which define the average quantities of radionuclides that would be released from the station under normal operation conditions. These source-terms are used by the staff to calculate doses to man and biota.

The proper evaluation of a radwaste system depends heavily on the information supplied by the utility in the Preliminary Safety Analysis Report and the Environmental Report. AEC Regulatory Guide 4.2¹ details the necessary information in Section 3.5 Radwaste Systems and Appendix 1 Questionnaire for Eliciting Data for Radioactive Source-Term Calculations. Section 3.5 states: "Provide a detailed description of the radwaste systems including flow diagrams showing origin, treatment, and disposal of all solid, liquid, and gaseous radioactive wastes generated by the plant under consideration. List estimated quantities, volumes, and flow rates from all sources, expected decontamination factors, holding times, and expected frequency and magnitude of variations within normal operation conditions." To further assist in standardizing the system analysis the Regulatory staff has compiled a list of parameters used in source-term calculations and the bases for their selection. This material is included in the three volume Final Environmental Statement (FES) on the criterion "As Low as Practicable."² The parameters were selected after careful evaluation of reactor operating experience, laboratory, field test, and design data. A convincing case must be presented by a utility before gaining acceptance of a parametric value varying significantly from those listed.

The FES on "As Low as Practicable" also includes codes for calculating the gaseous and liquid source-terms, using the parametric data supplied for the individual plant.

In summary, the analysis of the radwaste system of a nuclear station can be readily accomplished if proper care is taken in the preparation of material for the Preliminary Safety Analysis Report and Environmental Report so that all requirements for information are met. The calculation of the gaseous and liquid source-term is also easily accomplished using existing codes.

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