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SAFETY REQUIREMENTS FOR THE
DESIGN OF RADIOCHEMICAL
PROCESSING FACILITIES

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From: F. L. Culler

Date: October 30, 1958

Subject: SAFETY REQUIREMENTS FOR THE DESIGN OF RADIOCHEMICAL PROCESSING FACILITIES, TRANSMITTAL

The attached set of Safety Requirements has been prepared by the Chemical Technology Division Operational Safety Committee for the purpose of establishing and standardizing Divisional safety practices and procedures for the process and engineering design of radiochemical processing facilities. While the scope of these Safety Requirements has been directed toward the design of new radiochemical pilot plant facilities, much of the information contained is directly applicable to the design of chemical development and unit operations type facilities, or modifications to these and pilot plant facilities.

This initial issue of these Safety Requirements is a general and preliminary treatment of the subject and will be revised and expanded in the future to include a more detailed and specific enumeration of requirements for special problems. Questions concerning and suggestions for improving this initial issue should be directed to the Division's Operational Safety Committee.

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SAFETY REQUIREMENTS FOR THE DESIGN
OF
RADIOCHEMICAL PROCESSING FACILITIES

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1.0 PRELIMINARY PROCESS DESIGN

All too frequently the progress of a project is reported only in terms of the three basic stages; namely, design, construction, and operation. The cause of overall plant safety can be improved greatly by recognizing the importance of two additional stages: (1) preliminary process design, and (2) preoperational shakedown and training. Discussion of the second, while equally as important as the first, is outside the scope of these standards and will not be given further consideration here.

The preliminary process design stage is that formative stage of design which must precede the actual engineering design stage. It is the stage where philosophies regarding safety, operation, maintenance, decontamination, plant layout, containment, ventilation, off-gas, materials of construction, construction, procurement, etc., are developed and tied together in a compatible overall project design philosophy. Scale models and drawings prepared during this stage are of a highly tentative nature, consisting of preliminary equipment and engineering flowsheets and preliminary building and process layouts which are required to assist in "firming-up" the overall philosophy. This is the stage in design when these Design Safety Requirements must receive maximum attention. This does not mean that safety considerations should not receive continuing effort throughout the full progress of the project; it merely means that once the overall design philosophy has been "firmed-up" and engineering design, procurement, and construction have gotten underway, it may be too late for full compliance.

The objectives of the preliminary process design stage shall be: (1) to formulate a realistic overall project design philosophy which is compatible with these Safety Requirements; (2) to obtain written approvals of the various safety aspects of such a project design philosophy from the safety groups specified in Section 5.0 of these requirements; and (3) to prepare realistic cost estimates and schedules for the engineering design and the construction of the facility per such a project design philosophy.

The project organization shall be clearly established before the preliminary process design for the project is commenced. The project design engineer and the project operating engineer shall be responsible for formulating the overall project design philosophy. Normally, depending on the scope and nature of the project, an interval of from three months to a year shall be devoted to this phase of the design.

2.0 DESIGN FOR PROCESS FLEXIBILITY

Many of the hazardous situations existing in present facilities within the Division (Buildings 3019, 3505, and 4507) are the direct result of having designed these facilities for the minimum requirements of some short term program. While the hazards were considerable when these facilities were used to process the materials which they were designed to handle, the situation was greatly aggravated when the facilities were later modified and used to process either the same, or entirely different, feed materials from new chemical flowsheets. A facility which

is modified to accommodate an unanticipated flowsheet is generally less safe than one which is designed for a specific flowsheet. The situation becomes even worse when the feed material changes involve going to higher FP concentrations, shorter cooling periods, and higher enrichments.

This general situation can be corrected only by obtaining the additional capital required to build greater flexibility, in terms of operation, shielding, cell space, off-gas services, etc., into new processing facilities. Such additional outlays for original construction should be easily justified in terms of improved plant safety, reduced radiation exposures to operation personnel, and reduced capital outlays for later process modifications.

The Division's role as an interim processor for power reactor fuels during the next decade will, in all probability, involve much more drastic flowsheet and feed material changes for new and existing processing facilities than has occurred in the past. For this reason, it appears that the need for incorporating more over-design and more flexibility in the design of future facilities will be greater than even past experience would indicate to be necessary.

Specific items which should receive more attention from this general point of view are listed below:

(a) Criticality control procedures should be adequate for any of the enriched fissionable materials (U^{235} , U^{235} , or Pu^{239}).

(b) Shielding should be adequate for the most radive feed material anticipated during the next decade.

(c) Off-gas systems should have at least a 100% excess capacity in anticipation of later additions to the process, such as second and third cycles.

(d) Cell storage should be adequate for holding "off-specification" product streams until it is convenient to schedule a recycle run.

(e) Extra cell and cubicle space should be provided for improvements to the initial facility and for later processing additions.

(f) Waste disposal facilities should provide for separating, stripping, and disposing of degraded process solvent.

3.0 CONTROL OF PROCESS AIR-BORNE AND RADIATION HAZARDS

This section presents design standards for the control of the air-borne contamination and radiation exposure hazards associated with the operation of directly maintained, remotely operated, radiochemical processing facilities.

From an evaluation of the relative potentials of these two hazards and an analysis of the engineering problems involved in providing a positive line of defense against each, two conclusions can be drawn:

(a) The potential of the air-borne hazard is far greater than that of the radiation exposure hazard. Justification: (1) the air-borne hazard has a greater potential for harming large groups of people; (2) a curie of activity presents a far worse hazard air-borne than it does as a contained radiation source; (3) all types of radiation (alpha, beta, and gamma) present an air-borne hazard, whereas gamma is the only type of major concern as a radiation hazard; and (4) detection instruments for the air-borne hazard are less sensitive and less reliable than those available for the detection of the radiation hazard.

(b) The engineering problems involved in providing a positive line of defense against the air-borne hazard are considerably greater than those involved in providing a positive line of defense against the radiation hazard. Justification: (1) problems of corrosion and integrity of materials, fabrication, and inspection procedures make it extremely difficult to evaluate the positiveness of process containment; (2) leak-tightness requirements for process containment are more stringent than those for radiation shielding; and (3) the need for access through shielding for direct maintenance and the desirability of access into equipment for inspection and clean-out purposes greatly complicate design for air-borne containment.

The greater magnitude of the air-borne hazard and the engineering problems required for its control is alleviated somewhat by recognizing that there are two lines of defense or attack normally available for containing this hazard; (1) containment of the process solutions within the process equipment and piping, and (2) containment of the process equipment and piping within the radiation shield. The effectiveness and integrity of these two lines of defense can be improved greatly by supplementing each with an adequate and dependable off-gas system to ensure that all leakages will be inward rather than outward. The off-gas systems, in turn, must be equipped with adequate filtering and scrubbing stations to prevent the discharge of excessive activity to the service stack.

The standards presented in the following sections are predicated on providing a minimum of one positive line of defense against the radiation hazard and the air-borne hazard, even though the latter may actually involve a combination of two questionable lines of defense. For the more hazardous radiochemical processes, such as those operating under pressure like the HRT-CP, both potential lines of defense against the air-borne hazard should be virtually positive.

For the lines of defense against the radiation exposure and air-borne hazards to be positive, it is mandatory that the containment and off-gas standards presented in the following sub-sections are applied to all process equipment and piping which will, or which could as a result of single operating error or mishap, handle streams containing any type of radioactive material. Exceptions to this rule shall not be permitted on the basis of low activity levels expected for recycle solvent, product streams, etc. Adequate storage for off-specification products should be available within the containment area so that it will not be necessary to bring such streams outside of the containment area to await the scheduling of a recycle processing run. Special consideration must be given to selection of design standards at all points in the processing facility where it is necessary to remove radive streams from the process containment area, such as product withdrawal and process sampling stations. All instrument and service lines which enter the process containment areas and tie directly into the process should be equipped with the appropriate devices required to prevent the accidental escape of activity.

3.1 Equipment Containment of Radiochemical Process Streams

Materials of construction, welding and other fabrication techniques, and standards for inspection and leak testing should be carefully selected in order to minimize the possibility of radiochemical process equipment or piping failures. Any relaxation of established standards for equipment fabrication should be restricted to the top of the vessel where the probability of a failure is normally less and where the seriousness of a failure can be alleviated with an adequately designed vessel off-gas system. For instance, since it is extremely difficult to determine the integrity of a vessel nozzle weld by radiography (for this reason, such is specifically exempted by the ASME Code), all vessel nozzles should be located in the upper head of a vessel insofar as possible. The top girth weld should be the final closure weld on a vessel for similar reasons.

Every effort should be exerted to minimize the use of flanged, threaded, or tubing connections in the process containment complex, especially in those regions where internal process pressures exceed the external pressure. Such connections are exceedingly difficult to decontaminate and, in addition, are subject to leakage. Welding by the inert gas-shielded-arc non-consumable electrode process is the preferred method of assembly for radiochemical process equipment and piping. Ring joint flanges are acceptable when equipped with leak detection devices.

Standards for the design of the vessel and dissolver off-gas systems, required to supplement the containment of process solutions, are presented in Section 3.4.

3.2 Cell and Cubicle Containment of Radiochemical Process Equipment

A distinction is made between two types of equipment containment enclosures in this section. A cell is a large containment area capable of housing two or more dependable units of process equipment, the number in any particular case being a function of the degree of equipment reliability and the radiation levels involved. Storage and collection vessels are good examples of highly dependable units of equipment. A cubicle is a small containment area capable of housing one unit of vulnerable equipment, such as a mechanical pump or pulser. Cubicles are small cells located outside of, but adjacent to, the main processing cells. Cubicles are required in a directly maintained plant for the purpose of getting vulnerable mechanical equipment out where it can be serviced with a minimum of personnel exposure. Cubicles may also be used within a cell for the purpose of reducing the extent of total cell decontamination required preparatory for entry to repair some specific unit (Thorex "unit shielding" philosophy). Regardless of location, the design standards for cubicles and cells are essentially the same and are presented below.

(a) 100% Restricted Personnel Access: It should be impossible for operating, maintenance, or visiting personnel to enter any radiochemical processing cell or cubicle without involving a major plant decision. This means that all radiochemical processing equipment must be 100% remotely operated through the use of either air-operated or extension handle valves. Access into these areas should be required only during scheduled shut-down periods and should always be preceded by adequate decontamination, ventilation, and a thorough HP survey.

(b) Floor, Wall, and Ceiling Liners: All cell and cubicle floors shall be positively sloped and metal lined. While stainless steel has been used in the past, it is conceivable that other metals will be better suited to withstand the process and decontamination reagents of future facilities. The need for metal liners on walls and ceilings should be based on a thorough consideration of (1) process stream radiation levels; (2) the probability of equipment leakage dropping, splashing, or spraying on such surfaces; and (3) the operating pressure for the processing equipment. In general, corrosion resistant metal liners should be the rule for walls, rather than the exception. Metal liners for ceilings should certainly receive serious consideration when processing pressures exceed several atmospheres. Organic materials are not recommended for wall and ceiling liners or coatings where (1) radiation levels are expected to exceed 1000 r/hr and (2) there is a question concerning the chemical stability of such materials to the organic and aqueous process streams or the proposed decontamination reagents.

(c) Drainage: All cells and cubicles shall be equipped with adequate floor drains located at a positive low point in the floor. Cell drains should include an overflow type sump equipped with a liquid level instrument for detecting level build-ups within the sump and a jet for emptying the sump. Individual drain lines should be routed to main drain headers of adequate size and slope. Provisions must be included in such manifolded drainage systems to prevent the escape of contaminated air from the system into process cells and cubicles. The magnitude of this problem can be reduced considerably by avoiding jet transfers into the drainage system.

(d) Internal Construction: Piping, equipment, and platforms included in containment areas shall be supported in such a way as to facilitate the external decontamination of the equipment and piping and the decontamination of the containment area floor, walls, and ceiling. The material of construction for such supports shall be the same as that adopted for the floor liner.

(e) Leak-Tightness and Ventilation: A distinction must be made between two different orders of magnitude of ventilation flow for containment areas: (1) a relatively low volume operating flow which is required for heat dissipation purposes and to prevent inflammable gases and vapors from accumulating to explosive concentration levels, and (2) a larger volume access flow required for proper ventilation of the cell or cubicle prior to access for direct maintenance purposes. Cell and cubicle design should provide for both the distribution and the control of these two different flow requirements.

The leak-tightness requirements for process cells and cubicles should be determined on the basis of (1) the reliability of the first line of process containment (within the vessels and piping); (2) the operating pressure for the process equipment; (3) whether or not the bulk material processed is an alpha-active material; and (4) the reliability of the motive station for the ventilation system. If the process equipment being contained involves the handling of radive solutions or dry powdered solids in open equipment, or if the process is contained in the equipment but involves handling either volatile nuclides at pressures slightly in excess of atmospheric or radive solutions at pressures in excess of several atmospheres, the leak-tightness requirements should be quite stringent. The distribution and control system for introducing ventilation air to cells and

cubicles housing such processes should be equipped for total closure in the event of a failure in the ventilation exhaust system. High leak-tightness standards are required for facilities processing bulk quantities of alpha hazardous materials because of the poor sensitivity characteristic of alpha detection instruments currently available for personnel protection.

(f) Shielding: Shielding for cell containment areas should be designed for the highest activity levels expected during the next decade rather than for the immediate needs of the current program responsible for the construction. This is desirable in order to enhance the reuse value of the cells for future Laboratory programs.

Cubicle shields, on the other hand, are of a more temporary nature in that they will probably be removed, along with the unit of equipment contained within, at the conclusion of the program. Care must be exercised in tailoring cubicle shielding to specific program requirements, however. It is recommended that cubicle shielding for tail-end product streams be sized on the basis of an "off-specification" decontamination factor equal to the square root of that actually expected from the processing flowsheet. Recycle solvent should be treated as such an "off-specification" product stream. Assume that process filters, ion-exchange columns, silica gel beds, etc., will increase stream activity levels 100-fold, in the absence of better information.

With these reservations, it is recommended that cell and cubicle shielding be sized to reduce external surface doses to less than 1 mr/hr.

3.3 Containment Area Off-Gas Systems

All cells and cubicle enclosures which house radive or potentially radive process equipment shall be serviced by a containment area off-gas system. The system shall consist of a main header with valved subheaders manifolded from it to service individual process cells and convenient groups of process cubicles. The number of cubicles serviced by a single subheader shall depend on the volume of the cubicles, building arrangement, etc.

The main header shall be serviced by an exhaust station which is capable of providing continuous, uninterrupted service. The exhaust station and header system shall be instrumented to control a vacuum of 1-2 inches of water on all closed cells and cubicles at all times and sized to handle the access ventilation flows from one or more cells in conjunction with the operating flows required for all other cells and cubicles (see part "e" of 3.2). All air discharged by the exhaust station shall be routed to a service stack.

A decontaminating and/or filtering station shall be provided in the main headers from those processing facilities which require the more stringent leak-tightness standards for containment areas (part "c" of Section 3.2). When required, such cleaning stations shall be positioned upstream of the exhaust station and its vacuum control system.

In addition to the vacuum control instrumentation required at the exhaust station, containment area off-gas systems shall include the following instrumentation: (1) an alarm-type pressure recorder connected to the most remote

upstream position in the main header and each subheader on the system and (2) an alarm-type radiation monitor between the header exhaust and cleaning stations.

3.4 Vessel and Dissolver Off-Gas Systems

The dissolver, feed adjustment, and any other head-end boil-down equipment shall be serviced by a special dissolver off-gas header system. All other equipment handling radive, potentially radive, chemically toxic, or noxious materials shall be serviced by a vessel off-gas system. Since the general principles of layout, arrangement, and instrumentation for these systems shall be the same as that described for the containment area off-gas system (Section 3.3), further discussion here will be limited to the relatively higher standards required of vessel and dissolver off-gas systems.

Suitably designed decontamination and filtering stations shall be mandatory for all dissolver and vessel off-gas systems. Such cleaning stations for dissolver off-gas systems must be capable of removing gaseous and volatile fission products (iodine, ruthenium, etc.) in addition to particulate matter.

The vacuum on the vessel off-gas system shall be controlled at 3-4 inches of water while that on the dissolver system shall be controlled at 10-12 inches of water. Each system shall be sized to handle with ease all known inleakages from air-lifts, spargers, instruments, vented jet stream lines, etc., as well as miscellaneous inleakages to be expected from imperfect connections in the process equipment and piping. For the processing of highly radive materials, the need for supplementary air or inert gas purges through certain process vessels to prevent hydrogen and oxygen, formed from the radiolytic decomposition of water, from accumulating to explosive concentration levels must not be overlooked.

Condensers shall be included in all valved subheaders connecting into the main vessel and dissolver off-gas headers to prevent condensible vapors from entering such mains. Upstream of each condenser, the subheader shall be sloped to facilitate the removal of condensate and any process solutions which might accidentally enter the subheader via the individual tie-ins to the process equipment. Individual off-gas tie-ins to the equipment shall be sized to accommodate the full flow of live steam from the largest jet discharging into the unit of equipment serviced without developing a pressure drop through the tie-in in excess of 1/4-1/2 inch of water. The diameter of the subheader shall be at least twice that of the largest tie-in serviced.

Construction for vessel and dissolver off-gas systems shall be of stainless steel or some other more appropriate corrosion resistant material. Decontamination facilities and shielding should be provided for dissolver and vessel off-gas systems.

4.0 BUILDING LOCATION AND ARRANGEMENT STANDARDS

This section presents design safety requirements applicable to the selection of a radiochemical processing building site and applicable to the layout and general arrangement of operating, control, administrative, and access areas which surround the process containment areas within the process building. Design standards for the process containment areas within the building are presented in Section 3.0.

(a) Radiochemical process buildings shall be located down-grade from all other buildings not handling radive materials. In those locales where a prevailing wind exists, all radiochemical process buildings shall be aligned perpendicular to the direction of the prevailing wind and located downwind of the other non-radive buildings. The stack servicing the facility shall, in turn, be located downwind of the processing buildings.

(b) The design of each radioprocessing building shall include the establishment of a definite flow pattern for ventilation air through all change house, administrative, control, operating, and any other personnel access areas provided in the building. The air pressure in these personnel access areas shall be greater than that maintained in the process containment areas and controlled so that the clean ventilation air will always move, according to the established flow pattern, toward those areas having an increasing potential for air-borne activity and ultimately enter the process containment areas for discharge via the containment area off-gas system. Where doorways are required between the various personnel access areas, they shall be designed to minimize disturbances of the basic ventilation flow pattern when "opened and closed" or left open.

(c) All personnel entering or leaving the main processing areas of the building shall be required to enter and leave via a three-compartment change house consisting of (1) a locker room for street clothes, (2) a wash and shower room, and (3) a locker room for R-clothing. All entering personnel should traverse these areas in the order listed and all exit personnel in the reverse order. An adequate stock of protective clothing, film badges, pocketmeters, etc., should be provided in the locker room for street clothing for use by operating and maintenance personnel and visitors. An HP station shall be located between the locker room for street clothing and the wash and shower room. This station shall be equipped with "hand-and-foot counters" and "beta-gamma" monitors for use by exit personnel and shall be posted with appropriate instructions governing procedures for entrance and exit. The full or partial attendance of an HP man shall be required when the system is first put into effect until all personnel become thoroughly familiar with proper procedures.

(d) Service accesses into the main processing building, required for the access of equipment, raw materials, feed materials, etc., and for product removal, shall be designed to prevent the entrance of operating or maintenance personnel and visitors.

(e) Emergency exits shall be provided but shall be designed to prevent the entrance or exit of personnel except during emergencies.

5.0 PROJECT REVIEWS BY QUALIFIED GROUPS

At present there are no written safety standards of sufficient detail and scope which can be followed in the design of radiochemical processing plants. This memo has attempted to list general safety requirements to be considered, but many points are not covered in sufficient detail and others are subject to interpretation. Until such time as comprehensive design standards become available, it will be necessary to rely heavily upon project reviews by qualified groups within the CTD and the Laboratory as a whole for assurances that all

safety aspects of project design and operation are adequate. These review groups should not be required to assume responsibility for safe operation, since the ultimate responsibility for the safety of operating plants must rest with the project design engineer and project operating engineer, hereafter designated as project representatives.

5.1 Review Groups

Throughout the design and operation of a radiochemical plant, and especially during the preliminary design, the project representatives shall consult with the following groups concerning the various safety aspects of their process.

Health Physics - For personnel and area radiation and air-borne protection problems

A. D. Callihan - For criticality problems

Fire and Safety Departments - For general safety problems

Inspection Engineering Department - For material and fabrication standards, inspection and test procedures, etc.

These groups should be considered experts in their respective fields and the project representatives are responsible for seeing that the recommendations of these groups are incorporated in the project design and operating procedures.

5.2 Reviews by CTD Operational Safety Committee

(a) Preliminary Review: At the conclusion of the formative stage of design and before detailed engineering design is commenced, the general safety philosophies adopted for the facility shall be reviewed by the CTD Operational Safety Committee. A primary objective of the formative stage of design, when tentative engineering flowsheets and equipment layouts, scale models, and tentative design, procurement, construction and operating philosophies for the design are being "firmed up", shall be to prepare for this review.

The project design engineer shall be responsible for preparing a report to the Committee outlining the general safety philosophies to be followed in the design. Prior to this, it is expected that the project representatives will have consulted with the groups outlined in Section 5.1 and that all unusual safety problems have been recognized and adequate safety measures envisioned. After submission of this report, the project representatives will meet with the Committee to elaborate upon and defend the safety considerations of the design. The Committee will then either approve of the overall safety standards for the project or recommend additional safety precautions in writing.

Any points which are not agreed to by the project representatives and the Safety Committee will be resolved on a division or management level.

(b) Final Review: When the engineering design for the project has been completed, the overall safety considerations will again be reviewed by the CTD Operational Safety Committee under a procedure similar to the preliminary review.

The design report to the Committee should emphasize changes in philosophy since the preliminary review. The Committee cannot be expected to ferret out all potential hazards. It is the responsibility of the project representatives to point out all potential dangers and describe the procedures used to minimize the hazards. The Committee, as a group, will review the proposed safety measures and judge whether they appear satisfactory. Following this final review, the Committee will again prepare a written report summarizing approvals and recommendations.

The final review will be concerned primarily with potentially catastrophic accidents. Any situation in which either malfunction of equipment or operator error might cause lethal exposure to operating personnel or widespread dispersal of radioactive materials outside the facility must be carefully analyzed, and adequate safeguards designed to minimize the possibilities of an accident occurring.

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