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NUCLEAR SAFETY IN MANUFACTURING OPERATION

AUTHOR

J. E. Maider

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W. E. Johnson
General Manager
703 Building, 700 Area

NUCLEAR SAFETY IN MANUFACTURING OPERATIONS

Nuclear safety is recognized as being of prime importance in the conduct of manufacturing operations here at HANFO. Responsibility for this safety is shared by the Engineering and the Manufacturing Departments, with the former defining the hazards and the required precautionary limits, and the latter translating these specifications into effective operational controls and practices.

The Manufacturing Department has just completed a thorough review of its position with respect to nuclear hazards control, and the results of this analysis are presented herewith. All three of the plant Sections are involved and have been included in this review. However, the hazard potential and control requirements are clearly the greatest in the Reactor Section where operations are approaching closer and closer to rather uncertain absolute ceilings for safe operation, as the power levels and output of the comparatively fixed facilities are pushed higher and higher. Accordingly, the situation there has been given primary emphasis in the review and in this report.

REACTOR SECTION

General

With the exception of activities related to the handling of enriched fuel elements, the primary efforts of the Reactor Section are directed toward the control of, rather than the prevention of, nuclear reactions. To assure safe operation of the Hanford reactors, total control over two basic functions - process water flow and reactivity - must be maintained. The loss of control over either of these functions could result in damage to reactor components with possible uncontrolled release of fission products to the atmosphere.

Nuclear safety limits for reactor operation are established by the Pile Technology Section of the Engineering Department. These limits, stated in the form of Process Specifications, are interpreted by the Reactor Section into Process Standards and Standard Operating Procedures which reflect the operating philosophies of the Section and which, in many instances, contain a considerable degree of self-imposed conservatism. As a control measure, a Process Control Group, organizationally independent of the Operations Sub-Section, monitors the application of the Standards in reactor operation. While the matter of equipment adequacy enters freely into all considerations of nuclear safety, it is recognized that the ultimate responsibility for nuclear safety rests with the individuals who establish the limits and procedures, and who operate and maintain the equipment.

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Process Water Flow ControlFlow Abnormalities Involving Individual Process Tubes

The individual Panellit pressure gauges are recognized as primary safety devices monitoring pressure conditions in each process tube. While the gauges do not function as true flow meters under all conditions, the indicated pressures are interpreted as a measure of water flow through the process tubes after appropriate conservative corrections are assumed in the flow calculations.

As primary safety devices, the Panellit gauges are accorded careful attention during overhaul and calibration, pre-installation inspection against rigid standards by an independent group of inspectors, and routine operational "trip checks" during reactor outages to demonstrate the operability of their high and low pressure safety circuit trip features. While older Panellit gauges, dating to the original Hanford reactor installations, have been maintained in reasonable operating condition by intensive maintenance and engineering effort, a large scale replacement of these older units with improved gauges is now scheduled for the summer of 1955 under Project CG-558. Operating experience with these new gauges will serve as a guide in determining the need for and type of secondary or "back-up" flow instrumentation contemplated as a possible long-range program. While a second Panellit gauge is currently used as a "back-up" instrument on critical run-to-rupture tubes, the shortcomings of a pressure monitoring system as a true flow meter in a situation where an accurate measure of flow is highly desirable, prompted the Manufacturing Department to promote and support strongly an Engineering Department program for thorough investigation of tube-by-tube flow measuring devices which would be applicable to the Hanford reactors.

Properly operating Panellit gauges provide adequate detection of the relatively slow pressure (i.e., tube flow) changes accompanying incipient core screen plugging, swelling fuel elements, process tube plugging, and minor fluctuations in process water supply pressure. They cannot, however, assure protection of an individual tube and its slug charge following an immediate and total loss of cooling water such as might be experienced on the complete failure of the connector (pigtail) supplying water to the process tube. Protection of reactor components under such conditions can only be assured by stringent limitations on tube power values and, as a result, a high premium is placed on pigtail and nozzle integrity. Stainless steel tubing as a pigtail material enjoys a large measure of confidence despite three recent failures of a minor nature at the C Reactor where butt welded seams opened for a short length to produce high pressure leaks of an insignificant volume.

Pre-startup experience at the K reactors, with aluminum as a pigtail material, indicated a very real possibility of total failure of the tubing at the grain boundaries or at the ferrule fittings. Until the Engineering Department is successful in obtaining a satisfactory pigtail for the K reactors (estimated date, October 1), tube power levels are being restricted to values calculated to result in no process tube or fuel element damage in the event of complete pigtail failure with an accompanying automatic reactor shutdown via the Panellit gauge.

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As a precautionary measure in all reactors, current Process Standards require an immediate shutdown of the reactor for repairs on the first indication of difficulty involving a front pigtail. While the similar failure of a connector carrying water from the process tube is considered an inconvenience, calculations indicate that such an incident would not lead to process tube or slug damage under current operating conditions.

Concern for the breaking of front nozzles which may protrude into the elevator path during reactor operation because of unusual tube expansion conditions has led to restrictions on the use of the charging elevator during reactor operation and the development of a photoelectric actuated interlock which stops and prevents elevator operation when the light beam on the reactor side of the charging elevator is interrupted. The charge machine associated with the five-tube prototype charge-discharge equipment at C Reactor is interlocked with the elevator mechanism in such a manner that the machine must be retracted before elevator movement is possible.

Flow Abnormalities Involving an Entire Reactor

The several alternate cooling water systems of the six older reactors are considered to be adequate sources of emergency water under abnormal circumstances providing the sequence and/or timing of events follows an expected pattern. One can, however, visualize circumstances under which early demands on the high tank and raw water systems might result at the least in slug jacket and process tube damage before the residual heat load can be satisfied by available emergency flows.

An electrical power failure at current operating levels does not represent a hazard. This type of failure is infrequent but not unknown in normal operation. A steam failure in those areas where steam pumps supply an appreciable portion of the normal water requirements could result in effluent water boiling but not in slug and tube damage.

A simultaneous steam and electric power failure during reactor operation would almost certainly cause major damage to reactor components despite an immediate automatic reactor shutdown and the presence of the high tanks as a source of cooling water. This event has been considered so unlikely that Process Specifications do not impose restrictions to cover the possibility. In view of the proximity of steam and electric lines in all except the K Areas and the recent plane crash within the reservation, the simultaneous loss of both sources of power cannot, however, be considered impossible.

At present, it is not certain at what point following reactor shutdown the residual heat load of the reactor can be satisfied by the available flow of high tank water - or of raw water, in the event of high tank failure. This is currently under study. Under present circumstances, delivery of adequate raw water coolant to a given reactor can only be assured after an approximate 10-minute notification because of pump and surge suppressor limitations. Recognition of this limitation has led to a complete survey of the emergency cooling water systems by the Process Sub-Section. This study is currently being carried out.

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Additional efforts aimed at increasing the reliability and response time of the high tank and raw water systems include routine cleaning and checking of high tank screens, periodic testing of the restraining check valves, extension of standpipe drain risers a short distance into the high tanks to form a sediment trap, and relocation of sensing lines actuating the raw water emergency system.

The several possible operating combinations available in the cross-tie system serving the K1 and K2 Reactors provide a back-up cooling water system superior under most conditions to that found in the older areas. However, it is doubtful if this K system is any less vulnerable to disaster-type disruption. Extensive pre-startup tests provided the data on which operating procedures and Process Standards governing K Area water backup have been based.

The possibility of the rupture of critical water lines during normal operation is considered remote. However, as a precautionary measure, a program designed to determine and follow the condition of important water lines by periodic wall thickness determinations has been initiated. A step intended to conserve the available water supply in the 150 Building storage tanks in the event of a supply line rupture is the installation (where suitable mechanisms are not already present) of supply line check valves at the base of the storage tanks. The majority of this work is being carried out as a part of Project CO-55.

The extent of a nuclear disaster resulting from total failure of both normal and emergency water lines to a reactor as a result of earthquake or enemy action would, of course, depend on the length of time available for reactor shutdown and cooling prior to the loss of water. The analysis of such situations is beyond the scope of this review, but is currently receiving consideration by both Manufacturing and Engineering Department personnel in the evaluation of disaster-type control measures. Recent success with ball valve equipped tubes in poison control, and in the charging and discharging of uranium during reactor operation, suggests that the "crash" discharge of total reactor loadings should receive added consideration as an extreme emergency measure.

Flow Abnormalities During Normal Reactor Outages

Controlled cooling water flow reductions involving both individual tubes and the entire reactor must be made during normal outages to permit replacement of uranium at goal exposure with green metal. Although instruments are available to aid in setting the desired flows and in monitoring the resulting tube outlet water temperatures, the magnitude and timing of the flow reduction must be governed entirely by Operating Procedures and Standards and the judgment of responsible Operations personnel. Shutdown flow minimums are established, not by the damage points for process tubes and fuel elements, but by Standards designed to maintain effluent water temperatures of the tube or tubes in question well below the boiling point of water. Reduction of flows to charge-discharge pressures are not permitted until much of the residual heat from fuel elements and reactor components has been removed. While the rate of heat generation in a fuel element is comparatively low during shutdown conditions, it is conceivable that valving errors resulting in too little or no cooling water flow could, after a period of time and in the

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absence of proper temperature monitoring, result in damage to process tubes and fuel elements. While procedural control is the main deterrent to component damage, subsequent reactor start-up is impossible with a low flow condition existing in a process tube unless operating errors have been compounded.

At the K Reactors, the installation of "cross-under" lines on the rear face of the reactors was intended to eliminate the need for much of the rear face valving during charge-discharge operations. Experience has shown that water flow through top and bottom tubes of the reactors can only be assured if specific maximum and minimum reactor flows are observed during the use of the cross-under lines. Until the conditions under which the lines can be used with safety are more clearly defined, operation of the lines is forbidden by Process Specifications and Standards. In addition to the study of K Reactor cross-under line restrictions, the flow capacity of the rear face relief risers, used in the older reactors to divert flow during charge-discharge operations, is being studied by Process Sub-Section Engineers.

In the course of reactor maintenance, it is necessary on occasion to stop completely the flow to a process tube while cone screens are being cleaned, orifices changed, pigtails replaced, etc. While the conditions and times governing such flow stoppages are well defined in the Process Specifications and Standards, it remains the responsibility of reactor personnel to ascertain correctly the conditions, and control by close supervision the time that flow is withheld from the tube. In the discharge of stuck fuel elements (ruptured or warped) from the reactor by removal of the process tube with the charge, it is essential that cooling be maintained until such time as ambient reactor temperatures are sufficient to prevent further damage to the slug(s) and process tube. Since process tube water leaks sometimes accompany fuel element ruptures, there is a conflict of desire to maintain flow on the tube for the necessary period of time and to remove flow from the tube to avoid excessive graphite wetting. Again proper adherence to Specifications and Standards constitutes the major control over the potential hazards of aluminum and uranium melting during ruptured slug removal. It is of interest to note that uncertainties surrounding uranium ignition temperatures, particularly under reactor conditions, add a further degree of conservatism to ruptured slug removal considerations.

Reactivity Control

Control Systems

In general, the control rods and their accompanying mechanical and electrical systems are considered adequate from a nuclear safety standpoint. The relatively small amount of control represented by the nine horizontal control rods of the older reactors is an inconvenience and a source of production loss during periods of large reactor transients; however, no major nuclear hazard can be attributed to the small rod systems. A recent operating error at the K Reactor has indicated a possible need for an audio signal to supplement instrumentation provided to indicate direction of control rod travel. This is being investigated. The current program of horizontal rod replacement in many of the reactors has required that unusual care be exercised in determining mechanical operability prior to initial reactor start-up. A system of detailed

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written procedures covering the testing and acceptance of the newly installed rods is in use.

With current uranium loadings and continuous cooling water flow, either the present VSR or Ball II safety systems of each reactor have sufficient poison strength to shut down the reactor and hold it sub-critical indefinitely. Pre-startup tests in the K Reactors have shown that the available strength in the VSR and Ball II systems is not as great as expected and some increase in the control value of these systems will be necessary before enrichment of the reactors can be significantly increased. As an immediate corrective step, the plain steel balls in the outer 14 hoppers were replaced with boron-steel balls. Steps have been taken to procure sufficient additional boron-steel balls to replace (on a 50-50 basis) all of the remaining steel balls in the K Area Ball II safety systems. Ten additional vertical safety rods for each K Reactor (to be installed in existing spare VSR channels) are budgeted for Fiscal Year 1957.

There is confidence that at present power level ranges, the combined strength of the systems is adequate to hold a dry, xenon free reactor sub-critical. As power levels are increased, however, this protection may become marginal. As compensation for xenon decay under shutdown conditions, it is required by Process Standards that sufficient poison be charged into the process tubes to maintain the reactor 80 inhours sub-critical at any time the vertical safety rods are removed. Not only is this poison necessary to the subsequent reactor start-up, but it removes the burden of compensation for xenon decay from the VSR and Ball II system in the event of water loss during shutdown.

It is possible to visualize conditions of water loss which would not permit the charging of poison to compensate for xenon decay. As noted previously, the protection afforded may become marginal as power levels are increased, and this fact places a premium on the maintenance of cooling water flow through the process tubes under all conditions. The Engineering Department is continuing an active program designed to provide more accurate estimate of control system strength and reactivity status under emergency conditions. Previous tests at the C Reactor to provide data for such calculations were unsuccessful; however, the Technical tests carried out at the K Areas prior to start-up were successful in providing added data.

While it is obviously important to have available sufficient reactivity control strength to hold a reactor sub-critical under any conceivable condition, no amount of reactivity control can prevent major reactor and fuel element damage if fission heat cannot be removed from the fuel elements immediately following a shutdown.

Integrity of the cooling water supply is particularly important for a reactor with a special production loading of fuel and target slugs where large amounts of U-235 could, on slug melting, be distributed through the openings in the graphite and cause tremendous reactivity gains. The details of such hazards have been previously evaluated in Engineering Department reports, and are not pertinent at this time because of the absence of such a special loading. Initiation of new

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enriched isotope loadings must be carefully weighed in terms of the disaster potential inherent in the loss of cooling water flow.

Response time of the gravity actuated vertical safety rods has not been a problem to date; however, it is recognized that a faster response time with a corresponding increase in reactor safety can be realized with means (e.g., air pressure) for accelerating the speed with which these rods are inserted. This VSR revision, which becomes increasingly important at higher power levels, has been budgeted for Fiscal Year 1957 for all reactors.

The submerged type, low-lift process water pumps of the K Area design provide opportunity for the introduction of substantial quantities of air into the process water lines unless effective venting is practiced during pump start-up. Two minor reactor power excursions during start-up testing and early operation of the K Reactors are believed to have resulted from such an incident although this cannot be definitely determined. Engineering studies of the K Reactor process water systems are being conducted to determine at what points additional automatic venting is required.

Monitoring Instruments and Safety Circuits

The physical size of the action portion of the Hanford reactors is such that any neutron activated control or safety instrumentation which operates from a single sensing point in the reactor structure is monitoring local flux conditions and may not reflect conditions existing in the remainder of the reactor if, for any reason, flux distribution is unbalanced. Unbalanced flux distribution in a reactor is not uncommon; it is, in fact, a normal occurrence during reactor transient conditions and may also be induced by unbalanced rod withdrawal patterns, local neutron absorbers such as flattening materials and special irradiations, wet graphite, etc. It is, therefore, desirable that neutron sensitive operating and safety instrumentation be arranged to monitor flux conditions over the entire reactor structure. To this end, the following changes in reactor instrumentation are completed or in progress:

1. At the K Reactors, control relay trip circuits have been installed on each of the octant chambers (i.e., neutron sensitive chambers installed in each octant of the reactor matrix) and a similar trip circuit operates from the total signal received from the octant chambers. At the D Reactor, the latter trip circuit will shortly be connected into the No. 1 safety circuit with a trip setting of 110 per cent of a normal signal. Data are being obtained to establish proper trip settings for each of the octant chamber circuits. If operating experience with this octant trip system is satisfactory, it may replace the present under-pile Beckman systems.
2. Octant chamber systems are being installed at the D and E Reactors to provide a more representative galvanometer signal. The C Reactor galvanometer is already octant chamber driven.

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3. The Engineering Department is developing process tube size neutron chambers for use at the B, D, and F Reactors where octant chamber wells are not available. A prototype test model should be available in four to six months.
4. The octant trip system now under test at the K Reactors (see 1 above) will extend to all reactors if experience shows the system to be practical.

Other neutron monitoring instruments are in varying stages of development and installation. A prototype sub-critical monitor is being tested under operating conditions at the K Reactor by the Engineering Department. Project action is being initiated for such an installation in all reactors. Experience being obtained with the K Reactor low level period meter may indicate that such an instrument may supplement or even supplant the sub-critical monitor. Prototype instrumentation considering high-level period monitoring with a fixed high-level trip also is being evaluated at the K Reactors.

Recent emphasis on a program for determining on a routine basis the sensitivity of reactor flux monitoring instruments has resulted in a desirable extension of the lower range of both the standard proportional counter instruments (now used to detect criticality and measure the reactor rising period) and of the neutron sensitive Beckman monitors. Work is also in progress in the Reactor Section on the use of a second proportional counter neutron chamber to improve the usefulness of the instrument in "hot" start-ups (i.e., start-ups in the presence of appreciable neutron background from previous operation).

Tube outlet water temperature monitoring systems provided with safety circuit trip features are desirable as a means of control over local tube power abnormalities arising from flux distortions. The tube-by-tube monitoring of the K Reactors represents the ultimate application of the temperature monitor and provides, in addition to tube power controls, a back-up for the Panellit gauge under many changing flow conditions. In the interest of cost and time saving, a "cell" type monitoring system (e.g., one tube in nine, one tube in 25, etc.) is being investigated by the Engineering Department and the Reactor Section. While temperature map studies show that reasonable flux distortion protection is afforded by the more limited installation, the Panellit gauge back-up feature is then present only for those tubes having an attached temperature trip circuit. Tentative specifications for the system have been prepared and immediate sources of funds for installation of a "cell" monitoring system on the six older reactors are being investigated. This equipment is currently budgeted for Fiscal Year 1957.

In order to permit functional testing of the safety circuits and to meet other special conditions of a reactor outage, bypass switches are provided for the various safety circuit components. It is possible during reactor operation to bypass by means of individual bypass switches nearly all components providing trip signals to the safety circuits. Only the wiring of the Beckman trip circuits is such that a minimum of two Beckmans must be operable (i.e., in the safety circuit) if reactor operation is to take place under any circumstances. While

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the conditions permitting bypassing of individual safety circuit components are carefully outlined in the Process Specifications and Standards, procedures, alarms or lights, and the integrity of personnel must be relied on to prevent unauthorized bypassing to take place. The liberal use of check sheets provides added reminder of the sequence of events which must take place prior to and during reactor start-up.

A vital point in the reactor safety circuit system is the electrical equipment room which contains the relays necessary to the proper operation of the circuit. Rigid control is exercised over access to this area since it would be possible to block or bypass all components of the safety circuitry in a few minutes should an individual so desire.

Testing and inspection of safety circuit components is a regular feature of reactor outages.

Procedures and Personnel

Separate and special consideration is given to procedures and personnel because of the increasingly critical importance of both to the preservation of nuclear safety in reactor operations. As these comparatively fixed facilities are pushed to higher and higher power levels and outputs, their operation approaches closer and closer to the absolute ceilings for the various safety limits. Moreover, in most cases, it is not definitely known just where these ceilings are, or how much margin of safety really remains.

Reactor "hot" and "cold" start-ups are considered the most hazardous periods of reactor operation because of the rapid changes which are then taking place in flux distribution, flux intensity, and the resulting tube outlet temperatures. The Reactor Section's conservative approach to operation during these periods is reflected in the recent cancellation for a period of time of "hot" start-ups while procedures were being analyzed and revised, in the conservative limits and requirements for both "hot" and "cold" start-ups resulting from this analysis, and in the added attention accorded the "cold" start-up period by the presence of extra operations supervision and reactor physicists and engineers. The increased attention focused on start-up and operational problems by the above action, and by campaigns in both the Operations and Process groups to familiarize first line operations personnel with procedures and techniques, are believed to be successful in assuring a greater degree of nuclear safety.

Increased emphasis has been placed on Process Control monitoring activities and steps are being taken to provide full shift coverage by Process Control personnel by late summer. Efforts are being made to improve the calibre and number of individuals involved in process control activities with the objective of enhancing the quality of process control advice available, and of improving the quality, usefulness, and timeliness of the Process Standards.

In view of increasing demands for high quality performance, the standards of performance of employees have been raised by requiring a more stringent on-the-job

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appraisal. Insofar as compatible with union contract requirements, the standards for operator promotion have been similarly raised. One exempt employee now devotes full time to the selection of individuals for promotion. Supervisors and foremen are being appraised carefully with the objective of relocating those who show less effective performance. Several transfers have been made on this basis.

The recent expansion of Reactor Section responsibility to include the K Areas has resulted in a dilution of experienced Reactor Section personnel at the operating, supervisory, and technical levels at the time more rigorous operating conditions are being experienced. The need for training at all levels of the operating and technical groups in the Reactor Section to re-establish and improve the experience level has been recognized and a number of training activities are in progress. A series of special training meetings was started in March, 1955, conducted by the Operations Superintendent, Process Physicists, and Process Engineers for Chief Operators and Reactor Supervisors. This activity was paralleled with on-the-job operator training and a series of Operator level round table discussions (started in February, 1955) on nuclear safety. Unusual incidents, particularly those indicative of a potential nuclear hazard are being investigated, analyzed, and thoroughly publicized among operating and technical groups. In all of these activities, the importance of nuclear safety above production requirements is strongly emphasized.

Handling of Enriched Fuel Elements

One of the recognized hazards in dealing with enriched fuel elements is that of inadvertently assembling a critical mass. Although no incident relating to critical mass has occurred in the several years of Reactor Section experience with enriched materials handling, the hazard potential is sufficiently great that strong emphasis continues on methods designed to prevent the accumulation of a critical mass. In general, procedures, interlocks, and deliberate limitation of the size of handling equipment are the basic measures currently in use. These measures appear to be adequate for control of the problem.

The movement of enriched fuel elements to and from storage and onto the charging elevator is limited to the use of the conventional locked and cabled enriched metal handling boxes. Only one box may be unlocked at any given time. Key control remains with supervision. Charge make-up on the elevator is limited to two tube charges, and one tube is charged at a time. Peculiarities in size, weight, and slug numbering systems facilitate enriched slug identification. Process tubes containing enriched materials are locked by the supervisor when charging is completed.

Discharge of enriched materials is governed by a supervisor at a control desk in the discharge area. Strict regulations with respect to numbers of tubes discharged, piece count, and numbers of accumulated slugs are followed. Storage bucket inserts and extriguors aid in governing the number of slugs accumulated at any point in the process. The storage and shipping of enriched materials is the responsibility of one supervisor in each reactor concerned. This individual retains key control of storage room locks, and exercises the detailed supervision of shipping activities.

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Storage and shipping equipment is designed to retain a close-packed array of slugs regardless of the handling techniques employed. A series of "mis-handling" tests using dummy slugs has established confidence in this equipment.

Incidentally, full information on these nuclear safety practices in the handling of enriched fuel elements in shipping buckets has been transmitted to the AEC Hanford Operations Office for relay to Arco.

SEPARATIONS SECTION

General

In the separations plants, where production quantities of plutonium are processed routinely, nuclear safety is dependent upon always keeping conservatively below the "critical mass" limits which the physicists have calculated for the various conditions of plutonium concentration and/or configuration. Wherever possible, and particularly in the newer plants, the individual process vessels are designed with shape and/or capacity limitations so as to be "critically-safe"; i.e., so that it would be physically impossible for a critical mass condition to be reached therein.

All of the required critical mass limits, including suitable safety factors, are established formally by the Separations Technology Section of the Engineering Department, and are translated by the Separations Section into the Run Books and Standard Operating Procedures used in controlling the plant operations. Careful observance of these operating rules is a direct responsibility of the Operations Unit in each plant. They are assisted and audited by the independently-organized Process Engineering Units.

The detailed analysis of nuclear hazards and their control in the four XOD Area Sub-Sections who are (or will be) processing plutonium are summarized separately below. Analytical Sub-Section control in Building 234-5 also is covered.

T Plant

In the T Plant (and in B Plant, if activated), all processing is in batches, and nuclear safety is maintained through careful limitation of the maximum amount of plutonium contained in any one batch or process vessel (so-called "batch size" control). The specified batch-size limits are so conservatively low that double-batching through operating error could cause no difficulty, and are based on assumptions as to worst possible plutonium solution concentration and precipitate configuration which are so extreme as to appear impossible in practice.

Control over the starting solution batch-size poses no problems, but thereafter the control throughout the Canyon and Concentration Buildings is dependent in large measure upon material balance determinations made between established measurement points in the process. Unfortunately, material balances involve inherent errors in sampling and analysis, particularly with the precipitation processes concerned. Accordingly, a program of periodically flushing the cell equipment with acid was adopted some years ago in an effort to minimize the undetected accumulation of plutonium in the equipment.

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The uncertainty of the system flushing then being practiced was made very evident in November 1954, when some sludge cleaned from the final product solution tank (F-10) in the Concentration Building was found to yield 1294 grams of plutonium upon recovery processing. This very large accumulation, which was several times the normal batch-size limit, was without precedent in the history of the Bismuth Phosphate plants. Fortunately, the F-10 tank is of critically-safe dimensions, and the sludge was given safe handling after removal. From the thorough T Plant flushing at the start of the low g/t program, to the time of this incident, the overall material balance was 100.25 per cent, indicating a slight over-accounted-for. Nevertheless, even more product than had been contained in the F-10 sludge was recovered from the plant when it was given a rigorous flushing from one end to the other following this incident.

To prevent recurrence, the following tighter controls and additional flushings were placed in effect in December 1954:

1. Material balance calculations are made daily between each of the seven control points where product samples are taken. These seven daily check-points are in addition to the official material balance made for each batch from its starting point in the Canyon Building to the final product solution tank (F-10) in the Concentration Building. Cumulative material balance data also are monitored closely, to assure prompt detection of any apparent trends.
2. Equipment flushes are made whenever the material balance calculations indicate that as much as 50 per cent of a run is unaccounted for, either between control points, or from the start of processing to the finish of processing in the Canyon or the Concentration Buildings. These flushes are in addition to the one thorough acid flush which is put through the entire plant system each month.
3. Operating equipment which has been the cause of poor product control in the past is being checked frequently to assure its proper functioning. In this category are the product section precipitator sprays, the lanthanum fluoride by-product effluent tank agitation, and the sludge accumulation in the F-10 tank.
4. The sludge which is periodically removed from the F-10 tank is being handled as though it were pure plutonium, thus insuring complete nuclear safety in its storage and subsequent recovery processing.

Control on the foregoing basis is considered to have been excellent to date, and there have been no instances of over-size batches since it was placed in effect. The maximum amount of product removed from any single section in the May acid flush was 15 per cent of a run. Total recovery for the entire plant was 91 per cent of a run. These are believed to reflect good effectiveness for the several equipment flushes made during the month.

Rodan Plant

In Rodan, the type of protection employed to assure against nuclear criticality varies

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with the phase of the process involved. In the head-end, and throughout the uranium cycles, the protection is afforded by dilution of the plutonium with uranium. In the plutonium cycles, the required control is exercised over solution concentrations, batch volumes, and the prevention of plutonium precipitation; these same controls are applied in the processing of rework and recycle streams. Obviously, the fact that no precipitation steps are involved in the Redox process materially enhances the nuclear safety and facilitates its control.

The critical mass problem from the dissolution of the irradiated metal through the uranium cycles, and including the 1A and 1S extraction column systems, is negligible as the ratio of plutonium to uranium in these solutions is far below the critical level. Selective precipitation of plutonium is extremely unlikely, in view of the chemistry involved, and no such tendency has ever been observed in the course of Redox operations.

Vessels in the plutonium stream are limited both by concentration and by volume, and both are adjusted so that critical mass control limits (established conservatively on the assumption of total precipitation) are not exceeded. The concentration is determined by frequent sampling of product streams, and adjustments made as deemed necessary. All of the important batch-type transfers between vessels are controlled by supervision, using the gang-valve lock procedure. Since the presence of caustic could precipitate the plutonium as the hydroxide, this material is completely isolated from the aqueous make-up system supplying the plutonium cycles. No other essential materials present in Redox could cause precipitation.

The process system in the final plutonium concentration facility (Building 233) is critically-safe except for the L-1 final product receiver and the L-16 recycle tank, both of which are carefully limited messwise similar to the control over product receiving vessels in the Canyon. It is noteworthy that the compact arrangement of process equipment within this final concentration facility is such that the nuclear reflector effect of any maintenance personnel entry into the equipment enclosure must be closely controlled. This situation is currently under special study, and very conservative interim access controls are in effect.

2 Plant

Operations in the Isolation (231) and the Metal Fabrication (234-5) Buildings are devoted to the processing of plutonium, starting with relatively dilute solutions received from the separations plants, and ending with the final metal shapes. The maximum degree of nuclear safety is maintained throughout the wet and dry chemistry steps by rigid control over batch-size, wherever the process equipment itself is not critically-safe, and all handling of plutonium metal is done within very conservatively based critical mass limitations.

In Building 231, critically-safe stills and associated vessels for final product evaporation have been installed in all operating cells, but special measures are necessary to assure batch-size control through the peroxide precipitation process used for product purification. For the latter, a rigid system of material balance control involving a running inventory of all product charges and credits to each cell

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is in effect. Flashes of equipment are scheduled once per month and/or after any one parallel system has a product deviation of 2% O grams. This flash constitutes a clean-out, and is the basis for re-creating the product inventory within the equipment of the operating system flashed. If the product recovered from these flashes shows a significant discrepancy from the running inventory, additional cleanouts are made to insure that no product accumulation remains in the system.

It is noteworthy that the foregoing control of batch-size in Building 231 has been significantly easier and more positive since mid-April, when the oxalate precipitation step was transferred to the new and critically-safe equipment in Task I of Building 234-5. The peroxide process does not require the transfer of plutonium precipitate slurries, as does the oxalate process, and hence has less potential for the hazardous accumulation of product in the non-critically-safe vessels used in Building 231. In any case, two or more additive errors would have to be committed before the calculated minimum critical mass could be reached in any of these vessels.

The storage, handling and transfer of "sample cans" containing concentrated plutonium nitrate solutions in Building 231 (and in Building 234-5) are controlled by rigid procedures, and physical compartmentation is resorted to wherever feasible. Although the procedures which specify the distribution and location of these product containers are solely reliant upon the judgment of the individuals handling them, the limits are so conservatively based that chances of critically being attained in the event of an error are very remote.

Critical mass limits for the vessels used for off-standard product recovery operations in Building 231 have been established. Also, vessels used for transporting off-standard plutonium bearing materials have been defined with appropriate limitations. All sludge and crud of uncertain composition which is to be recovered is treated as pure plutonium on a weight basis, thereby avoiding any possibility of batch-size difficulty due to under-estimation of plutonium content.

In Building 234-5, beyond Task I, the product handled is so well-confined as to geometry that precise critical mass limits can be established and readily observed. All transfers and storage of material are covered by control procedures that clearly define safe geometry, and are made only by authority of supervision. Good judgment on the part of the operators is mandatory to insure adequate critical mass control. All transfer conveyances, hoods, and storage locations have signs posted indicating allowable storage limits and safe geometry. Although the design of the equipment makes it well-nigh impossible to reach criticality, it is of course conceivable that it could be reached if an individual deliberately set out to do so. Restrictive measures are used insofar as possible to prevent such a possibility. Process engineers assist operating supervision in closely monitoring the actions of the operators.

The dissolver hoods used in Building 234-5 for skull and powder reclamation have critically-safe vessels with the exception of one storage tank in the skull dissolver hood. The controlled batch-size of this tank establishes the batch size for the entire operation. The weight of powder charged to the powder dissolver is treated as pure plutonium, thereby always insuring that the amount of plutonium present in the dissolver will be less than the batch-size limit. In all cases, the batch-

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sizes are sufficiently small so that two-plus batches could be placed in the tank and still be below calculated critical mass. In most cases, accumulation of unaccounted-for heels does not present a problem in the 234-5 Building, because direct weight accountability is readily maintained between each step in the process.

Considerable quantities of plutonium are handled routinely in the 234-5 Control Laboratory, and the required precautions against ever approaching a critical mass condition are well established and carefully observed. Plutonium metal samples are involved, as well as various plutonium salt wastes in both solid and solution forms. Conservatively-based batch-size limits are imposed, and all storage points are controlled as to amounts and container array. One chemist is assigned to monitor these nuclear safety precautions.

The new Recuplex facility, which is being provided in Building 234-5 for the recovery of plutonium from miscellaneous process recycle materials, consists primarily of two systems: (1) a system for the handling of dilute, large-volume plutonium streams, and (2) a system for the processing of small-volume, concentrated plutonium streams. Criticality control of the dilute systems will be maintained by controlling batch-size. Criticality control in the remainder of the facility is achieved by the use of critically-safe vessels. Possible entry of concentrated plutonium streams into batch-controlled vessels is to be prevented by an interlock arrangement superimposed on the normal operational control measures. Nuclear safety will of course receive full consideration as this new facility is placed in operation.

Purex Plant

Nuclear safety in the Purex Plant is to be based on three different types of control: dilution with uranium, solution concentration, and critically-safe equipment. As in Redox, the overall control in Purex will be greatly facilitated by the total absence of plutonium precipitation steps in the process flowchart.

In the dissolution operation, the pre-cycle, and the partition cycle, nuclear safety is assured since in all equipment the uranium to plutonium weight ratio is to be far greater than the minimum limit for criticality.

In the sections of the process which will contain plutonium and little or no uranium, such as the 2A column, 2E column, and the product concentration and handling facilities, the equipment has been designed to be critically-safe. All of the equipment in these sections, including the pumps and samplers, is currently being re-checked physics-wise by the Engineering group responsible.

The backcycle ("reflux") flowchart for the final plutonium cycle is not being considered for initial plant operation. Replacement of the 2A column feed tank to keep it critically-safe would be required prior to plant use of the more concentrated streams of this backcycle flowchart.

The storage and loading of final product solution containers in jackets have been made geometrically safe. These "PX" containers have a lead shield alloyed with

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cadmium surrounding the solution. This will permit the storage of any number of loaded jackets without danger of criticality due to interactions between vessels.

The rework facilities for handling concentrated plutonium are to be kept critically safe by geometry and special batch-size control procedures. Close control by supervision will be exercised to assure nuclear safety by dilution and association with uranium whenever the rework plutonium is returned to vessels not critically-safe.

The waste system, the organic system, the LBP vessel, and the 2AF vessel are to be kept safe by dilution. Assured nuclear safety in these vessels will require positive sampling and control procedures to maintain complete control of the dilution factor. There appears to be no problem during normal operation, but close monitoring will be required during major system upsets to assure positive control.

Formal nuclear safety specifications for the Purex process have not yet been established by Engineering, but these are promised for issuance well in advance of plant start-up. Meanwhile, work is proceeding with the Standard Operating Procedures on the basis of present understandings.

METAL PREPARATION SECTION

General

Although no nuclear hazards are involved in the Metal Preparation Section's handling and processing of normal uranium, it has always been recognized that special precautions are required to assure nuclear safety in (1) the storage, processing and shipment of slug cores enriched in U-235, and (2) the operation of the JO5 Test Pile. The situation with respect to these two important phases of JOO Area operations is described under separate sub-headings.

Enriched Alloy Slug Handling

Substantial numbers of enriched uranium-aluminum alloy slugs ("C" and "J" types) have been processed in the Metal Preparation facilities. Nuclear reactions can occur if the critical number of slugs for a particular environment is brought into close proximity. However, handling of the enriched alloy slug cores has been very specifically controlled, and no potentially serious nuclear incidents have occurred.

Prior to Mid-1954, the special operating procedures used with enriched alloy slugs were based on safety precautions and control limits established jointly by Manufacturing and Technical in 1950. These procedures rigidly limited to 5 the maximum number of such slugs that could be contained in a single container, and this led to the fabrication and routine use of special "bird-cages". These consist of a 5-slug box supported centrally in a metal framework designed to assure the required minimum spacing between boxes. Each such box has a padlocked lid, and the procedures specifically limit the number of boxes that may be unlocked by supervision at any one time, as well as the number of slugs permitted out of boxes and in specific processing steps.

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Last summer, recognizing the need for further formalizing these controls, and for revising them in the light of process changes and more recent critical mass data, a Process Standard was developed to cover this phase of the Section's operations. This Standard was prepared from a complete review of the process, the existent procedures, and the most recent documents on critical mass studies. Doubtful limits were discussed with Oak Ridge personnel in off-site visits. The safe number of slugs in close proximity was limited for the air, liquid, and normal uranium environments that could be encountered in the handling, storage, inspection, and canning areas. To assure adequate control, the number of slugs in any processing vessel was limited so that at least two additive mistakes would be necessary before the number of slugs not known to be safe could be exceeded. When this Standard was issued, the Engineering Department had not yet prepared formal Process Specifications for the control of this hazard. Therefore, a copy of the Standard was referred to Engineering for review and concurrence. Verbal assurance of agreement was obtained.

Early this year, this entire matter of nuclear safety was reviewed in conjunction with the Engineering Department. Each location where nuclear reactions were possible was carefully inspected. The Experimental Physics Unit has re-calculated the critical number for each processing vessel, and formal Engineering Department Specifications are being reviewed in rough draft form. These Specifications indicate that present limits provide a greater margin of safety than previously realized. However, no plans exist to relax the Process Standards.

In addition to defining more precisely the limits of safe operation, techniques have been developed to minimize the chance of error and to assure close conformance by operating personnel to the established limits. The responsibility for conformance monitoring has been assigned to both the Radiation Monitoring and Quality Control personnel of the Process Sub-Section. Rigid adherence to the specified limits is demanded. Radiation detection instruments have been adapted for use in assuring the identity of enriched alloy slugs, and the slugs are periodically monitored to assure accountability of all "C" and "J" slugs, and thus guarantee that none of this material has become mixed with other slugs where nuclear safety limits would not apply. Neutron surveys have been made to assure that safe limits were not being approached. Production tests covering the processing of special enriched material (e.g., the "Ike" slugs of enriched uranium) are made to incorporate the required safe handling specifications.

The limits and controls enforced in the Metal Preparation Section have been compared with the corresponding procedures at the Oak Ridge and Savannah River Projects. It is felt that the Metal Preparation Section's controls are as safe and are actually more specific than those practiced at the other two sites.

Test Pile Control

The nuclear safety of the Test Pile Facility depends on the inherent safety features of the equipment and the operating limits and techniques. This facility has operated since its startup in 1944 with no evidence of a potentially serious nuclear incident.

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The Test Pile is a small, air-cooled, graphite-moderated reactor. The temperature coefficient is negative, and a violent reaction would not be expected even if all controls became inoperative. However, many mechanical and operating controls exist to prevent uncontrolled reactions. In addition to the control rod (HCR), the reactor is equipped with a mechanically operated horizontal safety rod (HSR), a manually operated horizontal safety rod, a horizontal shim rod, a vertical safety rod (VSR), and a boron-steel ball safety device. Any one of these safety devices is capable of stopping the pile reaction.

The VSR, HSR and HCR are connected to the automatic "scram" circuit which in turn is connected to two Beckman neutron flux monitors. This circuit is checked each day both electronically and functionally. The system is fail-safe with respect to electrical failures. The manual "scram" circuit is checked each day, and is used to shut down the reactor at night. The ball safety device is actuated at least once each week while the reactor is in operation. Two qualified operators are stationed in the control room whenever the unit is in operation. To protect the facility at night, all safety rods are inserted in the unit; the manual safety rod is locked; the electrical circuits for operating the reactor are locked; and the control room and building are locked. All of the above operating techniques are controlled by approved operating procedures, and a combination of several manipulative errors and miscalculations would be necessary before an incident could arise.

A recent joint review by Operations, Process, and Engineering personnel verified that the present equipment and operating techniques are adequate to control nuclear safety in Test Pile operations. However, it was concluded that the specific safety limits and controls should be further formalized and incorporated in the Process Standards Manual. Accordingly, a new procedure that lists only those operating techniques affecting nuclear safety has been prepared, and a new section of the Process Standards Manual for control of the Test Pile operation is being written.

In summary, it is believed that the Manufacturing Department is properly aware of the nuclear hazards associated with its plant operations, and is discharging its responsibility for their control as effectively as is possible in the light of present knowledge. This whole vital subject is being kept very much alive in all three plant Sections, with special emphasis being maintained on the necessity for improving control techniques, and for maximum safeguarding against human failure.

J. E. McIndoo
Manager-Manufacturing

J. E. McIndoo:TW:mb

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