GUIDELINES FOR DECONTAMINATION OF FACILITIES AND EQUIPMENT
PRIOR TO RELEASE FOR UNRESTRICTED USE
OR TERMINATION OF LICENSES FOR BYPRODUCT, SOURCE,
OR SPECIAL NUCLEAR MATERIAL

U.S. Nuclear Regulatory Commission
Division of Fuel Cycle Safety
and Safeguards
Washington, DC 20555

April 1993

The instructions in this guide, in conjunction with Table 1, specify the radionuclides and radiation exposure rate limits which should be used in decontamination and survey of surfaces or premises and equipment prior to abandonment or release for unrestricted use. The limits in Table 1 do not apply to premises, equipment, or scrap containing induced radioactivity for which the radiological considerations pertinent to their use may be different. The release of such facilities or items from regulatory control is considered on a case-by-case basis.

1. The licensee shall make a reasonable effort to eliminate residual contamination.

2. Radioactivity on equipment or surfaces shall not be covered by paint, plating, or other covering material unless contamination levels, as determined by a survey and documented, are below the limits specified in Table 1 prior to the application of the covering. A reasonable effort must be made to minimize the contamination prior to use of any covering.

3. The radioactivity on the interior surfaces of pipes, drain lines, or ductwork shall be determined by making measurements at all traps, and other appropriate access points, provided that contamination at these locations is likely to be representative of contamination on the interior of the pipes, drain lines, or ductwork. Surfaces of premises, equipment, or scrap which are likely to be contaminated but are of such size, construction, or location as to make the surface inaccessible for purposes of measurement shall be presumed to be contaminated in excess of the limits.

4. Upon request, the Commission may authorize a licensee to relinquish possession or control of premises, equipment, or scrap having surfaces contaminated with materials in excess of the limits specified. This may include, but would not be limited to, special circumstances such as razing of buildings, transfer of premises to another organization continuing work with radioactive materials, or conversion of facilities to a long-term storage or standby status. Such requests must:

    a. Provide detailed, specific information describing the premises, equipment or scrap, radioactive contaminants, and the nature, extent, and degree of residual surface contamination.

    b. Provide a detailed health and safety analysis which reflects that the residual amounts of materials on surface areas, together with other considerations such as prospective use of the premises, equipment, or scrap, are unlikely to result in an unreasonable risk to the health and safety of the public.

5. Prior to release of premises for unrestricted use, the licensee shall make a comprehensive radiation survey which establishes that contamination is within the limits specified in Table 1. A copy of the survey report shall be filed with the Division of Fuel Cycle Safety and Safeguards, U. S. Nuclear Regulatory Commission, Washington, DC 20555, and also the Administrator of the NRC Regional Office having jurisdiction. The report should be filed at least 30 days prior to the planned date of abandonment. The survey report shall:

   a. Identify the premises.

   b. Show that reasonable effort has been made to eliminate residual contamination.

   c. Describe the scope of the survey and general procedures followed.

   d. State the findings of the survey in units specified in the instruction.

   Following review of the report, the NRC will consider visiting the facilities to confirm the survey.

TABLE 1

ACCEPTABLE SURFACE CONTAMINATION LEVELS

| NUCLIDES[a] | AVERAGE[bcf] | MAXIMUM[bdf] | REMOVABLE[bef] |
|---|---|---|---|
| U-nat, U-235, U-238, and associated decay products | 5,000 dpm α/100 $cm^2$ | 15,000 dpm α/100 $cm^2$ | 1,000 dpm α/100 $cm^2$ |
| Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129 | 100 dpm/100 $cm^2$ | 300 dpm/100 $cm^2$ | 20 dpm/100 $cm^2$ |
| Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133 | 1000 dpm/100 $cm^2$ | 3000 dpm/100 $cm^2$ | 200 dpm/100 $cm^2$ |
| Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above. | 5,000 dpm βγ/100 $cm^2$ | 15,000 dpm βγ/ 100 $cm^2$ | 1,000 dpm βγ/100 $cm^2$ |

[a]Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.

[b]As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[c]Measurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each such object.

[d]The maximum contamination level applies to an area of not more than 100 $cm^2$.

[e]The amount of removable radioactive material per 100 $cm^2$ of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

[f]The average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/hr at 1 cm and 1.0 mrad/hr at 1 cm, respectively, measured through not more than 7 milligrams per square centimeter of total absorber..

# CHAPTER 6.0
# NUCLEAR CRITICALITY SAFETY

## 6.1 PROGRAM ADMINISTRATION

### 6.1.1 CRITICALITY SAFETY DESIGN PHILOSOPHY

The Double Contingency Principle as identified in nationally recognized American National Standard ANSI/ANS-8.1 (1983) is the fundamental technical basis for design and operation of processes within the GE-Wilmington fuel manufacturing operations using fissile materials. As such, "process designs will incorporate sufficient margins of safety to require at least two unlikely, independent, and concurrent changes in process conditions before a criticality accident is possible." For each significant portion of the process, a defense of one or more system parameters is documented in the criticality safety analysis, which is reviewed and enforced.

The established design criteria and nuclear criticality safety reviews are applicable to:

- all new processes, facilities or equipment that process, store, transfer or otherwise handle fissile materials, and
- any change in processes, facilities or equipment which may have an impact on the established basis for nuclear criticality safety.

### 6.1.2 EVALUATION OF CRITICALITY SAFETY

#### 6.1.2.1 Changes to Facility

As part of the design of new facilities or significant additions or changes in existing facilities, Area Managers provide for the evaluation of nuclear hazards, chemical hazards, hydrogenous content of firefighting materials, and mitigation of inadvertent unsafe acts by individuals. Specifically, when criticality safety considerations are impacted by these hazards, the approval to operate new facilities or make significant changes, modification, or additions to existing facilities is documented in accord

with established facility practices and conform to configuration management function 'Integrated Safety Analysis' (ISA) requirements described in Chapter 4.0.

Change requests are processed in accordance with configuration management requirements described in Chapter 3.0. Change requests which establish or involve a change in existing criticality safety parameters require a senior engineer who has been approved by the criticality safety function to disposition the proposed change with respect to the need for a criticality safety analysis.

If an analysis is required, the change is not placed into operation until the criticality safety analysis is complete and other preoperational requirements are fulfilled in accordance with established configuration management practices.

#### 6.1.2.2 Role of the Criticality Safety Function

Qualified personnel as described in Chapter 2 assigned to the criticality safety function determine the basis for safety for processing fissile material. Assessing both normal and credible abnormal conditions, criticality safety personnel specify functional requirements for criticality safety controls commensurate with design criteria and assess control reliability. Responsibilities of the criticality safety function are described in Chapter 2.0.

### 6.1.3 OPERATING PROCEDURES

Procedures that govern the handling of enriched uranium are reviewed and approved by the criticality safety function.

Each Area Manager is responsible for developing and maintaining operating procedures that incorporate limits and controls established by the criticality safety function. Area Managers assure that appropriate area engineers, operators, and other concerned personnel review and understand these procedures through postings, training programs, and/or other written, electronic or verbal notifications.

Documentation of the review, approval and operator orientation process is maintained within the configuration management system. Specific details of this system are described in Chapter 3.0.

## 6.1.4 POSTING AND LABELING

### 6.1.4.1 Posting of Limits and Controls

Nuclear criticality safety requirements for each process system that are defined by the criticality safety function are made available to work stations in the form of written or electronic operating procedures, and/or clear visible postings.

Posting may refer to the placement of signs or marking of floor areas to summarize key criticality safety requirements and limits, to designate approved work and storage areas, or to provide instructions or specific precautions to personnel such as:

- Limits on material types and forms.
- Allowable quantities by weight or number.
- Allowable enrichments.
- Required spacing between units.
- Control limits (when applicable) on quantities such as moderation, density, or presence of additives.
- Critical control steps in the operation.

Storage postings are located in conspicuous places and include as appropriate:

- Material type.
- Container identification.
- Number of items allowed.
- Mass, volume, moderation, and/or spacing limits.

Additionally, when administrative controls or specific actions/decisions by operators are involved, postings include pertinent requirements identified within the criticality safety analysis.

### 6.1.4.2 Labeling

Where practical, process containers of fissile material are labeled such that the material type, U-235 enrichment, and gross weights can be clearly identified or determined. Deviations from this process include: large process vessels, fuel rods, shipping containers, waste boxes/drums, contaminated items, $UF_6$ cylinders

containing heels, cold trap cylinders, samples, containers of 1 liter volume or less, or other containers where labeling is not practical.

## 6.1.5 AUDITS & INSPECTIONS

### 6.1.5.1 Audits and Inspections

Details of the facility criticality safety audit program are described in Chapter 3.0. Criticality safety audits are conducted and documented in accordance with a written procedure and personnel approved by the criticality safety function. Findings, recommendations, and observations are reviewed with the Environment, Health & Safety (EHS) function manager to determine if other safety impacts exist. The findings, recommendations, and observations are then transmitted to Area Managers for appropriate action.

Routine surveillance inspections of the processes and associated conduct of operations within the facility, including compliance with operating procedures, postings, and administrative guidelines, are also conducted as described in Chapter 3.

### 6.1.5.2 Independent Audits

A nuclear criticality safety program review is conducted on a planned scheduled basis by nuclear criticality safety professionals independent of the GE-Wilmington fuel manufacturing organization. This provides a means for independently assessing the effectiveness of the components of the nuclear criticality safety program.

The audit team is composed of individuals recommended by the manager of the criticality safety function and whose audit qualifications are approved by the GE-Wilmington facility manager or Manager, EHS. Audit results are reported in writing to the manager of the criticality safety function, who disseminates the report to line management. Results in the form of corrective action requests are tracked to closure.

### 6.1.6 CRITICALITY SAFETY PERSONNEL

#### 6.1.6.1 Qualifications

Specific details of the criticality safety function responsibilities and qualification requirements for manager, senior engineer, and engineer are described in Chapter 2.0.

#### 6.1.6.2 Authority

Criticality safety function personnel are specifically authorized to perform assigned responsibilities in Chapter 2.0. All nuclear criticality safety function personnel have authority to shutdown potentially unsafe operations.

## 6.2 TECHNICAL PRACTICES

### 6.2.1 CONTROL PRACTICES

Criticality safety analyses identify specific controls necessary for the safe and effective operation of a process. Prior to use in any process, nuclear criticality safety controls are verified against criticality safety analysis criteria. The ISA program described in Chapter 4.0 implement performance based management of process requirements and specifications that are important to nuclear criticality safety.

#### 6.2.1.1 Verification Program

The purpose of the verification program is to assure that the controls selected and installed fulfill the requirements identified in the criticality safety analyses. All processes are examined in the "as-built" condition to validate the safety design and to verify the installation. Criticality safety function personnel observe or monitor the performance of initial functional tests and conduct pre-operational audits to verify that the controls function as intended and the installed configuration agrees with the criticality safety analysis.

Operations personnel are responsible for subsequent verification of controls through the use of functional testing or verification. When necessary, control calibration and routine maintenance are normally provided by the instrument and calibration and/or maintenance functions. Verification and maintenance activities are performed per established facility practices documented through the use of forms and/or computer tracking systems. Criticality safety function personnel randomly review control verifications and maintenance activities to assure that controls remain effective.

#### 6.2.1.2 Maintenance Program

The purpose of the maintenance program is to assure that the effectiveness of criticality safety controls designated for a specific process are maintained at the original level of intent and functionality. This requires a combination of routine maintenance, functional testing, and verification of design specifications on a periodic basis. Details of the maintenance program are described in Chapter 3.0.

### 6.2.2 MEANS OF CONTROL

The relative effectiveness and reliability of controls are considered during the criticality safety analysis process. Passive engineered controls are preferred over all other system controls and are utilized when practical and appropriate. Active engineered controls are the next preferred method of control followed by administrative controls. A criticality safety control must be capable of preventing a criticality accident independent of the operation or failure of any other criticality control for a given credible initiating event.

#### 6.2.2.1 Passive Engineered Controls

These are physical restraints or features that maintain criticality safety in a static manner (i.e., fixed geometry, fixed spacing, fixed size, nuclear poisons, etc.). Passive engineered controls require no action or other response to be effective when called upon to ensure nuclear criticality safety. Assurance is maintained through specific periodic inspections or verification measurement(s) as appropriate.

6.2.2.2 Active Engineered Controls

A means of criticality control involving active hardware (e.g., electrical, mechanical, hydraulic) that protect against criticality. These devices act by providing predefined automatic action or by sensing a process variable important to criticality safety and providing automatic action (e.g., no human intervention required) to secure the system to a safe condition. Human intervention augmented by warning devices and interlocks that prevent continued operation may be used to sense a process variable. Assurance is maintained through specific periodic functional testing as appropriate. Active engineered controls are fail-safe (e.g., meaning failure of the control results in a safe condition).

6.2.2.3 Administrative Controls

Controls that rely for their implementation on actions, judgment, and responsible actions of people. Their use is limited to situations where passive and active control are not practical. Administrative controls may be proactive (requiring action prior to proceeding) or reactive (proceeding unless action occurs). Proactive administrative controls are preferred. Assurance is maintained through training, experience, and audit.

6.2.3 TABLE OF PLANT SYSTEMS AND PARAMETER CONTROLS

Table 6.0 identifies major process areas or support facility processes within the GE-Wilmington fuel manufacturing complex and support facilities. Table entries for each significant process item highlight the safety basis selected for the criticality safety analysis (CSA) and related worst credible contents (or bounding assumptions). Table column definitions are presented below:

AREA OR SYSTEM: A defined functional group of processes or pieces of equipment that operate as a single unit.

PROCESS SUBAREA OR EQUIPMENT: A defined subgroup of vessels, tanks, process and/or support equipment within an area that operate as a single unit.

BASIS FOR CRITICALITY SAFETY: The controlled parameters established within a CSA for nuclear criticality safety for the identified process subarea or equipment. For multiple parameter entries, the basis for nuclear criticality safety

established in the CSA may be based on the identified parameter(s), as appropriate, including the use of 'coupled' parameter control (e.g., mass/moderation).

CSA BOUNDING ASSUMPTIONS: These are the values used for physical process parameters which are not directly controlled but represent the most reactive credible values for the system, process subarea, or equipment under consideration. As such, the CSA is performed to consider all process operations and credible upsets that fall within this range of assumptions. For items containing no bounding assumptions, all process operations and credible upsets must be analyzed within the CSA. The approved CSA may limit the operation of the system to levels more conservative than those permitted by the bounding assumptions.

In the following Table 6.0, unless otherwise specified, the enrichment limit for all processes are 5.0 wt. % U235 (or HiE), with the exception of conversion lines 1,2 , and 4 and related MSG lines 1-6 which are presently analyzed for 4.025 wt. % U235 (or LoE). When pails are used for product, 5-gallon cans may be used for LoE enrichments, while 3-gallon containers may be used for HiE material. All scrap material is treated as HiE.

Table 6.0 Plant Systems and Parameter Controls

| AREA OR SYSTEM | PROCESS SUBAREA OR EQUIPMENT | BASIS FOR CRITICALITY SAFETY | CSA BOUNDING ASSUMPTIONS |
|---|---|---|---|
| Fuel Support: Storage Pads | $UF_6$ Cylinder Receipt and Storage | Enrichment | 99.5 wt. % pure $UF_6$<br>$\leq$ 0.5 wt. % $H_2O$ equivalent<br>Optimal Interunit $H_2O$ |
| | Scrap 3 and 5-gallon Container Storage | Geometry<br>Mass | Homogeneous or Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | RA-Inner and Outer Container Storage | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Waste Box Container Storage | Geometry/Mass<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | BU-J, BU-7, 7A Drum Storage | Geometry<br>Mass<br>Moderation } * | Homogeneous or Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| Fuel Support: New Decon | Waste Box Load | Mass | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Oil Drum Load | Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| Chemical ADU Conversion System | $UF_6$ Cylinders | Moderation | 99.5 wt. % pure $UF_6$<br>$\leq$ 0.5 wt. % $H_2O$ equivalent<br>Full Reflection |
| | Autoclave Vaporization | Moderation | 99.5 wt. % pure $UF_6$<br>$\leq$ 0.5 wt. % $H_2O$ equivalent<br>Full Reflection |
| | Cold Trap System | Geometry<br>Moderation | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Hydrolysis Receiver, Storage, and Scrubber Tanks | Geometry<br>Concentration | Homogeneous $UO_2F_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Sump | Geometry<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Precipitation Tanks (Lines 1,2,4) | Geometry | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |

*** two out of any three control parameters required for criticality safety.**

| AREA OR SYSTEM | PROCESS SUBAREA OR EQUIPMENT | BASIS FOR CRITICALITY SAFETY | CSA BOUNDING ASSUMPTIONS |
|---|---|---|---|
| | Precipitation Tanks (Lines 3, 5) | Geometry<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Dewatering Centrifugation | Geometry<br>Mass | Homogeneous ADU or $U_3O_8$<br>Optimal $H_2O$ Moderation<br>Full Reflection Outside Containment |
| | Clarifying Centrifugation | Geometry<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Calcination | Geometry<br>Geometry/Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Calciner Scrubber | Geometry<br>Concentration | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | 3 or 5-Gallon Product Container | Geometry<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | $UO_2$ Powder Pretreatment: Mill, Slug, Granulate (MSG) | Geometry or Mass<br>Moderation | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | LoE and HiE $UO_2$ Powder Blending | Geometry<br>Mass/Moderation | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | LoE Fluoride Effluent Vessels | Geometry<br>Concentration | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Line 3 Accumulator/Permeate Vessels | Geometry<br>Concentration | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Nitrate Quarantine Effluent Vessels | Geometry<br>Concentration | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Powder Pack Screener | Geometry<br>Moderation | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Powder Pack Product Container | Geometry<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | HVAC: Wet Areas | Geometry<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |

| AREA OR SYSTEM | PROCESS SUBAREA OR EQUIPMENT | BASIS FOR CRITICALITY SAFETY | CSA BOUNDING ASSUMPTIONS |
|---|---|---|---|
| | HVAC: Dry Areas | Mass<br>Moderation | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Exhaust Scrubber | Geometry/Mass<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Utilities: Steam , $N_2$, $H_2$, Dissoc. NH4, $H_2O$ Supply | Mass | Backflow into large supply vessels prevented by backflow prevention measures, physical barriers, and/or process characteristics. |
| | REDCAP: Oxidation Feed Containers | Geometry<br>Mass | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | REDCAP: Oxidation Furnace | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | REDCAP: Oxidation Output Containers | Geometry<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | REDCAP: Oxidation Off-Gas System | Geometry<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Miscellaneous: 3 and 5-Gallon Container Floor storage | Geometry<br>Mass | Homogeneous or Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Integration OXIDIZE 3 and 5-gal. Feed Containers | Geometry<br>Mass | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Integration OXIDIZE 3 and 5-gal. Feed Container Storage | Geometry<br>Mass<br>Moderation } * | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | Integration: OXIDIZE Feed Hood | Geometry<br>Mass | Homogeneous or Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Integration OXIDIZE Furnace | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Integration RECYCLE Powder Outlet | Moderation | heterogeneous $UO_2$<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |

*** two out of any three control parameters required for criticality safety.**

| AREA OR SYSTEM | PROCESS SUBAREA OR EQUIPMENT | BASIS FOR CRITICALITY SAFETY | CSA BOUNDING ASSUMPTIONS |
|---|---|---|---|
| | Integration RECYCLE Blender | Moderation | Heterogeneous $UO_2$<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| | Integration RECYCLE DM-10 Vibromill | Moderation<br>Mass | Heterogeneous $UO_2$<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| | Integration RECYCLE Unicone Container Storage | Moderation | Heterogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible wt. % $H_2O$<br>Optimal Interunit $H_2O$ |
| | Integration RECYCLE 3-gal. Product Container Storage | Geometry<br>Mass } *<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | Integration RECYCLE Powder Transfer Corridor | Moderation | Heterogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| Uranium Recovery Unit (URU) System | Fluoride Waste Process Vessels | Geometry<br>Concentration | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Fluoride Waste Surge Vessel (V-106) | Concentration<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Radwaste Process Vessels | Geometry<br>Concentration | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Nitrate Waste Process Vessels | Geometry<br>Concentration | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Nitrate Waste Surge Vessel (V-103) | Concentration<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Oxidation Feed Containers | Geometry<br>Mass | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Oxidation Furnace | Geometry | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Oxidation Furnace Boat Dump | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |

*** two out of any three control parameters required for criticality safety.**

| AREA OR SYSTEM | PROCESS SUBAREA OR EQUIPMENT | BASIS FOR CRITICALITY SAFETY | CSA BOUNDING ASSUMPTIONS |
|---|---|---|---|
| | Oxidation 3-gallon Container Storage | Geometry<br>Mass } *<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Oxidation Off-Gas System | Geometry<br>Mass | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Dissolution: Can Dump Feed Conveyor | Geometry<br>Mass<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Dissolution: Dissolvers, Pumps, Sumps, Filters, Piping | Geometry<br>Concentration | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Oberlin Filter | Geometry<br>Concentration | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Dissolution: NOX Scrubber | Concentration<br>Mass | Homogeneous $UO_2$<br>On-Line Density Meter<br>Full Reflection |
| | Counter-Current Leaching: Can Dump | Geometry<br>Mass/Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Counter-Current Leaching: Leach Troughs, Pumps, Filters, Storage Tanks, Product Containers | Geometry<br>Concentration | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Utilities: Steam, DI $H_2O$, Nitric Acid, Aluminum Nitrate | Mass | Backflow into large supply vessels prevented by backflow prevention measures, physical barriers, and/or process characteristics. |
| | Head-End Concentrator Process | Geometry<br>Concentration | Homogeneous UNH<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Solvent Extraction Process | Geometry<br>Concentration | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | UNH Product Storage Vessels | Geometry<br>Concentration | Homogeneous UNH<br>Optimal $H_2O$ Moderation<br>Full Reflection |

*** two out of any three control parameters required for criticality safety.**

| AREA OR SYSTEM | PROCESS SUBAREA OR EQUIPMENT | BASIS FOR CRITICALITY SAFETY | CSA BOUNDING ASSUMPTIONS |
|---|---|---|---|
| | Waste Solvent Drum Load | Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| Uranyl Nitrate Conversion (UCON) System | UNH LEM Tank Feed Tanks | Geometry<br>Concentration | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | UCON: Precipitation Tanks | Geometry<br>Mass | Homogeneous UNH<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | UCON: Dewatering Centrifugation | Geometry<br>Mass | Homogeneous ADU or $U_3O_8$<br>Optimal $H_2O$ Moderation<br>Full Reflection Outside Containment |
| | UCON: Clarifying Centrifugation | Geometry<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | UCON Process: Calcination | Geometry<br>Geometry/Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| Waste Treatment Facility (WTF) | Fluoride Waste Barrens Surge Vessel (V-108) | Concentration<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Nitrate Waste Barrens Surge Vessel (V-104) | Concentration<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Centrifuge | Geometry<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Oberlin Filter | Geometry/Mass<br>Concentration | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| Uranium Recovery from Lagoon Sludge (URLS) Facility Process | URLS Process Tanks | Concentration | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | URLS Process Non-Leach Filter Press | Geometry/Concent.<br>Concentration | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | URLS Process Product Waste Container | Concentration<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| Waste Oxidation/ Reduction (Incineration) Facility | Incinerator Combustible Box Feed Containers | Mass (Box Monitor)<br>Mass (E-Gun) | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |

| AREA OR SYSTEM | PROCESS SUBAREA OR EQUIPMENT | BASIS FOR CRITICALITY SAFETY | CSA BOUNDING ASSUMPTIONS |
|---|---|---|---|
| | Incinerator | Mass (UPHOLD)<br>Mass (INHOLD) | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Incinerator Product 3 or 5-Gallon Containers | Geometry<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| Dry Conversion Process (DCP) Conversion | $UF_6$ Cylinder Receipt and Storage | Enrichment | 99.5 wt. % pure $UF_6$<br>$\leq$ 0.5 wt. % $H_2O$ equivalent<br>Optimal Interunit $H_2O$ |
| | Vaporization Autoclave w/$UF_6$ Cylinder | Moderation | 99.5 wt. % pure $UF_6$<br>$\leq$ 0.5 wt. % $H_2O$ equivalent<br>Full Reflection |
| | Vaporization Cold Trap System | Geometry<br>Moderation | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Conversion: Reactor/Kiln | Moderation | Homogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| | Conversion: Powder Outlet Box | Moderation | Homogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| | Powder Outlet: Cooling Hopper | Moderation | Homogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| | Powder Transfer & Storage: Normal Product Container | Moderation | Homogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| | Powder Transfer & Storage: Out-of- Spec Moisture Product Container | Geometry<br>Moderation | Homogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| | Homogenization | Moderation | Homogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |

| AREA OR SYSTEM | PROCESS SUBAREA OR EQUIPMENT | BASIS FOR CRITICALITY SAFETY | CSA BOUNDING ASSUMPTIONS |
|---|---|---|---|
| | Blending, Precompaction, Gran. lation | Moderation | Heterogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| | Tumbling: in Powder Container | Moderation | Heterogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| | Powder Pack Screener | Moderation | Heterogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| | Powder Pack Product Container | Geometry<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Utilities: $N_2$, $H_2$, $H_2O$ Supply, Refrigerant | Mass | Backflow into large supply vessels not credible due to backflow prevention measures, physical barriers, and/or process characteristics. |
| | HF Effluent Recovery and Storage Vessels | Geometry<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Recycle Blender | Moderation | Heterogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| | Recycle Unicone Product Container/Storage | Moderation | Heterogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible Internal wt. % $H_2O$<br>Optimal Interunit $H_2O$ |
| | Recycle 3-Gallon Product Container/ Storage | Geometry<br>Mass<br>Moderation } * | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| Press Warehouse Facility Process | Conveyor Storage: 3 and 5-gallon Cans | Geometry<br>Mass<br>Moderation } * | Homogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | Powder Dump Transfer Hopper/Chute | Geometry<br>Moderation | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Pellet Presses | Geometry/Mass<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |

*** two out of any three control parameters required for criticality safety.**

| AREA OR SYSTEM | PROCESS SUBAREA OR EQUIPMENT | BASIS FOR CRITICALITY SAFETY | CSA BOUNDING ASSUMPTIONS |
|---|---|---|---|
| | Press Lubricant Sump | Geometry<br>Mass | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Press: Green Pellet Boat Product Container | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | 3-gallon Powder Cleanup Container | Geometry<br>Mass | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Integration:<br>PWDR-MRA<br>Press Feed | Moderation | Heterogeneous $UO_2$<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| | Integration<br>PWDR-MRA<br>Container-Storage | Geometry/Mass<br>Moderation | Heterogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| | Integration<br>PWDR-MRA<br>Powder Transfer Corridor | Moderation | Heterogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| Pellet Sintering System | Feed/Exit Conveyors | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Sintering Furnace | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| Pellet Grinding System | Feeder Hopper Bowl or Flat Feeder Table | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Grinder | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Grinder APITRON Filter | Geometry<br>Moderation | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Grinder Swarf 3-Gallon Container | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Grinder Hardscrap 3-Gallon Container | Geometry<br>Mass | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |

*** two out of any three control parameters required for criticality safety.**

| AREA OR SYSTEM | PROCESS SUBAREA OR EQUIPMENT | BASIS FOR CRITICALITY SAFETY | CSA BOUNDING ASSUMPTIONS |
|---|---|---|---|
| | Grinder Pellet Product Tray | Geometry<br>Mass<br>Moderation } * | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Pellet Transfer Cart | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| Rod Load, Out-Gassing, and Final Rod Welding System | Rod Load, Out-Gassing, and Final Rod Weld | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Pellet Storage Cabinet | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Rod Storage Cabinet | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| Gadolinia Shop | Press, Sintering, Grinding, Rod Load, Rod Storage, & Outgas | Similar to $UO_2$ Shop Above | Similar to $UO_2$ Shop Above |
| | Gadolinia 3 and 5-Gallon Feed Containers | Geometry<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Gadolinia 3 and 5-Gallon Feed & Product Container Storage | Geometry<br>Mass<br>Moderation } * | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Gadolinia DM-10 Vibromill (MCA) | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Gadolinia DM-3 Vibromill (MCA) | Mass<br>Moderation | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Pellet Storage: Ministacker | Geometry/Mass<br>Moderation | Heterogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Integration: Gadolinia MEZZ-MRA Unicone Feed Container | Mass<br>Moderation | Homogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| | Integration Gadolinia MEZZ-MRA DM-10 Vibromill | Moderation | Heterogeneous $UO_2$<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |

*** two out of any three control parameters required for criticality safety.**

| AREA OR SYSTEM | PROCESS SUBAREA OR EQUIPMENT | BASIS FOR CRITICALITY SAFETY | CSA BOUNDING ASSUMPTIONS |
|---|---|---|---|
| | Integration Gadolinia MEZZ-MRA Rotary Slugger | Moderation | Heterogeneous $UO_2$<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| | Integration Gadolinia MEZZ-MRA Granulator | Moderation | Heterogeneous $UO_2$<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| | Integration: Gadolinia MEZZ-MRA 3 and 5-Gallon Feed & Product Container Storage | Geometry<br>Mass<br>Moderation } * | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Integration Gadolinia MEZZ-MRA Powder Transfer Corridor | Moderation | Heterogeneous $UO_2$<br>Maximum Credible $UO_2$ Density<br>Maximum Credible wt. % $H_2O$<br>Full Reflection |
| Bundle Assembly | Rod Trays | Geometry<br>Mass | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | Rod Storage Cabinets | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | Rod Tray Transfer Vehicle: "Big Joe" | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | Magnetic and Passive Scanner: "MAPS" | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | Bundle Accumulator: "BACC" | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | Automatic Bundle Assemble Machine: "ABAM" | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | Rod Scanner: "Fat Albert" | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | Assembly Table | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | Upender: Bundle and RA Container | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |

*** two out of any three control parameters required for criticality safety.**

| AREA OR SYSTEM | PROCESS SUBAREA OR EQUIPMENT | BASIS FOR CRITICALITY SAFETY | CSA BOUNDING ASSUMPTIONS |
|---|---|---|---|
| | Inspection Pit | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | Bundle Storage: "Forest" | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | RA Container: Transfer Port & RA Conveyor | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | Rod Scanner: X-Ray-Unit | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | Rod Inspection: Surface-Plate | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | Rod Movement: One & Two-Tray Cart | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| | Container Storage: RA-Inner/Outer Storage | Geometry<br>Moderation | Heterogeneous $UO_2$<br>Optimal Interunit $H_2O$ Moderation<br>Full Reflection |
| Decontamination & Volume Reduction Facility (DVRF) | Wash Down Areas, Sumps, Bag Filters | Geometry/Mass<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | Dust Hog | Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | HVAC | Geometry<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |
| | 3-Gallon Waste Container Storage | Geometry<br>Mass | Homogeneous $UO_2$<br>Optimal $H_2O$ Moderation<br>Full Reflection |

### 6.2.4 SPECIFIC PARAMETER LIMITS

The **safe geometry** values of Table 6.1 below are specifically licensed for use at the GE-Wilmington facility. Application of these geometries is limited to situations where the neutron reflection present does not exceed that due to full water reflection. Acceptable geometry margins of safety for units identified in this table are 93% of the minimum critical cylinder diameter, 88% of the minimum critical slab thickness, and 76% of the minimum critical sphere volume.

When cylinders and slabs are not infinite in extent, the dimensional limitations of Table 6.1 may be increased by means of standard buckling conversion methods; reactivity formula calculations which incorporate validated K-infinities, migration areas ($M^2$) and extrapolation distances; or explicit stochastic or deterministic modeling methods.

The **safe batch** values of Table 6.2 are specifically licensed for use at the GE-Wilmington facility. Criticality safety may be based on U235 mass limits in either of the following ways:

- If double batch is considered credible, the mass of any single accumulation shall not exceed a safe batch, which is defined to be 45% of the minimum critical mass. Table 6.2 lists safe batch limits for homogeneous mixtures of $UO_2$ and water as a function of U235 enrichment over the range of 1.1% to 5% for uncontrolled geometric configurations. The safe batch sized for $UO_2$ of specific compounds may be adjusted when applied to other compounds by the formula:

  **kgs X = (kgs $UO_2$ • 0.88 ) / f**

  | | | |
  |---|---|---|
  | **where,** | **kgs X** | **= safe batch value of compound 'X'** |
  | | **kgs $UO_2$** | **= safe batch value for $UO_2$** |
  | | **0.88** | **= wt. % U in $UO_2$** |
  | | **f** | **= wt. % U in compound X** |

- Where engineered controls prevent over batching, a mass of 75% of the minimum critical mass shall not be exceeded.

Subject to provision for adequate protection against precipitation or other circumstances which may increase concentration, the following **safe concentrations** are specifically licensed for use at the GE-Wilmington facility:

- A concentration of less than or equal to one-half of the minimum critical concentration.
- A system in which the hydrogen to U235 atom ratio (H/U235) is greater than 5200.

**Table 6.1 Safe Geometry Values**

| Homogeneous $UO_2$-$H_2O$ Mixtures | Weight Percent U235 | Infinite Cylinder* Diameters (Inches) | Infinite Slab* Thickness (Inches) | Sphere Volume* (Liters) |
|---|---|---|---|---|
| | 2.00 | 16.70 | 8.90 | 105.0 |
| | 2.25 | 14.90 | 7.90 | 75.5 |
| | 2.50 | 13.75 | 7.20 | 61.0 |
| | 2.75 | 12.90 | 6.65 | 51.0 |
| | 3.00 | 12.35 | 6.25 | 44.0 |
| | 3.25 | 11.70 | 5.90 | 38.5 |
| | 3.50 | 11.20 | 5.60 | 34.0 |
| | 3.75 | 10.80 | 5.30 | 31.0 |
| | 4.00 | 10.50 | 5.10 | 29.0 |
| | 5.00 | 9.50 | 4.45 | 24.0 |
| | | | | |
| **Homogeneous Aqueous Solutions** | **Weight Percent U235** | **Infinite Cylinder Diameters (Inches)** | **Infinite Slab Thickness (Inches)** | **Sphere Volume (Liters)** |
| | 2.00 | 16.7 | 9.30 | 106.4 |
| | 2.25 | 15.0 | 8.40 | 80.5 |
| | 2.50 | 14.0 | 7.80 | 66.8 |
| | 2.75 | 13.3 | 7.30 | 56.2 |
| | 3.00 | 12.9 | 7.00 | 49.7 |
| | 3.25 | 12.5 | 6.70 | 44.8 |
| | 3.50 | 12.1 | 6.50 | 41.0 |
| | 3.75 | 11.9 | 6.30 | 38.0 |
| | 4.00 | 11.7 | 6.00 | 34.9 |
| | 5.00 | 9.5 | 4.80 | 26.0 |
| | | | | |
| **Heterogeneous Mixtures or Compounds** | **Weight Percent U235** | **Infinite Cylinder Diameters (Inches)** | **Infinite Slab Thickness (Inches)** | **Sphere Volume (Liters)** |
| | 2.00 | 11.10 | 5.60 | 35.7 |
| | 2.25 | 10.50 | 5.10 | 30.7 |
| | 2.50 | 10.10 | 4.80 | 27.3 |
| | 2.75 | 9.70 | 4.60 | 24.7 |
| | 3.00 | 9.40 | 4.40 | 22.6 |
| | 3.25 | 9.20 | 4.30 | 20.9 |
| | 3.50 | 9.00 | 4.20 | 19.2 |
| | 3.75 | 8.90 | 4.10 | 18.2 |
| | 4.00 | 8.80 | 4.00 | 16.9 |
| | 5.00 | 8.30 | 3.60 | 13.0 |

* These values represent 93%, 88% and 76% of the minimum critical cylinder diameter, slab thickness, and sphere volume, respectively. For enrichments not specified, smooth curve interpolation may be used.

Table 6.2 Safe Batch Values for $UO_2$ and Water*

| Nominal Weight Percent U235 | Homogeneous $UO_2$ Powder & Water Mixtures (Kgs $UO_2$) | Heterogeneous $UO_2$ Pellets & Water Mixtures (Kgs $UO_2$) | Nominal Weight Percent U235 | Homogeneous $UO_2$ Powder & Water Mixtures (Kgs $UO_2$) | Heterogeneous $UO_2$ Pellets & Water Mixtures (Kgs $UO_2$) |
|---|---|---|---|---|---|
| 1.10 | 2629.0 | 510.0 | 4.00 | 25.7 | 24.7 |
| 1.20 | 1391.0 | 341.0 | 4.20 | 23.7 | 22.9 |
| 1.30 | 833.0 | 246.0 | 4.40 | 21.9 | 21.4 |
| 1.40 | 583.0 | 193.0 | 4.60 | 20.2 | 20.0 |
| 1.50 | 404.0 | 158.0 | 4.80 | 19.1 | 18.8 |
| 1.60 | 293.3 | 135.0 | 5.00 | 18.1 | 18.1 |
| 1.70 | 225.0 | 116.0 | | | |
| 1.80 | 183.0 | 102.0 | | | |
| 1.90 | 150.6 | 90.5 | | | |
| 2.00 | 127.5 | 81.6 | | | |
| 2.10 | 109.2 | 73.1 | | | |
| 2.20 | 96.8 | 66.4 | | | |
| 2.30 | 84.3 | 61.0 | | | |
| 2.40 | 74.7 | 56.1 | | | |
| 2.50 | 68.9 | 52.1 | | | |
| 2.60 | 60.5 | 48.8 | | | |
| 2.70 | 56.6 | 45.4 | | | |
| 2.80 | 52.2 | 42.9 | | | |
| 2.90 | 47.6 | 40.1 | | | |
| 3.00 | 44.5 | 38.1 | | | |
| 3.20 | 38.9 | 34.1 | | | |
| 3.40 | 34.6 | 31.0 | | | |
| 3.60 | 31.1 | 28.5 | | | |
| 3.80 | 28.3 | 26.4 | | | |

***NOTE: These values represent 45% of the minimum critical mass. For enrichments not specified, smooth curve interpolation of safe batch values may be used.**

6.2.5 CONTROL PARAMETERS

Nuclear criticality safety is achieved by controlling one or more parameters of a system within established subcritical limits. The criticality safety review process is used to identify the significant parameters associated with a particular system. All assumptions relating to process equipment, material composition, function, and operation, including upset conditions, are justified, documented, and independently reviewed.

Identified below are specific control parameters that may be considered during the review process:

6.2.5.1 **Geometry** - Geometry may be used for nuclear criticality safety control on its own or in combination with other control methods. Favorable geometry is based on limiting dimensions of defined geometrical shapes to established subcritical limits. Structure and/or neutron absorbers that are not removable constitute a form of geometry control. At the GE-Wilmington facility, favorable geometry is developed conservatively assuming unlimited water or concrete equivalent reflection, optimal hydrogenous moderation, worst credible heterogeneity, and maximum credible enrichment to be processed. Examples include cylinder diameters, annular inner/outer dimensions, slab thickness, and sphere diameters.

Geometry control systems are analyzed and evaluated allowing for fabrication tolerances and dimensional changes that may likely occur through corrosion, wear, or mechanical distortion. In addition, these systems include provisions for periodic inspection if credible conditions exist for changes in the dimensions of the equipment that may result in the inability to meet established nuclear criticality safety limits.

6.2.5.2 **Mass** - Mass control may be used for a nuclear criticality safety control on its own or in combination with other control methods. Mass control may be utilized to limit the quantity of uranium within specific process operations or vessels and within storage, transportation, or disposal containers. Analytical or non-destructive methods may be employed to verify the mass measurements for a specific quantity of material.

Establishment of mass limits involves consideration of potential moderation, reflection, geometry, spacing, and material concentration. The criticality safety analysis considers normal operations and credible process upsets in determining actual mass limits for the system and for defining additional controls. When only

administrative controls are used for mass controlled systems, double batching is considered to ensure adequate safety margin.

6.2.5.3 **Moderation** - Moderation control may be used for nuclear criticality safety control on its own or in combination with other control methods. When moderation is used in conjunction with other control methods, the area is posted as a 'moderation control area'. When moderation control is the primary design focus and is designated as a the primary criticality safety control parameter, the area is posted 'moderation restricted area'.

When moderation is the primary criticality safety control parameter the following graded approach to the design control philosophy is applied in accordance with established facility practices (in decreasing order of restriction):

- At each enriched uranium interface involving intentional and continuous introduction of moderation (e.g., insertion of superheated steam into reactor), at least three controls are required to assure that the moderation safety factor is not exceeded. At least two of these controls must be active engineered controls.
- At enriched uranium interfaces involving intentional but non-continuous introduction of moderation at least three controls are required to assure that the moderation safety factor is not exceeded. At least one of these controls must be an active engineered control, unless a moderation safety factor greater than 3 is demonstrated.
- For situations where moderation is not intentionally introduced as part of the process, the required number of controls for each credible failure mode must be established in accordance with the double contingency principle.

When the maximum credible accident is considered, the safety moderation limit (i.e., % $H_2O$ or equivalent) must provide sufficient factor of safety above the process moderation limit. This 'moderation safety factor', which is the ratio of the safety moderation limit to the process moderation limit, will normally be three or higher, but never less than two. The value of the moderation safety factor depends on the likelihood and time required for this system being considered to transition from the process moderation limit to the safety moderation limit.

In some cases, as described above, increased depth of protection may be required, but the minimum protection is never less than the following: two independent controls prevent moderator from entering the system through a defined interface and must fail

before a criticality accident is possible. The quality and basis for selection of the controls is documented in accordance with Integrated Safety Analysis process described in Chapter 4.0. Controls for the introduction and limited usage of moderating materials (e.g. for cleaning or lubrication purposes) within areas in which the primary criticality safety parameter is moderation are approved by the criticality safety function.

6.2.5.4 **Concentration (or Density)** - Concentration control may be used for nuclear criticality safety control on its own or in combination with other control methods. Concentration controls are established to ensure that the concentration level is maintained within defined limits for the system. When concentration is the only parameter controlled to prevent criticality, concentration may be controlled by two independent combinations of measurement and physical control, each physical control capable of preventing the concentration limit being exceeded in a location where it would be unsafe. The preferred method of attaining independence being that at least one of the two combinations is an active engineered control. Each process relying on concentration control has in place controls necessary to detect and/or mitigate the effects of internal concentration within the system (e.g., Dynatrol density meter, Rhonan density meter, etc.), otherwise, the most reactive credible concentration (density) is assumed.

6.2.5.5 **Neutron Absorber** - Neutron absorbing materials may be utilized to provide a method for nuclear criticality safety control for a process, vessel or container. Stable compounds such as boron carbide fixed in a matrix such as aluminum or polyester resin; elemental cadmium clad in appropriate material; elemental boron alloyed stainless steel, or other solid neutron absorbing materials with an established dimensional relationship to the fissionable material are recommended. The use of neutron absorbers in this manner is defined as part of a passive engineered control.

Credit may be taken for neutron absorbers such as gadolinia in completed nuclear fuel bundles (e.g., packaged and stored onsite for shipment) provided the following requirements are met:

- The presence of the gadolinia absorber in completed fuel rods is documented and verified using non-destructive testing; and the placement of rods in completed fuel bundles is documented in accordance with established quality control practices.

Credit may be taken for neutron absorbers that are normal constituents of filter media (e.g., natural boron) provided the following requirements are met:

- The failure or loss of the media itself also prevents accumulation of significant quantities of fissile material.
- The neutron absorber content is certified.

For fixed neutron absorbers used as part of a geometry control, the following requirements apply:

- The composition of the absorber are measured and documented prior to first use.
- Periodic verification of the integrity of the neutron absorber system subsequent to installation is performed on a scheduled basis approved by the criticality safety function. The method of verification may take the form of traceability (i.e. serial number, QA documentation, etc.), visual inspection or direct measurement.

6.2.5.6 **Spacing (or Unit Interaction)** - Criticality safety controls based on isolation or interacting unit spacing. Units may be considered effectively non-interacting (isolated) when they are separated by either of the following:

- 12-inches of full density water equivalent, or
- the larger of 12-foot air distance or the greatest distance across an orthographic projection of the largest of the fissile accumulations on a plane perpendicular to the line joining their centers.

For Solid Angle interaction analyses, a unit where the contribution to the total solid angle in the array is less than 0.005 steradians is also considered non-interacting (provided the total of all such solid angles neglected is less than one half of the total solid angle for the system). Transfer pipes of 2 inches or less in diameter may be excluded from interaction consideration, provided they are not grouped in close arrays.

Techniques which produce a calculated effective multiplication factor of the entire system (e.g., validated Monte Carlo or $S_n$ Discrete Ordinates codes) may be used. Techniques which do not produce a calculated effective multiplication factor for the entire system but instead compare the system to accepted empirical criteria, (e.g., Solid Angle methods) may also be used. In either case, the criticality safety analysis must comply with the requirements of Sections 6.1.1 and 6.3.

6.2.5.7 **Material Composition (or Heterogeneity)** - The criticality safety analysis for each process determines the effects of material composition (e.g., type, chemical form, physical form) within the process being analyzed and identifies the basis for selection of compositions used in subsequent system modeling activities.

It is important to distinguish between homogeneous and heterogeneous system conditions. Heterogeneous effects within a system can be significant and therefore must be considered within the criticality safety analysis when appropriate. Evaluation of systems where the particle size varies take into consideration effects of heterogeneity appropriate for the process being analyzed.

6.2.5.8 **Reflection** - Most systems are designed and operated with the assumption of 12-inch water or optimum reflection. However, subject to approved controls which limit reflection, certain system designs may be analyzed, approved, and operated in situations where the analyzed reflection is less than optimum.

In criticality safety analysis, the neutron reflection properties of the credible process environment are considered. For example, reflectors more effective than water (e.g., concrete) are considered when appropriate.

6.2.5.9 **Enrichment** - Enrichment control may be utilized to limit the percent U-235 within a process, vessel, or container, thus providing a method for nuclear criticality safety control. Active engineered or administrative controls are required to verify enrichment and to prevent the introduction of uranium at unacceptable enrichment levels within a defined subsystem within the same area. In cases where enrichment control is not utilized, the maximum credible area enrichment is utilized in the criticality safety analysis.

6.2.5.10 **Process Characteristics** - Within certain manufacturing operations, credit may be taken for physical and chemical properties of the process and/or materials as nuclear criticality safety controls. Use of process characteristics is predicated upon the following requirements:

- The bounding conditions and operational limits are specifically identified in the criticality safety analysis and, are specifically communicated, through training and procedures, to appropriate operations personnel.

- Bounding conditions for such process and/or material characteristics are based on established physical or chemical reactions, known scientific principles, and/or facility-specific experimental data supported by operational history.
- The devices and/or procedures which maintain the limiting conditions must have the reliability, independence, and other characteristics required of a criticality safety control.

Examples of process characteristics which may be used as controls include:

- Conversion and oxidation processes that produce dry powder as a product of high temperature reactions.
- Experimental data demonstrating low moisture pickup in or on uranium materials that have been conditioned by room air ventilation equipment.
- Experimental/historical process data demonstrating uranium oxide powder flow characteristics to be directly proportional to the quantity of moisture present.

## 6.3 CONTROL DOCUMENTS

### 6.3.1 CRITICALITY SAFETY ANALYSIS (CSA)

In accordance with ANSI/ANS-8.19 (1984), the criticality safety analysis is a collection of information that "provides sufficient detail clarity, and lack of ambiguity to allow independent judgment of the results." The CSA documents the physical/safety basis for the establishment of the controls. The CSA is a controlled element of the Integrated Safety Analysis (ISA) defined in Chapter 4.0.

The CSA addresses the specific concerns (event sequences) of nuclear criticality safety importance for a particular system. A CSA is prepared or updated for each new or significantly modified unit or process system within the GE-Wilmington facility in accordance with established configuration management control practices defined in Chapter 3.0.

The scope and content of any particular CSA reflects the needs and characteristics of the system being analyzed and includes applicable information requirements as follows:

- **Scope** - This element defines the stated purpose of the analysis.
- **General Discussion** - This element presents an overview of the process that is affected by the proposed change. This section includes as appropriate; process description, flow diagrams, normal operating conditions, system interfaces, and other important to design considerations.
- **Criticality Safety Controls/Bounding Assumptions** - This element defines a minimum of two criticality safety controls that are imposed as a result of the analysis. This section also clearly presents a summary of the bounding assumptions used in the analysis. Bounding assumptions include; worst credible contents (e.g., material composition, density, enrichment, and moderation), boundary conditions, interunit water, and a statement on assumed structure. In addition, this section includes a statement which summarizes the interface considerations with other units, subareas and/or areas.
- **Model Description** - This element presents a narrative description of the actual model used in the analysis. An identification of both normal and credible upset (accident condition) model filenaming convention is provided. Key input listings and corresponding geometry plot(s) for both normal and credible upset cases are also provided.
- **Calculational Results** - This element identifies how the calculations were performed, what tools or reference documents were used, and when appropriate, presents a tabular listing of the calculational result and associated uncertainty (e.g., Keff + $3\sigma$) results as a function of the key parameter(s) (e.g., wt. fraction $H_2O$). When applicable, the assigned bias of the calculation is also clearly stated and incorporated into both normal and/or accident limit comparisons
- **Safety During Upset Conditions** - This element presents a concise summary of the upset conditions considered credible for the defined unit or process system. This section include a discussion as to how the established nuclear criticality safety limits are addressed for each credible process upset (accident condition) pathway.
- **Specifications and Requirements for Safety** - When applicable, this element presents both the design specifications and the criticality safety requirements for correct implementation of the established controls. These requirements are incorporated into operating procedures, training,

maintenance, quality assurance as appropriate to implement the specifications and requirements.

- **Compliance** - This element concludes the analysis with pertinent summary statements and includes a statement regarding license compliance.
- **Verification** - Each criticality safety analysis is verified in accordance with section 6.3.2.5 by a senior engineer approved by the criticality safety function and who was not involved in the analysis.
- **Appendices** - Where necessary, a summary of information ancillary to calculations such as parametric sensitivity studies, references, key inputs, model geometry plots, equipment sketches, useful data, etc., for each defined system is included.

## 6.3.2 ANALYSIS METHODS

### 6.3.2.1 Keff Limit

Validated computer analytical methods may be used to evaluate individual system units or potential system interaction. When these analytical methods are used, it is required that the effective neutron multiplication factors for credible process upset (accident) conditions are less than or equal to 0.97 including applicable biases and calculational uncertainties, that is:

$K_{eff} + 3\sigma - bias \leq 0.97$ (accident conditions).

Thus, the established delta-k safety margin used at the GE-Wilmington facility is 0.03.

Normal operating conditions include maximum credible conditions expected to be encountered when the criticality control systems function properly. Credible process upsets include anticipated off-normal or credible accident conditions and must be demonstrated to be critically safe in all cases in accordance with Section 6.1.1. The sensitivity of key parameters with respect to the effect on Keff are evaluated for each system such that adequate criticality safety controls are defined for the analyzed system.

### 6.3.2.2 Analytical Methods

Methodologies currently employed by the GE-Wilmington criticality safety function include hand calculations utilizing published experimental data (e.g., ARH-600 handbook), Solid Angle methods (e.g., SAC code), and Monte Carlo codes (e.g., GEKENO, GEMER) which utilize stochastic methods to solve the 3D neutron transport equation. Additional Monte Carlo codes (e.g., Keno Va and MCNP) or $S_n$ Discrete Ordinates codes (e.g., ANISN or XSDRNPM) may be used after validation as described in subparagraph (c) below.

GEKENO (Geometry Enhanced KENO) is a multigroup Monte Carlo program which solves the neutron transport equation in 3-dimensional space. The GEKENO criticality program utilizes the 16-energy group Knight-Modified Hansen Roach cross-section data set, and a potential scattering $\sigma_p$ resonance correction to compensate for flux depression at resonance peaks. GEKENO is normally used for homogeneous systems. For infinite systems, $K_\infty$ can be calculated directly from the Hansen Roach cross-sections using the program KINF.

GEMER (Geometry Enhanced MERit) is a multigroup Monte Carlo program which solves the neutron transport equation in 3-dimensional space. The GEMER criticality program is based on 190-energy group structure to represent the neutron energy spectrum. In addition, GEMER treats resolved resonances explicitly by tracking the neutron energy and solving the single-level Breit-Wigner equation at each collision in the resolved resonance range in regions containing materials whose resolve resonances are explicitly represented. The cross-section treatment in GEMER is especially important for heterogeneous systems since the multigroup treatment does not accurately account for resonance self-shielding.

### 6.3.2.3 Validation Techniques

Experimental critical data or analytical methods which have been validated (benchmarked) by comparison with experimental critical data in accordance with criteria described in section 4.3 of ANSI/ANS 8.1 (1983) are used as the basis for validation. An analytical method is considered validated when the following are established:

- the type of systems which can be modeled
- the range of parameters which may be treated
- the bias, if any, which exists in the results produced by the method.

Currently GEMER is validated against 123 critical experiments and GEKENO is validated against 56 critical experiments. Both validations produce a bias fit as a function of H/U235 atom ratio. This fit is established against the lower limit of the 3-sigma confidence band (see Figures 6.1 and 6.2). The bias ($K_{calc}$ - 1.0) is applied over its negative range and assigned a value of zero over its positive range. The range of applicability covers all compounds in use at GE-Wilmington and enrichments up to 5.0 % wt. % U235.

FIGURE 6.1 - GEMER BIAS DETERMINATION, PARTICLE WEIGHT

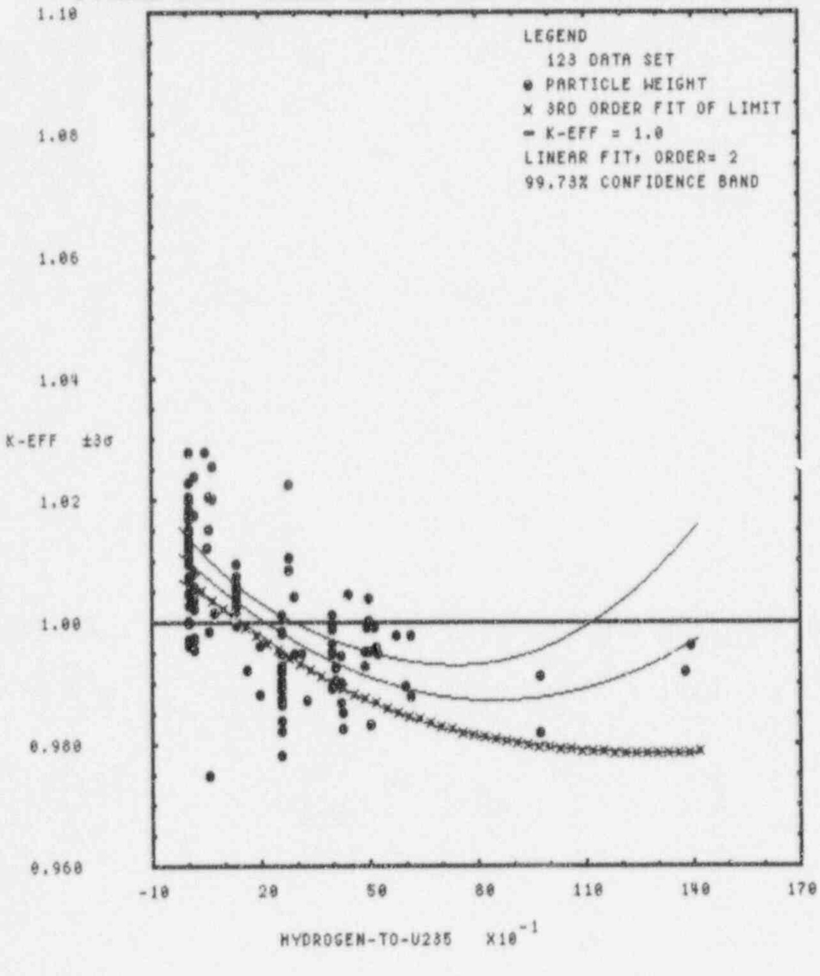
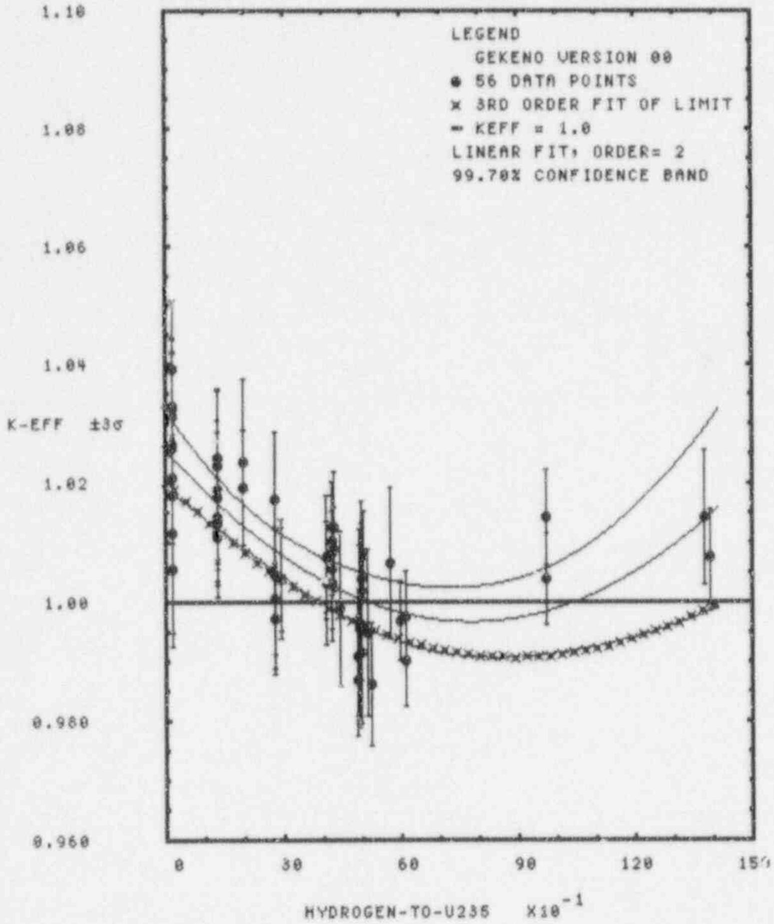


FIGURE 6.2 - GEKENO BIAS CALCULATION




6.3.2.4 Computer Software & Hardware Configuration Control

The software and hardware used within the criticality safety calculational system is configured and maintained so that change control is assured through the authorized system administrator. Software changes are conducted in accordance with an approved configuration control program described in Chapter 3.0 that addresses both hardware and software qualification.

Software designated for use in nuclear criticality safety are compiled into working code versions with executable files that are traceable by length, time, date, and version. Working code versions of compiled software are validated against critical experiments using an established methodology with the differences in experiment

and analytical methods being used to calculate bias and uncertainty values to be applied to the calculational results.

Each individual workstation is verified to produce results identical to the development workstation prior to use of the software for criticality safety calculations demonstrations on the production workstation.

Modifications to software that may affect the calculational logic require re-validation of the software. Modifications to hardware or software that do not affect the calculational logic are followed by code operability verification, in which case, selected calculations are performed to verify identical results from previous analyses. Deviations noted in code verification that might alter the bias or uncertainty requires re-qualification of the code prior to release for use.

6.3.2.5 Technical Reviews

Independent technical reviews of proposed criticality safety control limits specified in criticality safety analyses are performed. A senior engineer within the criticality safety function is required to perform the independent technical review.

The independent technical review consists of a verification that the neutronics geometry model and configuration used adequately represent the system being analyzed. In addition, the reviewer verifies that the proposed material characterizations such as density, concentration, etc., adequately represent the system. He/She also verifies that the proposed criticality safety controls are adequate.

The independent technical review of the specific calculations and computer models are performed using one of the following methods:

- Verify the calculations with an alternate computational method.
- Verify the calculations by performing a comparison to results from a similar design or to similar previously performed calculations.
- Verify the calculations using specific checks of the computer codes used, as well as, evaluations of code input and output.
- Verify the calculations with a custom method.

Based on one of these prescribed methods, the independent technical review provides a reasonable measure of assurance that the chosen analysis methodology and results are correct.