70-340

SNM-329

SPENCER CHEMICAL COMPANY

NUCLEAR FUELS DEPARTMENT

APPLICATION FOR

SPECIAL NUCLEAR MATERIAL LICENSE

June 22, 1959

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I

INTRODUCTION AND APPLICATION

1. This application for a special nuclear material license is submitted by Spencer Chemical Company. The company is incorporated in the state of Missouri and has its principal office in the Dwight Building in Kansas City, Missouri. The principal officers of the Company are:

   K. A. Spencer - President

   C. Y. Thomas - General Vice President (Operations)

   J. P. Miller - General Vice President (Finance)

   J. E. Culpepper - General Vice President (Marketing)

   E. V. Friedrich - Vice President, Administration, and Assistant Secretary

   J. C. Denton - Vice President, Agricultural Chemical Division

   H. R. Dinges - Vice President, Industrial Chemicals Division

   F. L. Pyle - Vice President, Plastics Division

   N. C. Robertson - Vice President, Research and Development Division

   E. W. Morgan - Treasurer

   A. Mag - Secretary

2. All these officers have their offices in the Dwight Building except for Mr. Mag whose address is 9 West Tenth Street, Kansas City, Missouri. All are natural born citizens of the United States. The company is not controlled by any alien, foreign corporation or foreign government.

3. This license is requested for the processing of any enrichment of uranium up to and including 5%. The uranium in the form of UF_6 or scrap is to be converted to the oxide. The processing will be done at the Jayhawk Works of the Spencer Chemical Company located between Pittsburg, Kansas, and Joplin, Missouri, with a freight shipping designation of Military, Kansas.

4. The license is requested for ten years.

5. The product of the process normally will be finely divided UO_2 powder. Oxides other than UO_2 may also be produced as finely divided powders. Nitrates and sulphates may also be produced.

6. The uranium will be processed for other licensees. Plant start-up is scheduled for July 20, 1959. The maximum design processing rate is 300 pounds of uranium per day. The actual processing rate will depend upon the exact nature of the feed material and upon customer demand. Inventory of U-235 at the plant will not exceed 1,000 kilograms. Processing losses generally will be held to less

than one percent, but may exceed this for small lots.

7. The Spencer Chemical Company is currently engaged in the manufacture of ammonia, nitric acid, ammonium nitrate, polyethylene, nylon, urea, methanol and other similar products. Since December 1, 1957, Spencer has been operating a uranium oxide pilot plant (under license No. SNM-154) and has gained much valuable experience in the handling and processing of enriched uranium.

II

QUALIFICATIONS OF PERSONNEL

1. The processing of uranium is the direct responsibility of Harold Lambertus, Manager, Nuclear Fuels. Mr. Lambertus reports directly to H. R. Dinges, Vice President, Industrial Chemicals Division.

2. Mr. Dinges received a B. S. degree in chemistry from College of William and Mary in 1938, where he also served as instructor from 1939 to 1941. He was employed by E. I. duPont de Nemours and Company 1941-42, and Olin Mathieson Chemical Company 1942-47 before joing Spencer Chemical Company in February, 1947. Since February, 1957, Mr. Dinges has been Vice President, Industrial Chemicals Division.

3. Mr. Lambertus received his B. S. and M. S. degrees in Mechanical Engineering from Purdue University and California Institute of Technology respectively. He was employed in 1946 by the American Bearing Corporation where he received a background in engineering, sales and production. He was a vice president at American Bearing prior to his leaving there in 1958, and was responsible for the planning, building and staffing of a nuclear fuel element manufacturing facility. Just prior to joining Spencer Chemical Company as Manager of the Nuclear Fuels Department in April, 1959, Mr. Lambertus served as a consultant to several manufacturers of nuclear fuel elements.

4. The operation of the uranium processing plant is the responsibility of George E. Chenoweth, Plant Superintendent. Mr. Chenoweth received a B. S. degree in chemical engineering from the University of Missouri in 1951. He was employed by Phillips Petroleum Company from 1951 to 1952, and joined Spencer Chemical Company in 1952. He has been responsible for much of the process equipment design for the experimental uranium facilities and has been in charge of the operation of the uranium pilot plant facility since January 1, 1959.

5. Mr. Sinesio A. Zagnoli has been responsible for a major portion of the process design. Mr. Zagnoli received his B. S. in chemical engineering from Purdue University and his M. S. in chemical engineering and M. S. in gas technology from Illinois Institute of Technology. He had some three years of industrial experience with petroleum and natural gas industry before his entry into

atomic energy activities in 1952. He entered the atomic energy program with Nuclear Power Group in Chicago representing the Commonwealth Edison Company. He participated in several studies made by the Public Service Company of Northern Illinois and Commonwealth Edison Company before the latter joined Nuclear Power Group. With NPG Mr. Zagnoli's work was with heat transfer, fuels processing and fuel element metallurgy. He joined Spencer Chemical Company in October 1955, and has helped plan and design experimental programs and facilities, and has made economic analyses of various projects in the atomic energy field.

6. Dr. Russell A. Mesler of the University of Kansas is our consultant for criticality considerations. Dr. Mesler's background includes the Oak Ridge School of Reactor Technology 1951-52; Ph.D., University of Michigan 1955; Project Engineer for Ford Nuclear Reactor and Assistant Professor of Nuclear Engineering, University of Michigan, 1955-57. He is presently Associate Professor of Chemical Engineering at the University of Kansas.

III

PROCESSING AREA

1. The following equipment and facilities will be used to protect health and minimize danger to life and/or property.

2. The building used for uranium processing is constructed of a steel framework and covered with transite siding. The building measures 45' x 112' and is 30' high except for a 50' high bay in the center of the building.

3. The processing equipment will be located along the east half of the building only. Storage area has been provided in the west side of the building.

4. A fence encompasses the entire Jayhawk plant works and entrance into the plant area is controlled by a 24-hour guard force.

5. Tornadoes are a possibility in Kansas. Plant design is on the premise that a condition of criticality resulting from tornado damage would do negligible damage compared to that of a tornado.

6. The building site is 30 feet above any previous flood stage.

7. Loss of electrical power presents the hazards of loss of ventilation and an inoperative radiation alarm system.

8. In compliance with section 70.24 a radiation alarm system will be installed in the plant. Two detectors will be located in the plant, one on the ground level near the hydrolysis and scrap dissolution area and one on the first balcony at the panel board. These positions are indicated on the plot plan

(Drawing No. 1-2600-4). Outside alarm horns will also be connected to these alarms which will be clearly audible in the surrounding area.

9. The monitoring system to be installed is the Nuclear Measurements Corporation Gamma Alarm system (GA-2). This system consists of individual integral units containing the detector, power supply, meter, alarm bell, alarm lights and relays for connecting external warning devices.

10. These units will be set to give an alarm when the meter reads 6 mr/hr. or more. The time constant of this instrument is 2 seconds so that a 6 mr/hr reading would occur after the following delay times when the radiation level at the detector is instantaneously changed to a higher value:

50 mr/hr	0.236 sec.
100 mr/hr	0.118 sec.
500 mr/hr	0.024 sec.

Once the meter reads 6 mr/hr, the alarm would sound within 0.1 second. The response time will be verified by tests after the system is installed.

11. The detector will be activated by a low level source installed at the probe so that the meter reads at least 0.1 mr/hr under normal conditions. If failure of the instrument causes the meter to drop to 0.05 mr/hr, a light on the unit (normally on) will go out. Another light on the unit indicates the instrument is drawing current.

IV

PRECAUTIONS FOR SAFETY

1. The following procedures are proposed to protect health and minimize danger to life and/or property.

2. All personnel working with uranium are required to pass a complete medical examination including a chest x-ray before starting to work. Monthly urine samples will be analyzed for uranium. Chest x-rays will be required annually. No smoking or eating will be permitted in the uranium processing building.

3. Coveralls, safety shoes, safety glasses, acid goggles, dust masks, and rubber gloves are furnished for all personnel working in the plant. A change house and locker room are provided so clothing may be changed before entering the plant area. A washing machine is provided and coveralls must be washed daily after use. Individual film badges are provided and are checked monthly.

4. Good housekeeping will be exercised. Wet mopping will be performed in order to minimize air polution.

5. Any minor spills will be cleaned up immediately both to recover the uranium and to avoid spread of contamination. Clean-up solutions will be stored in safe containers awaiting return to the process. Major spills may necessitate orderly plant shutdown and reducing of the inventory of uranium in the spill area to allow more freedom of movement.

6. Portable Geiger counters will be available in the plant for surveying working areas for contamination. Building and exhaust air will be sampled to see that concentrations are below permissible limits of 5.0×10^{-11} and 1.7×10^{-12} microcuries per ml respectively.

7. Aqueous wastes will be discharged to the sewer which carries an average daily flow in excess of ten million gallons away from the plant. The quantity of waste released to the sewer will be limited to a quantity which, if diluted by the average daily flow of sewage, will result in an average concentration less than 2×10^{-4} microcuries per ml. These conditions are set by Title 10, Part 20, Code of Federal Regulations.

8. Only one uranium container may be in motion at any one time and no uranium container may be moved unless all other uranium containers are in approved locations.

9. The uranium processing building will be posted and uranium containers will be labelled according to Title 10, Part 20, Code of Federal Regulations. Outside shipping containers will be labelled according to ICC regulations.

10. Safe geometry storage is provided for all process streams. Before pumping any solution from safe waste storage tanks to the sewer, it is to be sampled to assure that the uranium concentration is below the permissible level.

11. While the building housing the plant is essentially fireproof, a fire in the processing area presents three problems. First, the organic phase for extraction is inflammable. Second, the reducing atmosphere in the furnace is both inflammable and explosive. Third, water used in fighting a fire could mix with uranium and create a criticality condition. CO_2 will be used to control any fire in the uranium building and the plant fire department is instructed not to use water unless requested to do so by the Plant Supervisor. Precautions have been taken to prevent explosions of the atmosphere in the furnace. In the event of a fire or explosion, the area will be surveyed for uranium contamination prior to re-entry.

12. The radiation alarm detectors will be checked hourly and the meter reading recorded on log sheets. The built-in low-level source provides a calibration check at one point. A portable source will be used to check the instrument at higher levels. The calibration will be checked once per week.

13. A training program will be initiated for all personnel who would be affected by a high radiation incident. Instructional meetings will be held for all people involved in the handling and processing of uranium to familiarize them with the alarm system and the proper procedures for evacuating the area in the event of a radiation incident. Unannounced practice evacuation drills will be held once a week the first month, another one a month later and then once every three months.

14. Criticality is avoided primarily by proper spacing of "always safe" geometry vessels. Concentration and mass control is exercised in handling dilute solutions. Mass and moderation control is exercised in handling dry UO_2 and in shipping and storing scrap uranium. A combination of mass, volume and moderation control is used in specifying containers for shipping and storing UO_2 product. All safe parameters are safe with a thick water reflector. The interaction between all vessels containing uranium in significant concentrations is within allowable limits.

15. A process description and equipment layout are presented in the appendix with a discussion of methods used for prevention of criticality.

V

FINANCIAL QUALIFICATIONS

1. A copy of the 1958 annual report of the Spencer Chemical Company is submitted with this application in support of the company's financial qualifications to handle enriched uranium.

VI

INSURANCE

1. Spencer Chemical Company carries a $5,000,000 liability policy to cover property damage or bodily injury to the public attributable to the uranium facilities. Spencer is also fully insured against loss of materials at the plant or in shipment. These two policies are issued by Nuclear Energy Liability Insurance Association and Nuclear Energy Property Insurance Association respectively.

APPENDIX

I. PROCESS DESCRIPTION

1. This process is designed to produce primarily UO_2 from either UF_6 or scrap. With UF_6 as a starting material, a cylinder is weighed and then vaporized using steam heat. A vacuum pump preceded by a cold trap and a chemical trap permits evacuation and leak testing of the UF_6 piping.

2. The UF_6 is hydrolyzed by admitting the gas into a circulating stream of $AL(NO_3)_3$. Acid may also be added to adjust the acidity. The hydrolysis solution is transferred to rich acid storage.

3. With scrap UO_2 pellets, a weighed quantity of scrap is added to the empty dissolver and HNO_3 circulated through it and a rich acid storage tank until the desired concentration is reached. The dissolver vessel is jacketed to provide for heating or cooling.

4. Since "off-spec" product may be produced from time to time, provision is made for recycling it through the process. This scrap UO_2 powder is dissolved in a kettle using always mass safe batches, and then pumped to the rich acid storage tanks.

5. The rich acid is pumped to a countercurrent pulse extraction column. A solution of tri-butyl-phosphate in kerosene is used as the solvent. The rich organic phase from the extractor overflows to the scrub column. The raffinate flows to the waste storage tanks where it is sampled. From here it is either drained to the sewer or recycled to the system depending on the uranium concentration.

6. In the scrub column the rich organic is contacted with water. The water is recycled to the extraction column and the rich organic flows to the stripper where the uranium is stripped from it with water. The stripped organic phase overflows to a system which continuously cleans the solvent for reuse. The rich aqueous phase is fed to an evaporator to concentrate it and then precipitated with ammonia.

7. The ammonium diuranate precipitate is reduced to UO_2 in an electrically heated furnace. The UO_2 product is discharged through a mill to hoppers where it is sampled for moisture and other properties prior to being charged to the blender.

8. A dry atmosphere is maintained in the blender. Mass and moderation limits are used to determine the size of lots blended. After blending the UO_2 is discharged into approved shipping containers.

Appendix

II. PLANT LAYOUT AND EQUIPMENT DESCRIPTION

1. The building to house this facility is contained within the Jayhawk plant site. It is constructed of steel framework and covered with transite siding. All processing equipment is located along the east half of the building. High equipment such as the extraction columns is located in the 50' high bay in the center of the building. Layout of the equipment is shown on drawings 1-2600-4 and 1-2600-802.

2. The east wall behind the tanks and equipment is lined with stainless steel sheet to facilitate clean-up of spills and splashes. A stainless steel drip pan is provided along this wall under the equipment to contain leaks and spills. There are no floor drains to eliminate the possibility of a spill being lost to the sewer.

3. The UO_2 scrap pellet dissolver is 8.25" I.D. The dissolver for "off-spec" UO_2 powder is a kettle and will be used with mass safe batches. The cold trap is of 4" pipe and the evaporator is 8" Sch. 10 pipe. The pulse columns are 4" pipe with 8" pipe end section. All uranium-containing storage tanks are 10.25" maximum I.D.

4. The UF_6 cylinders are vaporized in a closed room. This room is provided with adequate forced ventilation. The exhaust air from the room is drawn through a scrubbing system to remove any UF_6 vapors. A fluorine detector is located in the duct carrying air from the room to detect any UF_6 leaks. The same fume scrubber system also is connected to a hood over the UO_2 powder dissolver to recover any uranium carry-over from the dissolutions.

*5. Storage area is provided in the southwest quadrant of the processing building for feed materials and/or packaged product. Safe spacing will be maintained on all containers of uranium stored in this area. If more space is required, UF_6 cylinders may be stored outside in their bird cages on a concrete pad near the southwest corner of the building.

III. CRITICALITY CONSIDERATIONS

A. Criticality With UF_6 Feed

1. UF_6 in cylinders at enrichments no greater than 5% U-235 will be removed from storage or brought directly to the southwest corner of the processing area. Cylinders will be transported into the processing area on a monorail and placed in stations provided for the vaporization of the UF_6. With full UF_6 cylinders at all stations, the total U-235 inventory will be 66 kilograms. According to TID-7016, page 9, there are no mass limits on a non-hydrogenous chemical compound with a U-235/U-238 ratio of .05. The individual cylinders are spaced at distances of greater than 1 foot edge-to-edge according to K-1019 Rev. 4, page 25.

2. The UF_6 is reacted with water and the resulting solution is stored in vessels R-1, R-2, R-3, R-4, T-1, T-2, T-3, and T-4. The maximum concentration of uranium in these solutions is 100 grams per liter which corresponds to a maximum U-235 concentration of 5 grams per liter for 5% U-235 enrichments. According to K-1019 Rev. 4, page 20, 5.0 grams of U-235 per liter is an "always-safe" parameter. Further, according to page 24, interaction need not be considered for homogeneous solutions with a U-235 concentration no greater than 5 grams per liter. Vessels R-1, R-2, R-3, R-4, T-1, T-2, T-3 and T-4, are all 10-1/4 inch diameter vessels which is a "limited safe" parameter according to K-1019 Rev. 4, page 21, for 5% enrichment and below.

3. The UF_6 solution is pumped to the extraction columns where the uranium is extracted into an organic solution of TBP. The minimum ratio of H to U-235 in the organic phase is 6320. According to TID-7016, page 9, there are no restrictions for solutions if the atomic ratio of H/U-235 is greater than 2300. The maximum concentration of U-235 in the aqueous stream from the strip column (TA-3) is again 5 grams U-235 per liter for 5% U-235. In addition, the columns are 4 inches diameter with 8 inch separating sections. This stream flows to the neutralizer where the uranium concentration is slightly decreased. The neutralizer is a 10-1/4 inch diameter vessel as an extra precaution.

4. Out of the neutralizer the stream flows to E-3 on the first balcony. In E-3 the uranium concentration is increased to 450 grams per liter (22.5 grams U-235 per liter at 5% enrichment). E-3 is an 8 inch pipe with a 2 inch leg. By comparison to a "limited-safe" diameter of 10.25 inches, E-3 is considered safe. Interaction has been calculated between the evaporator and (1) the furnace, (2) vessel R-9, (3) the UO_2 hoppers, T-18 and T-19, (4) the blender M-5, (5) UO_2 packages on the first and second floors, and (6) vessels T-13 and T-14. The total solid angle viewed of these is less than 0.5 steradians.

5. The stream from E-3 is stored in two vessels, T-13 and T-14. These vessels are 10-1/4 inches I.D. x 8 feet tall, so that they are safe. Interaction must be considered between each other and the blender. The total interaction is .9 steradian which is less than the allowable 1.0 (K-1019 Rev. 4, page 24.)

6. From R-13 and R-14 the rich aqueous is pumped to R-9 on the second balcony. R-9 is a 10.25 inch diameter vessel. It sees even less than the neutralizer (R-8) which sees .50 steradians so that interaction is safe.

7. The product from R-9 is transferred to the furnace. The furnace proper is fitted with a 9 inch I.D. liner. The feed screw drops the uranium bearing material onto this furnace liner. There are three screws each operating in 2 inch pipe conveying the uranium. The furnace gases pass countercurrent to the uranium, and conceivably could carry light dried material into the breech where the gases leave the furnace. No significant carryover has ever been observed. The volume in the breech is .625 cubic foot compared to a safe volume of .95 cubic foot. The gas discharge line is steam traced to prevent condensation in the gas line before the condenser.

8. The furnace tube itself never operates more than one quarter full. It discharges into a breech of 1.465 cubic feet capacity. At a discharge rate of .25 cubic foot per hour, hourly inspection will prevent anything approaching an unsafe accumulation. Should the furnace exit gas temperature fall 50° below its normal value, the feed to the furnace will be shut off automatically. The furnace sees less than .9 steradians which is safe.

9. The furnace discharges into T-18 and T-19. The quantity of UO_2 allowed to accumulate in T-18 or T-19 will be kept below the safe amounts as limited by enrichment. (Table XVII, K-1019 Rev. 4). These vessels each have a k of .65 because they are mass safe (K-1019 Rev. 4, page 26). The allowable solid angle is 2.51 compared with an actual value of 1.28 steradians.

10. After a moisture analysis has been obtained on their contents, T-18 or T-19 can either be transferred to M-5 or to storage.

11. The entire inventory of UO_2 in M-5, SC-1 and at the bullion balance is limited to a safe mass quantity as limited by moderation. Table XIX of K-1019 Rev. 4 will be used to specify the safe mass to that corresponding to the highest H/U-235 ratio of any material added to the inventory. Table XIX is for UF_6, but since the density of UO_2 here is no greater than for UF_6, the table is applicable. The maximum solid angle of interaction at M-5, SC-1 or the bullion balance is .77 compared to a safe interaction of 1.0 steradians.

12. After filling the UO_2 containers, they are spaced at least one foot edge-to-edge from each other while they are weighed and transported to storage.

B. UO_2 Feed

1. General

   a. The criticality conditions of the uranium process using UF_6 feed have already been described. Use of UO_2 feed alters the situation in the following respects:

      (1) Dissolution of fired UO_2 represents a special problem because of the high density of fired UO_2.

      (2) The solutions produced from UO_2 dissolution are more concentrated than those produced from UF_6.

   b. The portion of the plant beyond the extraction columns operates the same regardless of the feed. However, there is more interaction which must be considered.

   c. There are two types of UO_2 -- high density and low density. High density UO_2 is that which has been pressed and fired, while the low density material is characteristic of scrap generated in the process.

2. Low Density UO_2 Dissolution

   a. Low density UO_2 (less than 3 grams per ml) is batch dissolved in R-5. The charge into R-5 is limited to the mass limits shown in Table XVII of K-1019 Rev. 4, page 22.

   b. The UO_2 scrap is generated at T-18 and T-19. The scrap is drained from the hopper into a 5 gallon pail on the first balcony. After each pail is filled, it is carried down the north stairs to the first floor where it is weighed on SC-1. The pails will be marked with the weight and assay. From weighing, the pail is carried either to storage, or is carried to R-5. The route taken is to be over to the west side of the process line to the south stairs and up them to the UO_2 dissolver.

   c. When dissolving a batch of low density UO_2, R-5 is first emptied. Then the safe mass or less is carried in 5 gallon pails to the dissolver. Never will the total quantity of uranium in the vicinity of R-5 or within R-5 exceed a safe mass. Before making up a batch, the supervisor is to certify that the quantity of uranium in pails is a safe batch.

   d. When a batch is dissolved, it is pumped to storage. A check valve and a manually operated valve prevent solution in storage from increasing the uranium in R-5.

3. High Density UO_2 Dissolution

a. High density UO_2 is dissolved in R-13 which has safe dimensions. The UO_2 is hoisted to the first balcony on a monorail at the southwest corner of the process. The monorail carries the UO_2 to the north side of R-13. Only that amount of UO_2 which R-13 can accomodate at any one time is hoisted. The UO_2 is dumped into R-13. The total amount of UO_2 being added to R-13 is mass safe by moderation. R-13 must be emptied prior to recharging.

b. The safe diameter for R-13 was determined in the following fashion: Calculations in HW-57861, page 24, show the maximum buckling for 5% U-235 metallic uranium rod in water lattices to be 150×10^{-4} cm^{-2}. Values for other parameters, near this maximum buckling, are as follows:

$$k_\infty = 1.65$$

$$L^2 = 1.1 \text{ cm}^2$$

$$\tau = 32.5 \text{ cm}^2$$

For an 8.25 inch diameter vessel, K-1380, page I-13 to 15, shows $B_1^2 = .0344$, $B_2^2 = 0.049$. The value for k effective is:

$$k = \frac{k_\infty e^{-B_1^2 \tau}}{1 + L^2 B_2^2} = 0.513$$

A value of 10.25 for the radius gives k = .7, but the actual vessel radius of 8.25 is specified as an added factor of safety. Another safety factor is included because UO_2 with its lower density shows lower maximum buckling than does the metallic uranium as discussed in HW-57861, page 19.

c. The random placement of the rods when merely dumped into a vessel presents some uncertainty. Lattice values given above are for orderly spaced, uniform rods. Preliminary experiments mentioned in HW-56919, page 20, indicate the randomness tends to lower the buckling. This was assumed also in TID-7016, page 21.

d. Interaction between R-13 and its neighbors is less than 1.75 steradians compared to an allowable of 3.9 steradians (see Table I).

4. Allowable Interactions With UO_2 Feed

a. The interactions between all vessels which contain uranium at concentrations above 5 grams U-235/liter with UO_2 feed have been conservatively estimated by the methods given in TID-7016, page 14. These estimates are shown in Table I. Where the

Table I

Vessel	Diameter (Inches)	Contents	Interaction (Steradians)
E-3	8.25	b*	1.6
F-4	7.75	a*	2.8
F-5	7.75	a	2.5
KL-1	9.0	---	2.32
M-5	---	UO_2	1.15
R-1	10.25	a	1.56
R-2	10.25	a	1.91
R-3	10.25	a	1.65
R-4	10.25	a	1.97
R-5	22.0	a	.45
R-8	10.25	a	1.56
R-9	10.25	b	.93
R-13	8.25	---	1.73
SC-1	---	UO_2	2.05
T-1	10.25	a	1.92
T-2	10.25	a	1.98
T-3	10.25	a	2.22
T-4	10.25	a	1.83
T-13	10.25	b	.86
T-14	10.25	b	.86
T-18 & T-19	9.0	UO_2	2.28
TA-1	4 & 8	a	1.80
Bullion Bal.	---	UO_2	1.92

"a" and "b" are process solutions containing uranium interaction is below one steradian, there is no limit on what may be placed in the vessels since each vessel is "always-safe". The basis for this is a statement in K-1019 Rev. 4, page 25, which states that if the vessels meet "always-safe" parameters the k value may be assumed equal to 0.8 for which the maximum solid angle is 1.0 steradian.

b. For those vessels where the interaction is greater than one steradian, a limit is placed on the maximum concentration or mass of U-235 which can be placed in these vessels.

c. Uranium in the process is contained in aqueous solutions in two different concentrations above 5 grams U-235 per liter. The more dilute of these two is designated solution "a" in Table I, while the more concentrated solution is designated "b".

d. The maximum permissible concentration for solution "a" is calculated as follows: Among the vessels containing solution "a" and excluding F-4 and F-5, the maximum interaction is encountered with vessel T-3 at 2.215 steradians. The next highest is T-2 at 1.982 steradians. The maximum k for an allowable 2 steradians is 0.713 (K-1019 Rev. 4, page 39). Now $k = \eta f \, U_f \, U_{th}$ (page I-9, K-1380).

Assume $U_{th} = 1$ (conservative estimate)

$B_1^2 = .0242$ for $D = 10.25"$ (K-1380, page I-13)

$U_f = .596$ (K-1380, page I-14)

$$\eta f = \frac{k}{U_f} = \frac{.713}{.596} = 1.195$$

This is the maximum value for ηf. Assuming the solution contains nitrogen, hydrogen, U-238 and U-235, an ηf less than 1.195 requires the following quantity to be greater than 455.

$$\frac{1.88\ N}{U\text{-}235} + \frac{.33\ H}{U\text{-}235} > 455,$$

where N/U-235 is the ratio of nitrogen atoms to U-235 atoms and similarly for H/U-235. If T-3 is in the system, this must be greater than 510.

e. Returning to F-4 and F-5, these vessels have a diameter of 7-3/4 inches and have an allowable solid angle of 3.5 when $\eta f = 1.195$. The allowable solid angle for R-13 was discussed above.

f. The maximum concentration of solution "b" is such that the minimum H/U-235 is 920. Under these conditions the maximum ηf is 1.36. This concentration gives the maximum allowable interaction for E-3 of 2.26 compared to the actual 1.6. T-13, T-14 and R-9 all have interactions less than 1 steradian.

g. The furnace has an I.D. of 9 inches. However, it never runs more than 25% full. This gives it an equivalent diameter less than 5 inches. The safe interaction for a 5 inch pipe is 3.2 steradians (Table XX, K-1019 Rev. 4) compared to the actual value of 2.32.

h. The quantity of UO_2 allowed in either T-18 or T-19 is limited to the safe mass as limited by enrichment, (Table XVII, K-1019 Rev. 4). The k for these mass safe vessels is taken as 0.65 (K-1019 Rev. 4, page 26), so that the allowable solid angle is 2.51 compared to the actual value of 2.28.

i. After a moisture analysis has been obtained on their contents, T-18 or T-19 can either be transferred to M-5 or to storage.

j. The entire inventory of UO_2 in M-5, SC-1 and at the bullion balance is limited to a mass safe quantity as limited by moderation. Table XIX of K-1019 Rev. 4 will be used to specify the safe mass to that corresponding to the highest H/U-235 ratio of any material added to the inventory. Table XIX is for UF_6, but since the density of UO_2 here is no greater than the density of UF_6, the table is applicable.

k. The k value for this total mass is taken as 0.65. This is in accordance with K-1019 Rev. 4, page 26 for safe masses. Although this reference is not specifically justified in this instance, a value of .65 is considered conservative for two reasons. First the uranium is at most 5% enriched, while Table XIX is for any enrichment. Secondly, all the mass will not be accumulated in a configuration approaching an optimum arrangement. For a k of .65, the allowable interaction is 2.51 steradians. The maximum interaction from M-5, SC-1 or the bullion balance is 2.05 steradians.

l. Almost all piping which might conceivably carry uranium solution is 1/2 inch which presents no interaction problem (K-1019 Rev. 4, page 24). In the front of the process, sizes no greater than 3 inches are used sparingly. They are all spaced at least 2 feet from any vessel and enter the vessels either near the top or bottom so that they are safe.

m. Drip pans beneath process vessels overflow at 1/2 inch so that they are safe (K-1019 Rev., page 24).

n. All pumps and pulsers are located on the floor and are of safe volume, each having less than a gallon holdup. They are included in interaction calculations as extensions of the process vessels.