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August 15, 1985

TMI Program Office
Attn: Dr. B. J. Snyder
Program Director
US Nuclear Regulatory Commission
Washington, DC 20555

Dear Dr. Snyder:

Three Mile Island Nuclear Station, Unit 2 (TMI-2)
Operating License No. DPR-73
Docket No. 50-320
Defueling Canister Technical Evaluation Report

Attached are responses to your comments on the Defueling Canister Technical Evaluation Report (TER) transmitted by your letter dated June 10, 1985. Based on these responses, GPU Nuclear will submit a revision to the Defueling Canister TER.

Sincerely,

F. R. Standerfer
Vice President/Director, TMI-2

FRS/RDW/eml

Attachment

cc: Deputy Program Director - TMI Program Office, Dr. W. D. Travers

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Question 1: Section 1.2 of the TER states that "criticality concerns associated with the use of lead shields around the canisters is addressed in Attachment 1", and that "criticality concerns associated with a drained spent fuel pool is addressed in Attachment 2".

Attachment 1, TMI-2 Transfer System Criticality Technical Report, and Attachment 2, Assessment of a Drained Pool Scenario, have not been provided for NRC staff review.

Response: The analyses are currently in their final stages and will be provided to the NRC upon their completion. This information is scheduled for submittal to the NRC in August.

Question 2: What is the maximum predicted radiolytic gas generation rate in a canister? What is the basis for this predicted gas generation rate? Has the possibility of the generation of gases other than H₂ and O₂ been considered, such as those gases resulting from radiolytic decomposition of organic contaminants in the RCS?

Response: The maximum predicted gas generation rate in a canister has been determined by two separate models; (1) the maximum theoretical gas generation rate and (2) the maximum realistic gas generation rate. The maximum theoretical gas generation rate was determined by Rockwell Hanford Operations (RHO) in their document RHO-WM-EV-7 (GEND-051) for purposes of developing the catalytic recombiner bed design. The maximum realistic gas generation rates were determined by GPU for purposes of predicting canister internal pressures during periods when the canisters are water solid.

Both models are based on the Turner paper, "Radiolytic Decomposition of Water in Water-Moderated Reactors Under Accident Conditions", referenced in the RHO report. The basic relationship is:

$$H_2 = (W)(F)(G)(r) 8.4 \times 10^{-3} \text{ liters/hour}$$

where:

F = fraction of γ and β energy absorbed in water

G = H₂ generation value in moles/100 eV

r = ratio of peak to average decay heat energy in the fuel debris

W = ionizing radiation per canister

8.4×10^{-3} = unit conversions

For the maximum theoretical generation, the above factors are maximized as follows:

o W - the maximum quantity of fuel debris in any canister, not including residual water weight or weighing accuracy, is assumed. (W = 54.2)

- o F - The fraction of γ and β energy absorbed is conservatively high and large amounts of water are also assumed to be available for absorption which is in excess of what is possible in the canisters. (F = 0.2)
- o G - The hydrogen gas generation value is based on a) completely turbulent/boiling conditions when the radiolytic gases are instantly removed from the generation site and b) no build up of hydrogen overpressure which tends to retard radiolysis. (G = 0.44)
- o r - The ratio of peak-to-average decay heat energy in the fuel is based on the most active region of an undamaged core. This assumes the fuel is intact and not scattered to other regions. (r = 1.9)

For the maximum realistic generation of hydrogen and oxygen, the worst case realistic factors for the damaged TMI core are used as follows:

- o W - The maximum quantity of fuel debris expected in any canister is used which includes allowances for residual water and weighing accuracy. (W = 50)
- o F - The fraction of γ and β energy absorbed is based on the maximum amount of water possible in an actual canister. (F = 0.07)
- o G - The hydrogen gas generation value is based on the actual worst case core debris conditions expected in a canister which includes lower temperature, quiescent conditions. (G = 0.12)
- o r - The ratio of peak to average decay heat energy in the fuel debris is based on the worst case conditions in the damaged TMI core. (r = 1.4)

The resulting hydrogen/oxygen generation rates for the two models are:

	<u>Max. Theoretical liter/hour</u>	<u>Max. Realistic liter/hour</u>
H ₂	7.6×10^{-2}	5.0×10^{-3}
O ₂	3.8×10^{-2}	2.5×10^{-3}

The generation of other gases was not considered. Since the amount of contaminants in the RCS is small, the generation of other gases from the radiolytic decomposition of these contaminants is not expected to be significant.

Question 3: What is the minimum volume of recombiner catalyst necessary to assure a recombination rate equal to the maximum hydrogen generation rate? How much catalyst will be inserted in each canister and how will it be distributed within the canister to assure that the minimum volume needed is not immersed in the residual water regardless of canister orientation?

Response: A total of 200 g of catalyst is initially installed in each canister. Then extra catalyst is installed in the beds to fill remaining voids. The 200 g quantity was determined from the catalyst tests run by RHO (RHO-WM-EV-7, Feb. 85) which used 100 g and a H₂/O₂ generator which simulated the maximum gas generation stated in the report of 0.076 liter/hr hydrogen. Additionally, the beds were designed to meet the shape and volume requirements established by the tested catalyst beds.

200 g of catalyst are installed in the canister in order to be assured that 100 g is above the maximum water level for all canister orientations. 100 g is at either end of the canister and the bed arrangement at each end is symmetrical.

Conservatisms: (1) It is unlikely that the canister water level would be above half after dewatering in the fuel handling building.

(2) There is an average 20% excess catalyst installed in each canister.

(3) H₂/O₂ generation rates are based on the maximum theoretical generation rates defined in the response to question #2.

Question 4: Assuming stoichiometric H₂/O₂ generation in the canisters without recombination, at what internal canister pressure would a flammable gas mixture exist in the canister? Provide this information for both the flooded and dewatered canisters. If ignition of the gases occurred inside the canisters, what would the effect be on canister integrity?

Response: It should be noted that GPUN's position is that the catalytic recombiners have been shown to be effective under the conditions expected and that a flammable mixture would not exist inside the canister unless the catalyst was submerged. When the catalyst is submerged, only a small volume is available for gases to collect. Hence this situation does not present a problem.

The evolution of H₂/O₂ gas will occur at a 2 to 1 ratio without recombination at all pressures. In the case of a dewatered canister, the pressure at which a flammable mixture exists will be approximately 15 psig, which assumes:

- o cover gas is 100% argon at 13 psig
- o canisters do not leak

- o lower limit of flammability for H_2/O_2 mixture in argon occurs when $H_2 + O_2$ concentration is 10.6 v/o ("Limits of Flammability of Gases and Vapors," H. F. Coward and G. W. Jones, Bulletin 503, Bureau of Mines, March 1949)

Additionally, a flammable mixture can exist at lower pressures if the amount of the argon cover gas is reduced.

In the case of a flooded canister, no cover gas is present, therefore a flammable mixture can occur at any pressure if voids are produced.

The ultimate stresses will be reached for various canister components at the estimated pressures listed below:

- o canister shell - 2160 psi
- o fuel canister bolts - 2900 psi
- o threaded connections - 2500 psi

The maximum pressure that can be reached inside the canister prior to a hydrogen ignition, because of the relief valve, is approximately 42 psia. This pressure includes the 25 psig set pressure and the 5 feet of water submergence. Considering the large margin that exists between this pressure and the ultimate stress pressures (i.e., approximately a factor of 50), the overpressurization resulting from the ignition of hydrogen within the canister is not expected to affect the overall canister integrity.

Question 5: Assuming an ignition source, what are the effects of ignition of the gases vented through the relief valves? In particular, can backflash into the canister occur and if so what is the effect on canister integrity?

Response: Canisters are handled either underwater or in transfer casks or shields. A conservative calculation has been performed to assess the effects of a hydrogen burn within the canister transfer shield assuming the canister was water solid. This was considered to be the most credible of hydrogen ignition scenarios. If the canister was not water solid, the recombiner catalyst would prevent canister overpressurization and consequently the relief valve should never open. The major assumptions used in the calculation were:

- o The source of hydrogen was a water-filled knockout canister (useable volume - 9.10 ft^3) saturated with hydrogen in solution. Water was assumed to fill the entire useable volume.
- o The canister relief valve opened at 25 psig and remained open.
- o All hydrogen discharged from the canister burned completely within the transfer shield.

The results of this calculation were that the pressure increase within the transfer shield would be limited to less than 5.0 psi. Additionally there are no flammables within the cask or shields. Consequently the canister and canister handling equipment should not be affected.

Assuming a hydrogen burn occurs external to the canister, a backflash into the canister would be theoretically possible, but not likely since the burn would have to exactly coincide with an open relief valve. Any burn inside the canister would affect the canister as stated in question #4.

Question 6: What is the design basis for the setpoint of the 15 psig relief valve? What is the effect of submergence pressure on the relief setpoint?

Response: The setpoint of the relief valve has been changed to 25 psig, consequently the question is responded to in terms of 25 psig, rather than 15 psig.

The relief valve has a setpoint of 25 psig for the following reasons:

The canisters are designed for 150 psig per ASME Section VIII. Overpressure protection of the canisters as required by ASME Section VIII is afforded by the systems in which the vessels are installed. These systems are the Defueling Water Cleanup System and the vacuum system which have operating pressures less than the design pressure of the canister and also have relief valves meeting the requirements of ASME Section VIII.

- o Based on the current design functions of the canister the 25 psig relief valve serves only as a redundant relief path for overpressurization due to gas generation. In this situation any set pressure between 15 psig and 150 psig could have been selected. It is advantageous however to keep the first relief valve setpoint as low as possible to reduce the total quantity of any gases which may evolve inside the canister and also to facilitate connecting and disconnecting the various fittings on the canisters.
- o Note that a low setpoint is advantageous for the unlikely scenarios postulated in questions #4 and #5.

The fact that the canisters will be operated under approximately 5 feet of water will not affect the gage pressure setpoint of the relief valve, however it will cause the absolute pressure inside the canister to be greater by 5 feet of water head at the point at which the relief valve lifts. This has no adverse effect on canister operation, but rather, it is a benefit to have 5 feet of submergence during storage at TMI since it increases the margin between absolute cover gas pressure and absolute relief valve setpoint.

Question 7: What is the setpoint on the backup relief valve?

Response: The backup relief valve is set at 150 psig, which is the canister design pressure.

Question 8: What are the relief capacities of both the 15 psig relief valves and the backup relief valves, and what are the safety classifications on the valves?

Response: The setpoint of the relief valve has been changed to 25 psig, consequently the question is responded to in terms of 25 psig, rather than 15 psig.

The relief valve capacities are not a significant design parameter for the canisters, since the capacity of even the smallest relief valve available would be very large when compared to the gas generation volumes. The capacities of the relief valves chosen are:

25 psig-10 SCFM
150 psig-65 SCFM

The relief valves are classified as Nuclear Safety Related (NSR).

Question 9: Explain the basis for your assumption that the first or second opening of the relief valve will expel enough water to expose the recombiner catalyst.

Response: The catalyst beds are located at the extreme ends of the canisters. Since the canisters will be operated vertically, evolved gases will migrate to the top of the canisters and the catalyst beds. See attached sketches.

Question 10: What provisions will be in place to contend with activity released to the pool due to a stuck open relief valve or periodic relief valve opening prior to operability of the Defueling Water Cleanup System?

Response: Prior to the DWCS becoming fully operational, processing of water in the fuel transfer canal (FTC) and the spent fuel pool "A" will be accomplished, if required, by routing the water through SDS via the FTC drainage system. A direct return path to the FTC from SDS may be provided by using portions of the DWCS Fuel Canal/Spent Fuel Pool Cleanup System.

Monitoring of the pool water activity and dose rates in the pool area will be routinely conducted to assess the need to process the pool water.

Question 11: How long will it take for a dewatered canister to reach design pressure in the event of stoichiometric gas generation with recombiner failure? How long will a dewatered canister remain stagnant prior to commencement of monitoring for water inleakage and pressure build up.

Response: Since the canisters are equipped with a 25 psig relief valve, they should never reach the design pressure of 150 psig. If however this valve is neglected, the canisters will reach the design pressure of 150 psig as listed below:

	<u>days</u>
Fuel	4286
Knockout	9375
Filter	32609

These values were determined based on the following assumptions:

- o Gas generation rates based on the realistic factors developed in question #2 and on the anticipated debris loadings in each type of canister.
- o No recombination
- o Canisters are dewatered (100 pounds of water assumed to remain)
- o Void volumes based on conservative debris loadings in each type of canister.
- o Constant void volume and constant temperature.

Note that since the different debris loadings were assumed for each type of canister, the gas generation rates and void volumes for each type of canister were different.

The amount of time a canister remains stagnant prior to commencement of monitoring to determine pressure build-up is dependent on a number of variables, some of which are not known at the present time. The major determinants are (1) the availability of the dewatering station, (2) the generation rate of filled canisters from the reactor building, (3) the actual monitoring time required to determine the status of the canister. The purpose of the monitoring program is to determine pressure build-up, thereby, verifying that the recombiner is functioning properly. The fact that water inleakage can also be determined is an added advantage that may be useful. To properly monitor for pressure build-up the canister should be in relative temperature equilibrium with the "A" SFP. For this reason, it is undesirable to start a monitoring program in less than 8 hours after arrival in "A" pool. Because of these factors, the date by which the monitoring must commence is rather arbitrary, but all canister monitoring could commence within 90 days of the initial

dewatering. During the stagnant period the canisters would be visually monitored for signs of bubble formation once a day or if necessary once a shift.

Question 12: Section 3.1 of the TER states "examination of the shroud subjected to drop tests indicated that the inner wall (protecting the boron plates from exposure to a corrosive environment) is resistant to debris impacts and scrapes. What testing/analysis has been done to assure that the inner wall can resist puncture from dropping a small diameter object such as an individual fuel pin?"

Response: The inspection of the stainless shrouds after the canister drop tests demonstrated that only distortions and galling were caused by the sharp edged steel shop scraps used as simulated debris. No penetrations into the shroud occurred using this simulated debris. Because of the shape and material used to simulate the debris, the test results (i.e., galling) are felt to be more severe than expected during actual use. These observations demonstrated the shrouds to be resistant to puncture and suggested that additional testing or analysis need not be performed to show this to be the case. In B&W report 77-1156372-00, which gives the results of the drop test, the shroud cladding is characterized as ductile, tough and not easily penetrated. Based on the above, it is concluded that core debris free-falling or placed into a fuel canister will not impart significant galling of the shroud. Additionally, there is presently no way to create a significant horizontal load on the shroud since there are no plans for forcing or compacting debris into the canisters.

Question 13: Section 3.1 of the TER states? "Although not expected..., leakage of the core material from the canister...is allowed provided that the contents left in the canister remain subcritical."

If the contents that leak fall in contact with an adjacent canister, what is the effect of k_{eff} of the adjacent canister. If the leaking material falls into a dry environment such as the shallow end of the FTC or the truck bay, what is the effect of a pyrophoric event?

Response: Because of design of the canister transfer shield and the fuel transfer cask, the potential for dropping a canister is highly remote. Based on the B&W drop tests, even if a canister would fall, it is not expected that leakage would occur. However, if material leaks from a canister and comes in contact with an adjacent canister, the leaked material will be under water in either the fuel transfer canal or the spent fuel pool. The boron concentration in both of these locations will be ≥ 4350 ppm. With this boron concentration, the RCS Criticality Report demonstrated that the fuel in any configuration, will remain subcritical (i.e., $k_{eff} \leq 0.99$). It should be noted that the

0.99 limit is not in the present revision of the TER, it will however be added as the accident k_{eff} criterion in the next revision of the TER.

Any existing debris fines which are small (less than 50 μm) have been oxidized as a result of their submersion since the accident. The apparent concern for pyrophoric reaction resulting from canister failure involves the existence of unoxidized metallic particles whose diameters are less than 50 microns that may have been generated during defueling mechanical operations. The following basic calculations illustrate that if such metallic fines were generated the newly created surfaces would rapidly oxidize and hence negates a pyrophoric event. Furthermore, the oxidation of these newly generated particles surfaces is very rapid. Two estimates for the time to form an oxygen monolayer (oxide surface) on a zirconium particle surface are presented.

A) Utilize the existing Steam-Zircaloy parabolic rate law experimental data; specifically use the tabulated rate constants (reference*) that will be evaluated at the lower temperature limit applicable for the listed reaction kinetics (i.e., 900°C). It should be recalled that the activation energy for a monolayer of oxygen on a newly created metal surface is usually regarded as zero. Hence, the rate constant, K, evaluated from the parabolic rate law may be considered as a conservative value with respect to time for reaction. The parabolic rate law may be expressed as follows.

$$W^2 = Kt \quad \text{where } W = \text{Mass of metal reacted per unit surface area of metal (mgZr/cm}^2\text{)}$$

$$K = \text{Rate constant evaluated from steam oxidation data at the lower temperature limit (mgZr/cm}^2\text{)}^2$$

$$t = \text{Time (sec)}$$

Utilizing data from the reference* and the lower temperature limit of 900°C corresponds to a $K = 0.1 \text{ (mgZr/cm}^2\text{)}^2$.

The mass of zirconium in the surface layer of a given diameter sphere and corresponding surface area are required to evaluate the time for monolayer oxidation. The calculation may be carried out as follows. The density for zirconium is approximately 6.4 gZr/cm³. The surface-to-volume ratio, density, and corresponding mass for a sphere may be expressed as follows:

$$S/V = 6/D, \quad \rho = m/V, \quad \text{and } m = S \rho D/6$$

*reference: H. Ocken, R. R. Biederman, C. R. Hann, and R. E. Westerman, "Evaluation Models of Zircaloy Oxidation in Light of Recent Experiments", Zirconium In The Nuclear Industry, ASTM Special Technical Publication 681 (1979).

The volume of Zr in the outer surface layer may be estimated from the general formulation for spherical volume, i.e.,

$$V = (4/3) (3.1416) ((r_0)^3 - (r_1)^3)$$

where r_0 = Radius of spherical debris particle (cm)

$r_1 = r_0 - r_{Zr}$ = Difference between r_0 and the diameter of a Zr atom in a metallic structure with a coordination of 12 (i.e., $r_{Zr} = 1.6 \text{ E-8 cm}$).

Therefore for a 10 micron diameter particle (sphere) the mass of Zr in the outer surface corresponds to $m = V\rho = 6.4 \text{ E-10 mgZr}$ and $m/S = 2.1 \text{ E-4 mgZr/cm}^2$.

Therefore, $W^2 = 4.2 \text{ E-8 (mgZr/cm}^2)^2$ and the rate constant evaluated above from the parabolic rate law corresponds to $0.11 (\text{mgZr/cm}^2)^2/\text{sec}$; hence, the time for monolayer oxidation is approximately 4 E-7 seconds .

B) Another basic calculation for the time of monolayer oxidation may be performed based on kinetic theory which may be approximated by the following formulation:

$$n = (3.5 \text{ E22}) (P/(MT))^{1/2}$$

where n = Collision rate in number of molecules per cm^2 per second

P = Pressure

M = Molecular weight

T = Temperature

therefore, if assume a 50% sticking efficiency for oxygen molecules on the zirconium surface, the time for monolayer oxidation of a 10 micron particle (sphere) corresponds to approximately 1 E-8 seconds .

Consequently, the simplified calculations above indicate that less than a microsecond (1 E-6 seconds) is required to react a monolayer of oxygen on a reactive metal (Zr) surface. Now, if one were to assume that these calculations are in error by six orders of magnitude (i.e., 1 E6) the resultant time for oxidation of the metal surface is still miniscule compared to the time available for oxidation of these surfaces in the canister prior to accidental dropping (i.e., the approximate time from filter loading until canister transfer is 12 hours).

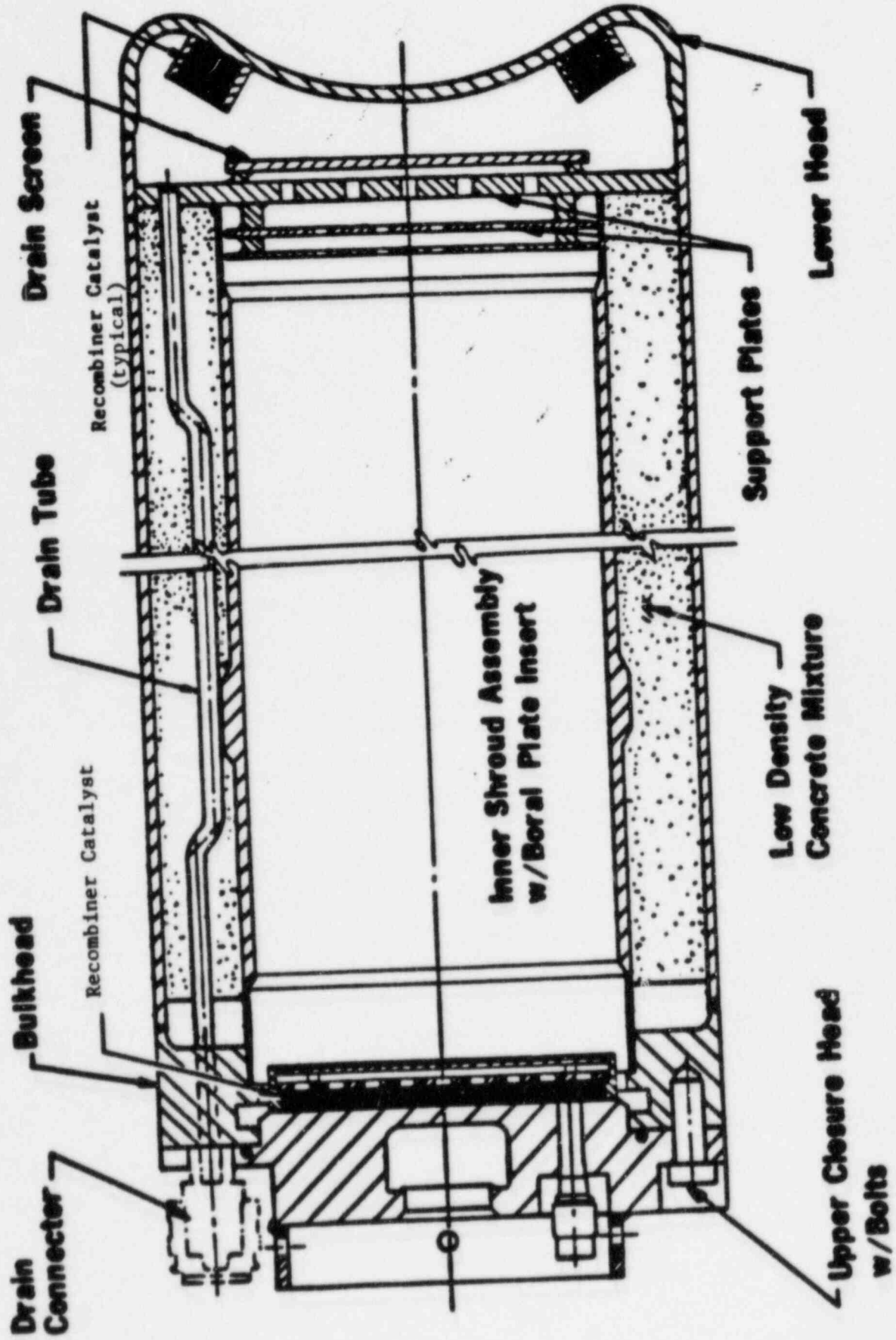
Therefore, the assumption that all newly created surfaces of a reactive metal will be oxidized prior to canister integrity failure is established. Furthermore, the Pilling- Bedworth ratio indicates that successive layers of oxygen are necessary before spalling becomes an important issue with respect to new surface creation. Also, the thermodynamic relationships for oxide formation indicate that decomposition of the metal oxide is not energetically favored.

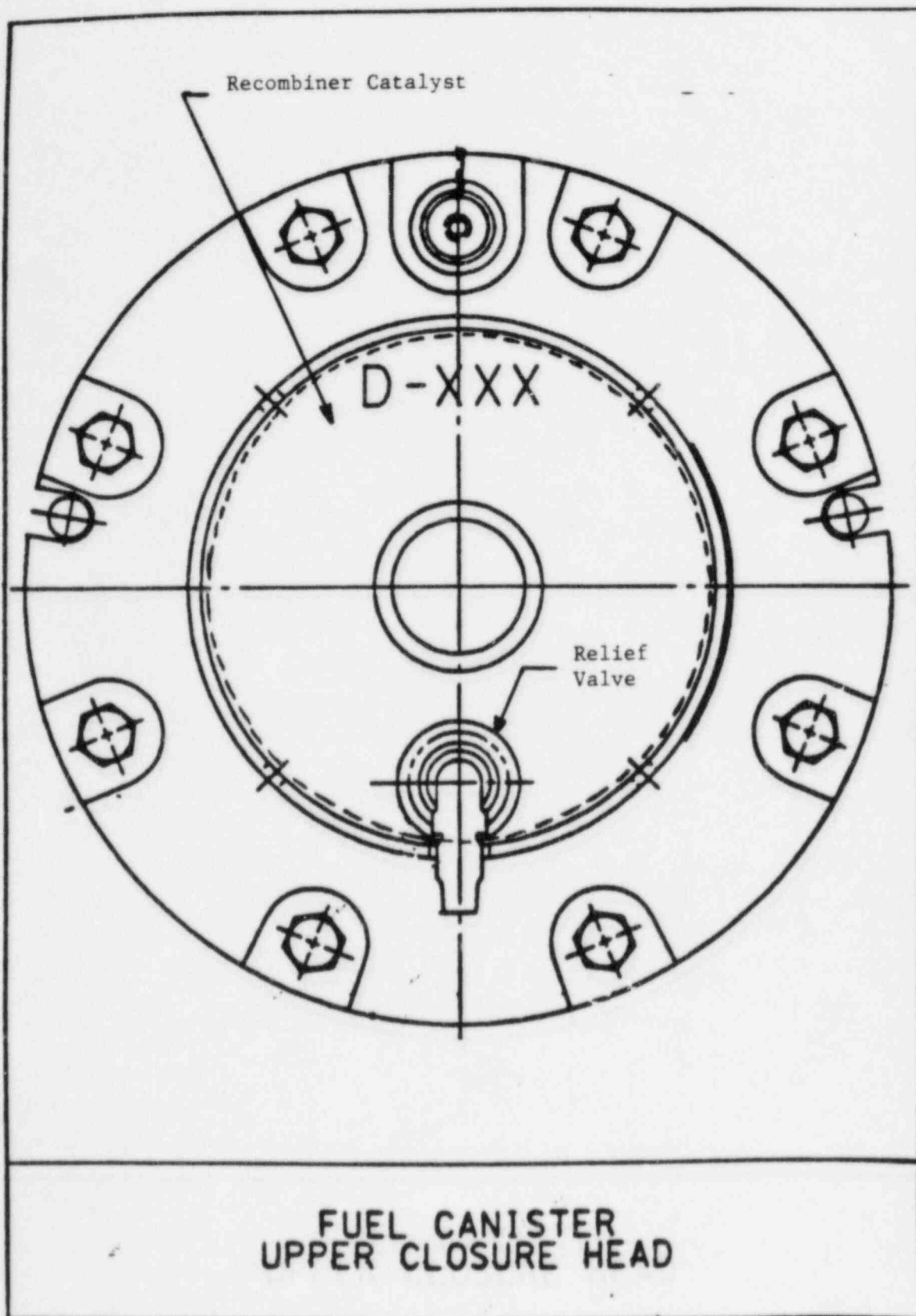
Therefore, the assumption that all newly created surfaces generated by mechanical means during defueling operations will be partially oxidized prior to any possible canister failure which subsequently reduces the pyrophoric potential significantly as continued oxidation is permeability (and/or diffusion) limited. The smaller the particle diameter (i.e., the greater the surface-to-volume ratio) the more extensive the anticipated oxidation relative to the overall particle mass. Consequently, for the TMI-2 system the situation can be viewed as follows:

- o the larger the particle diameter (greater than 50 microns) the greater the heat dissipation capability (low pyrophoric potential)
- o the smaller the particle diameter (less than 50 microns) the more fully oxidized the particle (low pyrophoric potential) because of the availability of oxygen in the system.

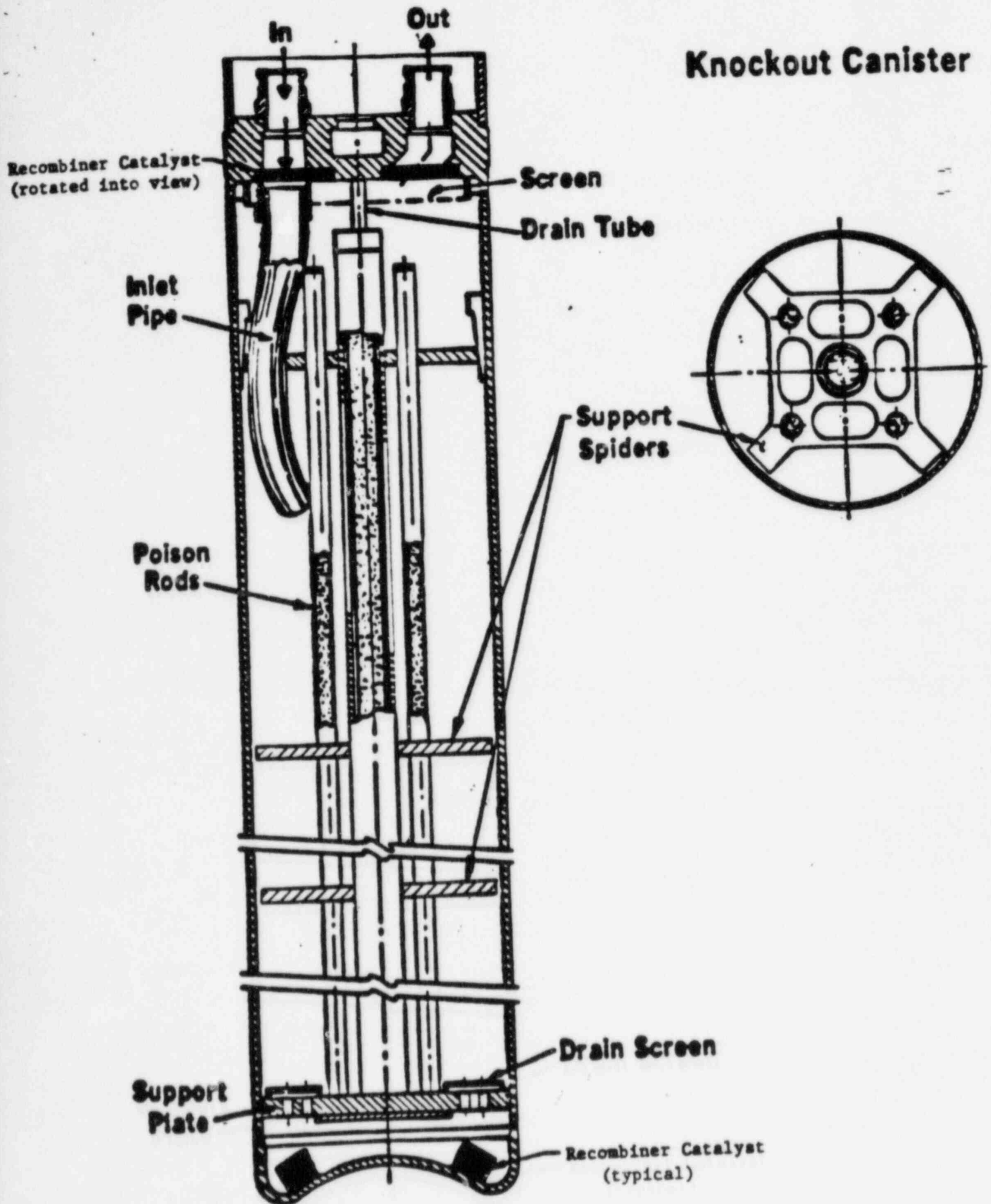
In conclusion, the potential for ignition and a sustained pyrophoric reaction at TMI-2 is not possible during planned activities, and postulated accidents, associated with defueling and the transfer of defueling canisters.

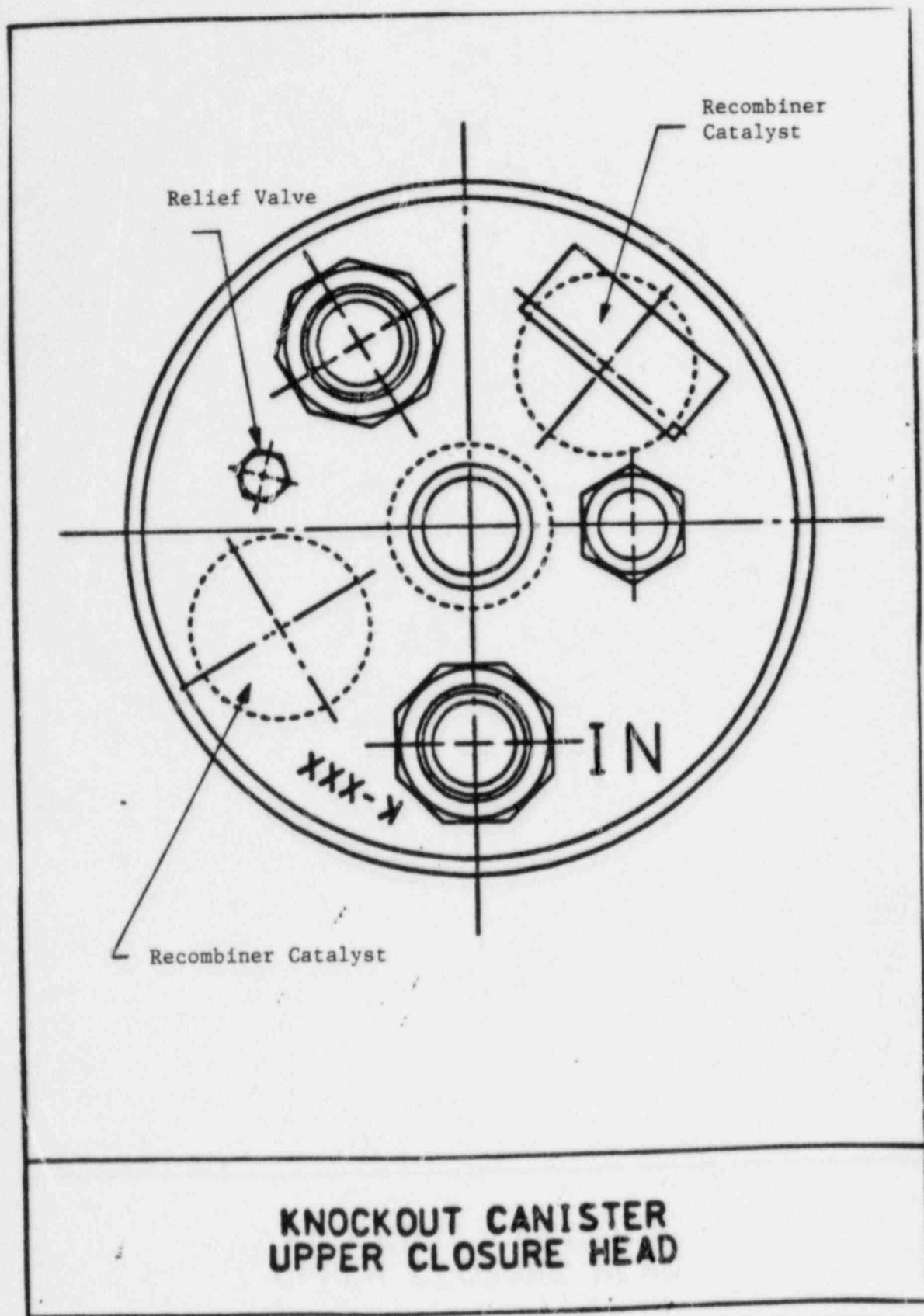
Fuel Canister





Knockout Canister





Filter Canister

