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# TECHNICAL REQUIREMENTS AND CRITERIA FOR THE COPRODUCT TARGET ELEMENT


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Chemistry & Metallurgy
Research & Engineering
N-Reactor Department


January 7, 1966

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# TECHNICAL REQUIREMENTS AND CRITERIA FOR THE COPRODUCT TARGET ELEMENT

## REQUIREMENT I

The coproduct target element shall be compatible with the driver element in the environment of the N-Reactor primary loop.

### Technical Basis

The fuel-target element design is largely determined by complex calculations that establish the size and composition of element components which will allow production objectives to be met, will permit efficient heat removal, and will provide sufficient excess reactivity for the safe and efficient operation of the reactor. Since these aspects of the target design are not directly the subject of this report, the dimensions and compositions calculated using the FLEX computer code are accepted categorically here.

The cladding used on the driver element is Zr-2. The primary loop coolant is high purity water adjusted to pH-10 by ammonia additions. The N-Reactor neutron spectrum contains a large proportion of thermal or near-thermal neutrons. Avoidance of possible galvanic or other corrosion problems, control of "crud" in the primary loop, and the balancing of material costs against neutron losses and reliability place stringent limits on the selection of the target cladding material. Zr-2 was selected several years ago as the best cladding for the target component. Large scale tests of Zr-2 clad target elements have been completed successfully and no new factors affecting the analysis have developed. Thus, Zr-2 is the specified material for the target cladding and supports.

For convenience in handling, to avoid fretting corrosion of supports and cladding, and to maintain a positive relative location of fuel and poison in the reactor, the target element is firmly seated inside the fuel tube and fastened thereto. During the charging of fuel, large axial forces are exerted on the element. To guarantee that the target-to-driver connection is not compromised, no force should be applied to the target component.

### CRITERION A

Thermal-hydraulic compatibility will be satisfied by adherence to the following nominal finished element dimensions:

Driver element
- Outer diameter --- 2.399 inches
- Inner diameter --- 1.718

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| | | |
|---|---|---|
| Target element | | |
| Diameter | --- | 1.335 |

A further condition is the use of six conventional buggy spring supports (0.315" wide) per target element, symmetrically arrayed in sets of three near each end of the element.

Advice

Allowable tolerance ranges will be determined by analysis, using a computer code developed for this purpose. Pending completion of the study it may be assumed that the tolerance requirements will be no more stringent than for the standard tube-tube fuel.

Development of buggy-spring supports made with 20 mil Zr-2 sheet for use with the thinner annulus of this design (0.19 compared to 0.25" for tube-tube fuel) is currently in progress. Demonstration of fabricability, the sizing-up operation, vibrational stability, and the ability of these supports to maintain the driver-to-target connection remains to be accomplished. It is possible that changes in support dimensions will be made should some aspect of the demonstration be unsuccessful. Modifications will be made only in such a way as to leave the hydraulic resistance of the total support system unchanged.

## CRITERION B

Nuclear physics compatibility will be satisfied by adherence to the following conditions:

| | | |
|---|---|---|
| Target core dimater | --- | 1.075 inches |
| Li-6 content of target core | | |
| Standard element | --- | .00559 gms/cm$^3$ |
| Spike element | --- | .00315 gms/cm$^3$ |
| Poison element | --- | .0178 gms/cm$^3$ |

(Note: These values are for uniform distribution in an infinite length target rod. The values should be scaled up to allow for end caps and longitudinal gaps using the following relation:

$$\text{Li-6} \times \frac{\text{Driver element length}}{\text{Length of active core per element}} \quad \text{gms Li-6/cm}^3.)$$

Li-6 concentration tolerances ---
± 2% for a reactor load
± 5% for a single column
± 10% for a single element

A further condition is that the target element shall be positively fastened to the driver tube. (See also Requirement II).

Advice

Permissible tolerances on the target core diameter have not been established. If, in selection of the target core fabrication process, it becomes necessary to determine what diameter range, independent of Li-6 content, can be used (if, for instance, sintered but unground pellets are to be used), this information can be obtained. For present planning purposes, ± 0.010" may be used.

CRITERION C

Material compatibility will be satisfied by use of Zr-2 cladding, supports, fixing clips, and end caps (welded in place), subject to the final inspection techniques normally used for certifying Zr-2 quality for pressurized water reactor service.

Advice

The high temperature autoclave test is an acceptable inspection technique for demonstrating adequate corrosion resistance of Zr-2 components.

CRITERION D

Mechanical compatibility with the charging equipment and process will be satisfied if no target element is as long as or longer than the driver tube associated with it and if no target element is fastened to its driver element so that either end of the target component extends up to or beyond the end of the driver component.

REQUIREMENT II

The target element shall be compatible with nuclear safety requirements under all credible reactor accident conditions.

Technical Basis

The amount of nuclear poison contained in the target elements is such that if some fraction of it (approximately 20%) were removed from the reactor, or relocated to a sufficient degree, by any mechanism, it would not be possible to control the reactor. Thus, the target elements must retain essentially all of the lithium during all credible reactor accidents.

The most severe accident, loss of coolant and failure of the backup water system, involves a calculated temperature transient peaking at about 1100 C after approximately ten minutes. The temperature then falls to a low level over a period of hours. The target environment during this period is steam at a pressure of about one atmosphere.

In a variant of this accident, the backup cooling water comes on about five minutes after the loss of coolant. The target element experiences a transient to about 900 C in steam followed by a water quench to 75 C. The temperature then declines to room temperature (or river temperature) over a period of minutes.

A lithium component with a melting point above 1100 C is required and gamma lithium aluminate pellets have been selected for the design. No irradiated coproduct target elements of this design have yet been subjected to simulated accident conditions so one can only speculate on target behavior during these accidents. However, data on gas release and material properties as a function of temperature indicate that in some significant fraction of the target elements in the reactor at any given time the cladding will fail from internal gas pressure during the more severe transient where the backup water system does not come on. The central elements in high exposure columns would be expected to fail first. It is required then that lithia losses during exposure of bare lithium aluminate cores to 1000 C steam for several hours be small. It is known that the lithia vapor pressure over lithium aluminate in air is insignificant below about 1350 C. It is also known that the presence of water vapor greatly increases the volatility of lithia at high temperatures through conversion to lithium hydroxide which has a relatively high vapor pressure. The aluminum cladding will melt, of course, and much of it may escape from the element. The Zr-2 cladding must retain sufficient mechanical integrity to keep the core in place. Escaping aluminum, lithia or lithium hydroxide may damage the cladding to some degree.

[redacted]



In the latter case, in which the backup cooling system comes on after five minutes, fewer elements will have failed cladding (perhaps none). However, the overheated target element must remain in place during the restoration of flow, which will be violent during the initial stages. The rate at which lithia is leached, dissolved, or eroded from bare cores by the cool flowing water must not be great because of the possibility that some elements may have failed cladding.

Without knowledge of the actual behavior of target elements during these accidents only criteria pertaining to use of relatively massive pieces of gamma lithium aluminate (to reduce the surface available for lithia to escape by any mechanism) and to the need for firm attachment of the target to the driver can be stated.

Discharge of fuel-target elements from the reactor is by free-fall. Nuclear safety requires that the number of elements per storage basket from which the targets have become separated be very small. The cost of basin operations will be excessive if target separation is not a rare event.

## CRITERION A

The target element shall be positively attached to the driver tube.

### Advice

Subject to further analysis and testing, the use of one fixing clip per element may be assumed. In the event that this is later deemed inadequate, the most likely direction for improvement will be the use of two or even three fixing devices at one end of the element.

## CRITERION B

The target core shall be made of gamma lithium aluminate ($\gamma$-$LiAlO_2$).

## CRITERION C

Individual lithium aluminate pieces used to make up the target "rod" shall be 1.075" in diameter and no shorter than 1" in length, except that up to two shorter pieces may be used per foot of target core.

 [redacted]

REQUIREMENT III

The coproduct element shall be unmistakeable distinguishable from other fuel element models in use or expected to be in use during the period 1966-68.

Technical Basis

The control of nuclear safety hazards during fuel handling operations (prior to irradiation as well as during 100-N basin operations) requires that the enrichment level of fuel be readily determinable by visual examination or by a simple positive measuring technique. Fuel length has been established as the determinant for this purpose.

Potentially available fuel lengths are the integral sub-multiples of the established column length. It has been subjectively judged that length differences must be greater than 1.5" (approximately) to assure distinguishability. Lengths for new fuel models are determined by constructing a table of integral sub-multiples for the column length (31.0 ft. for the coproduct element) and comparing this with lengths already assigned to production models. Long lengths are desireable for fuel economy but lengths above about 28" are not used.

CRITERION

The length of the coproduct driver element shall be 26.5 inches. Rework lengths of 24.80 and 21.88 inches shall be acceptable.

REQUIREMENT IV

The target element shall have a degree of reliability that is compatible with reactor performance objectives.

Technical Basis

The consequences of failure of a target element are not fully known, although the severity is judged to be substantially less than for failure of a driver component. Failure of the cladding of a target will result in release of some of the contained tritium and helium and, perhaps, eventually, all of it. Water entry will lead to some leaching of lithia from the core and an associated increase in power of the driver tube. In addition, swelling of the element may occur as a result of corrosion of aluminum (without escape of the corrosion product) or some interaction with the core. Without complete knowledge of the nature of target element failures and the implications for reactor operation, it is deemed prudent to insist on essentially the same requirements for target cladding integrity as are in effect for the fuel cladding.

Because of economic considerations, the term failure must also include cases in which the product is lost for any reason. Because of the well-known proclivity of Zr-2 to absorb hydrogen (or tritium), an inner aluminum sheath has been specified because even the very thin oxide coating formed on aluminum in air is an effective hydrogen (or tritium) barrier. The aluminum serves also as a post-irradiation handling "package" as described under Requirement V. Here, in connection with target reliability, however, its purpose is to retain any tritium which escapes from the core during irradiation.

Irradiation tests of prototype lithium aluminate elements to exposure levels well beyond that planned for the coproduct target indicate that the material is dimensionally stable under irradiation and retains most of the gas formed if the free volume inside the cladding is not too great. The greatest threat to survival of these elements arises from the use of non-freestanding cladding. This is, in the N-Reactor primary loop where the pressure is about 1400 psi and the temperature nearly 300 C, the cladding may require internal support to prevent its collapse. For Zr-2 cladding of 1.3" outer diameter, wall thickness of 75-100 mils is required to be freestanding in the N-Reactor environment. Thus, if thinner cladding is used the lithium aluminate core must not only resist densification during service but the gaps between components must be reduced to a low level to prevent partial collapse and the formation of ridges on the cladding. Strain cycling of ridged cladding has, on several occasions in the nuclear industry, led to failure of the cladding in the regions of greatest curvature. The thinner the cladding the more severe is the

[redacted]



ridging since bending is involved in the formation of the ridges or wrinkles. For similar reasons, longitudinal gaps must be kept below some value (which is not known) to prevent circumferential collapse of the cladding into the gap.

Working against these needs is the fact that fabrication of the target elements has involved assembly of the components and, therefore, core-to-aluminum and aluminum-to-Zircaloy-2 gaps are needed for assembly. In addition, the tolerance ranges deemed to be practical are of a size comparable to the minimum gaps needed for assembly. One group of prototype elements have been fabricated for reactor testing. The average diametral gaps were 6 mils, making a total nominal diametral gap of 12 mils (since there are two gaps). The cladding collapsed in these elements to a variable but slight degree (maximum diameter - minimum diameter $\leq$5-10 mils).

Tightening up the process to eliminate collapse will require tolerances approaching those used for components of watch movements. This approach is regarded as too costly so development work has been started on processing steps which will eliminate the gaps after assembly. Thus, details of the target assembly process are not yet firmly established and the criteria must reflect this.

The thermal incompatibility of the three materials used in the target element and the fact that it is an unbonded system are factors which, to some unknown degree, may introduce damage mechanisms which will shorten the life of the element. The thermal expansion coefficients are:

| | | |
|---|---|---|
| Zr-2 | --- | $6 \times 10^{-6}$ in/in-°C |
| Al | --- | 24 |
| $LiAlO_2$ | --- | 12 |

The situation is somewhat worse than indicated by these values because the internal materials, with the greater expansion coefficients, operate at a higher temperature than the Zr-2 which has the lowest coefficient. There are several mechanisms by which one can visualize operation of a ratchet in this system. Whether one is really operative can only be determined by trial.

## CRITERION A

Same as Criterion C for Requirement I (use of Zr-2 for cladding, etc.).

## CRITERION B

The target element cladding shall be Zr-2 tubing with a nominal wall thickness of at least 0.030".

 [redacted]

Advice

Earlier criteria (Requirement I, A&B) state that the cladding outer diameter shall be 1.335" and the lithium aluminate core diameter shall be 1.075". Criterion E (below) states that there shall be an inner jacket of aluminum. Thus, the combined thickness of Zr-2 cladding, Al cladding and assembly gap is 0.130" (assuming no gap between the Al cladding and the lithium aluminate core). Use of nominal 30 mil Zr-2 cladding is recommended for economic reasons. This criterion permits use of heavier Zr-2 cladding with thinner aluminum cladding, a course of action recommended only if tests in progress now indicate that freestanding Zr-2 cladding is required.

CRITERION C

The Zr-2 end closure weld penetration shall be greater than 30% of the cladding thickness.

Advice

This need not be measured on each element. Rather, process control should be used to assure that this penetration minimum is exceeded. An effort should be made to achieve a nominal penetration significantly greater than this minimum value.

CRITERION D

There shall be no holes in the Zr-2 enclosure (including cladding, end caps and welds).

Advice

The autocalve test cannot be relied upon to detect perforations in the cladding. The helium leak test or equivalent should be used to check all elements.

CRITERION E

The target element shall have an inner jacket of aluminum that meets the normal tests for integrity before insertion into the Zr-2 cladding

Advice

The high temperature autoclave test cannot be relied upon for this purpose. Helium leak testing on a 100% basis is recommended to start with. This may be relaxed as experience is acquired and indicates that it is prudent to do so.

[redacted]



CRITERION F

The aluminum cladding shall have a nominal wall thickness of at least 0.030".

Advice

See Criterion B, above.

CRITERION G

The target cores shall be made up of pieces of lithium aluminate having a diameter of 1.075", a minimum length of 1" (See also Requirement II, Criteria B&C), and a bulk density of at least 70% of the theoretical value, the most recent value of which is 2.61 gm/cc.

Advice

The basis for the minimum density isnot firm. Results of tests now in progress may lead to upward revision of this value.

CRITERION H

The finished element shall be subjected to high temperature pressurization (1300 psi, 300 C minimum). Localized deviations from circularity of cross-section (i.e. ridges) of the Zr-2 cladding shall not be acceptable. Indentations of the cladding over internal longitudinal gaps shall also not be acceptable.

 [redacted]

REQUIREMENT V

The target element shall be compatible with procedures for post-irradiation processing, including Zr-2 jacket removal, 100-N basin handling, shipping, and tritium extraction at Savannah River Plant. In addition, the quality of the gases evolved during the extraction step shall not depart significantly from that of normal production at Savannah River.

Technical Basis

The target elements will be subjected to a variety of handling operations after discharge from the reactor and prior to the time that the tritium extraction step begins. Because of the high levels of radioactivity induced in zirconium, the outer cladding will be removed in the 100-N basin and disposed of separately. Thus, the impurity levels of the Al cladding and the lithium aluminate must be controlled so as to keep the induced activity of the Al-clad targets at an acceptable level for shipping and for handling at the Savannah River Plant.

The integrity of the aluminum cladding must be maintained during the post-irradiation handling steps to prevent loss of tritium, both for economic reasons and to prevent personnel exposure in the basin area, during shipping or at the Savannah River Plant. Equipment for mechanically decladding the Zr-2 is currently under development. Criteria for compatibility with this equipment and process cannot be stated at this time.

A lubricant between the Zr-2 and aluminum may be required. A lubricant, such as graphite, would permit assembly with smaller gaps without galling or siezing, it may eliminate the possibility of operation of a thermal ratchet mechanism in the element during operation, it should prevent Al-Zr bonding as occurred on one occasion in a target test irradiation, and it could make disassembly easier should the current process development effort not work out as well as is currently expected. However, graphite embedded in or in intimate contact with aluminum causes galvanic corrosion of the aluminum (by pitting attack) in water. In addition, there is some question regarding the consequences in the Savannah River extraction plant of the presence of graphite on the element. Resolution of this point has been requested of DuPont personnel. Alternate lubricant materials must not (a) cause rapid aluminum corrosion in water, (b) become too radioactive, or (c) interfere unduly with the extraction process.

Material known to cause expensive maintenance problems in the extraction plant when present as impurities are sulfur and fluorine. These materials as impurities in either the aluminum cladding, the lithium aluminate, or the lubricant must be maintained at a very low level. Carbon is believed to cause plant downtime also but it is not as critical as sulfur and fluorine.

 [redacted]

[redacted]



Moisture present as an impurity in the finished target element will not be separated from the tritium in the early stages of the extraction step. Levels of 10% hydrogen impurity are not uncommon now and, for this reason, a several-stage thermal diffusion column is used to upgrade the tritium. Some expense is involved in this step, however, so for economic reasons the moisture content must be kept under control. One hundred parts per million of water present initially, for example, corresponds to a tritium GVR of about 0.3 or a total GVR of 0.9. The average goal exposure of the coproduct target element is 3.5 GVR. Thus, 100 ppm of water will produce a product containing about 25 volume percent hydrogen (about 9 w/o).

CRITERION A

Previous criteria (III-E, G) pertaining to use of a high integrity inner aluminum can and specifying a minimum lithium aluminate bulk density must be met in order to reduce the frequency and severity of tritium releases in the 100-N basin to a low level.

CRITERION B

The aluminum cans and end caps shall contain no alloying additions or impurities (in type or degree) which will produce an induced radiation level, three months after irradiation, that is greater than 125% of that of C-64 alloy under comparable irradiation conditions.

Advice

Preliminary data indicates that 8001 aluminum alloy (1% Ni, 0.5% Fe) is satisfactory from the induced radiation standpoint compared to C-64 alloy. Direct radiation readings will be made on irradiated prototype elements here and at Savannah River to confirm these data. Pending this confirmation, it may be assumed that either alloy will be acceptable.

CRITERION C

The lithium aluminate shall contain no impurities (in type or degree) which will produce an induced radiation level greater than ______.

Advice

Pending determination of a quantitative limit, a value of 10 mR per hour at one foot after 90 days decay time may be assumed for the aluminum clad element.

 [redacted]

[redacted]





CRITERION D

No process operation or design feature shall be used which will increase the corrosion rate of the aluminum cladding in 100-N basin water to a degree such that penetration can occur in less than one week.

CRITERION E

The water content of thelithium aluminate in the finished element shall be less than ___ ppm.

Advice

A tentative limit of 400 ppm may be assumed.

CRITERION F

The lithium aluminate shall contain less than ___ ppm of sulfur, ___ ppm of fluorine, and ____ ppm of carbon.

Advice

Tentative limits of 10 ppm for sulfur and fluorine and 500 ppm for carbon may be assumed.

CRITERION G

The lithium aluminate density shall not exceed 85% of the theoretical density. (See also Criterion IV-G).

Advice

The 85% figure is somewhat arbitrary. Preliminary data on unirradiated material indicates that the rate of dissolution in sodium tetraborate in the extraction step falls off rapidly as the density increases above this level.

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