United States Department of the Interior

U. S. GEOLOGICAL SURVEY
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IN REPLY REFER TO:

November 16, 2004

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington DC 20555

Gentlemen:

The U.S. Geological Survey is herein requesting an amendment to its research reactor facility license (No. R-113, Docket 50-274) to allow the use of aluminum-clad TRIGA fuel in the core.

This request has been reviewed and approved by the USGS Reactor Operations Committee. Correspondence concerning this request should be directed to Tim DeBey, Reactor Supervisor.

Sincerely,

Warren Day

Warren Day
Reactor Administrator

A020

License amendment request to use aluminum-clad fuel in the GSTR

Background: The USGS TRIGA Reactor (GSTR) is a 1 MW(th) research reactor facility that has been in operation since February, 1969. The mission of the facility is to perform nuclear research in basic earth sciences in support of the U.S. Geological Survey, a bureau within the U.S. Department of Interior. The GSTR uses cylindrical fuel elements that contain <20% enriched U-235 in a zirconium-hydride matrix. The GSTR technical specifications currently authorize the use of fuel elements that have a stainless-steel cladding. This request asks that the GSTR technical specifications be amended to allow the use of similar TRIGA fuel elements that have an aluminum cladding. The primary motivation for this request is to provide for the efficient utilization of 56 TRIGA fuel elements that were previously used at the Alan J. Blotcky Nuclear Reactor that was operated by the Veterans Administration in Omaha, Nebraska. These 56 elements have very minimal utilization, with approximately 0.5 g out of 35 g of U-235 used in each element. GSTR utilization of these 56 fuel elements will reduce the amount of irradiated fuel sent to the DOE storage facilities and will reduce the fuel replacement costs for the USGS.

Aluminum Clad Fuel Historical Use: Aluminum-clad TRIGA fuel was the first type of TRIGA fuel element manufactured by General Atomics. All of the early TRIGA reactors were fueled with aluminum-clad elements. The General Atomics Mark F reactor was the first facility to operate at 1 MW with aluminum clad fuel. The University of Illinois reactor was licensed to operate at 1.5 MW with aluminum clad fuel in its F and/or G rings without any additional restrictions on the power level or measured fuel temperature limit. Research reactor facilities in the United States that are currently operating with aluminum clad TRIGA fuel are Aerotest, Reed College, and the University of Utah.

GSTR Technical Specifications: The current GSTR technical specifications that address the limitations on the fuel used are in Section D, copied as follows:

Current:

D. Reactor Core

1. The core shall be an assembly of TRIGA stainless steel clad fuel-moderator elements, nominally 8.5 to 12 wt% uranium, arranged in a close-packed array except for (1) replacement of single individual elements with incore irradiation *facilities or control rods; (2) two separated experiment positions in the D through E rings, each occupying a maximum of three fuel element positions. The reflector (excluding experiments and experimental facilities) shall be water or a combination of graphite and water. The reactor shall not be operated in any manner that would cause any fuel element to produce a calculated steady state power level in excess of 22 kW.*

2. The excess reactivity above cold critical, without xenon, shall not exceed 4.9% delta k/k with experiments in place.

3. Fuel temperatures near the core midplane in either the B or C ring of elements shall be continuously recorded during the pulse mode of operation using a standard thermocouple fuel element. The thermocouple element shall be of 12 wt% uranium loading if any 12 wt% loaded elements exist in the core. The reactor shall not be operated in a manner which would cause the measured fuel temperature to exceed 800°C.

4. Power levels during pulse mode operation that exceed 2500 megawatts shall be cause for the reactor to the shut down pending an investigation by the reactor supervisor to determine the reason for the pulse magnitude. His evaluation and conclusions as to the reason for the pulse magnitude shall be submitted to the Reactor Operations Committee for review. Pulse mode operation will not be resumed until approved by the Committee.

5. If the reactor is operated in the pulse mode during intervals of less than six months, the reactor shall be pulsed semiannually with a reactivity insertion of at least 1.5% delta k/k to compare fuel temperature measurements and peak power levels with those of previous pulses of the same reactivity value. If the reactor is not pulsed during intervals of six months, then for the first pulse after the time of the last comparative pulse, the reactor shall be pulsed with a reactivity insertion of at least 1.5% delta k/k to compare fuel temperature measurements and peak power levels with those of previous pulses of the same reactivity value.

6. Each standard fuel element shall be checked for transverse bend and longitudinal elongation after the first 100 pulses of any magnitude and after every 500 pulses or every 60 months, whichever comes first. The limit of transverse bend shall be 1/16-inch over the total length of the clad portion of the element (excluding end fittings). The limit on longitudinal elongation shall be 1/10 inch. The reactor shall not be operated in the pulse mode with elements installed which have been found to exceed these limits.

Any element which exhibits a clad break as indicated by a measurable release of fission products shall be located and removed from service before continuation of routine operation.

7. The power produced by each fuel element while operating at the rated full power shall be calculated if the reactor is to be operated at greater than 100 kW with less than 100 fuel elements in the core. Recalculations shall be performed:

a) at 6 ± 1 month intervals, or

b) whenever a core loading change occurs.

Power per element calculations are not required at any time that the core contains at least 100 fuel elements or if reactor power is limited to 100 kW. If the calculations show that any fuel element would produce more than 22 kW, the reactor shall not be operated with that core configuration.

This request proposes to amend Section D of the GSTR Technical Specifications to read as follows, with changes marked in bold and vertical lines drawn in the associated margins:

Proposed:

D. Reactor Core

*1. The core shall be an assembly of TRIGA **aluminum or** stainless steel clad fuel-moderator elements, nominally 8.**0** to 12 wt% uranium, arranged in a close-packed array except for (1) replacement of single individual elements with incore irradiation facilities or control rods; (2) two separated experiment positions in the D through E rings, each occupying a maximum of three fuel element positions. The reflector (excluding experiments and experimental facilities) shall be water or a combination of graphite and water. The reactor shall not be operated in any manner that would cause any **stainless-steel clad** fuel element to produce a calculated steady state power level in excess of 22 kW. **Aluminum clad fuel-moderator elements will only be allowed in the F and G rings of the core assembly.***

2. The excess reactivity above cold critical, without xenon, shall not exceed 4.9% delta k/k with experiments in place.

3. Fuel temperatures near the core midplane in either the B or C ring of elements shall be continuously recorded during the pulse mode of operation using a standard thermocouple fuel element. The thermocouple element shall be of 12 wt% uranium loading if any 12 wt% loaded elements exist in the core. The reactor shall not be operated in a manner which would cause the measured fuel temperature to exceed 800°C ***in a stainless steel clad element or 530°C in an aluminum clad element.***

4. Power levels during pulse mode operation that exceed 2500 megawatts shall be cause for the reactor to the shut down pending an investigation by the reactor supervisor to determine the reason for the pulse magnitude. His evaluation and *conclusions as to the reason for the pulse magnitude shall be submitted to the Reactor Operations Committee for review. Pulse mode operation will not be resumed until approved by the Committee.*

5. If the reactor is operated in the pulse mode during intervals of less than six months, the reactor shall be pulsed semiannually with a reactivity insertion of at least 1.5% delta k/k to compare fuel temperature measurements and peak power levels with those of previous pulses of the same reactivity value. If the reactor is not pulsed during intervals of six months, then for the first pulse after the time of the last comparative pulse, the reactor shall be pulsed with a reactivity insertion of at least 1.5% delta k/k to compare fuel temperature measurements and peak power levels with those of previous pulses of the same reactivity value.

6. Each standard fuel element shall be checked for transverse bend and longitudinal elongation after the first 100 pulses of any magnitude and after every 500 pulses or every 60 months, whichever comes first. The limit of transverse bend shall be 1/16-inch over the total length of the clad portion of the element (excluding end fittings). The limit on longitudinal elongation shall be 1/10 inch ***for stainless steel clad elements and ½-inch for aluminum clad elements.*** *The reactor shall not be operated in the pulse mode with elements installed which have been found to exceed these limits.*

Any element which exhibits a clad break as indicated by a measurable release of fission products shall be located and removed from service before continuation of routine operation. ***Fuel elements that have been removed from service do not need to be checked for transverse bend or longitudinal elongation.***

7. The power produced by each fuel element while operating at the rated full power shall be calculated if the reactor is to be operated at greater than 100 kW with less than 100 fuel elements in the core. Recalculations shall be performed:

a) at 6 ± 1 month intervals, or

b) whenever a core loading change occurs.

Power per element calculations are not required at any time that the core contains at least 100 fuel elements or if reactor power is limited to 100 kW. If the calculations show that any fuel element would produce more than 22 kW, the reactor shall not be operated with that core configuration.

The proposed changes to the technical specifications are:

1. Allow the use of aluminum clad elements in the GSTR core.
2. Change the lower limit of uranium loading from 8.5 wt% to 8.0 wt%.
3. Restrict the use of aluminum clad elements to the F and G rings.
4. Restrict the fuel temperature of aluminum clad elements to 530 °C.
5. Set the longitudinal elongation limit for aluminum clad elements to be ½".
6. Specify that fuel elements that have been removed from service do not need to be checked for bowing or elongation.

Technical Details

The following table details the physical properties of the three types of fuel elements that are proposed to be used at the GSTR. Note that the 8.5 wt% and 12 wt% elements that are clad with stainless steel are currently authorized by the license and technical specifications. The samarium burnable poison in the aluminum –clad elements is in the form of thin wafers at each end of the fuel section of each element.

Fuel element property	8.5 wt% U, stainless steel clad	12 wt% U, stainless steel clad	8.0 wt% U, aluminum clad
Overall length (inches)	28.37	28.37	28.44
Diameter (inches)	1.47	1.47	1.48
No. of fuel segments	1 to 3	3	1
Total length of fuel (in.)	15	15	14
Nominal grams U	39	55	36
Enrichment %	<20	<20	<20
Wt% uranium	8.5	12	8
H/Zr atom ratio	1.7:1	1.7:1	1:1
Cladding material	stainless steel	stainless steel	aluminum
Cladding thickness (in)	0.02	0.02	0.03
Graphite end plugs?	yes	yes	yes
Burnable poison	no	no	yes - 0.05" Sm

Max. recommended operating temp (deg C)	800	800	530
ßeff w/graphite reflector	0.007	0.007	0.0073
Prompt neutron lifetime	43 µsec	43 µsec	60 µsec

Safety Analysis

The GSTR safety analyses show that the worst case credible accident is the gross failure (in air) of the cladding of the "hottest" single fuel element in the core that has been operating at full power for an infinite amount of time. This analysis shows effects that are directly related to the fission rate (fission product inventory) in the element and therefore directly related to the fuel loading of the element. Since the aluminum-clad elements have lower fuel loadings than any of the stainless steel elements (by ~8% to ~35%), they pose a threat that is well within the previously analyzed fuel failure accident parameters.

The one limitation that must be observed for the aluminum clad elements that is more limiting than for stainless steel clad elements is that the maximum fuel temperature must not exceed 530°C. This limitation is due to a phase transformation in the ZrH (1:1 atom ratio) that begins at 530°C. This phase transformation can cause large dimensional changes in the ZrH that could deform the element and rupture the cladding; therefore, the phase transformation must be avoided. In the GSTR, empirical data (below) show that a maximum fuel temperature of 530°C will not be exceeded under any conditions of allowed operation (1 MW steady state or $3.00 pulse insertion). A maximum allowed $3.00 pulse at the GSTR results in peak fuel temperatures that are less than those from operating at the maximum allowed steady state power of 1 MW.

Operation	Core loading (elements)	Max. central core temp (B or C ring)
1 MW steady state - March 1969	78 elements (new 8.5 wt%)	511 C
$3.00 pulse - March 1969	78 elements (new 8.5 wt%)	441 C
$3.00 pulse – in General Atomics Mk I	100 elements (new 8.5 wt%)	405 C
$3.00 pulse - December 1969	80 elements (small burnup 8.5 wt%)	355 C
$2.49 pulse (max pulse rod worth) - July 2001	125 elements (mixed 8.5 and 12 wt%)	320 C in 12 wt% element
1 MW steady state - March 2002	125 elements (mixed 8.5 and 12 wt%)	365 C in 12 wt% element

Data from the General Atomics Mk I TRIGA facility with aluminum-clad fuel showed that performing over 1000 pulses of $3.08 did not produce a peak fuel temperature above 500C in any of the elements. These data were from a smaller core (F-ring), so pulsing of the GSTR (G-ring core) would produce a broader pulse with a lower peak temperature. Since the GSTR has a technical specification restriction for a maximum pulse insertion of $3.00, the empirical data support the conclusion that the 530 C temperature limit would not be breached for aluminum-clad fuel elements in any core position in the GSTR.

Restricting the aluminum clad elements to the F and G rings will provide a further safety margin on the fuel temperature of those elements. For example, the maximum fuel temperature of stainless-steel clad elements in the G ring of the GSTR at steady-state power of 1MW is approximately 180 C, about half of the temperature of B-ring elements. The proposed restriction on aluminum clad element location will not be burdensome for the planned operations of the GSTR with this fuel.

During pulsing operations, the longer prompt neutron lifetime of the aluminum-clad elements will produce some broadening of the pulse. During a $3.00 pulse, the minimum period for the stainless steel-clad fuel is ~ 2 msec. Due to the increased prompt neutron lifetime in the aluminum-clad fuel, that same pulse with a core made up entirely of aluminum-clad fuel would have a minimum period of ~2.9 msec, or a 45% increase. This pulse-broadening is the same effect that has been seen as the core has grown from ~80 elements to ~125 elements over the first 25 years of operation. It does not present a safety hazard. At the same time, the aluminum-clad fuel has a smaller prompt-negative temperature coefficient than the stainless steel-clad fuel, with approximate values of -11×10^{-5} vs -13×10^{-5}, respectively. This ~20% change in the prompt negative temperature coefficient will cause the energy of the pulse (and therefore the temperature increase) to be slightly higher in aluminum-clad fuel than it is in stainless steel-clad fuel of the same uranium loading. A 20% increase in peak pulse fuel temperature would give a maximum calculated temperature of approximately 525 C in the B-ring of a 78-element core made up entirely of aluminum-clad fuel. This is below the 530 C limit and it is also unrealistically conservative because (1) aluminum-clad elements will be in the F and G rings only, where the power production is much lower than the B-ring, (2) the reactor core now contains 125 fuel elements, making the power produced per element much lower than in a 78-element core, (3) the core will not be made up entirely of aluminum-clad elements, but it will be a maximum of approximately 50% aluminum-clad, and (4) empirical data from General Atomics shows that a $3.08 pulse yields maximum fuel temperatures of less than 500 C in aluminum-clad fuel.

In any case, there are no operations that can be performed within the limitations of the GSTR license and technical specifications that would produce a peak fuel temperature of 530 C or higher in aluminum-clad fuel elements. By observing the license and technical specification limits for a maximum power of 1 MW, a maximum pulse insertion of $3.00, a maximum stainless-steel fuel temperature limit of 800 C, and a location restriction of F and G rings only for aluminum-clad fuel, we are assured that the aluminum-clad fuel temperature will not reach 530 C.

In consideration of the deformation limits for aluminum-clad fuel, General Atomics informed the USGS that the standard, historically-accepted limits are 0.5" for elongation and 1/16" for bowing over the total length of the fuel cladding (~22"). The 0.5" elongation limit has been used as a technical specification at other TRIGA facilities that used aluminum-clad fuel. This is an increase in the elongation limit when compared to the 0.1" limit for stainless-steel clad fuel. The reduced tensile strength and increased strain before failure of the aluminum clad justifies this elongation limit increase. The yield strength of 6061 aluminum at 500 F is ~5 ksi and ~60% elongation is expected before rupture. In contrast, the yield strength of 304 stainless steel is ~100 ksi with ~40% elongation before rupture.

Although the diameter of the aluminum-clad elements is 0.01" larger (1.48") than the stainless steel-clad elements (1.47"), the holes in the grid plate are 1.505" diameter (+0.005", -0.000") and they provide sufficient clearance for use of the aluminum elements. Aluminum-clad graphite elements have been used in the GSTR, with diameters of 1.48". The 1.505" holes were also used in earlier TRIGA reactors that were fueled with aluminum-clad fuel. The flow path for cooling water past the top grid plate continues to be supplied by spaces around the top triflute fittings as it is with stainless-steel elements.

Conclusion

It is our conclusion that the use of aluminum-clad TRIGA fuel elements in the F and G rings of the GSTR does not endanger the health or safety of the public. All possible accidents and consequences, both in type and severity, associated with the use of aluminum-clad fuel fall within the safety analysis envelope previously provided for operation of the GSTR with 8.5 wt % and 12 wt % stainless-steel clad fuel. The only additional restriction needed is the limitation of peak fuel temperature in the aluminum-clad fuel to 530 C. It is unreasonable to expect that this temperature limit could be reached in <u>any</u> core location by observance of the existing license and technical specification limitations; however, the proposed restriction to use aluminum-clad fuel only in the F and G rings provides a very conservative, added measure of safety for the maximum temperature of the fuel.