UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of THE REGENTS OF THE UNIVERSITY OF CALIFORNIA (UCLA Research Reactor)	Docket No. 50-142 (Proposed Renewal of Facility License)

Docketed
USNRC
JAN 17 1983

DECLARATION OF STEVEN AFTERGOOD AS TO CONTENTION XIII

I, Steven Aftergood, do declare as follows:

1. I am an environmental researcher with the Committee to Bridge the Gap and a member of the Southern California Federation of Scientists (SCFS). A statement of professional qualifications is attached to my declaration as to Contention I.

2. As part of an SCFS project examining methods of reducing Highly Enriched Uranium (HEU) inventories worldwide because of the significant proliferation risks associated with HEU use, I have researched the availability of Low Enriched Uranium (LEU) replacement fuel for conversion of non-power reactors currently operating with fuel of weapons grade. This review has included a search of the technical literature associated with the RERTR program (Reduced Enrichment for Research and Test Reactors) as well as direct contacts with manufacturers of research reactor fuels and with operators of a research reactor that has been converted from HEU to LEU fuel.

3. It is my conclusion that LEU fuels are currently available; that a reactor such as UCLA's would, after conversion, have essentially the same educational and research capabilities as it does presently; and that such conversion to LEU fuel could have very significant safety benefits, in addition to the very important contribution to the national (and NRC) policy of reducing wherever possible HEU inventories for non-proliferation reasons.

8301180397 830112
PDR ADOCK 05000142
G PDR

4. One firm currently offering LEU fuel commercially is the General Atomic Company of San Diego. General Atomic currently has available 19.7 % enriched TRIGA-type fuel, specifically designed for use in research reactors presently using MTR-type flat-plate HEU fuel of the kind used in the UCLA reactor. The General Atomic publication "TRIGA" (attachment A) at page 11 shows a photograph of the replacement TRIGA bundle alongside a standard flat-plate bundle. As indicated in the section on "Research Reactor Conversions":

> A number of reactors originally built for plate-type fuel elements have been converted to use TRIGA fuel. In most instances, the converted reactors have retained their existing core grid structure, control rod drives, and control console.

5. Attachments B (p. 5) and C list numerous research reactors originally utilizing plate-type fuel which have been successfully converted to TRIGA fuel. These include Penn State, Washington State, the University of Wisconsin, Texas A & M, the University of Maryland, and a number of others.

6. To confirm that such conversions are possible and to ascertain whether any problems have arisen, I contacted a Dr. Muno of the University of Maryland reactor staff. The attached item C indicates that the University of Maryland reactor was converted in 1974, which Dr. Muno confirmed. The reactor now runs at about 250 kw_{th}, with a thermal neutron flux in the range of 2 to 5×10^{12}. (UCLA, in its application at p. III/6-5 reports its thermal flux at 100 kw as about 1.5×10^{12} n/cm^2-sec).

7. Dr. Muno indicated that conversion was undertaken in part because there was concern that after 11 years in water, the aluminum cladding on the original flat-plate fuel might be losing its integrity. LEU fuel was chosen because it was anticipated that the NRC would eventually require a high degree of security for HEU and that it was unlikely the reactor staff could convince the University to fund guards and the like. TRIGA fuel was chosen for its inherent safety features, primarily the prompt negative temperature coefficient which provides a far greater degree of protection against destructive power excursions than found with flat-plate fuel. It was reasoned that it would be "a lot easier to license" a reactor that had the protection against destructive reactivity incidents afforded by the TRIGA fuel.

8. A completely new control console was installed at the time because the old one was a vacuum tube system, and tubes were not easily available. In addition, it was hard to find technicians who had been trained on tubes. Dr. Muno indicated that a slight drop in flux upon conversion to TRIGA fuel can be compensated for by a more efficient geometry, and that in any case, the current flux (2 to 5×10^{12}) was more than adequate for the University's needs (mainly activation analysis). One researcher in materials science occasionally requires a flux of around 10^{14}, so he sends his samples off to Argonne or Oak Ridge.

9. I confirmed with the TRIGA division of General Atomic the current commercial availability of TRIGA LEU fuel for plate-type reactors and that conversion to LEU TRIGA fuel involves no significant drop in neutron flux. I was informed that the average flux is comparable; the shape of the flux, however, will vary, tending to peak in the reflector region. Water-filled flux traps can increase the available flux; even without such flux traps, though, the reactor would still be able to perform the same functions as prior to conversion. Conversion rarely requires changes to the control rod or cooling systems, furthermore.

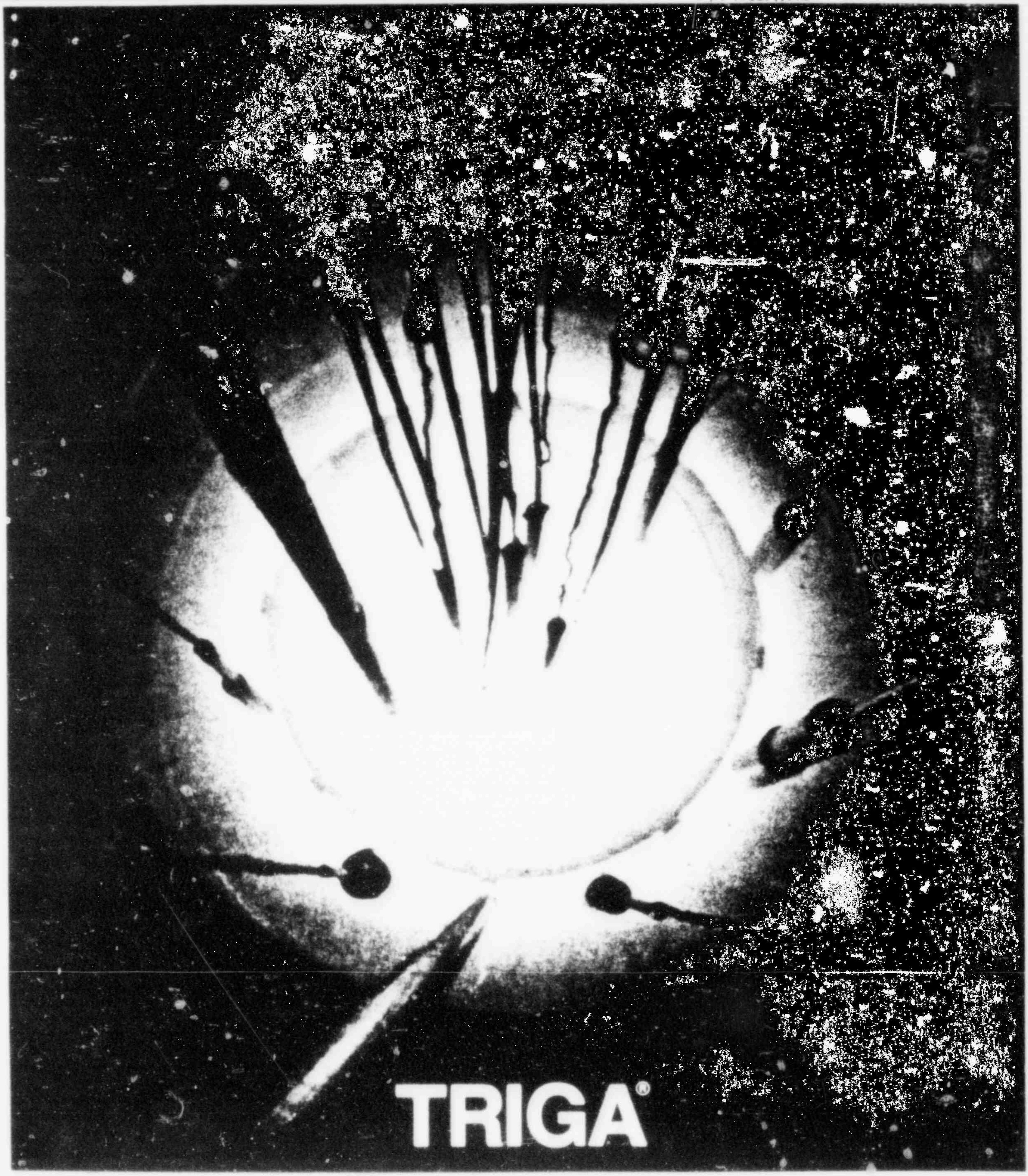
10. General Atomic, I was assured by its marketing division, currently has commercially available LEU TRIGA fuel for conversion of plate-type reactors and is "ready, willing, and able" to provide conversions as they come up. Furthermore, I was informed, General Atomic has competitors in the LEU field--NUKEM in Germany and CERCA in France currently having available LEU flat plate fuel for research reactors.

11. I conclude that LEU fuel is currently available for use in the UCLA reactor.

I declare under penalty of perjury that the foregoing is true and correct to the best of my knowledge and belief.

Steven Aftergood

Executed at Los Angeles, California, this 12 day of January, 1983



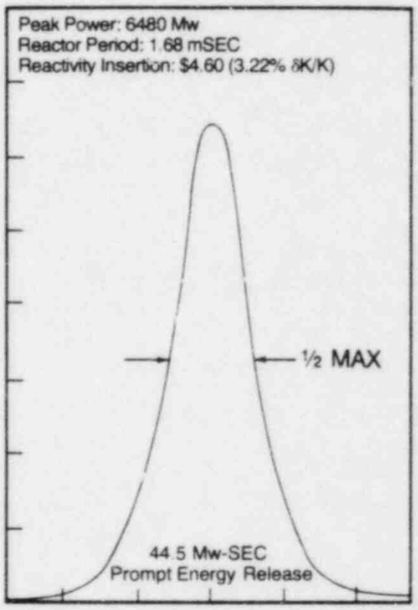
TRIGA®

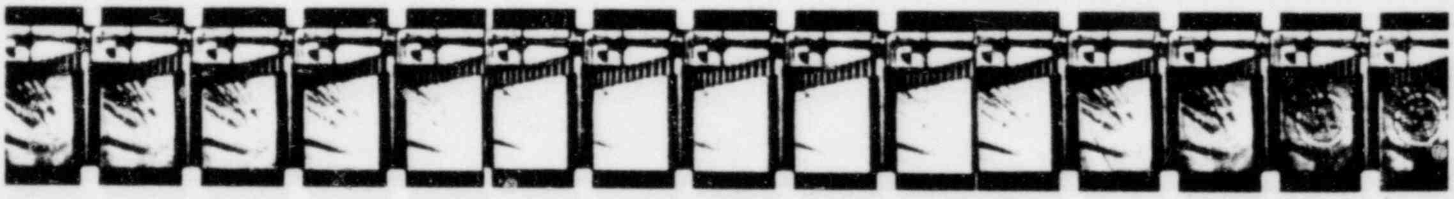
Pulsing to 22,000,000 kw

Pulsing Extends Applications. The TRIGA reactor's controlled pulsing operation, made possible by its built-in safety, has opened up important new reactor applications. This pulsing capability may be used to investigate reactor kinetics and transient testing of power reactor fuel, or to study the effects of extreme radiation environments on biological and electronic systems. Pulsing may also be used for the production of very short half-life isotopes, and in many other basic studies where high-intensity pulses of neutron and gamma radiation are required.

The 1500 kw TRIGA reactor at General Atomic has been used extensively to prove the pulsing capability of TRIGA fuel. This reactor has been pulsed safely to peak power levels well in excess of 8,000,000 kw. More than 50,000 pulses on all TRIGA reactors have demonstrated the performance, safety and high reliability of TRIGA fuel.

Annular core pulsed reactors have been designed for routine pulsing to power levels of 22,000,000 kw.





TRIGA Safety

Inherent Safety. The TRIGA reactor's inherent safety is due primarily to a physical property of its uranium-zirconium hydride fuel elements, which gives the TRIGA core a large *prompt* negative temperature coefficient. Power rises initiated by the rapid insertion of large amounts of excess reactivity are automatically suppressed without external controls and the reactor immediately returns to normal operating levels. By contrast, a *delayed* negative temperature coefficient found on conventional reactors provides safety only against relatively small insertions of excess reactivity.

A combined total of more than 500 reactor years of safe operation has been achieved by TRIGA reactors throughout the world. The proven and inherent safety of TRIGA reactors permits installation in a conventional building and siting in urban areas such as university campuses, hospitals or classrooms. Installation within a conventional building without the need for a pressure type containment results in significant savings in facility construction costs and the potential for economical installation in an existing building.

Research Reactor Conversions

A number of reactors originally built for plate-type fuel elements have been converted to use TRIGA fuel. In most instances, the converted reactors have retained their existing core grid structure, control rod drives, and control console. In addition to increased safety and flexibility, the TRIGA conversion has provided a dual steady state/pulsing capability with steady state performance levels up to 2 MW, still with natural convection cooling of the core. The conversion to a complete TRIGA core can be a step-wise process whereby TRIGA 4-rod clusters are added a few at a time to an operating plate-type core.

General Data

27 fuel clusters for 1 MW operation; 4 fuel rods to each cluster, containing $UZrH_{1.6}$ using uranium enriched to 20%.

Up to 2000 kw steady state power level, 2,000,000 to 6,400,000 kw pulse power level.

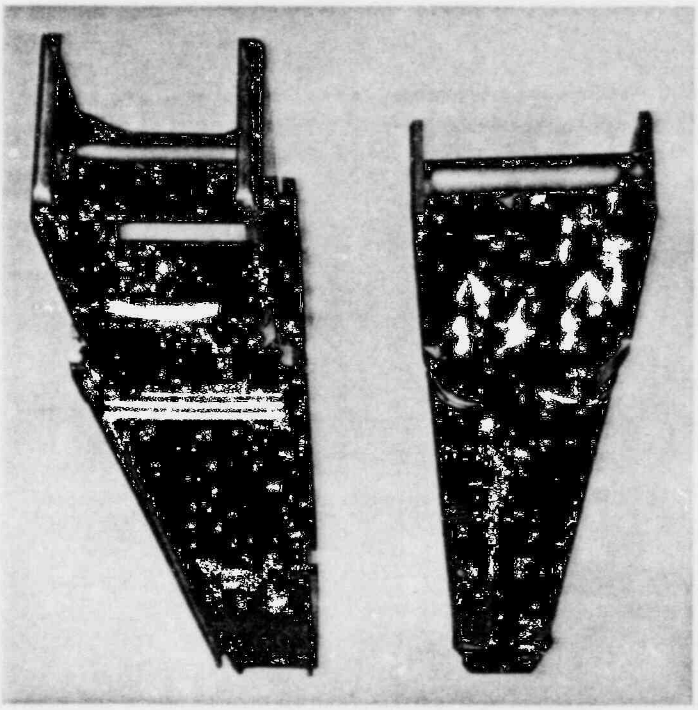
High Power Level Reactor Conversions

The 16-rod, 25-rod and 36-rod fuel clusters used in TRIGA reactors for steady state operation at 5 MW to 25 MW are designed to be installed in reactors originally incorporating plate-type elements. Conversion of a plate-type reactor to a high power TRIGA reactor permits use of the existing forced circulation cooling system but gains the inherent safety characteristics of TRIGA reactors and the improved fuel cycle economics.

General Data

Square fuel cluster containing 4x4, 5x5, or 6x6 rods, dependent upon final power level.

Each fuel rod contains 20% enriched $UZrH_{1.6}$ fuel with erbium as a burnable poison.



Inspection of finished TRIGA fuel elements.

Attachment B

CON-11 (Rev. 1)

ADVANTAGES OF TRIGA FUEL FOR RESEARCH REACTORS

October 1981

ADVANTAGES OF TRIGA FUEL FOR RESEARCH REACTORS

All TRIGA fuel is made by GA with a uranium enrichment of just under 20% and thus is classified as Low Enrichment Uranium (LEU) fuel.

The following discussion of advantages applies to TRIGA fuel clusters which can be inserted in existing grid plates to convert plate-type fueled reactors, and some pin-type fueled reactors, to TRIGA. TRIGA's advantages have motivated the owners of twelve plate-type fueled reactors to convert to the use of TRIGA fuel. TRIGA LEU fuel is available now for use in existing reactors operating at steady state power levels to 50 MW.

1. UNIQUE SAFETY

All of GA's research and test reactors are fueled with UZrH. This unique fuel provides the highest degree of safety available in any type of nuclear reactor. In these days of increasing public concern with perceived hazards of nuclear facilities, these safety advantages alone should justify use of UZrH fuel.

A. The UZrH fuel has a prompt negative temperature coefficient of reactivity, vs. a delayed coefficient in aluminum-clad plate-type fuel. This allows UZrH cores to safely withstand accidental reactivity insertions that have completely destroyed plate-fueled cores.

B. UZrH is chemically stable. It can be safely quenched at 1200°C in water, while exothermic metal-water reactions take place with aluminum at 650°C.

C. High-temperature strength and ductility of TRIGA's Incoloy-800 fuel cladding provide a yield strength greater than 10,000 psi at 900°C. The aluminum cladding on plate-type fuels melts at about 650°C.

D. The UZrH fuel material has very superior fission product retention. The aluminum-clad plate-type fuels melt at 650°C, releasing 100% of the volatile fission products. Whereas, at this same temperature UZrH retains about 99.9% of these fission products even with the cladding removed.

E. New TRIGAs do not require expensive pressure-containment buildings because of these unique safety features.

2. ECONOMY

A. Major operating cost savings result from the fact that UZrH fuel contains several times as much U-235 as plate fuels. GA sells its fuel at standard published fixed prices with standard terms and a commercial warranty. Although the initial cost of UZrH fuel is usually higher than plate fuel, the total fuel cycle costs are lower for UZrH due to the much longer core life, and reduced shipping and reprocessing costs.

B. Individual fuel rods within a cluster can be easily replaced in case of damage (vs. replacement of entire plate-type element).

C. There are fewer reactor shutdowns (with corresponding savings in fuel handling costs and increased experiment time/continuity) because fewer core changes are required with TRIGA fuel.

D. Uranium costs are lower because TRIGA's uranium lasts as long as that in several plate-type cores, which must be purchased at prices that are continuing to escalate.

E. Less time and money is spent on inter-government problems to export/import fuel and the contained uranium since TRIGA fuel outlasts several plate-type cores. Thus the potential for unplanned reactor shutdowns due to slow or delayed fuel delivery is significantly reduced.

3. PULSING OPERATION

A. Routine pulsing is not possible with plate-type fuel but is a normal mode of operation with most TRIGAs. Since 1958, TRIGA reactors have pulsed over 50,000 times.

B. Standard TRIGA fuel with 8.5 wt-% uranium is licensed for routine pulsing with reactivity insertions of 3.2% $\delta k/k$ up to a peak power of about 6,400,000 kW. The prototype TRIGA at GA has been pulsed with reactivity insertions of 3.5% δk/k to a peak power of about 8,400,000 kW. Pulsing allows production of very short-lived isotopes, transient testing of materials, and other unique applications.

C. The TRIGA-ACPRs (Annular Core Pulse Reactors) at the Japan Atomic Energy Research Institute and the Institute for Nuclear Technologies in Romania are in operation and pulsing to ~20,000,000 kW for safety testing of power reactor fuels.

4. LARGER EXPERIMENT REACTIVITIES AND MORE FLEXIBLE OPERATIONS

A. Due to its larger prompt negative temperature coefficient, TRIGA can safely withstand larger accidental reactivity insertions which mean maximum flexibility for student use, training and experiments.

B. TRIGAs are licensed for in-core experiments having a reactivity worth of up to 2.1% δk/k for one experiment and a total of 2.8% δk/k for several.

C. TRIGA is also less sensitive than plate-fueled reactors to reactivity changes in the reflector region. As a result, the TRIGA core can be moved from a position with a void on one side to a position which is completely reflected by water without removing fuel elements.

D. TRIGA's special square wave mode of very fast reactor startup (rise to normal steady state power levels in a few seconds) is available on all TRIGA pulsing reactors. This mode of operation, which is possible due to TRIGA's large prompt negative temperature coefficient, means higher utilization, more "on-line" time and reproducibility of irradiation doses.

5. LICENSE PRECEDENTS

Because of their inherent safety, TRIGA reactors are currently licensed for the following types of experiments:

A. In-core pneumatic transfer systems under both steady-state and pulsing modes of operation;

B. In-core experiments at cryogenic temperatures;

C. In-core experiments at temperatures of up to 2000°C;

D. In-core experiments at elevated temperatures in which samples of fissile material can be subjected to both steady-state and pulsing conditions;

E. In-core experiments in which explosives are detonated.

6. PROVEN RELIABILITY

A. Sixty-three TRIGA reactors have been or are being constructed throughout the world, and of these, 34 routinely operate in the pulsing mode.

B. TRIGA reactors have greater than 800 reactor years of safe operating experience and over 50,000 pulses.

7. FUEL GUARANTEE AND SUPPLY

A. TRIGA LEU fuel is the only LEU fuel currently available in power levels to 50 MW steady state.

B. GA designs, develops, manufactures, and guarantees the TRIGA fuel.

C. GA stocks spare fuel for the immediate, unplanned needs of customers; TRIGA fuel may be purchased a few elements at a time as the need arises.

D. The continuing requirements of the many TRIGA reactors in operation give assurance of a continuing, reliable fuel and spare parts supply.

8. PREFERENCE OF TRIGA BY EXPERIENCED CUSTOMERS

A. More TRIGA reactors are in operation than those of any other research reactor manufacturer.

B. TRIGA is still the most widely chosen research reactor; no type of research reactor other than TRIGA has been purchased commercially anywhere in the world since 1968.

C. The TRIGA system was chosen by the following experienced reactor groups for conversion of their plate-type research reactors to TRIGA fuel:

1) Pennsylvania State University
2) Washington State University
3) University of Wisconsin
4) Texas A&M University
5) USAEC at the Puerto Rico Nuclear Center
6) University of Maryland
7) Aerojet Corp., California
8) University of Frankfurt, Germany (water-boiled type)
9) Office of Atomic Energy for Peace, Thailand
10) Nuclear Research Center, Iran
11) National Tsing Hua University, Taiwan
12) Atomic Energy Commission, Philippines

9. GENERAL ATOMIC CAPABILITIES/SERVICES

A. Corporate assets of GA's owners is over $50 billion.

B. GA is the world's largest and only remaining U.S. research reactor supplier.

C. GA designs and manufactures control rod drives and complete nuclear instrumentation and control systems for reactor facilities which also wish to update these components. GA's instrumentation and control systems use state-of-the-art, micro-processor-based electronics making extensive use of integrated circuits; these systems are used in power reactors and therefore are designed to meet stringent safety requirements.

D. GA's competent staff of nuclear physicists, engineers, seismic experts and reactor designers has the most modern techniques and computational equipment to perform any safety or reactor analyses that may be required as part of a reactor conversion or its licensing. The current TRIGA staff, with 200 man-years of TRIGA reactor engineering experience, is also available for consultation on any aspect of nuclear facility planning, engineering or operation.

E. GA routinely conducts in-depth training and technology transfer programs for TRIGA customers. The two TRIGA reactors owned and operated by GA at its San Diego laboratories are utilized to provide "hands on" operational experience to supplement the lectures and homework assignments. At the conclusion of the course, U.S. students take the U.S. Nuclear Regulatory Commission Senior Reactor Operators license examination; foreign students take a similar exam administered by the GA staff.

F. TRIGA owners in the U.S. and in Europe hold bi-annual TRIGA Owners Conferences where experimental work, innovative ideas, reactor modifications and common problems associated with the nuclear community are discussed and, where appropriate, united actions taken. The proceedings of these meetings are published and distributed to all TRIGA owners.

G. GA's TRIGA Reactor Division is dedicated to the continuing improvement and reliability of TRIGA reactors.

Attachment C

C

TRIGA® Reactors

INSTALLATIONS AND CONVERSIONS

GENERAL ATOMIC

GEN-10
Feb 1980

				MAXIMUM RATING		
		LOCATION	TYPE	STEADY STATE	PULSING	INITIAL CRITICALITY
Arizona	1	University of Arizona Tucson	TRIGA Mark I	250 kW	300,000 kW	12-7-58
California	2	General Atomic San Diego	TRIGA Mark I	250 kW	800,000 kW	5-3-58
	3	General Atomic San Diego	TRIGA Mark F	1,500 kW	8,400,000 kW	7-2-60
	4	General Atomic San Diego	TRIGA Mark III	Decommissioned		1-17-66
	5	Norair Division of Northrop Corporation Hawthorne	TRIGA Mark F	1,000 kW	1,500,000 kW	3-6-63
	6	University of California Berkeley	TRIGA Mark III	1,000 kW	2,000,000 kW	8-10-66
	7	University of California Irvine	TRIGA Mark I	250 kW	250,000 kW	11-25-69
	8	Aerotest Operations San Ramon	TRIGA Conversion	250 kW		7-9-65
Colorado	9	U.S. Geological Survey Denver	TRIGA Mark I	1,000 kW	1,200,000 kW	2-26-69
Idaho	10	Argonne Nat'l. Lab. West (HFEF, INEL) Idaho Falls	TRIGA Conversion	250 kW		10-12-77
Illinois	11	University of Illinois Urbana	TRIGA Mark II	1500 kW	6,500,000 kW	8-16-60
Kansas	12	Kansas State University Manhattan	TRIGA Mark II	250 kW	250,000 kW	10-16-62
Maryland	13	Harry Diamond Laboratories (U.S. Army) Forest Glen	TRIGA Mark F	Decommissioned		9-18-61
	14	Nuclear Agency (AFRRI) Bethesda	TRIGA Mark F	1,000 kW	2,000,000 kW	6-26-62
	15	University of Maryland College Park	TRIGA Conversion	250 kW		6-13-74
Michigan	16	The Dow Chemical Company Midland	TRIGA Mark I	100 kW		7-6-67
	17	Michigan State University East Lansing	TRIGA Mark I	250 kW	250,000 kW	3-21-69
Nebraska	18	Veterans Administration Hospital Omaha	TRIGA Mark I	18 kW		6-26-59
New Mexico	19	Sandia Corporation (USAEC) Albuquerque	TRIGA-ACPR	600 kW	12,000,000 kW	6-2-67
New York	20	Columbia University New York	TRIGA Mark II	250 kW	250,000 kW	Licensed
	21	Cornell University Ithaca	TRIGA Mark II	100 kW	250,000 kW	1-12-62
Oregon	22	Oregon State University Corvallis	TRIGA Mark II	1,000 kW	3,200,000 kW	3-8-67
	23	Reed College Portland	TRIGA Mark I	250 kW		7-2-68
Pennsylvania	24	Pennsylvania State University University Park	TRIGA Mark III Conversion	1,000 kW	2,000,000 kW	12-31-65
Puerto Rico	25	Puerto Rico Nuclear Center Mayaguez	TRIGA Conversion	Decommissioned		1-19-72
Texas	26	Texas A & M University College Station	TRIGA Conversion	1,000 kW	2,000,000 kW	8-1-68
	27	University of Texas Austin	TRIGA Mark I	250 kW	250,000 kW	8-2-63
Utah	28	University of Utah Salt Lake City	TRIGA Mark I	250 kW		10-23-75
Wisconsin	29	University of Wisconsin Madison	TRIGA Conversion	1,000 kW	2,000,000 kW	11-14-67
Washington	30	Washington State University Pullman	TRIGA Conversion	1,000 kW	2,000,000 kW	7-14-67
	31	Westinghouse-Hanford - 300 Area Richland	TRIGA Mark I	250 kW		3-26-77

TRIGA® REACTORS Research, Training, and Isotope Production

				MAXIMUM RATING		
		LOCATION	TYPE	STEADY STATE	PULSING	INITIAL CRITICALITY
Austria	32	Federal Ministry of Education Vienna	TRIGA Mark II	250 kW	250,000 kW	3-7-62
Bangladesh	33	Institute of Nuclear Technology, Dacca Bangladesh	TRIGA Mark II	3,000 kW	1,200,000 kW	Under Construction
Brazil	34	University of Minas Gerais Belo Horizonte	TRIGA Mark I	250 kW		11-6-60
England	35	Imperial Chemical Industries Billingham, Teesside	TRIGA Mark I	250 kW		8-19-71
Finland	36	The State Institute for Technical Research Helsinki	TRIGA Mark II	250 kW	250,000 kW	3-27-62
Germany	37	German Cancer Research Center Heidelberg	TRIGA Mark I	250 kW		[illegible]
	38	Johannes Gutenberg University Mainz	TRIGA Mark II	100 kW	250,000 kW	8-3-65
	39	Association for Radiation Research Munich	TRIGA Mark III	1,000 kW	2,000,000 kW	8-23-72
	40	Medical College of Hanover Hanover	TRIGA Mark I	250 kW		1-31-73
	41	University of Frankfurt Frankfurt	TRIGA Conversion	1,000 kW	1,000,000 kW	Under Construction
Indonesia	42	National Atomic Energy Agency Bandung	TRIGA Mark II	1,000 kW		10-16-64
	43	National Atomic Energy Agency Yogyakarta	TRIGA Mark II	250 kW		1979
Iran	44	Nuclear Research Center Tehran	TRIGA Conversion	5,000/10,000 kW		Under Construction
Italy	45	National Committee for Nuclear Energy Rome	TRIGA Mark II	1,000 kW		6-10-60
	46	University of Pavia Pavia	TRIGA Mark II	250 kW	250,000	11-15-65
Japan	47	Japan Atomic Energy Research Institute Tokai Mura	TRIGA-ACPR	300 kW	22,000,000	6-30-75
	48	Musashi College of Technology Tokyo	TRIGA Mark II	100 kW		1-29-63
	49	Rikkyo University Yokosuka	TRIGA Mark II	100 kW		12-8-61
Korea	50	National Atomic Energy Institute Seoul	TRIGA Mark II	250 kW		3-19-62
	51	National Atomic Energy Institute Seoul	TRIGA Mark III	2,000 kW	2,000,000 kW	4-10-72
Malaysia	52	Tun Ismail Atomic Research Centre Kuala-Lumpur	TRIGA Mark II	1,000 kW	1,200,000 kW	Under Construction
Mexico	53	National Commission for Nuclear Energy Mexico City	TRIGA Mark III	1,000 kW	2,000,000 kW	11-8-68
Morocco	54	Mohammed V University Rabat	TRIGA Mark I	100 kW		Under Construction
Romania	55	Institute for Nuclear Technologies Bucharest	TRIGA-ACPR	500 kW	15,000,000 kW	12-1-79
	56	Institute for Nuclear Technologies Bucharest	TRIGA	14,000 kW		11-18-79
Taiwan	57	National Tsing Hua University Taipei	TRIGA Conversion	1,000 kW		8-1-77
Thailand	58	Office of Atomic Energy for Peace Bangkok	TRIGA Mark III Conversion	2,000 kW	2,000,000 kW	11-7-77
Turkey	59	Technical University of Istanbul Istanbul	TRIGA Mark II	250 kW	250,000 kW	3-11-79
Viet Nam	60	Institute of Nuclear Research Dalat	TRIGA Mark II	Decommissioned		2-26-63
Yugoslavia	61	Jozef Stefan Nuclear Institute Ljubljana	TRIGA Mark II	250 kW		5-31-66
Zaire (Congo)	62	Nuclear Science Commission Kinshasa, Zaire	TRIGA Mark II	1,000 kW	1,000,000 kW	5-27-59

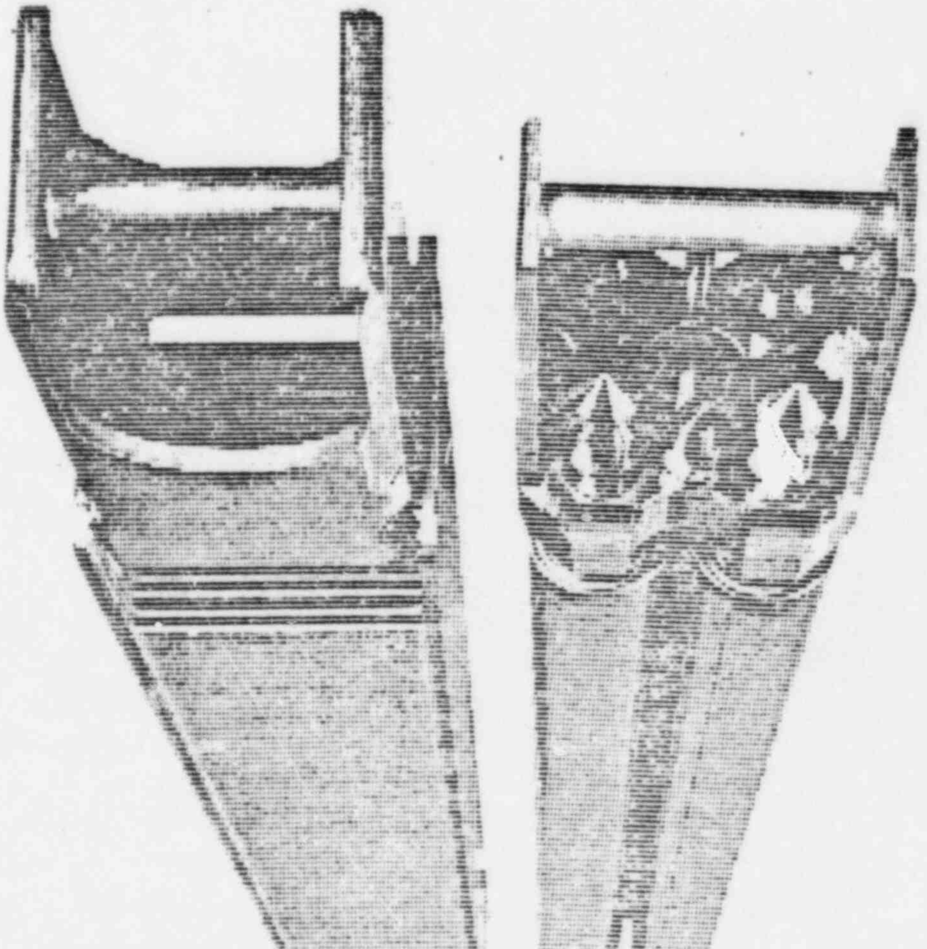
TRIGA® Reactors

Attachment D

GENERAL ATOMIC

CON-10

CONSIDERATIONS FOR UPGRADING NUCLEAR RESEARCH REACTORS BY CONVERTING TO TRIGA FUEL



P.O. BOX 81608, SAN DIEGO, CALIFORNIA 92138 (714) 453-1000 TWX: 910-335-1260

1. INTRODUCTION

Nuclear research reactor facility capabilities must be expanded periodically to accommodate increased and more specialized experimental requirements or face the alternatives of replacement or obsolesence. The most obvious route to augmented capability is to increase flux levels through greater reactor power or to make provision for special reactor performance, such as pulsing operation.

Administrators of many reactor facilities are also interested in increasing the reliability of their systems because they recognize that fuel, electronics, and control systems decrease in reliability with age. In addition, spare parts for older equipment are usually difficult to obtain because most of the original equipment suppliers are no longer in the research reactor business. These questions of reliability and availability and the awareness that an existing installation may not be adequate for more advanced experiments, such as for power reactor technology, lead a research facility staff to consider facility modification.

Section 2 presents some important considerations to be evaluated before an alteration project is begun and explains how the TRIGA system can accomplish them. Section 3 discusses the specific approaches and engineering aspects of some completed reactor conversions. This paper provides information to assist a research reactor staff in solving the dilemma of expanding facility needs with limited finances and personnel.

2. SPECIFIC CONSIDERATIONS FOR UPGRADING AND CONVERSION

The upgrading of research reactors will be discussed in terms of providing higher power levels, with corresponding higher fluxes, and providing for pulsing. One of the best approaches to fulfilling both of these requirements is to install TRIGA fuel. TRIGA fuel can operate in the natural convection mode at power levels up to 2.0 MW (with forced convection the standard fuel can operate up to 3.0 MW) and is uniquely designed for pulsing due to the prompt negative temperature coefficient of reactivity. Because of these factors, the characteristics of the TRIGA fuel are presented briefly in the following section, followed by the considerations that are associated with upgrading and conversion of research reactors and the unique ability of TRIGA fuel to satisfy upgrading/conversion requirements.

2.1. CHARACTERISTICS OF TRIGA

TRIGA fuel is a second generation fuel system incorporating the latest advances in UZrH fuel technology. TRIGA fuel clusters are designed to replace MTR plate-type fuel and provide the many advantages of the TRIGA system. Figure 1 shows the TRIGA 4-rod fuel cluster and standard MTR plate-type fuel.

2.1.1. TRIGA Fuels

Standard TRIGA and the TRIGA FLIP fuels are two basic versions of research reactor fuels available for reactor conversion. The standard fuel contains 8.5 to 12.0 wt % uranium enriched to 20% U-235 and does not contain a burnable poison. This standard fuel is capable of routine high pulsing operation and steady state operation at powers up to 2 MW. TRIGA FLIP fuel (FLIP is the acronym for Fuel Life Improvement Program) is enriched to 70% in U-235, contains the burnable poison erbium-167, and provides an operating core lifetime of 10 to 20 MW-years. TRIGA FLIP fuel is recommended for reactors with significant duty cycles of operation at 1 MW or greater.

The adjustable transient control rod on TRIGA pulsing reactors is actuated by an electro-pneumatic system controlled from the reactor console. The drive system permits the transient control rod to be used in the steady state mode or the pulse mode of operation. In the pulse mode, the drive system is adjustable so that any size pulse may be fired, up to the maximum reactivity worth of the control rod.

With a TRIGA pulsing reactor, an optional piece of control instrumentation can be provided to permit square-wave operation. In this mode, the reactor is pulsed to the desired preset steady state power level in a few seconds and automatically maintained at this level by a high speed servo drive. This unique mode of steady state operation provides a high degree of reproducibility in reactor startups and assures a reproducible integrated flux to test specimens in successive irradiations.

2.3. SAFETY

Increasing concern about the environment and the safety of nuclear reactors compel those planning any reactor upgrading program to strive for a reactor that is inherently safe, i.e., not relying on engineered safeguards systems. A safer reactor obviously increases operational flexibility and provides greater staff and community confidence.

TRIGA fuel has demonstrated the greatest inherent safety of any research reactor fuel in the world. These features are discussed in the following paragraphs.

2.3.1. Prompt Negative Temperature Coefficient

TRIGA UZrH fuel has intrinsic properties that will prevent a nuclear accident in the event of human error or mechanical malfunction. Other research reactors depend partially or entirely on electronic circuitry, moving parts, and the delayed negative temperature coefficient of the fuel to counteract any large positive reactivity insertion. This type of delayed shutdown mechanism depends on the transfer of heat from fuel material to the water, responding somewhat slowly to any sudden increase in power level. This, if the reactivity addition is large, the power level can rise to a point that vaporizes the water moderator, resulting in dangerously high fuel temperatures.

On the other hand, TRIGA fuel has a large, prompt negative temperature coefficient of reactivity that effectively controls large prompt positive reactivity insertions. Any sudden increase in power heats both the fuel and the moderator simultaneously, causing the moderator to become less effective immediately and to return the reactor automatically and instantaneously to normal operating levels. Such control is intrinsic to the TRIGA reactor fuel and does not rely on mechanical or electrical control devices. This most important property is due to the fact that the fuel elements are constructed of a solid homogenous alloy of uranium fuel and zirconium hydride moderator, making them "fuel-moderator elements."

2.3.1.1. Standard TRIGA Fuel. For the standard stainless steel clad $UZrH_{1.6}$ fuel in a water-reflected core, the temperature coefficient is about -1.26×10^{-4} δk/k per °C. There are several factors contributing to this prompt coefficient. Their relative magnitude is noted below:

	Approx Contribution (%)
1. Cell effect--increased disadvantage factor with increased fuel temperature leading to a decrease in neutron economy	60
2. Irregularities in the fuel lattice due to control positions--essentially same effect as item 1 above	10
3. Doppler broadening of U-238 resonances--increased resonance capture with increased fuel temperature	15
4. Leakage--increased loss of thermal neutrons from the core when the fuel is heated	15

IAEA-TECDOC-233

Attachment E

RESEARCH REACTOR CORE CONVERSION FROM THE USE OF HIGHLY ENRICHED URANIUM TO THE USE OF LOW ENRICHED URANIUM FUELS

GUIDEBOOK

PREPARED BY A CONSULTANTS' GROUP,
COORDINATED AND EDITED BY THE
PHYSICS SECTION
INTERNATIONAL ATOMIC ENERGY AGENCY

A TECHNICAL DOCUMENT ISSUED BY THE
INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1980

INTRODUCTION

General Atomic Company has developed shrouded 4-rod and 16-rod clusters utilizing the TRIGA low-enriched uranium zirconium hydride (UZrH) fuel for use in converting and upgrading existing MTR plate-type reactors and also for fueling new TRIGA reactors. The use of low-enriched uranium is in keeping with non-proliferation policies and is readily exportable. The 4-rod cluster is designed to operate at power levels up to 3 MW and the 16-rod cluster is designed for power levels up to 10 MW in existing reactor core structures.

Both types of clusters use fuel-moderator rods which contain the well proven UZrH fuel in an Incoloy cladding. The rod diameter in the 4-rod cluster (3.24 cm) is only slightly smaller than that used in standard TRIGA fuel for more than 20 years. The 16-rod cluster uses a rod of 1.295 cm diameter and is identical in design to the fuel rods used in the 14 MW TRIGA now in operation at the Romanian Institute for Nuclear Technology. The fuel alloy used in the 4-rod cluster contains 20 wt-% uranium and in the 16-rod cluster 45 wt-% uranium. This provides a very high U-235 content with low enrichment, i.e., 440 grams U-235 in the 4-rod cluster and 880 grams U-235 in the 16-rod cluster. A small amount of erbium is included as a burnable poison and is a major contributor to the prompt negative temperature coefficient, the dominant safety feature of the TRIGA fuel. The high uranium loading combined with the burnable poison result in a very long burnup lifetime and favorable fuel cycle economics.

This Appendix is divided into two parts: B.1, which describes a 2 MW reactor using the 4-rod cluster and B.2, which describes a 10 MW reactor using the 16-rod cluster.

Contention XIV

RESPONSE TO NRC STAFF ASSERTED MATERIAL FACTS

1. DISPUTED (Plotkin as to XIV, ¶8-13)

2. NOT DISPUTED

3. DISPUTED (Norton, ¶61-68; Kaku, ¶80-81)

4. DISPUTED (Plotkin as to XIV, ¶11; Pulido, ¶ 32)

5. DISPUTED (Pulido, ¶32)

6. DISPUTED (Pulido, ¶32)

7. DISPUTED (Norton, ¶57-8,60-68)

8. DISPUTED (Norton, ¶57-8,60-68)

9. DISPUTED (Dupont, ¶26-27)

10. NOT DISPUTED

11. NOT DISPUTED

12. DISPUTED (Kaku, Dupont, Warf, Norton full declarations; Plotkin on XIV, ¶ 13)

RESPONSE TO UCLA ASSERTED FACT

18. DISPUTED (Kaku, Dupont, Warf, Norton, Plotkin on XIV full declarations)