INL/RPT-22-66550
Revision 0

MARVEL Fuel Fabrication Strategy

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Material Sourcing, Fabrication, Transport, and Disposition of MARVEL Fuel Elements

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**Prepared for the
U.S. Department of Energy
Office of Nuclear Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517**

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ACRONYMS

CCA	criticality control area
EBC	equivalent boron content
DOE	Department of Energy
HALEU	high-assay low-enriched uranium
ID	inner diameter
IFSF	Irradiated Fuel Storage Facility
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
MARVEL	Microreactor Application Research Validation and Evaluation
MFC	Materials and Fuels Complex
NRAD	Neutron Radiography Reactor
OD	outer diameter
RRI	Research Reactor Infrastructure
RSWF	Radioactive Scrap and Waste Facility
SNF	spent nuclear fuel
TBR	to be reported
TFFF	TRIGA Fuel Fabrication Facility
TI	TRIGA International
TREAT	Transient Reactor Test Facility
T-REXC	TREAT microReactor eXperiment Cell
TRIGA	Training, Research, Isotopes, General Atomics

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MARVEL Fuel Fabrication Strategy

1. INTRODUCTION

This report documents the strategy to fabricate nuclear fuel for the Microreactor Applications Research Validation and Evaluation (MARVEL) reactor, including the fabrication method and location, fuel and material forms for transport, integration with programs and facilities, and a high-level, integrated schedule.

1.1 MARVEL Project Description

The MARVEL Project will demonstrate a new microreactor concept and associated processes. MARVEL is a 100 kWth scaled, prototypic microreactor intended for installation and demonstration in the north storage pit at the Transient Reactor Test Facility (TREAT) reactor building at the Materials and Fuels Complex (MFC-720). Process demonstrations include, but are not limited to, design and authorization processes, new fabrication processes, power production, and streamlined readiness, start-up, and National Environmental Policy Act processes.

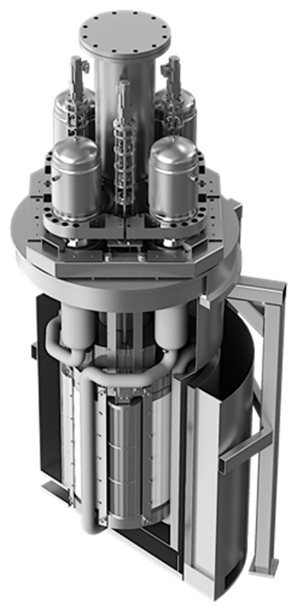

Figure 1. Conceptual rendering of MARVEL reactor.

Microreactors are defined as factory fabricated, transportable, and self-adjusting, with power rated between approximately 1 and 50 MWth. MARVEL is scaled smaller than a typical microreactor by a factor of 10–500 times. MARVEL will be fueled with stainless-steel-clad Training, Research, Isotope, General Atomics (TRIGA) fuel, composed of a UZrH alloy, enriched to 19.75%. Natural circulation of the eutectic sodium-potassium (NaK) primary coolant will remove heat through four parallel primary loops. Heat from the primary coolant will transfer through identical tube and shell heat exchangers to four Stirling engines used for power production. Reactivity control will employ a beryllium reflector and control drum, with boron carbide (B_4C) on one face of the drum for negative reactivity.

The primary and reactivity control systems will fit within TREAT's north storage pit and occupy a space smaller than 8-feet long, 12-feet wide, and 10-feet high (less than 960 cubic feet, roughly equivalent in size to a small bedroom). Additional equipment needed for testing, such as heat rejection equipment and microgrid components, will be installed outside MFC-720 in portable trailers or in other temporary arrangements. The installation of support equipment, such as MARVEL control cabinets inside MFC-720, will be temporary, and permanent TREAT modifications are excluded from this project.

The equipment storage pit in the North High Bay of the TREAT Reactor Building is being configured as part of a separate, indirectly funded, General Plant Project to establish a multipurpose, technology-agnostic critical experiment testing capability, designated as the TREAT microReactor eXperiment Cell (T-REXC). TREAT modifications to establish T-REXC for this purpose includes establishing appropriate radiation shielding, providing appropriate support systems to the pit (electrical, HVAC, instruments, and controls, etc.), and installing generic reactor components (neutron source, neutron reflectors, etc.). This equipment will be applicable to most critical experiments and small scale microreactor demonstrations.

The MARVEL reactor will be remotely operated from the MFC-724 control room. It will be fabricated offsite and temporarily installed in T-REXC. It will not be permanently affixed and, at the end of its useful life, will be defueled and removed. The equipment will be dispositioned as waste or used nuclear fuel.

An overview of the MARVEL core is shown below in Figure 2. It is composed of 36 fuel pins, each consisting of five fuel slugs, provided by TRIGA International (TI). The central reactor position contains a central insurance adsorber, which is a criticality control rod. The primary core is surrounded by beryllium oxide (BeO) reflectors, all within a primary containment vessel. Outside of the vessel are control drums, containing boron carbide (B_4C) plates to act as neutron poisons, as the drums are rotated the poison plates are moved into position. This is then surrounded by another reflector, cooling channels, and finally, the guard vessel.

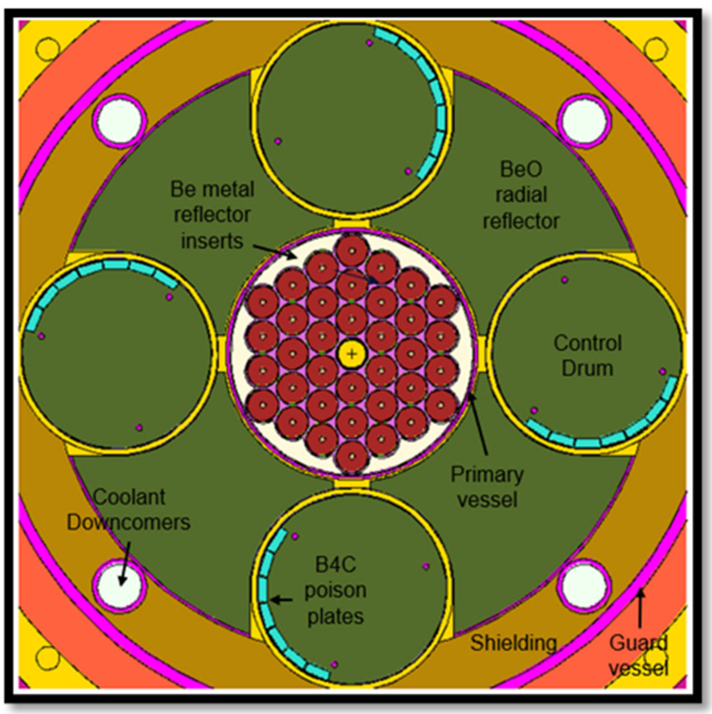

Figure 2. Core layout of MARVEL reactor.

1.1.1 Use of TRIGA Fuel—Project Decision

The NE-5 division of the Department of Energy (DOE) directed the MARVEL project to procure all fuel from TI to mitigate the risks associated with the fuel supply for the MARVEL reactor. TI is an established vendor with an accepted process. MARVEL requires minimal changes to this process through the introduction of a five fuel slug stack per pellet compared to the traditional three. Using TI eliminated the need for fuel fabrication and process development at Idaho National Laboratory (INL) and Los Alamos National Laboratory.

Not all risk has been eliminated from the fuel procurement. The process change, accompanied by the high demand placed on TI through other programs, creates secondary schedule risks associated with TI meeting production timelines for MARVEL deployment.

1.1.2 Process Overview

At a high level, Y-12 will send high-assay low-enrichment uranium (HALEU) fuel to TI for processing into the final fuel form for the MARVEL reactor. Once completed, TI will send this finished fuel to INL for integration into the MARVEL reactor. Once the MARVEL test is complete, the reactor will be decommissioned, and the used fuel processed as necessary and then transferred to long-term storage at another facility at INL. This process overview is shown in the process map below. Individual portions of this map are expanded on in the following sections of this report.

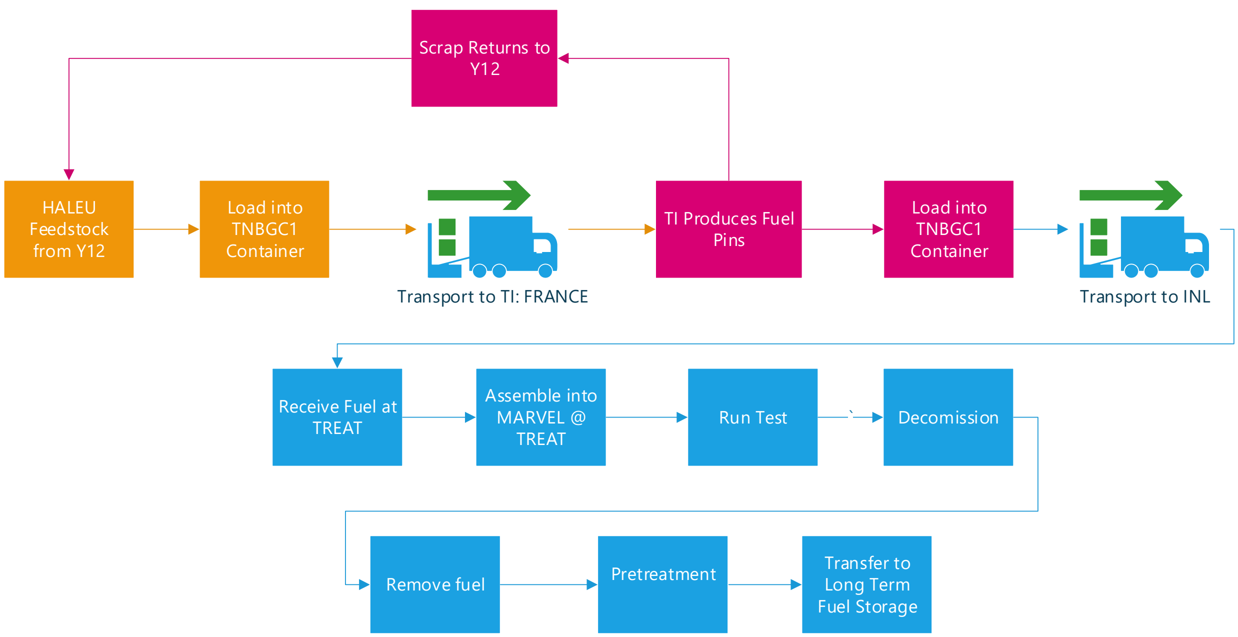

Figure 3. Process flow diagram from material transport though used fuel storage.

1.2 TRIGA International—Background

General Atomics began the development of TRIGA reactors in 1956, with the first TRIGA Mark I reactor commissioned in 1958 in San Diego, CA. This first reactor continued operating until 1997. Since the commissioning of the first reactor, an additional 66 TRIGA reactors have been deployed in 26 countries. In 1996, TI was formed as a joint venture between General Atomics and CERCA (a subsidiary of AREVA). Since its inception, it has manufactured all TRIGA fuel assemblies at CERCA’s plant in Romans-sur-Isere, France.

In 2014, the fuel fabrication facility was shut down as part of a multiyear renovation project. The United States Department of Energy and the National Nuclear Security Administration provided funding and resources to help renovate the manufacturing facility to ensure a safe and stable fuel supply for

TRIGA reactors. In March 2021, the facility was brought back online, and initial fabrication testing was completed. In early 2022, the first enriched fuels were fabricated since the facility was taken offline in 2014.

Figure 4. TRIGA Fuel Fabrication Facility (TFFF) at Romans-sur-Isere, France.

1.3 MARVEL Fuel Element Description

MARVEL fuel elements will consist of five fuel slugs (i.e., the discrete rod-like pieces of fuel compromising the fuel column, also referred to as “fuel meats”), two graphite reflectors, molybdenum spacer disks, zirconium rod, and Type 304 stainless-steel cladding and endcaps. The fuel stack height in each element will be 25 inches (635 mm), and the entire fuel pin will be 1.556 inches (39.52 mm) in diameter and about 39.2 inches (996 mm) in length. Fuel slugs will be about 5 inches (127 mm) in length, with outer diameters (ODs) of about 1.37 inches (34.8 mm) and inner diameters (IDs) of about 0.22 inches (5.6 mm).

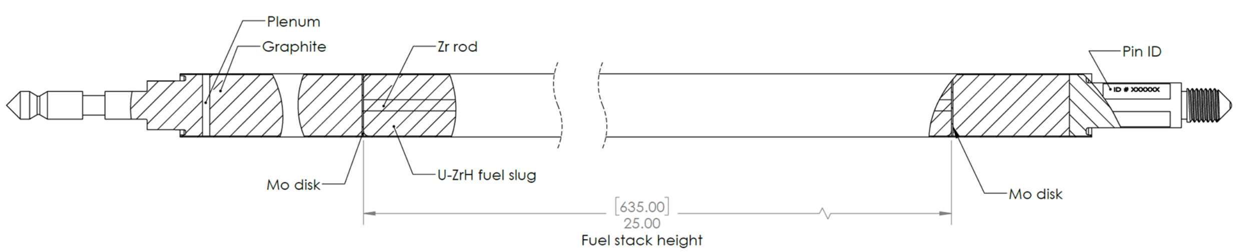

Figure 5. Schematic of MARVEL fuel pin.

Figure 6. U-ZrH TRIGA fuel slug.

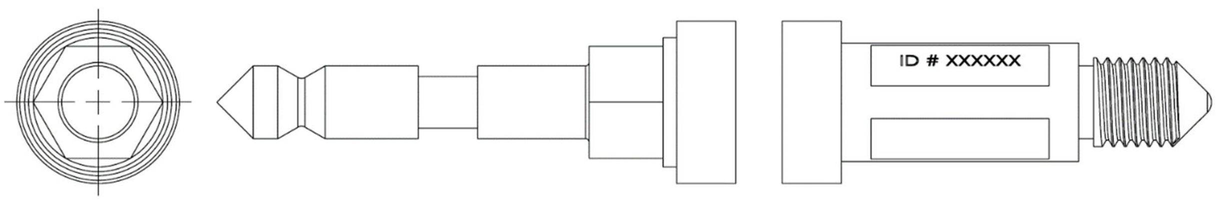

Figure 7. Type 304 stainless-steel end plugs.

2. SOURCE MATERIAL

INL will procure the uranium source material from Y-12. Based on the material scrap rate, the MARVEL project will require approximately 80 kg of feed material to produce the required fuel load, which assumes a 40% scrap rate and an allowance for manufacturing defects. The feed stock will be in the form of 19.75% enriched U-235 cast into hollow logs by Y-12, which are then sized to provide the appropriate amount and form of material for shipping. Table 1 shows a typical chemical analysis from the Y-12 HALEU materials.

Table 1. Preliminary chemical analysis of typical HALEU materials from Y-12.

Element	Symbol	Units	LEU	EBC Factor	Element	Symbol	Units	LEU	EBC Factor
Uranium (metal)	U	wt%	≥99.880%	—	Gadolinium	Ga	µg/gU	≤1.0	4.4
U-232	U-232	µg/gU	≤0.002	—	Iron	Fe	µg/gU	≤250.0	0.0006
U-234	U-234	wt%	≤0.260%	—	Lead	Pb	µg/gU	≤5.0	0
U-235 ± 0.2 wt%	U-235	wt%	19.75%	—	Lithium	Li	µg/gU	≤2.0	0.144
U-236	U-236	µg/gU	≤4,600	—	Magnesium	Mg	µg/gU	≤50.0	0
Trans-U (alpha)[1]	TRU	Bq/gU	≤100	—	Manganese	Mn	µg/gU	≤24.0	0.0034
Total beta[1]	TotBeta	Bq/gU	≤5,000	—	Molybdenum	Mo	µg/gU	≤100.0	0.0003
Activation products[1]	ActProd	Bq/gU	≤100	—	Nickel	Ni	µg/gU	≤100.0	0.0011
Fission products[1]	Gamma	Bq/gU	≤600	—	Niobium	Nb	µg/gU	TBR[2]	0.0002
Aluminum	Al	µg/gU	≤150.0	0.0001	Nitrogen	N	µg/gU	TBR[2]	0.0019
Arsenic	As	µg/gU	TBR[2]	0.0008	Phosphorus	P	µg/gU	≤50.0	0
Beryllium	Be	µg/gU	≤1.0	0.0001	Potassium	K	µg/gU	TBR[2]	0.0008
Boron	B	µg/gU	≤1.0	1	Samarium	Sm	µg/gU	≤2.0	0.534
Cadmium	Cd	µg/gU	≤1.0	0.3717	Silicon	Si	µg/gU	≤100.0	0.0001
Calcium	Ca	µg/gU	≤100.0	0.0002	Silver	Ag	µg/gU	TBR[2]	0.0083
Carbon	C	µg/gU	≤600.0	0	Sodium	Na	µg/gU	≤25.0	0.0003
Chromium	Cr	µg/gU	≤50.0	0.0008	Tin	Sn	µg/gU	≤100.0	0.0001
Cobalt	Co	µg/gU	≤5.0	0.0089	Tungsten	W	µg/gU	≤100.0	0.0014
Copper	Cu	µg/gU	≤50.0	0.0008	Vanadium	V	µg/gU	≤30.0	0.0014
Dysprosium	Dy	µg/gU	≤5.0	0.0818	Zinc	Zn	µg/gU	TBR[2]	0.0002
Europium	Eu	µg/gU	≤2.0	0.425	Zirconium	Zr	µg/gU	≤250.0	0

Total impurities	µg/gU	≤1200.0	
Equivalent boron content[3,4]		≤3.0	

[1] The values shown reflect the sum of the listed nuclides: Trans-U (alpha): Am-241, CM-243/244, Np-237, Pu-238, and Pu-239/240; Total beta: Tc-99, Sr-90; Activation products: Co-58, Co-60; Fission products: Sb-125, Ce-144, Cs134, Cs-137, Nb-95, Ru-103, Ru-106, Zr-95.

[2] TBR means the value is "to be reported."

[3] EBC factors are taken from ATSM, C1233-09 "Standard Practice for Determining Equivalent Boron Content of Nuclear Materials." The EBC calculation will include B, Cd, Dy, Eu, Ga, Li, and Sm. Other EBC factors are provided for informational purposes only.

[4] The limit on EBC may restrict some elements to lower values than shown in the table above

After the feed stock material has been gathered, it will be loaded into a TN-BGC-1 package for transport from Y-12 in Oak Ridge, TN to the TI facility in Romans-sur-Isere, France. This process has been performed before and is well understood between Y-12 and TI. The TN-BGC-1 package is certified by both the French and American regulator for nuclear material transport and is anticipated for MARVEL transports; no other certification activities for other packages are planned.

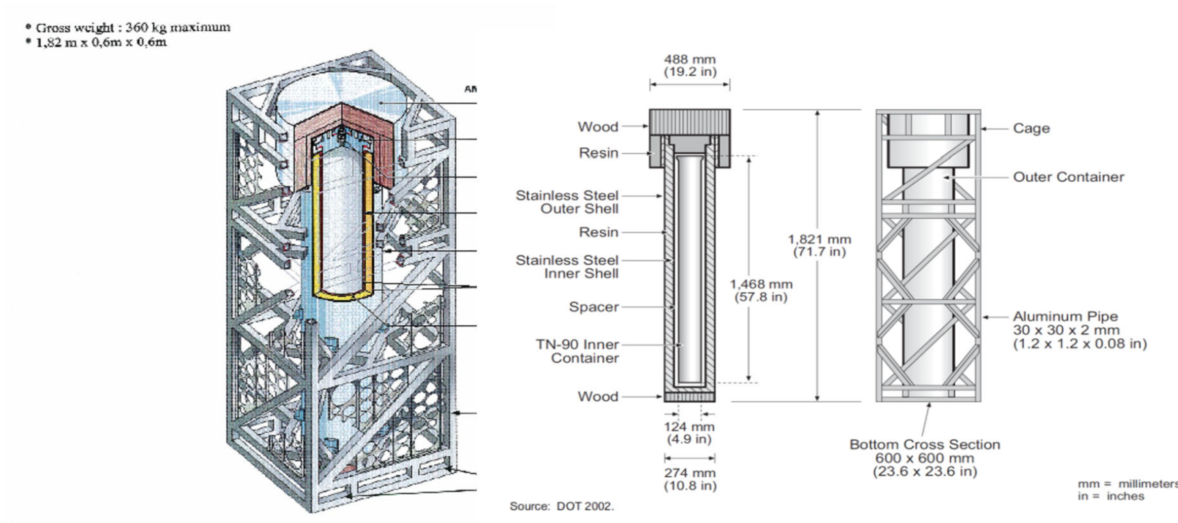

Figure 8. TN-BGC-1 schematic.

Figure 9. Sample of feedstock (oxidized).

3. FUEL FABRICATION

INL will contract with TI to produce the fuel pins from the Y-12 feedstock for the MARVEL reactor. This procurement will include the necessary transportation from Y-12 to TI and from TI to INL. The packages used for this transport are owned by (or available to) TI and will be leased to INL for this use. The lease time on these packages starts from the time they leave the facility and ends once the packages are received back by TI.

Fuel fabrication for TRIGA fuel assemblies follows a robust process that has been developed and optimized for more than 60 years. The process consists of alloying uranium and zirconium into ingots and then subjecting the cast ingots to a hydriding cycle, forming U-ZrH. A process flow diagram as well as descriptions of each of the steps are shown in Figure 10.

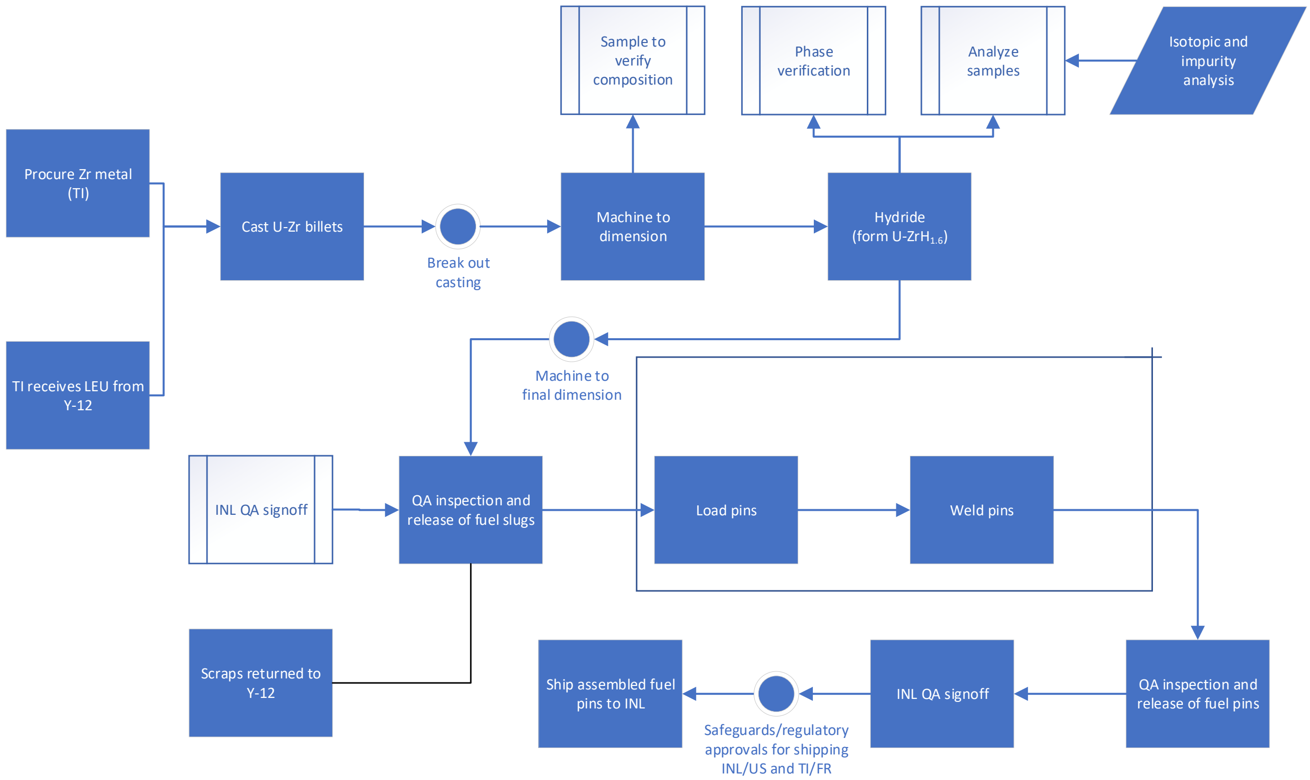

Figure 10. Process flow for fabrication of U-ZrH fuel meats at TI.

After obtaining the feedstock material (U and Zr), it is placed into TI's fusion furnace (Figure 11) where the rough U-Zr (70 wt% Zr) alloy will be cast. Prior to casting, all components are carefully weighed and checked to ensure compliance to the target specifications. During casting, a controlled atmosphere will be maintained to create the target alloy blend.

Figure 11. Fusion furnace at TI's TFFF in Romans-sur-Isere, France; Left: fusion furnace, Right: inside of furnace.

The ingot will be cast in a graphite mold that will be removed upon the completion of casting activities. After the initial casting, the mold will be allowed to cool to room temperature, and then a second fusion is performed to homogenize the alloy and impart structural quality into the ingot in the mold. After the casting is removed from the mold, the U-Zr ingots (Figure 12) will be machined to specified dimensions; this includes drilling the characteristic central hole. The process is also used to remove the carburized layer that forms as a result of the casting process.

Figure 12. U-Zr castings prior to machining.

After casting and machining, the ingots will be thoroughly cleaned to remove contaminants (e.g., machining residue) and unwanted surface impurities (oxide), that could otherwise have drastic effects on the hydriding process.

The hydriding process is a slow process that takes place in TI's hydriding furnace (Figure 13). This furnace can hold 60 cast ingots; each is roughly 1.25-in. OD by 4.5-in. long and weigh about 250 g. The hydriding process is deliberately slow to ensure formation of a structurally sound fuel slug. In essence, the U-Zr ingot undergoes a process that causes a significant volume expansion, which, if done too quickly, causes severe cracking in the fuel slug.

Figure 13. Hydride furnace located at TI's TFFF in Romans-sur-Isere, France.

After the hydriding process is complete, the U-ZrH fuel slugs (Figure 14) will be final machined with a centerless grinder (Figure 15) and controlled for surface defects. This final machining step ensures that the fuel slug OD will meet acceptance criteria.

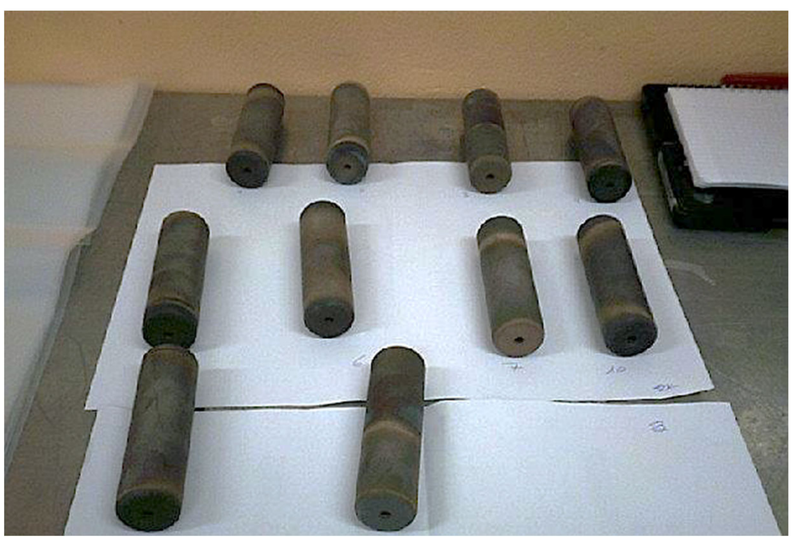

Figure 14. U-ZrH fuel slugs after hydriding, prior to final machining.

Figure 15. Centerless grinder located at TI's TFFF.

After the fuel slugs have been inspected for quality, they will be released for fuel pin assembly. The process of loading the fuel pin is illustrated in Figure 16.

The excess feedstock, and any remains generated, from the fabrication process will need to be returned to Y-12. This is the same process currently utilized during the fabrication of the Research Reactor Infrastructure (RRI) fuel.

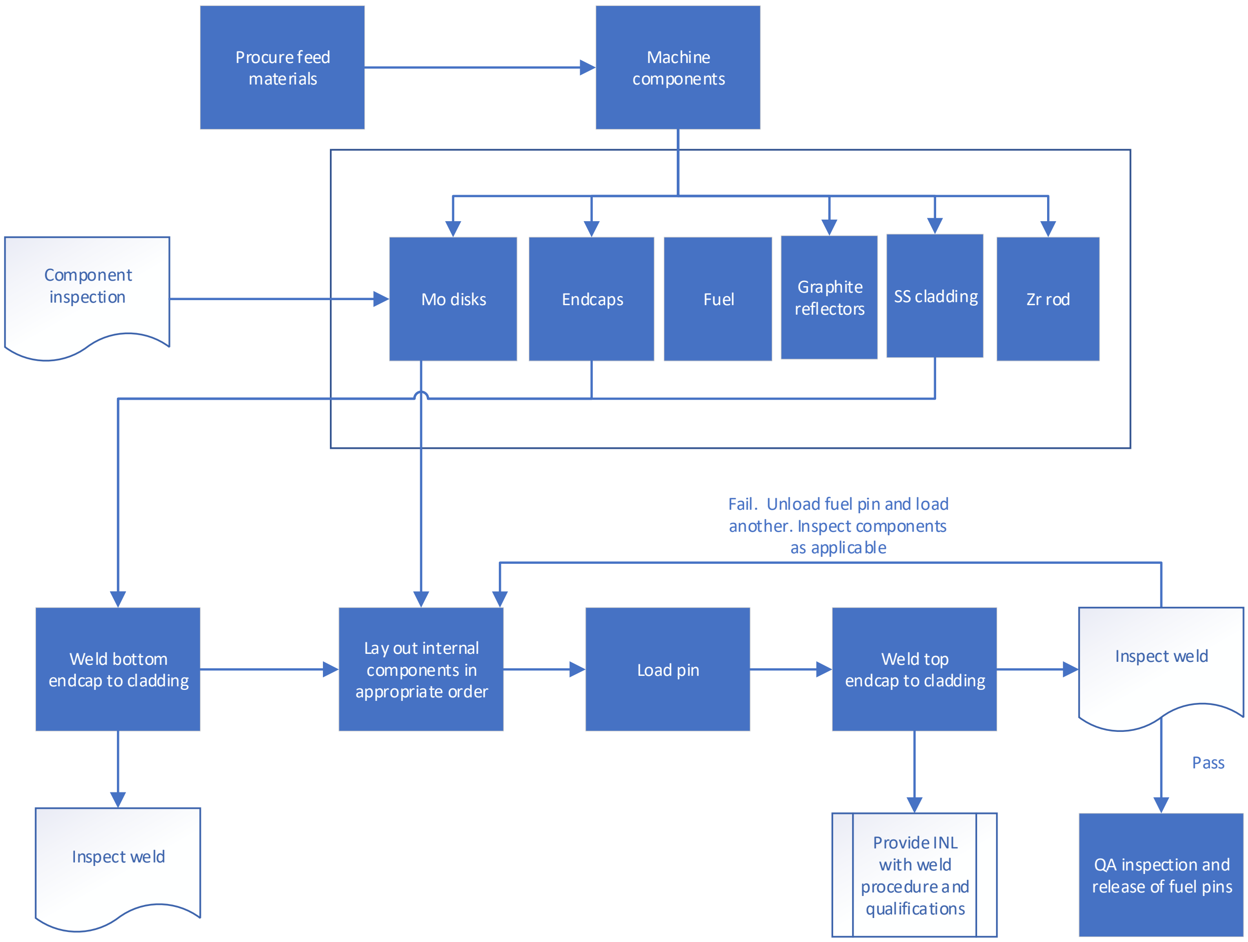

Figure 16. Process flow for the assembly of fuel pins.

Upon completion of final inspection to ensure the fuel pins meet quality requirements, the fuel pins will be ready for loading in the shipping container and shipment to INL.

4. TRANSPORTATION AND STORAGE

4.1 HALEU

The following process flow diagram shows the transportation and storage of HALEU fuel from Y-12 to TI.

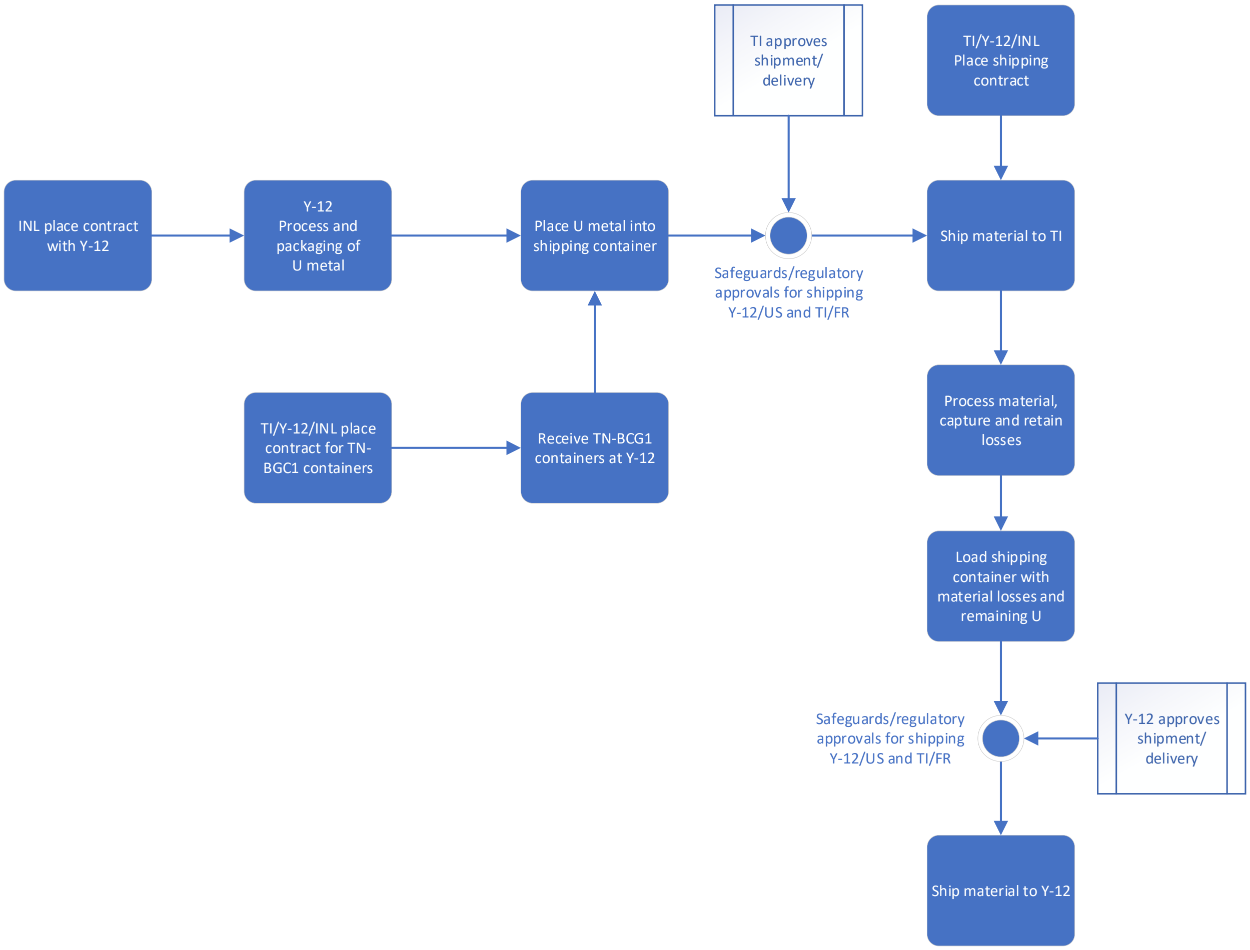

Figure 17. Process flow for shipping feedstock materials from Y-12 to TI. Includes shipping waste and remnants from TI to Y-12.

INL will initially place an order for HALEU to Y-12, in the form of metal scraps from castings. For MARVEL, this order will be approximately 80 kg. Once gathered, the material will be transported in TN-BGC-1 packages to the TI facility in France. Each container can hold approximately 20 kg of HALEU, and at least four containers will be needed to ship the required materials.

4.2 Unirradiated Fuel

4.2.1 Storage at TRIGA International

The MARVEL fuel order will be one of several concurrent fuel orders placed by INL-led programs. This will require TI to manufacture and store significant amounts of HALEU and finished fuel prior to shipping. TRIGA has indicated that their facility has a storage limit of 200 completed fuel elements. Careful consideration will be required to coordinate the material needs of RRI, Neutron Radiography Reactor (NRAD), and MARVEL. This is further detailed in Section 5.1.

4.2.2 Transport to INL

It is assumed that a TN-BGC-1 package will be used to transport the finished fuel pins from TI to INL. Currently this is the only package certified for transport by the French and U.S. regulators. A critical step for to enable transport is the evaluation of the certification of the TN-BGC-1 package to ship MARVEL fuel pins, which contain two additional fuel slugs compared to a standard TRIGA fuel assembly. For reference, a copy of the TN-BGC-1 package certification is included in the appendix. Due to criticality limits, each TN-BGC-1 package can hold four MARVEL fuel pins, requiring a total of at least nine shipments. The timely unloading, receipt, and return of the shipping packages will be important to minimize the amount of rent owed for the packages.

Upon receipt at INL, a team of approximately four trained operators will unload the TN-BGC-1 package. It is anticipated that TI will be contracted to provide the necessary training and hardware for an INL team to be able to successfully unload the fuel from the shipping packages. This will allow a single INL team to serve multiple programs receiving fuel from TI in the TN-BGC-1 package. Several scenarios are possible for the offloading sequence, a few of which are identified below.

Preferred Scenario: Ideally, shipments of MARVEL fuel elements will be coordinated such that the entire fuel load for MARVEL is staged in such a way that the fuel can be directly offloaded from the package into the MARVEL reactor assembly in the north storage pit. This will require several steps in order to ensure its success:

a. A schedule of deliveries to coincide with MARVEL reactor installation
b. A revision to the criticality control area (CCA) area on the main TREAT floor to allow for material for MARVEL to be considered separate from the TREAT reactor. Ideally, a separate reactor test area CCA would be established at some point between the F and G column lines at TREAT. This will allow continued TREAT facility operations, as the criticality limits for the TREAT reactor will not be exceeded.
c. A criticality assessment and required analysis to allow fuel pins to be considered in storage while inside of the opened transport package and any interim storage containers. The current criticality limits for the TREAT floor are 350 grams. It is anticipated that multiple fuel pins will be contained in each shipping package. This revision will allow the pins to be individually unloaded into either storage cans or the MARVEL core.

Alternate Scenario 1: In this scenario, the fuel elements will arrive from TI in a staggered manner and need to be stored during the interim time between arrival and installation into the MARVEL system.

a. Fuel arrives from TI to the TREAT facility and is offloaded into a storage container, possible a 7A drum with holders of the type used by NRAD for fuel storage.
b. The location of the drum storage will need to be determined. It is anticipated that a minimum of 12 pallets, and possible more, will be needed to store all the fuel elements. The floor space to do this is not available on the TREAT floor. Other potential locations may be in the TREAT warehouse or in other designated storage at TREAT.
c. When MARVEL is ready for fuel loading, the drums will be brought into the facility. Single pins will be transferred from the storage drum to the reactor core.

Alternate Scenario 2: In this scenario, fuel elements will arrive from TI to a facility-wide storage location, possibly building CPP-651.

a. Fuel will arrive from TI to the facility storage area and be transferred from the shipping package to a designated storage container.
b. If necessary, fuel will be loaded into a transport container for a non-commerce transfer along the haul road from CPP to TREAT. An evaluation will be needed to determine whether a 7a container or a TRIGA-1/2 container will be required for this transport.
c. Fuel will be transferred from the transport container to the MARVEL reactor.

The two storage areas are listed below with requirements for each to be viable.

4.2.3 Lag Storage at INL

4.2.3.1 TREAT FACILITY

If interim storage location is necessary, it would be most efficient to do that at the TREAT facility. The NRAD facility stores their standard TI fuel elements in a 7A drum with an engineered holder. In order to facilitate this storage, a specific location will need to be identified at the TREAT facility. Possible locations are the main floor, the TREAT warehouse, or an alternate storage container (Connex) placed on the TREAT site. All of these locations would require a criticality analysis and possible safeguards review.

4.2.3.2 CPP-651

There is currently an evaluation being made for a TRIGA fuel element receipt facility at INL to support the large number of TRIGA fuel shipments that will need to be handled and stored by various entities at INL over the next several years. It is anticipated that this facility will be located at CPP-651 and be fully functional prior to MARVEL fuel element shipments. Storage at CPP-651 provides benefits in the ability to centrally locate all TRIGA fuel receipt but may incur additional costs in the form of intra-INL transport and increased handling operations. This option helps provide risk mitigation in the event that the TREAT facility can't be used for clean fuel storage. It is anticipated that the storage in CPP-651 would be in 7A type drums, similar to the method detailed previously.

4.2.3.3 INTRA-INL TRANSPORT

It is anticipated that intra-INL transport can be accomplished using non-commerce transport between facilities. If the fuel is stored at an INL location besides TREAT, multiple container options can be evaluated to determine their suitability. As a back-up option, the existing TRIGA-2 container may be used for transport. INL currently has at least one of these containers available. There may be additional analysis and maintenance to be performed prior to its use.

4.3 Irradiated Fuel

Irradiated fuel from MARVEL will not be completely depleted at the end of testing and will be radioactive enough to require isolated management and storage. There is no permanent disposition path, and like many used fuels at INL, it will require intermediate term storage for a period of time that may span decades. It is anticipated that MARVEL will generate approximately 105 kg of irradiated fuel, 45 kg of which will be heavy metals.

Management of spent nuclear fuel (SNF) includes the processes necessary to support the safe and secure storage of the SNF in a configuration that is ready for shipping to an independent spent fuel storage installation or permanent repository. This includes: (1) the interim storage for the dissipation of heat and reduction of radiation dose immediately after discharge, (2) treatment of reactive materials and damaged fuel, (3) potential recovery of TRU material (if desirable or as a result of treatment processes), (4) packaging for extended dry storage or transport to a repository, (5) extended dry storage while awaiting packaging or transport to a repository, and (6) transport to a repository. Disposition refers to the permanent disposal of the SNF.

After testing, MARVEL fuel pins will be removed from the reactor and surveyed for radiation and contamination. After inspection, the assemblies will be placed in designated shipping or storage containers following criticality control protocols. Containers can be dry stored at TREAT or shipped to MFC for storage or reprocessing in accordance with legal, regulatory, operations, and scheduling requirements for the transfer and storage of these fuels.

The current SNF inventory at INL includes over 250 different types of SNF, and MARVEL SNF may be managed in existing INL facilities so far as the legal, regulatory, operational, and scheduling requirements for the transfer and storage of these fuels in existing facilities are met. The transfer to existing facilities will be predicated on the appropriate analyses and procedures. Existing INL facilities are available to provide extended dry storage for the MARVEL microreactor SNF, including the Radioactive Scrap and Waste Facility (RSWF) at MFC, until final disposition is available.

A second option for the storage of MARVEL SNF is the Idaho Nuclear Technology and Engineering Center (INTEC, formerly the ICPP facility). Spent TRIGA fuel, from multiple sources, is currently stored in the Irradiated Fuel Storage Facility (IFSF) at INTEC. INTEC is managed by the Idaho Environmental Coalition under contract to DOE as part of the Idaho Cleanup Project. IFSF currently accepts SNF from the Advanced Test Reactor and other sources. At current rates, IFSF capacity will be filled between 2040 and 2050. An agreement with the Idaho Environmental Coalition (or subsequent subcontractor) and associated DOE programs will be required to complete the transfer of MARVEL SNF before IFSF fills, or other arrangements will be needed to for long-term interim storage of the SNF.

Preliminary criticality and radiation shielding evaluations for various transfer and storage configurations of the 36 MARVEL microreactor fuel elements indicate that various transfer casks currently in use at INL are suitable for the transport of MARVEL SNF. The Advanced Test Reactor transfer cask, HFEF-5 transfer cask, and the High Load Charger are used for the transfer of irradiated fuel between INL facilities, and these casks could potentially be used to transfer irradiated MARVEL microreactor fuel between INL facilities.

The transport of MARVEL SNF to RSWF or to INTEC would likely be an out-of-commerce shipment consistent with “The INL Transportation Safety Document” and specifically governed by a specific transport plan or functional equivalent. SNF transportation of this type is performed periodically within INL and does not pose a significant risk to the disposition of the MARVEL SNF. Final disposal options for many used fuels, including TRIGA SNF, were identified as part of the Yucca Mountain Repository project, including all necessary treatment packaging and transportation requirements for final disposition.

5. INTEGRATION OF FUEL FABRICATION

5.1 Programs

TI is currently fabricating TRIGA fuel for DOE’s RRI program. NRAD at MFC will need TRIGA fuel in the next several years as well and intends to leverage RRI’s contract with TI to serve that need. Because MARVEL intends to contract with TI for fuel fabrication, coordination between these three programs is essential for pricing advantages and conflict prevention. All three programs intend to obtain HALEU material from Y-12, ship that material to France, and receive fabricated fuel back in the U.S. using the TN-BGC-1 package. A preliminary, high-level sequence of coordinated activities is summarized below in Table 2. The assumptions that form the basis of this table were developed by topical experts familiar with individual programs, but no formal agreement exists between programs. Further discussion between programs may alter some of the assumptions and consequently, alter the sequence of activities.

Table 2: Material integration between RRI, NRAD, and MARVEL - Preliminary Plan

		FY-22	FY-23	FY-24	FY-25	FY-26	FY-27	FY-28	FY-29	Totals
RRI	Feedstock (kg) shipped to TI	100	120	80	80	80	80	80	45	665
	TN-BCG1 feedstock packages	—	6	4	4	4	4	4	3	29
	Slugs fabricated at TI	125	120	285	297	294	294	294	295	2004
	Elements shipped to INL	—	65	50	113	110	110	110	110	668
	TN-BCG1 packages shipped	—	13	10	23	22	22	22	22	134
NRAD	Feedstock shipped to TI	—	55	—	—	—	—	—	—	55
	TN-BCG1 feedstock packages	—	3	—	—	—	—	—	—	3
	Slugs fabricated at TI	—	—	15	15	30	24	27	27	138
	Elements shipped to INL	—	—	5	5	10	8	9	9	46
	TN-BCG1 packages shipped	—	—	1	1	2	2	2	2	10
MARVEL	Feedstock shipped to TI	—	80	—	—	—	—	—	—	80
	TN-BCG1 feedstock packages	—	4	—	—	—	—	—	—	4
	Slugs fabricated at TI	—	180	—	—	—	—	—	—	180
	Elements shipped to INL	—	—	36	—	—	—	—	—	36
	TN-BCG1 packages shipped	—	—	9	—	—	—	—	—	9

The information presented in Table 2 is based on the set of assumptions listed below along with relevant comments. These assumptions will change over the course of shipping and fuel fabrication for each program, and continued integration is needed to optimize performance for all three programs for the greatest benefit to DOE.

- All HALEU metal feedstock will be shipped directly from Y-12 to TI.
- Approximately 100 kg of RRI HALEU feedstock is already at TI.
- RRI needs 668 elements (three slugs each; total of 2,004 slugs; total of approximately 665 kg feedstock) of various uranium densities.
- NRAD needs 36 elements (three “standard 30/20” slugs each; total of 138 slugs; total of 55 kg feedstock).
- MARVEL need is for 36 elements (five “standard 30/20” slugs each; total of 180 slugs; total of 80 kg feedstock).
- Each “standard 30/20” slug contains approximately 0.25 kg total HALEU and the “average” RRI slug contains approximately 0.20 kg.
- TRIGA slug process loss is approximately 40% (hence, a “standard 30/20” slug needs approximately 0.40 kg HALEU and an “average” RRI slug needs approximately 0.33 kg).

- The TI annual production rate is approximately100 standard elements (roughly 300 slugs) per year, after the first year of production following an extended shutdown, during which time the process will undergo a shakedown and optimization.
- HALEU feedstock shipments from Y-12 are in Ø4.25 × 8.75 in. paint cans with ~20 kg per TN-BCG1.
- Fuel element shipments from TI are in TN-BCG1 packaging with less than five standard fuel elements per package.
- Instrumented standard elements take up two positions in the TN-BCG1.
- MARVEL elements will be shipped in TN-BCG1 with four elements per package (depending on future criticality safety evaluation outcome).
- The availability of TN-BCG1 packages is not a constraint.
- RRI and NRAD elements will be shipped to CPP-651 for inspection and temporary storage pending shipments to users.
- MARVEL elements will be shipped directly to TREAT for inspection and temporary storage.
- Priority for first 55 elements will be produced directed at urgent RRI reactor needs.
- MARVEL elements have second priority for fuel slugs produced.
- HALEU feedstock receipt and storage capabilities at TI will not be a constraint.
- Projections assume sufficient and timely funding available from associated programs.
- This table does not include any materials desired for archive purposes

5.2 INL Facilities

The following facilities are envisioned to be used at the INL:

- TREAT: As fresh fuel storage, assembly, and test facility
- CPP-651: As a potential fresh fuel storage site.

5.3 High-Level Schedule

A preliminary schedule for MARVEL fuel fabrication is shown below in Figure 18. Critical path activities are identified in red. The timeline shown in the schedule relies on placing a contract to transport HALEU material from Y-12 to TI and a second contract with TI to fabricate the MARVEL fuel. Recertification of the TN-BGC-1 package will likely be part of that contract, and although there is some variability in the time required to recertify the package, it is not on the critical path.

Instead, the critical path is determined early in the schedule by the Y-12 production cycle. After the Y-12 contract is in place, the fabrication and sizing of HALEU material can begin in early FY-23. There is some float in the schedule for contract development with Y-12 and TI to address the moderate risk that contract negotiations will take longer than expected.

HALEU material can be shipped to TI in the second quarter of FY-23, at which time the critical path shifts to fuel production. Fuel production at TI may be as high as 300 pellets per year (MARVEL will need 180). Following pellet production, the pellets will be pressed into a 5-pellet pin, loaded, and shipped to INL. The actual duration of fuel loading at INL will be determined by the final design and constraints imposed by the safety basis at TREAT. The duration shown in the presented schedule is notional.

Pin fabrication can likely be accomplished in parallel with pellet production, but the completion of pin production will lag the final pellet production. Typical rework rates for cracked, broken, or otherwise out-of-specification pellets is unknown, but 5 kg (of the 80 kg total) HALEU material was allocated for potential rework. Production rates at TI have not yet been demonstrated, and a site visit is planned in early summer 2022 to assess TI's ability to produce the pellet quantity, at specified quality, required by MARVEL.

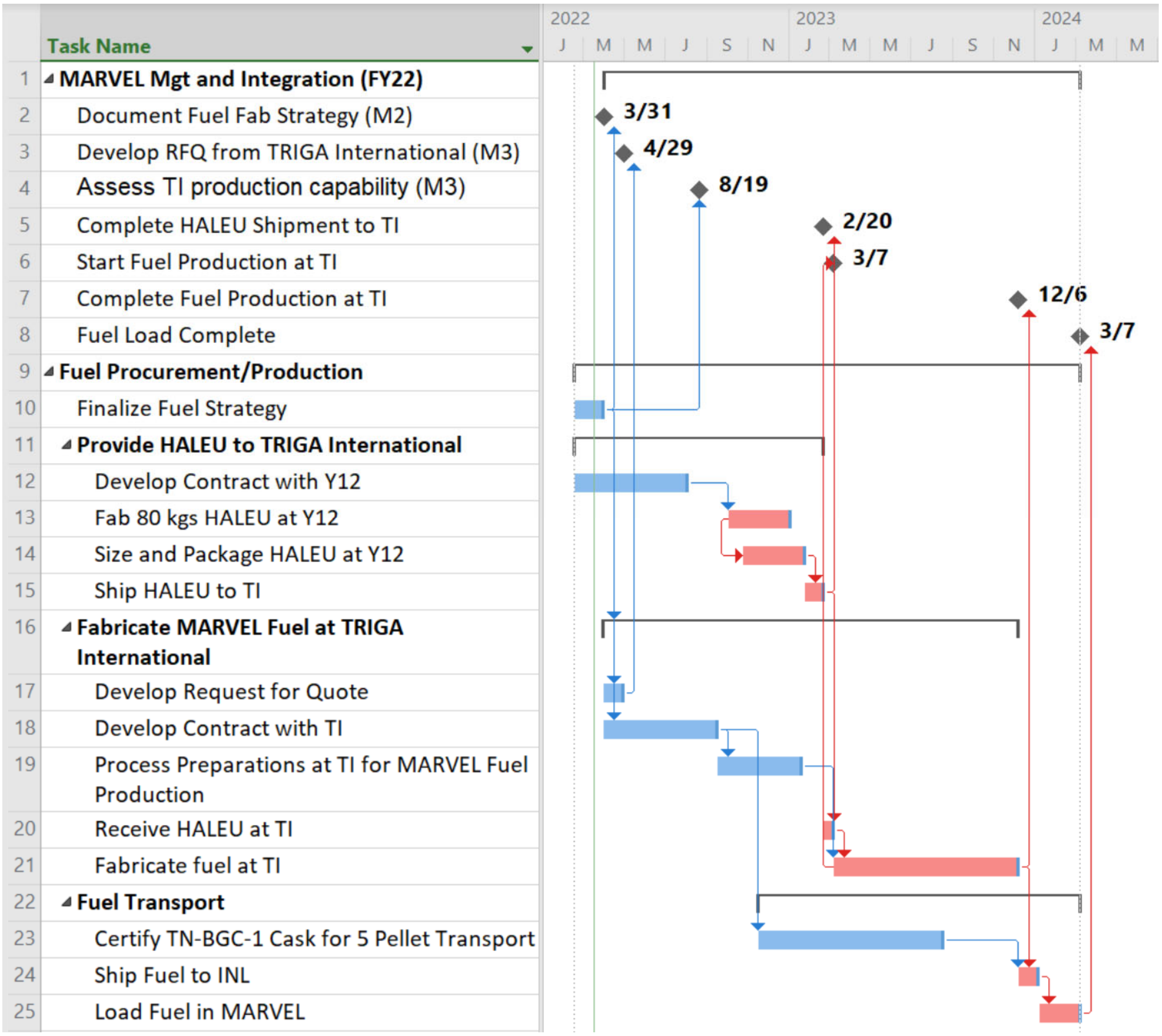

Figure 18. Preliminary schedule for MARVEL fuel fabrication.

6. SUMMARY

6.1 Risks

The table below show a summary of risks and opportunities currently understood for the MARVEL fuel fabrication process.

Table 3. Identified risks to the MARVEL fuel fabrication process.

Title	Description	Mitigation
Fuel pin size	Adding two additional fuel slugs to a standard TI fuel element may impact fabrication and transport. New licensing and manufacturing analysis will be required. This will add cost and schedule complexity.	The MARVEL team will need to work closely with TI to ensure the appropriate documentation is generated in a manner that supports delivery schedule.
Single source supplier	TI has been identified as the sole supplier for the fuel elements. This brings risks associated with supply chain disruptions from overseas supply.	INL personnel will closely coordinate with TI to ensure that mitigation to supply chain disruption can be implemented.
TN-BGC-1 availability	INL will be reliant on TN-BGC-1 packages provided from other sources (TI). These packages may be heavily scheduled between multiple programs in order to meet fuel delivery needs.	Close collaboration with RRI and NRAD will ensure schedules are developed to support all parties with package availability.
Fresh Fuel storage at TREAT	Fresh fuel storage at TREAT will require additional facility criticality calculations and control modifications.	CPP-651 is a backup location for fresh fuel storage.
Package unloading	INL does not currently have any personnel trained and qualified to unload the TN-BGC-1.	Enter into an agreement with TI to provide training and tools to facilitate package unloading.
Funding constraints	Out year funding may impact the ability to maintain schedule.	Provide updated cost and schedule estimates following Request for Quote response from TI.

6.2 Remaining Work

The following is a summary of remaining analyses, contracting, and manufacturing tasks remaining for this project. There may be other items that arise that will need to be finished as well:

- Issue Request for Quote to TI for fuel fabrication
    - Generate drawings, specifications, and other documentation to support procurement.
- Update estimates and schedule based on TI response to allow updated FY-23 funding requests to be developed
- Develop travel plan for necessary personnel to travel to the TI facility in France
- Procurement of uranium feed stock—INL TO Y-12
- Issue contract to TI for fuel fabrication—INL TO TI
- Update licensing of TN BNC-1 package by the MARVEL program in coordination with TI (If the program falls within the established U kg limit this may be an easy step)

- Develop coordinated fuel handling schedule between RII, NRAD, and MARVEL
- Perform a detailed criticality analysis for fuel storage at TREAT
- Develop a decommissioning, treatment, and storage plan for MARVEL after the test has been completed
- Develop training plan for TN-BGC-1 unloading using INL personnel.

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Appendix A
TN-BGC-1 Package Licensing from DOT

U.S. Department
of Transportation

**Pipeline and
Hazardous Materials
Safety Administration**

East Building, PHH-23
1200 New Jersey Ave, SE
Washington, D.C. 20590

COMPETENT AUTHORITY CERTIFICATION FOR A TYPE B(U)F FISSILE RADIOACTIVE MATERIALS PACKAGE DESIGN CERTIFICATE USA/0492/B(U)F-96, REVISION 20

REVALIDATION OF FRENCH COMPETENT AUTHORITY CERTIFICATE F/313/B(U)F-96

The Competent Authority of the United States certifies that the radioactive material package design described in this certificate satisfies the regulatory requirements for a Type B(U)F package as prescribed in the regulations of the International Atomic Energy Agency[1] and the United States of America[2].

1. Package Identification - TN-BGC1.

2. Package Description and Authorized Radioactive Contents - as described in French Certificate of Competent Authority F/313/B(U)F-96, Revision Lbj (attached). Contents are restricted to:

   a. Solid non-irradiated uranium bearing materials contained within a TN-90 secondary conditioning container as described in French Certificate of Approval No. F/313/B(U)F-96(Lbj), Appendix 11, Content No. 11 (attached), except that Content 11h is not authorized.

   b. Non-irradiated TRIGA fuel elements as described in French Certificate of Approval No. F/313/B(U)F-96(Lbj), Appendix 26, Content No. 26 (attached).

3. Criticality - The minimum criticality safety index is 1.0 for Content No. 11 and 0 for Content No. 26. The maximum number of packages per conveyance is determined in accordance with Table 11 of the IAEA regulations cited in this certificate.

[1] "Regulations for the Safe Transport of Radioactive Material, 2012 Edition, No. SSR-6" published by the International Atomic Energy Agency (IAEA), Vienna, Austria.

[2] Title 49, Code of Federal Regulations, Parts 100-199, United States of America.

CERTIFICATE USA/0492/B(U)F-96, REVISION 20

4. General Conditions -

   a. Each user of this certificate must have in his possession a copy of this certificate and all documents necessary to properly prepare the package for transportation. The user shall prepare the package for shipment in accordance with the documentation and applicable regulations.

   b. Each user of this certificate, other than the original petitioner, shall register his identity in writing to the Office of Engineering and Research, (PHH-23), Pipeline and Hazardous Materials Safety Administration, U.S. Department of Transportation, Washington D.C. 20590-0001.

   c. This certificate does not relieve any consignor or carrier from compliance with any requirement of the Government of any country through or into which the package is to be transported.

   d. This certificate provides no relief from the limitations for transportation of plutonium by air in the United States as cited in the regulations of the U.S. Nuclear Regulatory Commission 10 CFR 71.88.

   e. Records of Management System activities required by Paragraph 306 of the IAEA regulations[1] shall be maintained and made available to the authorized officials for at least three years after the last shipment authorized by this certificate. Consignors in the United States exporting shipments under this certificate shall satisfy the applicable requirements of Subpart H of 10 CFR 71.

5. Special Conditions -

   a. Content No. 11h is prohibited.

   b. For Content Nos. 11a thru 11g transported by land, the maximum mass of uranium, the maximum enrichment in uranium-235, the allowable containment diameter and the presence of hydrogen-bearing materials having a hydrogen content greater than water shall be as allowed in French Package Design Certificate No. F/313/B(U)F-96.

   c. For Content Nos. 11a thru 11g, the transport of reprocessed uranium is prohibited.

   d. For Content Nos. 11a thru 11g, the transport of uranium carbides and uranium nitrides is prohibited.

CERTIFICATE USA/0492/B(U)F-96, REVISION 20

e. For Content Nos. 11a thru 11g, the mass of water and the equivalent mass of other hydrogenous materials must not exceed 2000 grams per package.

f. For Content Nos. 11a thru 11g, the maximum allowable fissile mass is 5 kg when transported by air.

g. For Content No. 26, the maximum number of TRIGA fuel elements per package is not to exceed 5 standard elements or 23 thin elements, where standard and thin elements are defined in F/313/B(U)F-96 26bj, Appendix 26, Content No. 26. The total mass of cardboard must not exceed 1200 grams, the moisture content of the wood components must not exceed 10 percent, and the total water content (including moisture content of the wood and water equivalent in the form of cardboard) must not exceed 2900 grams per package. No other hydrogenous packaging materials are permitted within the package containment vessel.

6. Marking and Labeling - The package shall bear the marking USA/0492/B(U)F-96 in addition to other required markings and labeling.

7. Expiration Date - This certificate expires on March 1, 2024. Previous editions which have not reached their expiration date may continue to be used.

This certificate is issued in accordance with paragraph(s) 810 and 816 of the IAEA Regulations and Section 173.472 and 173.473 of Title 49 of the Code of Federal Regulations, in response to the May 23, 2019 petition by TN Americas LLC, Columbia, MD, and in consideration of other information on file in this Office.

Certified By:

for William Schoonover
Associate Administrator for Hazardous Materials Safety

June 13, 2019
(DATE)

CERTIFICATE USA/0492/B(U)F-96, REVISION 20

Revision 20 - Issued to revalidate French Certificate of Competent Authority F/313/B(U)F-96, Revision Lbj, restricted to contents 11a, 11b, 11c, 11d, 11e, 11f, 11g and 26, subject to special conditions listed in paragraph 5.

AUTORITÉ DE SÛRETÉ NUCLÉAIRE

DEPARTMENT OF INDUSTRIAL ACTIVITIES AND TRANSPORT

APPROVAL CERTIFICATE

FOR A PACKAGE DESIGN

The French Governing Authority,

Considering the request presented by the **Commissariat for Atomic Energy and Alternative Energies** by the letter CEA DPSN DIR 2017-437 of November 20, 2017, and the letter CEA DSSN/DIR/2018/632 of November 30, 2018;

and in light of safety analysis report CEA DSN/STMR/LEPE/TNBGC1 DSEM 0600 Ed. 05 dated 16 November 2018,

Certifies that the package model constituted by the **TN-BGC 1** packaging described below in appendix 0, index bj, and loaded with one of the following contents:

- rods or sections of rods or pellets of uranium oxide, as described in Appendix 7, index bj;
- solid uranium materials, as described in Appendix 11, index bj;
- TRIGA fuel, as described in Appendix 26, index bj;
- an aqueous solution of uranyl nitrate, as described in Appendix 40, index bj;
- fuel element or plates U_3Si_2Al, as described in Appendix 50, index bj;
- FSV fuel, as described in Appendix 52, index bj,

is compliant, as a type B(U) package design loaded with fissile materials, with the requirements of the regulations and agreements listed below:

- International Atomic Energy Agency, Regulations for the Safe Transport of Radioactive Material, Safety Standards Series, No. SSR-6, 2012 Edition;
- European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR);
- Technical Instructions for the safe air transport of hazardous goods (ICAO-TI),
- amended Order of May 29, 2009, relating to the carriage of dangerous goods by land (known as the "TDG Order");
- Instruction of June 26 2008 regarding the technical rules and administrative procedures applicable to commercial transport by aircraft and EU regulation no. 859/2008 of August 20 2008 (EU-OPS1).

However, only contents 11, 26 and 52 are allowed for air transport.

This certificate does not relieve the shipper from complying with the requirements established by the authorities of the countries through or into whose territory the parcel will be transported.

The validity of this certificate expires on March **1, 2024.**

Registration number: **CODEP-DTS-2019-010485**

Done at Montrouge on March 1, 2019

For the President of the ASN, and on the authority of,
the Director Industrial Activities and Transport

SUMMARY OF CERTIFICATE VERSIONS

Issued	Expiry	Type of version and modifications	Authority	Certificate Ref. No.	Revision index								
					Body	t	0	1	2	3	4	5	6
25/08/2008	15/11/2010	extension: contents 2, 4, 7, 11 and 26	ASN	F/313/B(U)F-96	Iak	-	ak	-	ak	-	ak	-	-
25/08/2008	31/08/2013	extension: contents 5, 6 and 15	ASN	F/313/B(M)F-96 T	Ial	al	al	-	-	-	-	al	al
12/02/2009	31/08/2013	extension: inclusion of contents 1 and 3	ASN	F/313/B(M)F-96 T	Iao	ao	ao	ao	-	ao	-	-	-
10/04/2009	31/08/2013	extension: modification of contents 1 and 3	ASN	F/313/B(M)F-96 T	Iap	ao	ao	ap	-	ap	-	-	-
04/11/2009	31/08/2013	extension: modification of contents 1, 3, 5, 6 and 15; inclusion of contents 8, 9, 10, 18, 19, 20 and 23	ASN	F/313/B(M)F-96 T	Iaq	aq	aq	aq	-	aq	-	aq	aq
28/04/2010	31/08/2013	extension: inclusion of content 39	ASN	F/313/B(M)F-96 T	Ias	as	as	-	-	-	-	-	-
04/06/2010	31/08/2013	extension: cancels and replaces certificate F/313/B(U)F-96 (Iak)	ASN	F/313/B(U)F-96	Iat	-	at	-	at	-	at	-	-
04/08/2010	31/08/2013	extension: inclusion of content 42	ASN	F/313/B(U)F-96	Iav	-	av	-	-	-	-	-	-
10/11/2010	31/08/2013	extension: inclusion of content 40	ASN	F/313/B(U)F-96	Iax	-	ax	-	-	-	-	-	-
10/05/2011	31/08/2013	extension: modification of content 40	ASN	F/313/B(U)F-96	Iay	-	ay	-	-	-	-	-	-
17/08/2011	31/08/2013	Extension: inclusion of CH_2	ASN	F/313/B(U)F-96	Iaz	-	az	-	az	-	az	-	-
20/04/2012	31/08/2013	extension: inclusion of content 46	ASN	F/313/B(M)F-96 T	Iba	ba	ba	-	-	-	-	-	-
10/10/213	30/06/2018	extension: contents 2, 4, 7, 11, 26, 40, 41 and 42	ASN	F/313/B(U)F-96	Jbb	-	bb	-	bb		bb	-	-
01/10/2014	30/06/2018	extension: contents 1, 3, 5, 8 - 10 18-20, 23 and 46	ASN	F/313/B(M)F-96 T	Jbc	bc	bc	bc	-	bc	-	bc	-
01/07/2016	30/06/2018	extension: content 11i	ASN	F/313/B(U)F-96	Jbd	-	bd	-	-	-	-	-	-
28/09/2017	30/06/2018	extension: modification of content 40	ASN	F/313/B(U)F-96	Jbe	-	be	-	-	-	-	-	-
28/09/2017	30/06/2018	extension: content 48	ASN	F/313/B(U)F-96	Jbf	-	bf	-	-	-	-	-	-
27/06/2018	31/12/2018	administrative extension: contents 2, 4, 7, 11, 26, 40, 41 and 42	ASN	F/313/B(U)F-96	Kbh	-	bh	-	bh		bh	-	-
27/06/2018	31/12/2018	extension: contents 1, 3, 5, 8 to 10, 18 - 20, 23 and 46	ASN	F/313/B(M)F-96 T	Kbi	bi	bi	bi	-	bi	-	bi	bi
01/03/2019	01/03/2024	extension: contents 2, 7, 11, 26 and 40 extension: contents 5, 50 and 52	ASN	F/313/B(U)F-96	Lbj	-	bj	-	-	-	-	-	-
01/03/2019	01/03/2024	extension: contents 1, 3, 5, 8 to 10, 18 to 20, 23 and 46	ASN	F/313/B(M)F-96 T	Lbk	bk	bk	-	-	-	-	-	-

01/03/2019	01/03/2024	extension: contents 5, 51 and 53	ASN	F/313/B(U)F-96	Lbl	-	bl	-	-	-	-	-	-	-

Revision index																												
Body	7	8	9	10	11	15	16	17	18	19	20	21	22	23	24	25	26	27	39	40	41	42	46	48	50	51	52	53
Iak	ak	-	-	-	ak	-	-	-	-	-	-	-	-	-	-	-	ak	-	-	-	-	-	-	-	-	-	-	-
Ial	-	-	-	-	-	al	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iao	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iap	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iaq	-	aq	aq	aq	-	aq	-	-	aq	aq	aq	-	-	aq	-	-	-	-	-	-	-	-	-	-	-	-	-	-
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Iat	at	-	-	-	at	-	-	-	-	-	-	-	-	-	-	-	at	-	-	-	-	-	-	-	-	-	-	-
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Iax	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	ax	-	-	-	-	-	-	-	-
Iay	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	ay	-	-	-	-	-	-	-	-
Iaz	az	-	-	-	az	-	-	-	-	-	-	-	-	-	-	-	az	-	-	-	-	-	-	-	-	-	-	-
Iba	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	ba	-	-	-	-	-
Jbb	bb	-	-	-	bb	-	-	-	-	-	-	-	-	-	-	-	bb	-	-	bb	bb	bb	-	-	-	-	-	-
Jbc	-	bc	bc	bc	-	-	-	-	bc	bc	bc	-	-	bc	-	-	-	-	-	-	-	-	bc	-	-	-	-	-
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Kbi	-	bi	bi	bi	-	-	-	-	bi	bi	bi	-	-	bi	-	-	-	-	-	-	-	-	bi	-	-	-	-	-
Lbj	bj	-	-	-	bj	-	-	-	-	-	-	-	-	-	-	-	bj	-	-	bj	-	-	-	-	bj	-	bj	-
Lbk	-	bk	bk	bk	-	-	-	-	bk	bk	bk	-	-	bk	-	-	-	-	-	-	-	-	bk	-	-	-	-	-
Lbl	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	bl	-	bl

APPENDIX 0

TN-BGC 1 PACKAGING

1. PACKAGING DEFINITION

The packaging is designed, manufactured, inspected, tested, maintained and used in compliance with safety analysis report CEA DSN/STMR/LEPE/TNBGC1 DSEM 0600 Ed. November 2018.

The packaging, which consists of a parallelepiped cage inside which a generally cylindrical body equipped with a closure system and a cover are fixed, is presented in figure 0.1.

The packaging design drawings are as follows:

- design drawings for the set : TN 9990-65 (C),
- cage : TN 9990-118 (B),
- fitted plug : TN 9990-117 (B),
- cover : EMB TNBGC PBC PDC CA 010001 A.

The main dimensions of the packaging are as follows:

- cage cross-section : 600 × 600 mm;
- overall height of the cage : 1,821 mm;
- diameter of the body - uninterrupted section : 295 mm;
- cover diameter : 466 mm;
- overall body height with cover : 1,808 mm

The maximum permissible mass of the packaging, loaded for transport, is 396 kg; its mass when empty is 280 kg.

Given the tolerances on the dimensions and densities of balsa and poplar contained in the packaging (shock absorbing cover and bottom of the body), the total mass of water in these elements does not exceed 1,670 grams.

The packaging consists of the main subsets specified below.

1.1 Packaging body

The cavity, with a useful internal diameter 178 mm and useful length 1475 mm, is formed of a stainless steel shell, 6 mm thick, and a bottom of thickness 8 mm, also in stainless steel.

A second stainless steel shell, 1.5 mm thick, and with an internal diameter 292 mm delimits, with the first shell, a space filled with resin which acts as a neutron absorbent and active thermal insulation.

The bottom is completed, from the inside of the package to the outside, by a distribution plate of 25 mm high tensile steel, a layer of 24 mm resin, an intermediate bottom, a wooden damper disc and a stainless steel sheet.

In the upper part, a machined stainless steel flange is welded to the two shells to host the closure system described below.

1.2 Cage

The cage is a structure in aluminium tubes of 30 × 30 mm section and 2 mm thick.

Angle-reinforced passageways are provided at two levels on the cage to allow for the forks of a forklift and thereby for packaging handling.

Inside the cage, frames are provided to connect the cage to the body of the packaging. They are welded to the vertical struts of the cage and drilled to allow the body's mounting bolts to be inserted.

1.3 Closing system

The body cavity is closed using a system consisting of 3 main parts: a plug, a clamp ring and a bayonet ring.

The plug is held against the body by the clamping ring. This component is screwed into the bayonet ring, which is itself pressed against the body flange.

In the centre of the cap, a bore hole equipped with a quick coupling can be used to reduce the pressure inside the packaging before shipment and to re-establish atmospheric pressure before unloading at the destination. This orifice is closed off by a cap.

The plug on the body and the quick-connect cap are sealed by two pairs of O-rings. The spaces between the seals both communicate with a common control port which can be used to check the tightness of the closure system.

1.4 Shock absorption system

In the event of a fall, a leaktight shock absorbing cover over the head of the body and the closing system will absorb impact forces.

The shock absorbing cover consists of two stainless steel sheeting boxes filled, for the one that is closest to the body, by resin and, for the second, by wood (balsa and poplar).

The lid is fixed on the body by two bent rods which are housed in lugs integral with the body and, secondly two latches whose ends are screwed on the lid and welded to the body of the packaging.

1.5 Handling and tie-down components

The cage is used to handle and tie-down the packaging.
The tie-down of the packaging is in particular carried out in accordance with the instruction referenced DSN / STMR / LEPE / TN-BGC 1 PCD 0007 Ind. 01 of 15/10/2018.

1.6 Safety functions

Containment is ensured by the packaging enclosure, made up of the inner shell, the base of the body and their circumferential welds, the plug and the quick-connect cap, which are fitted with silicone internal gaskets.

Radiological protection is provided mainly by:

- the lateral stainless steel shielding of the inner and outer shells against gamma radiation and the resin against neutron radiation;
- the stainless steel bottom shield of the bottom of the cavity and the two closure plates as well as the carbon steel of the distribution plate against the gamma radiation and by the resin and the wood against the neutron radiation;

- the stainless steel head shielding of the plug and the sheets of the lid against gamma radiation and by the resin and the wood against the neutron radiation.

S**ubcriticality is maintained** by the isolation system, which is composed of the elements described in the appendix to the contents and of:

- the packaging taking into account its geometry and its materials;
- the internal fittings given their geometries and materials. For these internal fittings, the parameters which are important for safety are recalled in the table below.

Internal fittings	Internal diameter (mm)	Thickness (mm)	Material
TN90	≤ 120	≥ 2	Z2 CN 18-10
AA 41 – AA 203 – AA 203c – AA 204	≤ 115	≥ 2	Z2 CN 18-10
E7	≤ 60	≥ 2	UA4G

The **dissipation of the internal thermal power** is ensured by radiation between the radioactive materials and the internal shell of the body, by conduction in the body and heat exchange between the body and the ambient air.

Impact protection is ensured by the shock-absorbing cover and the cage.

Fire protection is mainly provided by wood and resin. The body and the hood are equipped with fusible plugs which avoid the risk of overpressure due to the accumulation of steam.

2. MEASURES TO BE TAKEN BY THE SHIPPER PRIOR TO SHIPPING THE PACKAGE

The packaging is used according to procedures in accordance with the operating instructions of chapter 10 of the CEA safety reference file DSN/STMR/LEPE/TNBGC1 DSEM 0600 Ind. 05 of 16 November 2018.

In addition, when checking the tightness of the closure system through the test port, the sender ensures that the leakage rate is less than 6.65×10^{-4} Pa m^3 s^{-1} SLR.

3. MAINTENANCE PROGRAMME

The packaging is maintained according to the procedures in compliance with the instructions of chapter 10 of the safety analysis report with the reference CEA DSN/STMR/LEPE/TNBGC1 DSEM 0600 Ind. 05 of 16 November 2018.

4. NOTIFICATION AND RECORDING OF SERIAL NUMBERS

Any putting out of use or any change of ownership of a packaging is brought to the attention of the competent authorities. For this purpose, any owner passing on a packaging transmits the name of the new buyer.

5. MANAGEMENT SYSTEM

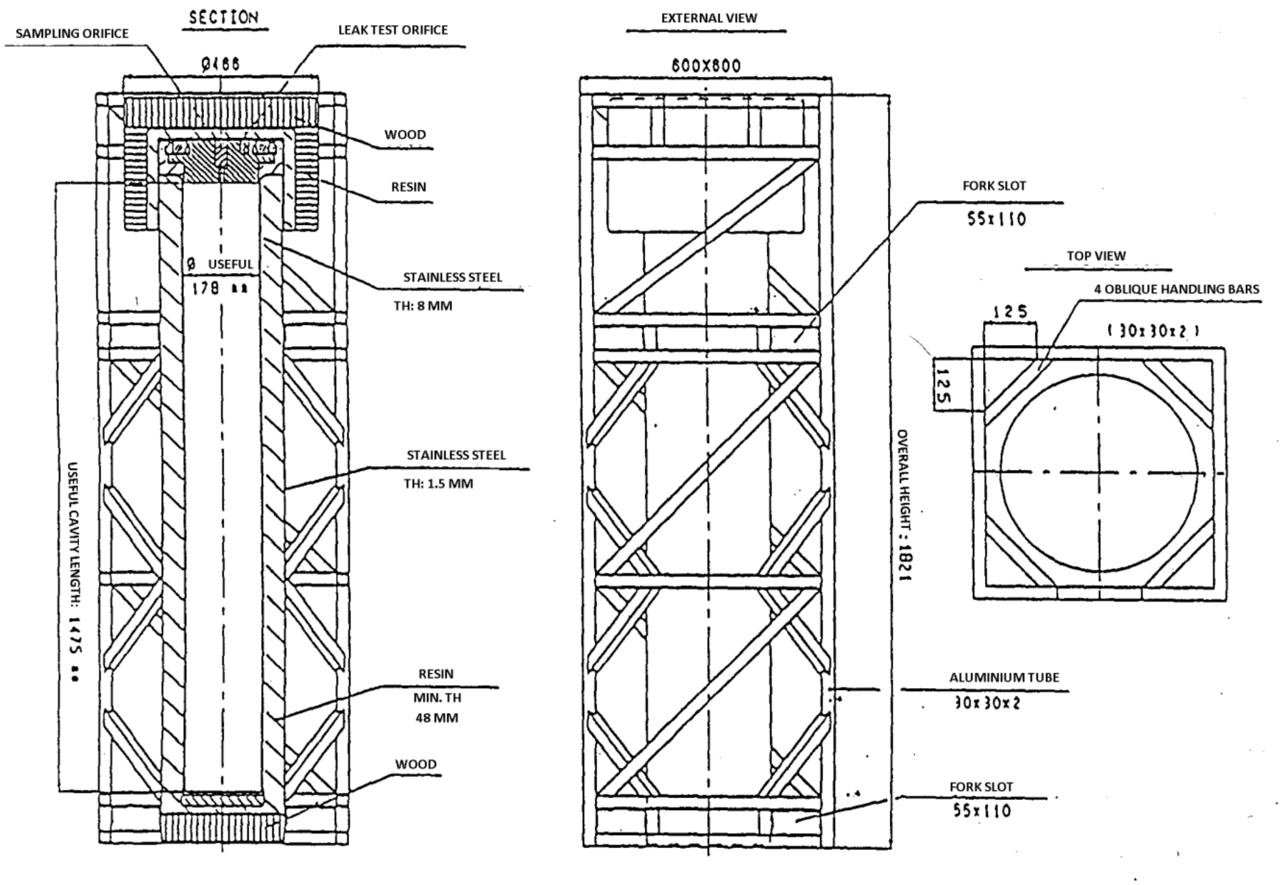
The principles of the management system to be applied during the design, manufacture, inspection, testing, maintenance and use of the package are in accordance with those described in chapter 11 of the CEA safety analysis report with the reference DSN/STMR/EMBAL/LEPE/DSEM 0600 ind. 05 of 16 November 2018.

6. ADDITIONAL PRESCRIPTION FOR TRANSPORT IN A CONFINED ENVIRONMENT

The transport of the CB9 box package is authorised under exclusive use.

FIGURE 0.1

SCHEME OF PACKAGING



NB.: dimensions are in mm.

APPENDIX 11

UNIRRADIATED SOLID URANIFEROUS MATERIALS

1. DEFINITION OF AUTHORISED CONTENT

The safety analysis report justifying the authorised content is referenced CEA DSN/STMR/LEPE/TNBGC1 DSEM 0600 Ind. 05 of 16 November 2018.

The permitted radioactive content consists of uraniferous materials which have not been irradiated in solid form.

If the uranium comes from reprocessing, the material did not undergo irradiation subsequent to reprocessing.

The presence of neutron absorbents (Boron, Gadolinium, Erbium, Europium, Dysprosium, Hafnium and Cadmium) is permitted in any quantity.
The presence of materials other than those defined in this appendix (contents and internal fittings) is excluded. The presence of transuraniens, capped at one gram is, however, allowed.

Isotopic composition and masses

For transport by air, the maximum mass of uranium 235 transported by TN-BGC 1 package as a function of the mass of water and polymeric materials present in the package is set out in the following table.

Maximum mass authorised of 235U (kg)	Maximum mass of water and polymeric materials permitted (g)
7.7	0
5.4	500
3.2	1000

For all transport by land, the sub-contents, whose maximum masses and isotopic compositions are presented below, are described in the safety analysis report referenced CEA DSN/STMR/LEPE/TNBGC1 DSEM 0600 Ind. 05 of 16 November 2018. Mixing different sub-contents within the same packaging is prohibited.

1/ The enrichment of uranium is any:

Sub-content no.	Presence of materials with higher hydrogen content than water authorised	Containment diameter (mm)	Maximum mass of 235U (kg)	Maximum number of packages
11a	Yes	∅ ≤ 120	2	10
11b		∅ ≤ 100	19.5	5
11d (*)	No	100 < ∅ ≤ 120	7	50
11e		60 < ∅ ≤ 100	15	16
11f		∅ ≤ 60	40	50

*: For sub-content No. 11d, the presence of aluminium or carbon in any quantity is permitted in the cavity of the internal fitting if the mass of ^{235}U is less than or equal to 300 g.

2/ The enrichment of uranium in uranium 235 is less than or equal to 20%:

Sub-content no.	Presence of materials with higher hydrogen content than water authorised	Containment diameter (mm)	Maximum mass of U (kg)	Maximum number of packages
11c	Yes	$\varnothing \leq 120$	40	10
11g	No	$\varnothing \leq 120$	40	50

3/ Uranium enrichment in uranium 235 is less than or equal to 30%:

Sub-content no.	Presence of materials with higher hydrogen content than water authorised	Containment diameter (mm)	Maximum mass of U (kg)	Maximum number of packages
11h	Yes	$\varnothing \leq 115$	40	25

Physical characteristics

The density of the material is arbitrary.

If metal powders are transported, the powder-conditioning boxes, the internal fitting used and the cavity of TN-BGC 1 are inerted.

Chemical form

The material is exclusively in one of the following chemical forms (or in the form of a mixture of these forms):

- Metallic Uranium,
- Uranium oxides: UO_2, UO_3, U_3O_8;
- Uranium tetrafluoride: UF_4 ;
- Uranium nitrides: UN, U_2N_3, UN_2;
- Uranium carbides: UC, UC_2 et U_2C_3;
- Uranium alloys with: aluminium, molybdenum, silicon, zirconium.

Special form

The material is not in a special form.

Special provisions

In the presence of polymer materials or water, the time between the closure of the internal fitting in the shipping facility and the arrival of the package at the destination facility is less than 1 year.

If transuraniens are present in the content, the sender verifies that the specific activity of the content does not exceed 25 A_2 / g.

2. INTERNAL FITTINGS AND PACKAGING

If the mass of the content is greater than or equal to 30 kg, the content is blocked in its internal fittings with shims.

The material is optionally placed in a primary packaging consisting of metal cans, bottles or polymer shells. Everything is placed in an internal fitting.

The permitted polymeric materials are polyethylene, polyurethane, polyvinyl chloride and tetrafluoroethylene.

For transport by land, the presence of polyethylene or polyurethane more hydrogenated than water:

- is not allowed in sub-contents 11d, 11e, 11f and 11g,
- is allowed in other sub-contents capped at 500 g for polyethylene and in any quantities for polyurethane.

For transport by air, the presence of polyethylene or polyurethane more hydrogenated than water is not allowed, whatever the sub-content.

The internal fittings that can be used are TN 90, AA 41, AA 203, AA 203c or AA 204.

If the required internal diameter is strictly less than 100 mm, the internal fitting used is of type TN 90 and E7 type spacers are used for positioning and the radial shim inside the TN 90.

The following spacers are used to position the internal fitting in the cavity of the packaging:

- for 1 TN 90 : spacers E1 and E2,
- for 1 AA 41 : spacers E1 and E11,
- for 2 AA 41 : spacers E1, E12 and E13,
- for 3 AA 41 : spacers E1, E9 and 2 × E13
- for 1 AA 203 : spacers E1 and E8,
- for 1 AA 203 : spacers E1 and E8,
- for 1 AA 204 : spacers E1 and E10 or E6.

The total mass of the entire load of internal fittings AA 41, AA 203, AA 204 and TN 90 (material + primary packaging) must not exceed 60 kg.

3. STUDY TO MAINTAIN SUB-CRITICITY

The sub critical maintenance study is the subject of chapter 8 CEA reference DSN/STMR/LEPE/TNBGC1 DSEM 0608 Ind. 03 of November 10, 2017, supplemented by CEA/SEC/T n°89-18 of 20/01/89 and NT 000 48,550.01 of October 30, 2018.

For the contents 11a, 11b, 11c and 11h, it admits the presence of polymeric materials of hydrogen concentration higher than that of the water in the enclosure.

For contents 11d, 11e, 11f and 11g it admits the presence of polymer substances with a hydrogen concentration equal to or lower than that of water in the enclosure.

Criticality Safety Index

For contents 11a and 11c	: CSI = 5 (where N = 10)
For content 11b	: CSI = 10 (where N = 5)
For content 11e	: CSI = 3,125 (where N = 16)
For contents 11d, 11f and 11g	: CSI = 1 (where N = 50)
For content 11h	: CSI = 2 (where N = 25)

APPENDIX 26

TRIGA FUEL

1. DEFINITION OF AUTHORISED CONTENT

The safety analysis report justifying the authorised content is referenced CEA DSN/STMR/LEPE/TNBGC1 DSEM 0600 Ind. 05 of 16 November 2018.

The authorised radioactive content consists of bars of non-irradiated TRIGA fuel elements. These bars are based on U-ZrH_x (with x between 0 and 2); they are cylindrical, and of two types, standard or fine, with the following geometric characteristics:

- standard : diameter = 3.63 cm; length = 12.7 cm,
- end : diameter = 1.29 cm; length = 18.6 cm.

The uranium does not come from reprocessing.

The presence of other materials than those defined in the certificate of approval is prohibited.

Isotopic composition and masses

The maximum 235U enrichment level is 20%. The mass content of uranium varies between 8 and 47%, depending on the type of element:

Element type	U (% by maximum mass)	ZrH_X (% by maximum mass)	Maximum U-Zr mass (g/cm^3)	Mass of U-ZrH_2 maximal (g/cm^3)
Composition of standard TRIGA elements				
103	8	92	6.9	6.04
105	12	88	7.1	6.22
107	12	88	7.1	6.22
117	21	79	7.4	6.64
119	31	69	8.1	7.24
Composition of thin TRIGA fuel elements				
424	47	53	9.3	8.40

Mixing different sub-contents within the same packaging is prohibited.

Maximum transportable quantities

The maximum transportable quantities are specified in the following tables.

- for **transport by air**: the maximum mass of uranium transported by TN-BGC 1 package depends on the type of element, according to the table below:

Element type	Maximum mass of U (kg)
103	1.1
105	1.7
107	1.7
117	3.3
119	5.3
424	6.6

– for **overland transport**, the maximum mass of uranium transported by TN-BGC 1 package is a function of the type of element, according to the table below, subject, however, to the maximum mass indicated in paragraph 2, for the loading of internal fittings:

Element type	Maximum mass of U (kg)
103	9
105	14
107	14
117	27
119	43
424	76

Chemical form

Metal.

Special form

The material is not in a special form.

Special provisions

In the case of air transport, the mass of water present with the fissile material, irrespective of that contained in the hydrogenated materials of the packaging, does not exceed 1,200 g or 1,937 g, depending on whether standard or fine elements are present respectively.

The time between closing the internal fitting in the shipping facility and opening the package at the receiving facility is less than 365 days.

2. INTERNAL FITTINGS AND PACKAGING

If the mass of the content is greater than or equal to 30 kg, the content is blocked in its internal fittings with shims.

The TRIGA bars are placed in cardboard protective cases placed in an internal fitting. The presence of polyvinyl chloride and polyurethane is permitted. If polyurethane is used, it is less hydrogenated than water.

The internal fittings, equipped with silicone gaskets, are of the TN 90, AA 41, AA 203 or AA 204 type.

A type E7 primary packaging container can be used with TN 90 for the conditioning of uranium material.

The following spacers are used to wedge the internal fitting in the cavity of the packaging:

- for the TN 90 : shims E1 + shim E2,
- for 1 AA 41 : shims E1 + shim E11,
- for 2 AA 41 : shims E1 + shim E12 + shim E13,
- for 3 AA 41 : shims E1 + shim E9 + 2 shims E13,
- for the AA 203 : shims E1 + shim E8,
- with one AA 204 : shims E1 + shim E11.

The total mass of the entire load of internal fittings AA 41, AA 203, AA 204 and TN 90 (material + primary packaging) must not exceed 60 kg.

3. STUDY TO MAINTAIN SUB-CRITICITY

The sub critical maintenance study is the subject of chapter 8 CEA reference DSN/STMR/LEPE/TNBGC1 DSEM 0608 Ind. 03 of 10 November 2017.

It allows for the presence of polymer materials with a hydrogen concentration lower than or equal to that of water in the enclosure.

Criticality Safety Index: CSI = 0 (where N = infinity),

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U.S. Department of
Transportation

**Pipeline and
Hazardous Materials
Safety Administration**

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CERTIFICATE NUMBER: USA/0492/B(U)F-96

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