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Reference Fuel Development for Non-Aluminum Spent Nuclear Fuel Management

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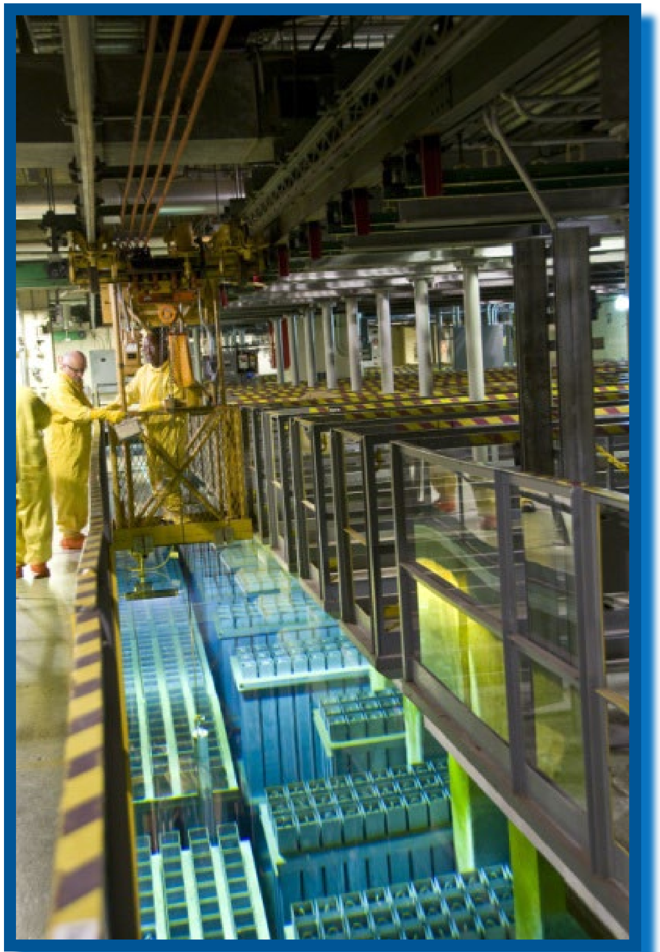
Facility Background and Mission

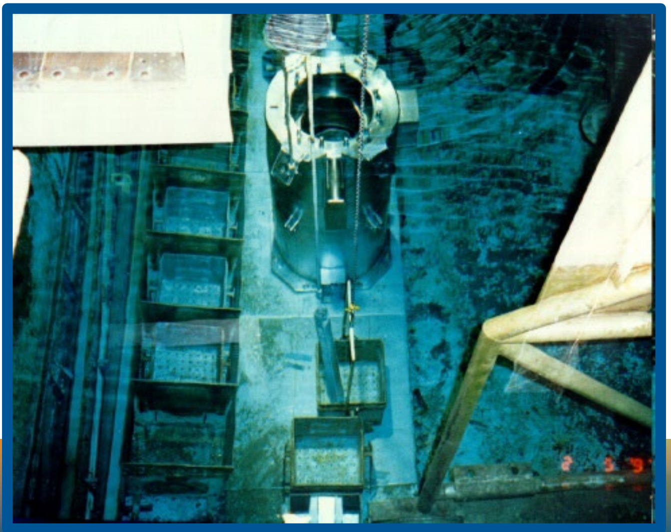
- **Background**
  - The L Area Facility was initially constructed as a nuclear reactor for nuclear material production in the 1950s
  - The reactor was shut down in the late 1980s: in the 1990s the mission changed to storing nuclear material
- **Current Mission**
  - L Area provides for the safe receipt, storage, handling, and shipping of spent nuclear fuel (SNF) and other nuclear materials
  - Received more than 47,000 SNF assemblies since 1964 from power and research reactors (domestic and foreign)

SRS Spent Fuel Project

- **Majority of SNF in L Area is stored and handled underwater in the Disassembly Basin**
  - 3.5 million gallons of water
- **Operations include underwater cask unloading, fuel cropping and bundling, rack storage, underwater cask loading, and shipping for disposition**



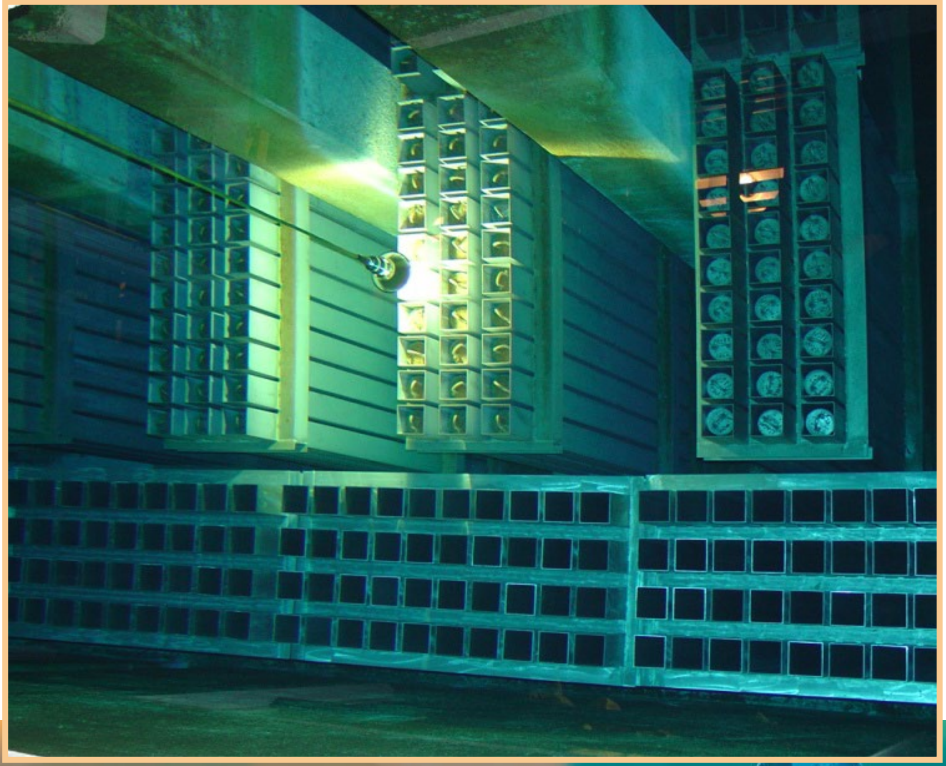
L Basin



L Basin Inventory of Spent Nuclear Fuel

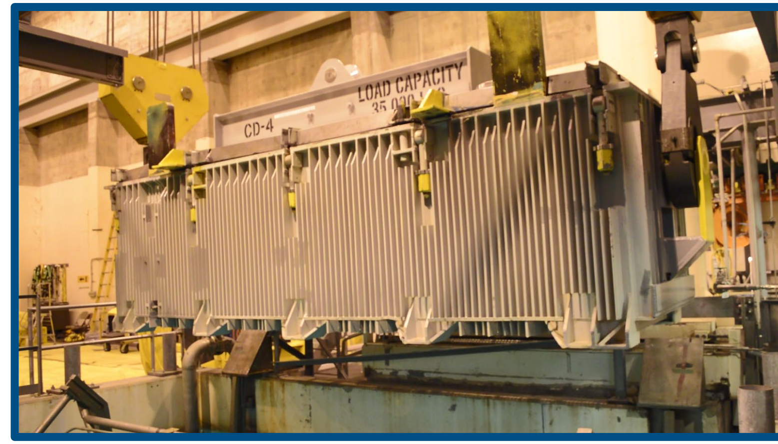
- **The L Basin SNF inventory represents a wide range of fuel forms**
  - Tubular assemblies, annular assemblies, fuel plate assemblies, fuel pin assemblies
  - Variety of enrichments, cladding materials, fuel compositions, etc.

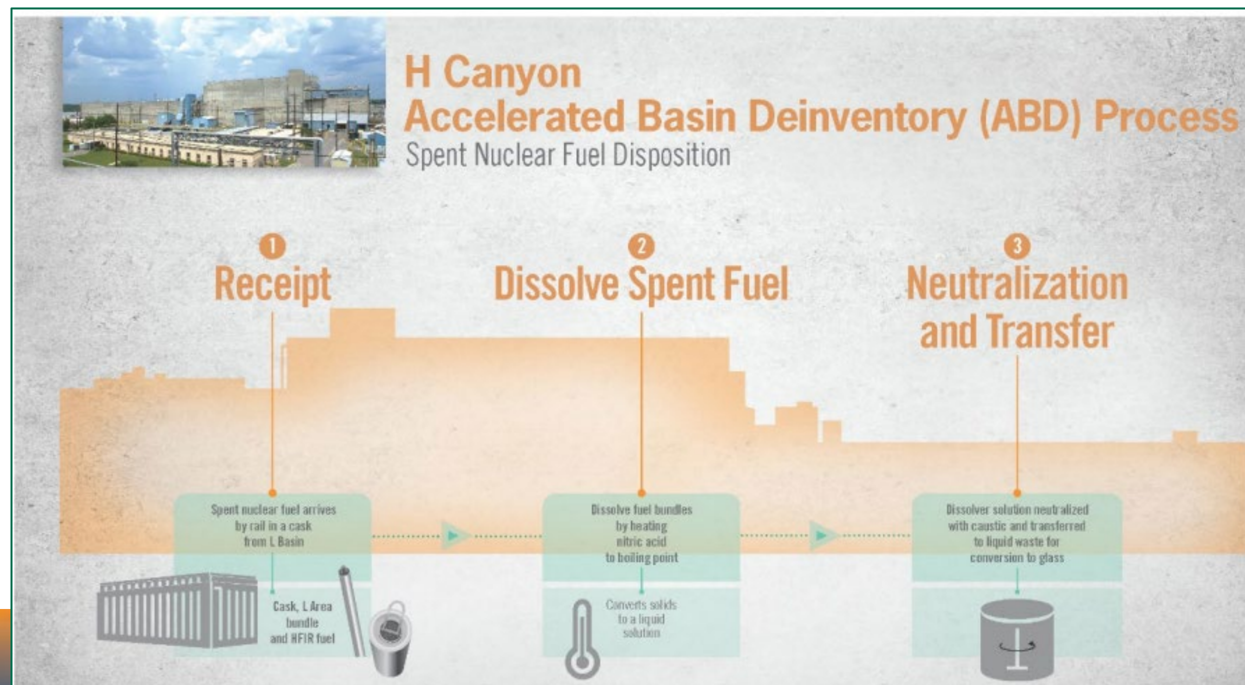
- **SNF is typically packaged into long storage containers (bundles)**
- **The bundles geometrically constrain the SNF and allow for the storage of highly varied fuel types in modular rack storage system**
- **Vertical bundles in a fixed square array**



Current Operations - L Basin to H Canyon Transfers

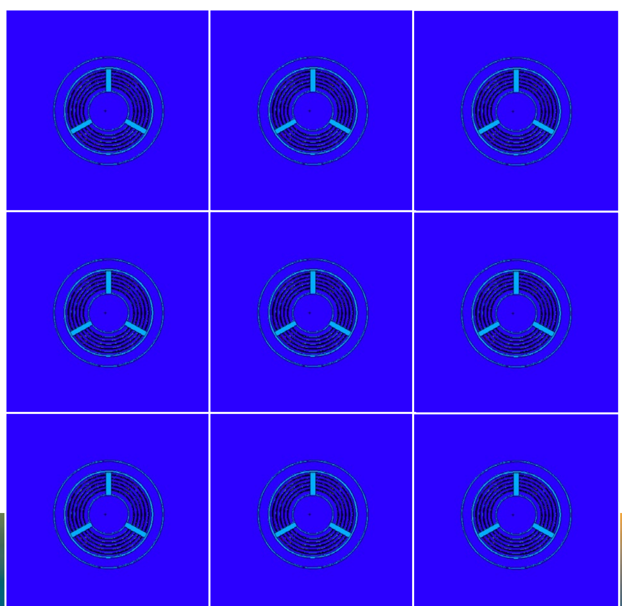
- **Shipment of SNF from L Area to H Canyon for dissolution, purifying and blending HEU into LEU**
- **Utilize 70-ton casks for on-site transfer**
- **New Accelerated Basin Deinventory (ABD) program for disposition of legacy SNF**

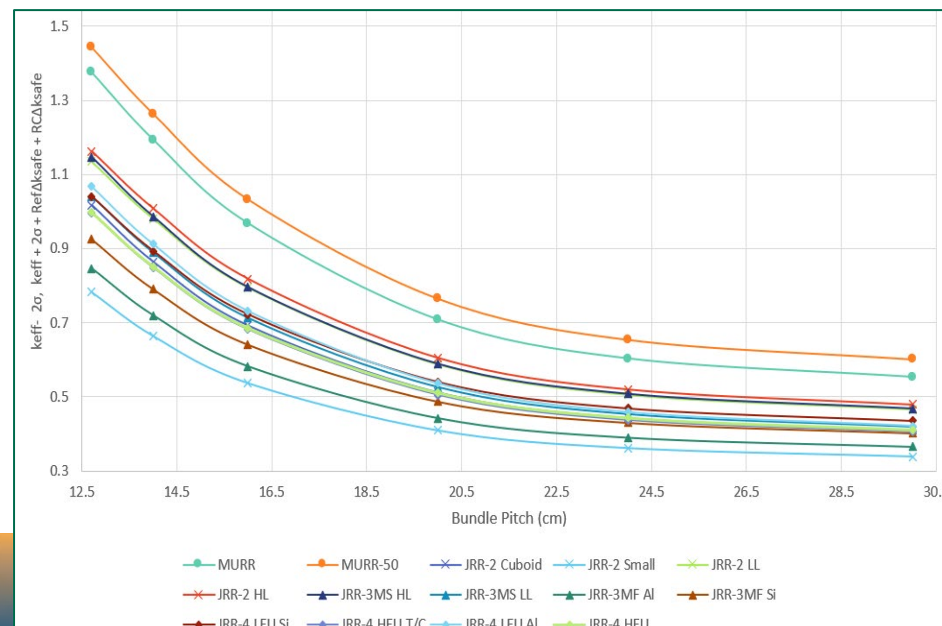




Reference Fuels in L Area

- **SPF Criticality Safety Engineering has historically used several "reference fuels" to establish bounding storage, handling, and cask loading limits for bundled fuel**
  - Reactivity comparison approach compares candidate fuel to reference fuel to demonstrate that candidate fuels may be processed under reference fuel limits
- **SRS Standardized Approach for Storage and Handling Analysis (SASHAY) methodology evaluates infinite lattice of bundled fuel in a modular rack over a range of inter-bundle spacing (from zero separation to full neutronic separation)**





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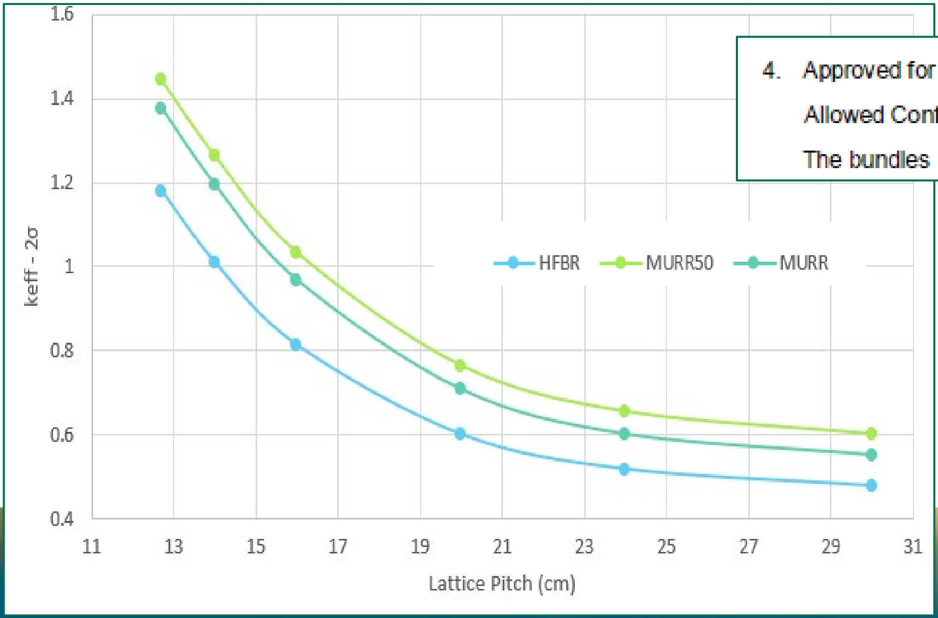
- This methodology significantly reduces the complexity and time required to perform evaluations that would otherwise need to be performed for a wide variety of fuel types.
- Many candidate fuels are be processed in L Area using limits and controls pre-established for reference fuels: reference fuel evaluations consider shipping, handling, safe number, rack storage, accident scenarios, etc.
- Current reference fuels in use: MURR, MURR-50 (fictional fuel based on MURR) and HFBR



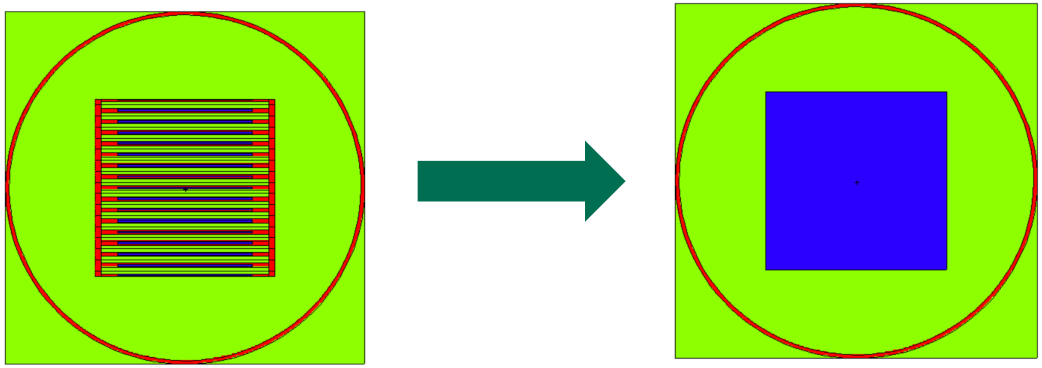
4. Approved for Shipment in SRS 70-Ton Cask? ■ Yes ☐ No

Allowed Configurations: ■ RRF Insert ☐ Other (See Below)

The bundles must be loaded in accordance with: NSDS 119 (MURR) 70-Ton Cask Limits

Homogenized Reference Fuels

- Current reference fuels are homogeneous models
- Candidate fuel may be modeled homogenously (in addition to explicit models) for conservativism and to bound damaged assembly cases



- Homogenous mixtures are developed using the proportional masses of fuel, cladding, moderator, and extraneous materials (ex. side plates, cladding) contained within the assembly volume divided by the assembly volume. The mixture is then modeled over the active fuel region
- Not applicable to all fuel types

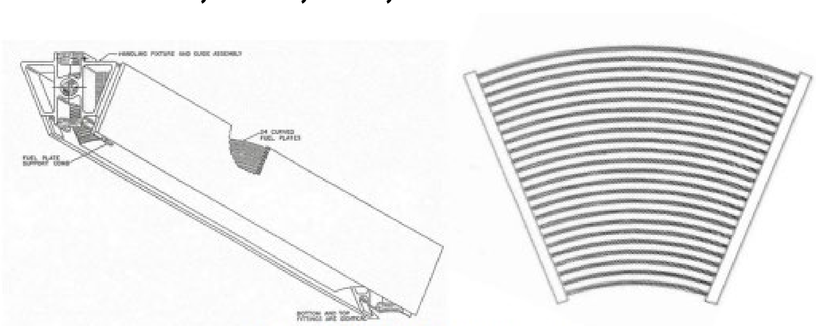
MTR vs NASNF

MTR

(Material Test Reactor Fuel)

- U-Al_x alloy fuel meat
- Thin plate fuel (straight or curved)
- Aluminum cladding
- Typically stored in 5-inch aluminum bundle
- Majority of L Area inventory: has established shipping limits

Ex. MURR, JRR, MIT, HFIR



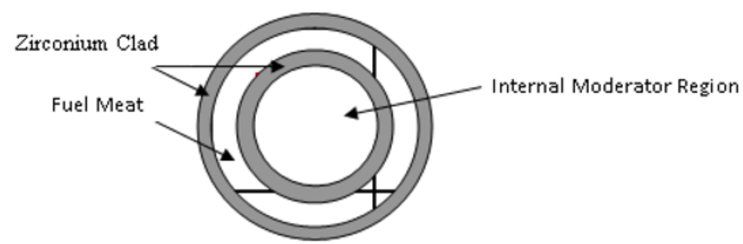
2. MURR Fuel Element.

NASNF

(Non-Aluminum Spent Nuclear Fuel)

- UO_2, U metal, or U-Zr fuel meat
- Tubes, pins, plates, segmented tubes, etc.
- Zircalloy, stainless-steel, or hastelloy clad
- Stored in multiple bundle types
- Variety of unique fuels currently stored in L Area: no established shipping limits

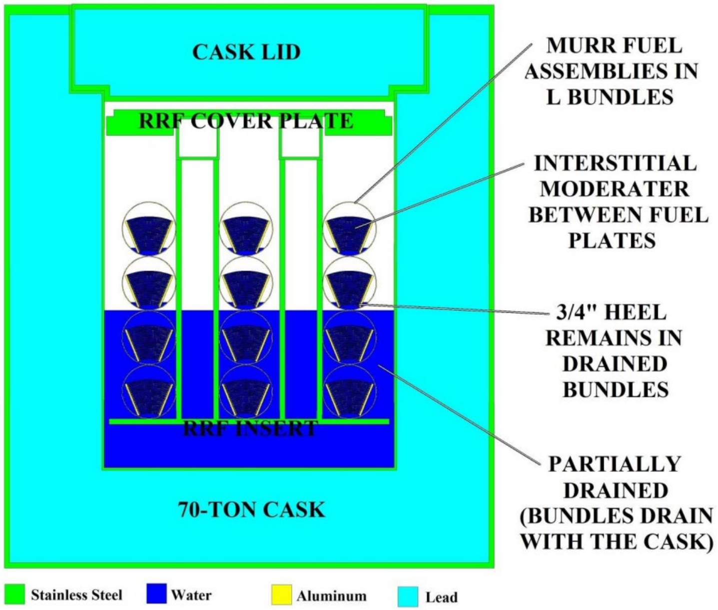
Ex. EBWR, SOT, CVTR, SPRO, SMT, etc.



HWCTR Intact Oxide Tube

Driver for New Reference Fuel

- The cask loading limits developed for aluminum clad fuels are not applicable to the NASNF slated for transfer to H Canyon during early ABD campaigns. Unlike underwater storage, conditions during the loading and transferring of an onsite cask are dynamic. Conditions associated with transfers may result in configurations sensitive to characteristics of NASNF not captured by current MTR reference fuels.
- The need to develop a new reference fuel with neutronic properties comparable to the NASNF inventory in L basin was identified to support the authorization of the ABD NASNF disposition path.
- The process and results of creating a new fictional homogenous NASNF reference fuel, “MITZ”, to support NCSEs for upcoming SNF disposition operations are discussed herein.



New Reference Fuel Methodology

- Primary goal: create a new reference fuel which bounds the characteristics of the L Area NASNF inventory
- Secondary goal: new reference fuel is more reactive than all early ABD fuels slated for transfer but less reactive than current MTR reference fuels (maximum use cases)
- Performed scoping calculations with existing fuels – couldn't find an existing fuel type with common NASNF attributes that was within the target reactivity range
- Used homogeneous mixture of previously evaluated HEU MTR plate fuel and equivalently substituted assembly materials
- Tweaked H/U ratio while preserving assembly cross section to achieve desired fuel attributes and reactivity behavior trends

MITZ

- **New fictional homogenized reference fuel, “MITZ”**
- **Initially based on homogenized MIT fuel with modified composition to resemble NASNF inventory:**
  - Non-Aluminum (Zr “cladding”)
  - UO2 fuel meat
  - H/U5 ratio = ~95

	MITZ	MIT
Length x width [cm]	7 x 7	6.11 x 6.11
Height [cm]	56.83**	66.68
Cross Sectional Area [cm^2]	49	37.3321
Assembly Volume [cm^3]	2784.7	2489.3
Enrichment [wt.%]	93.5	93.5
235U Mass [g]	527.3	510
Total U Mass [g]	564	549
Fuel Meat Matrix	UO_2	UAlx-Al
Structural Material (Side Plates and Cladding)	Zr	Al
Zr or Al Mass [g]	5227.81	8250
H/ U^{235}	94.828	~75

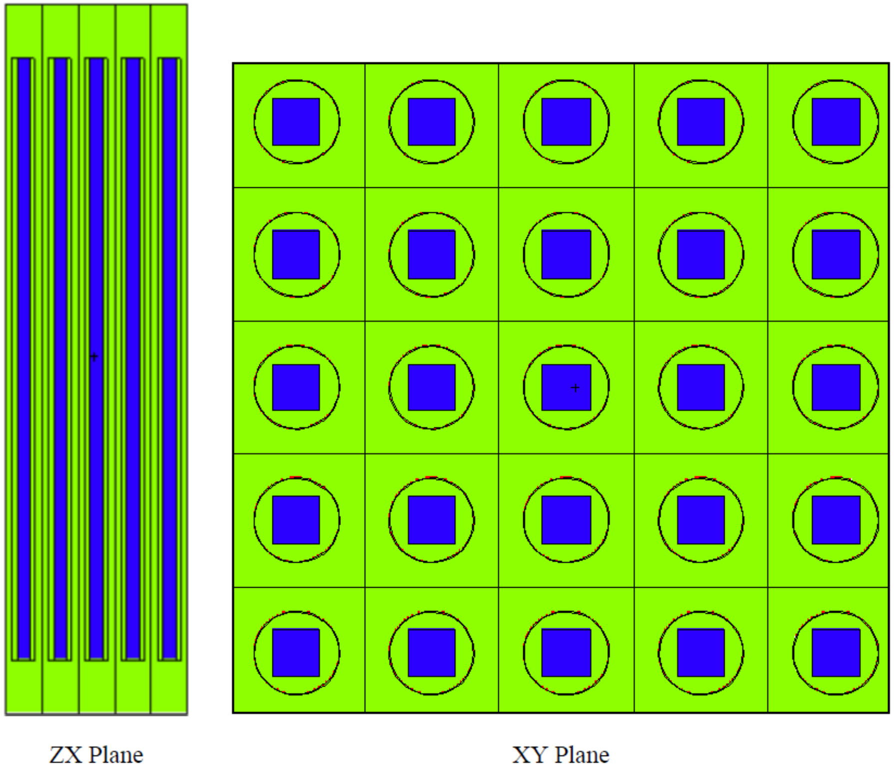


Figure 5–1 Infinite Planar Array of MITZ in an EBS Bundle at 20.0 cm Lattice Pitch (in VisEd)

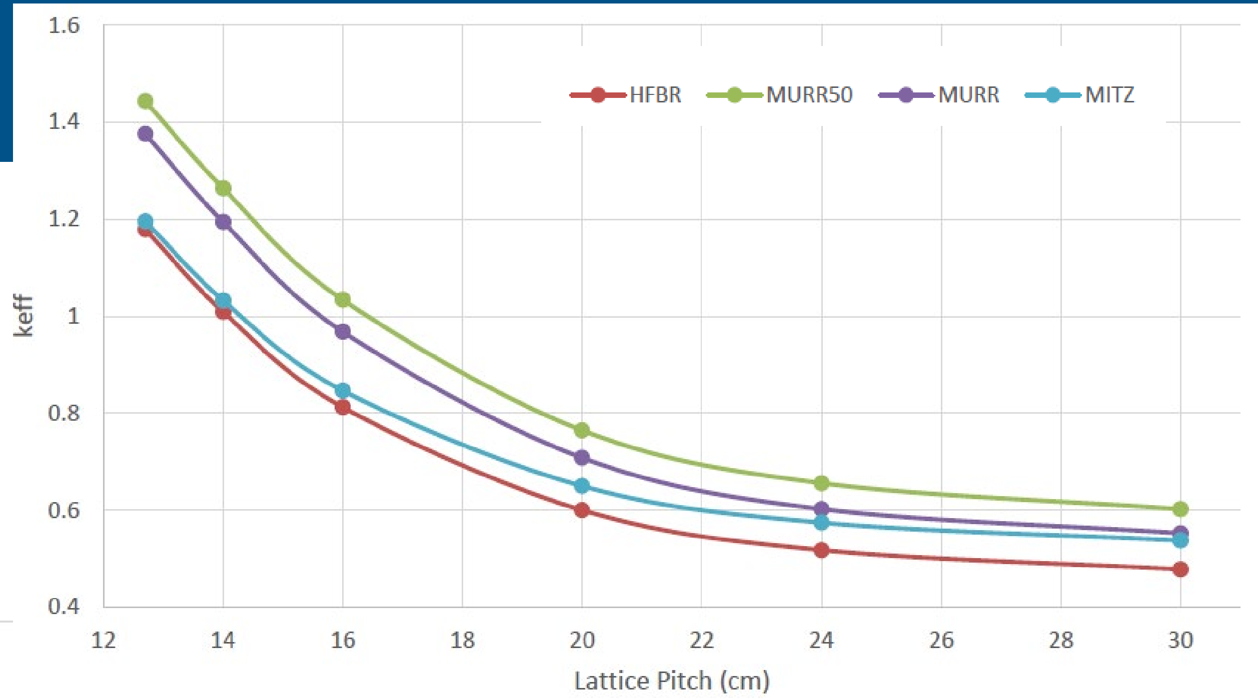
Reference Fuel Specifications

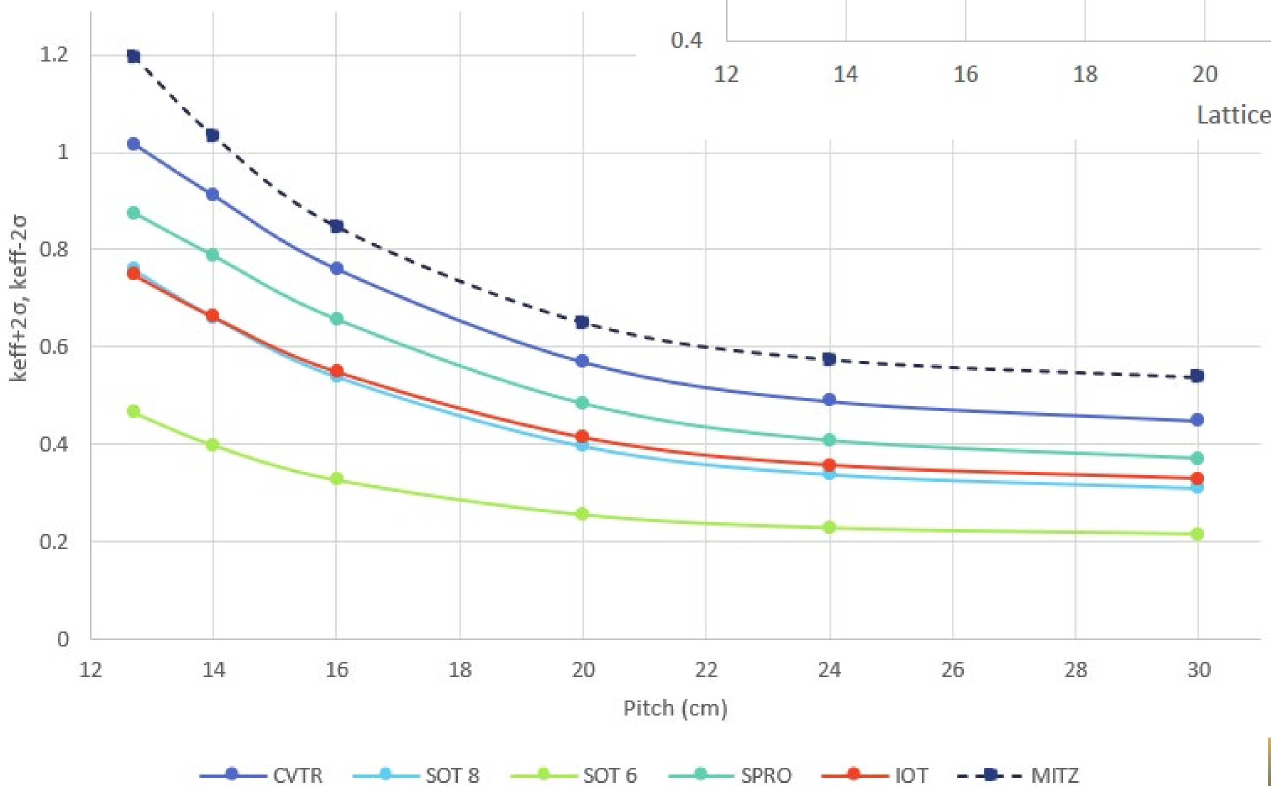
Parameter		HFBR [3]	MURR [4]	MURR-50 [5]
Nuclide Densities [$10^{-6} \times$ atoms / barn-cm]	^{1}H	38366	36388	38718
	^{16}O	19944	18194	19359
	^{27}Al	24599	25591	24642
	^{235}U	265.36	480.20	774.36
	^{238}U	18.214	32.635	53.153
	Total	83193	80685	83547
$H/^{235}U$		145	76	50
Fuel Meat Matrix // Cladding		$U\text{-}Al_x$ // Al	$U\text{-}Al_x$ // Al	$U\text{-}Al_x$ // Al
Homogeneous Assembly Shape		square	cylinder	cylinder
Assembly Size [cm]		side = 7.6516	r = 4.6557	r = 4.6575

Parameter		MITZ
Nuclide Densities [$10^{-6} \times$ atoms / barn-cm]	^{1}H	46010.44
	^{16}O	24042.22
	^{90}Zr	6376.37
	^{91}Zr	1390.53
	^{92}Zr	2125.45
	^{94}Zr	2153.96
	^{96}Zr	347.02
	^{235}U	485.20
	^{238}U	33.30
	Total	82964.49
$H/^{235}U$		94.83
Fuel Meat Matrix // Cladding		UO_2 // Zr
Homogeneous Assembly Shape		square
Assembly Size [cm]		side = 7.0

Reactivity Comparison

MITZ vs MTR Reference Fuels
(MURR, MURR-50, HFBR)





MITZ vs NASNF Fuels
(CVTR, EBWR, etc.)

Reference Fuel Results

HFBR				
Pitch	k_{eff}	σ	$k_{eff} - 2\sigma$	$k_{eff} + 2\sigma$
12.7	1.17921	0.00011	1.17899	1.17943
14	1.00944	0.00012	1.00920	1.00968
16	0.81278	0.00013	0.81252	0.81304
20	0.60049	0.00013	0.60023	0.60075
24	0.51817	0.00013	0.51791	0.51843
30	0.47849	0.00013	0.47823	0.47875

MITZ				
Pitch	k_{eff}	σ	$k_{eff} - 2\sigma$	$k_{eff} + 2\sigma$
12.7	1.19570	0.00012	1.19546	1.19594
14	1.03288	0.00013	1.03262	1.03314
16	0.84690	0.00014	0.84662	0.84718
20	0.65024	0.00014	0.64996	0.65052
24	0.57457	0.00014	0.57429	0.57485
30	0.53802	0.00014	0.53774	0.53830

MURR				
Pitch	k_{eff}	σ	$k_{eff} - 2\sigma$	$k_{eff} + 2\sigma$
12.7	1.37612	0.00011	1.37590	1.37634
14	1.19487	0.00013	1.19461	1.19513
16	0.96836	0.00014	0.96808	0.96864
20	0.70845	0.00014	0.70817	0.70873
24	0.60268	0.00014	0.60240	0.60296
30	0.55289	0.00014	0.55261	0.55317

MURR-50				
Pitch	k_{eff}	σ	$k_{eff} - 2\sigma$	$k_{eff} + 2\sigma$
12.7	1.44355	0.00011	1.44333	1.44377
14	1.26430	0.00013	1.26404	1.26456
16	1.03412	0.00014	1.03384	1.03440
20	0.76506	0.00014	0.76478	0.76534
24	0.65622	0.00015	0.65592	0.65652
30	0.60261	0.00014	0.60233	0.60289

MITZ Applications

- **One NCSE performed for MITZ: established criticality safety limits and controls for MITZ shipping in a 70-Ton Cask**
- **Additional NCSE modeled multiple candidate fuels and performed reactivity comparison to MITZ**
  - Approved 70-Ton Cask shipping for CVTR, EBWR, SOT, IOT, SPRO fuel
  - Limited inventory of each type: evaluation allows these fuel types to be processed and shipped together interchangeably
  - Repeat this method for NASNF candidate fuels as needed
- **Current evaluations only consider fuel stored in the 5-inch round aluminum bundle: MITZ NCSE can be revised to include other bundle types as needed**
  - Initial calculation note evaluated MITZ in several bundle types and noted consistent reactivity behavior
  - Initial calculation note included test mixture of MITZ with representative impurities known to exist in some NASNF fuels to demonstrate mixture conservatism

Questions?