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Task 3 Desired Stakeholder Outcomes

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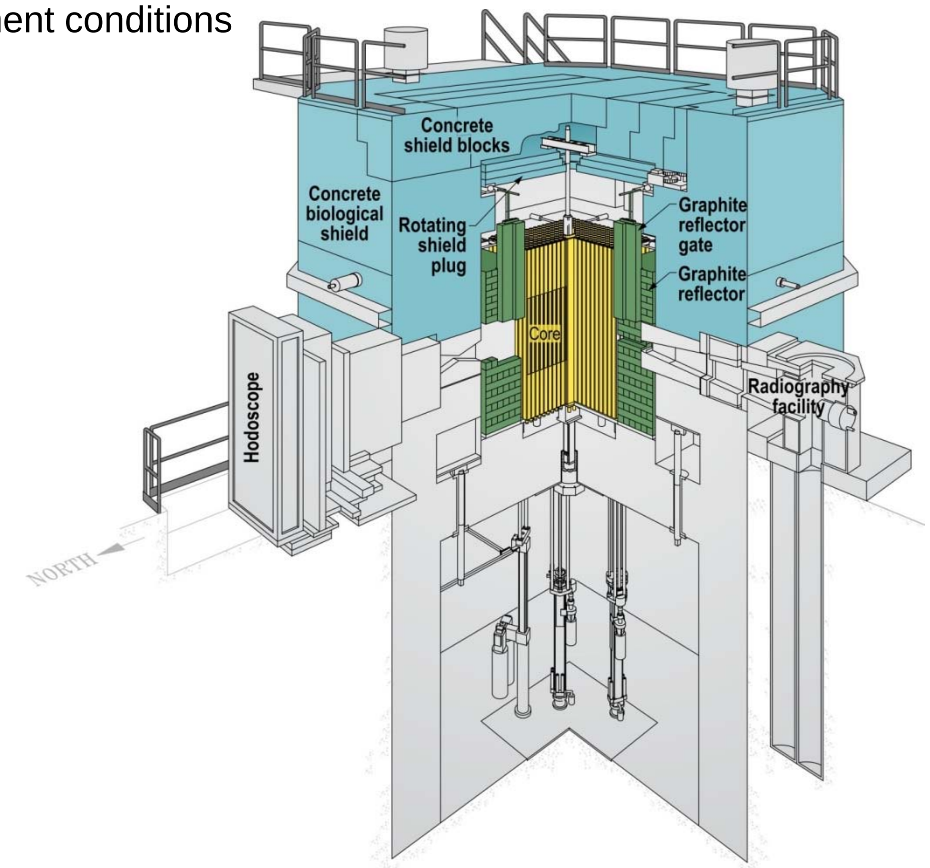
Instrumentation Overview

- **Three general levels of core instrumentation:**
  - Reactor control and operation
  - Additional reactor physics characterization – Validate reactor physics models
  - Experiment focused - Near or within the experiment vessel to provide experiment environment conditions



Historical Power Measurement

- **Reactor Power**
  - Core temperature rise measurements (delay => integrated power only)
  - Linear power ion chambers – integrated power output, maximum values
  - Log power chambers – initial and ending power levels, general transient characteristics
  - Fission counters
  - Flux wires and foils

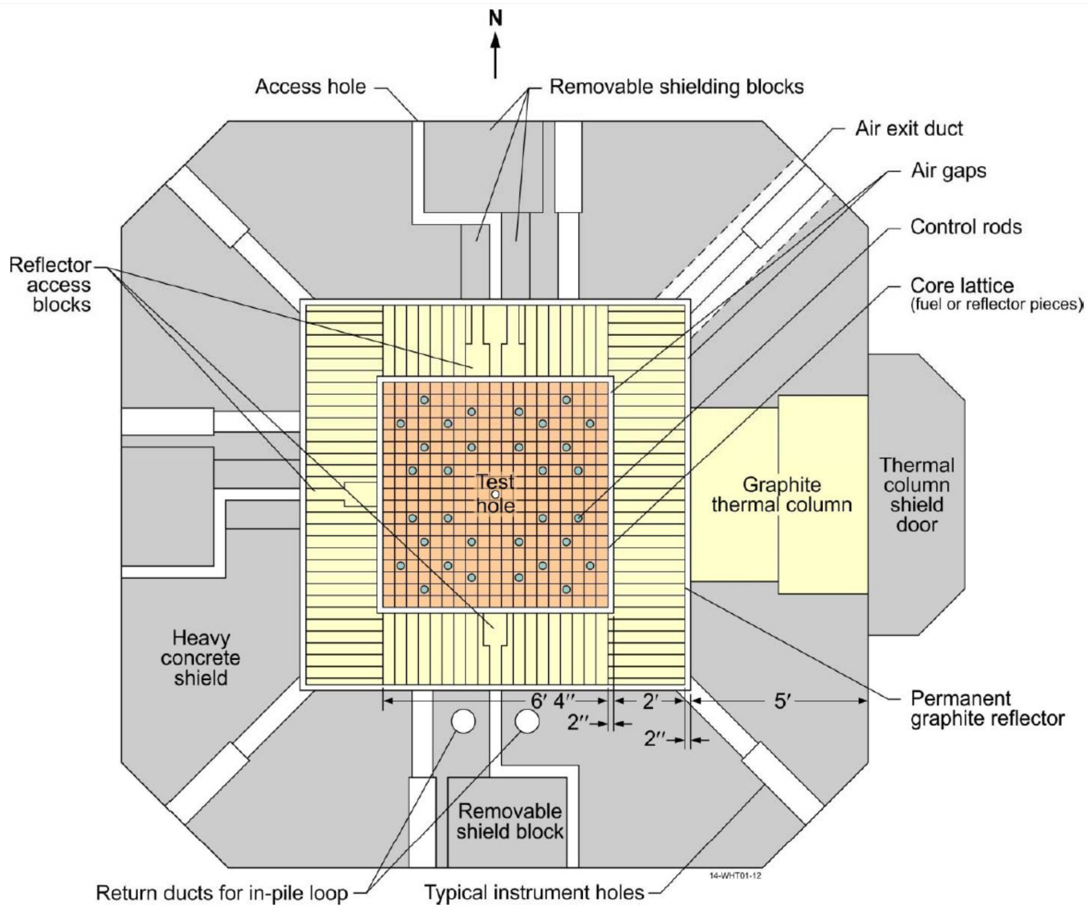
	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P	R	S	T	U
1	0.014	0.023	0.699	0.701	0.707	0.708	0.703	0.697	0.698	0.007	0.697	0.694	0.697	0.696	0.689	0.681	0.689	0.023	0.014
2	0.024	0.724	0.718	0.725	0.724	0.713	0.691	0.671	0.701	0.009	0.700	0.670	0.688	0.708	0.719	0.721	0.720	0.736	0.024
3	0.759	0.755	0.778	0.792	0.774	0.734	0.713	0.540	0.736	0.011	0.737	0.540	0.713	0.735	0.776	0.798	0.788	0.776	0.793
4	0.800	0.817	0.859	0.884	0.850	0.620	0.815	0.828	0.841	0.012	0.843	0.832	0.819	0.624	0.858	0.896	0.878	0.846	0.847
5	0.868	0.896	0.952	0.993	0.997	0.976	0.993	0.992	0.955	0.013	0.957	0.997	1.000	0.986	1.009	1.009	0.974	0.927	0.916
6	0.944	0.975	1.043	0.818	1.142	1.158	1.153	1.120	1.044	0.014	1.045	1.124	1.162	1.170	1.157	0.832	1.066	1.006	0.984
7	1.009	1.047	1.125	1.201	1.259	1.282	1.268	1.210	1.098	0.016	1.101	1.216	1.277	1.296	1.276	1.222	1.148	1.075	1.045
8	1.063	1.106	0.886	1.285	1.351	1.015	1.349	1.268	1.109	0.018	1.112	1.274	1.359	1.025	1.368	1.306	0.904	1.134	1.096
9	1.104	1.153	1.249	1.350	1.420	1.443	1.413	1.302	1.067	0.012	1.070	1.309	1.424	1.459	1.439	1.373	1.274	1.179	1.132
10	1.127	1.181	1.284	1.389	1.465	1.494	1.465	1.347	1.066	mS	1.068	1.354	1.477	1.511	1.485	1.413	1.309	1.206	1.154
11	1.130	1.184	1.285	1.395	1.477	1.513	1.503	1.421	1.218	0.059	1.221	1.428	1.515	1.530	1.496	1.417	1.310	1.207	1.156
12	1.115	1.163	0.937	1.369	1.455	1.111	1.518	1.489	1.416	1.368	1.421	1.497	1.530	1.122	1.473	1.390	0.953	1.187	1.140
13	1.084	1.129	1.220	1.316	1.400	1.457	1.492	1.503	1.493	1.487	1.499	1.512	1.506	1.474	1.419	1.337	1.242	1.153	1.110
14	1.039	1.077	1.157	0.917	1.303	1.358	1.406	1.443	1.463	1.472	1.468	1.451	1.419	1.375	1.322	0.934	1.180	1.101	1.064
15	0.983	1.009	1.077	1.136	1.161	1.171	1.242	1.308	1.352	1.371	1.356	1.317	1.254	1.188	1.181	1.159	1.102	1.035	1.008
16	0.923	0.936	0.987	1.027	1.005	0.755	1.036	1.104	1.181	1.220	1.186	1.112	1.048	0.767	1.027	1.052	1.012	0.961	0.948
17	0.876	0.871	0.900	0.927	0.924	0.902	0.907	0.712	1.009	1.068	1.014	0.718	0.920	0.921	0.949	0.956	0.928	0.899	0.903
18	0.027	0.835	0.832	0.848	0.864	0.874	0.873	0.877	0.932	0.966	0.939	0.887	0.890	0.898	0.896	0.883	0.866	0.868	0.028
19	0.016	0.026	0.804	0.808	0.834	0.860	0.880	0.900	0.922	0.934	0.928	0.913	0.903	0.893	0.879	0.860	0.850	0.027	0.017

0	Minimum
0.153	10%
0.306	20%
0.459	30%
0.612	40%
0.765	50%
0.918	60%
1.071	70%
1.224	80%
1.377	90%
1.530	Maximum

Peak-to-Average Power per TREAT Assembly

Historical Core Instrumentation

- **Nuclear Measurements**
  - Ion chambers – ~13 located around the core mid-plane in biological shielding
  - Compensated and uncompensated
  - Combination of linear translation and electronic gain to provide ideal detector/measurement ranges
- **Flux wires and foils**



Historical Core Instrumentation (continued)

- **Thermal Measurements**
  - Thermocouple instrumented fuel assemblies and coolant inlets and outlets

	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P	R	S	T	U
01	ZRD	ZRD	108	398	283	324	247	319	408	H01	289	140	356	271	178	366	313 *	ZRD	SRC
02	ZRD	169 *	305	391	128	393	294	213	236	H02	224	285	115	383	358	367	196	198	ZRD
03	522 A2	147	221	384	303	244	203	702 CS	217	H03	186	728 CS	164	142	161	342	246	286 **	287
04	194	298	382	314	389	701 CS	145	183	257	H04	207	165	291	718 CS	127	405	353	284	360
05	348	388	171	295	360	175	249	138	179	H05	173	344	302	117	120	148	182	312	399
06	155	369	226	700 T	230	228	231	241	296	H06	214	118	341	256	297	712 T	263	381	262
07	396	152	211	222	317	216	280	136	149 **	H07	197	269	277	215	156	242	253	177	349
08	328	141	726 T	258	121	722 C	160	321	114	H08	343	336 **	170	723 C	264	172	705 T	407	329
09	248	167	254	332	377	412	206	204	281	H21	378	229	309	279	403	300	157	116	272
10	347	133	113	112	359	290	210	527 A2	166	M-2 CAL	322	531 A2	523 A2	529 A2	259	106	310	306	414
11	395	129	239	331	190	163	316	502 A1	371	HZD	126	500 A1	372	282	202	252	135	245	386
12	392	397	729 T	278	262	716 C	243	530 A2	185	153	209	525 A2	304	721 C	192	292	714 T	413	355
13	102	311	123	238	323	250	330	526 A2	158	521 A2	233	503 A1	416	417	265	237	246	288	299
14	318	232	240	771 T	184	154	159	137	501 A1	528 A2	122	104	101	109	334	713 T	357	273	333
15	387	168	401	132	187	119	144	327	201	520 A2	223	370	199	227	208	220	320	143 *	162
16	351	415	406	364	111	717 CS	189	255	174	301	110	200	293	720 CS	100	394	236	124	139
17	107	361	379	363	103	146	180	724 CS	195	130	150	703 CS	188	225	380	228	266	131	375
18	ZRD	385	308	365	205	402	151	181	307	212	352	218	125	390	404	374	235	368	ZRD
19	ZRD	ZRD	191	409	315	337	134	373	339	251	335 *	354	176	345	400	234	325 **	ZRD	ZRD

M8 Cal Half-Slotted Core Map

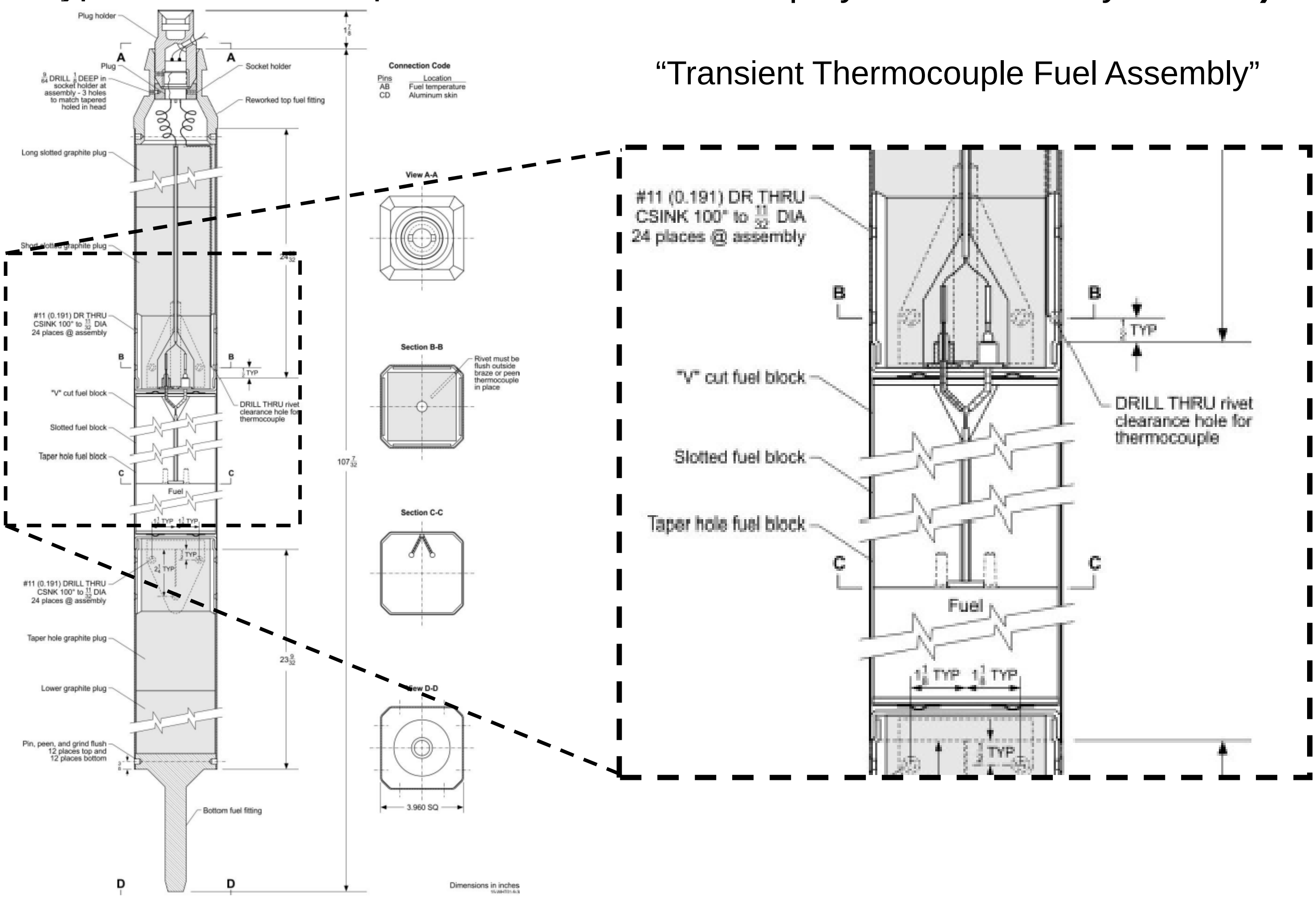
Fuel Assemblies
100, 200, 300, 400 Series = Standard Fuel Assembly (37.5g U235)
500 Series = Thermocouple Fuel Assembly (37.0g U235)
A1 = Type A Thermocouple (42 inches from top of Zr can)
A2 = Type A Thermocouple (24 inches from top of Zr can)
700 Series = Control Rod Fuel Assembly (26.0g U235)
C = Compensation/Shutdown Rod
CS = Control/Shutdown Rod Pair
T = Transient Rod Pair

Special Assemblies
H-Series = Access Hole Assemblies for Hodoscope (Center 4 feet of fuel replaced with Zr struts to provide 2.75" x 48" viewing hole) (0g U235)
ZRD = Zircalloy Dummy
SRC = AmBe Source Assembly (Zr Dummy)
HZD = Access Hole Zr Dummy Assembly for Hodoscope

Oxidation Measurements:
* = 1975 Measurement
** = 1983 Measurement

Historical Core Instrumentation (continued)

- **Instrumented fuel element (**five types of thermocouples assembly designs incorporating three types of thermocouple installations were employed – 2 currently allowed**)**



"Transient Thermocouple Fuel Assembly"

Physics Testing for TREAT Restart

Planned physics testing:

- Initial critical position
- Calibration of steady-state nuclear instrument chambers at 50 W
- Correlation of startup to steady-state nuclear instrument chambers at 50 W
- Calibration of transient nuclear instrument chambers at 50 kW
- Thermal heat balance at 50 kW
- Control rod reactivity measurements

Additional desired testing:

- Large core reactor transfer function measurement
- Isothermal temperature coefficient verification
- Axial and radial thermal and fast flux mapping of large core
- Measurement of temperature-limited transient thermal feedback

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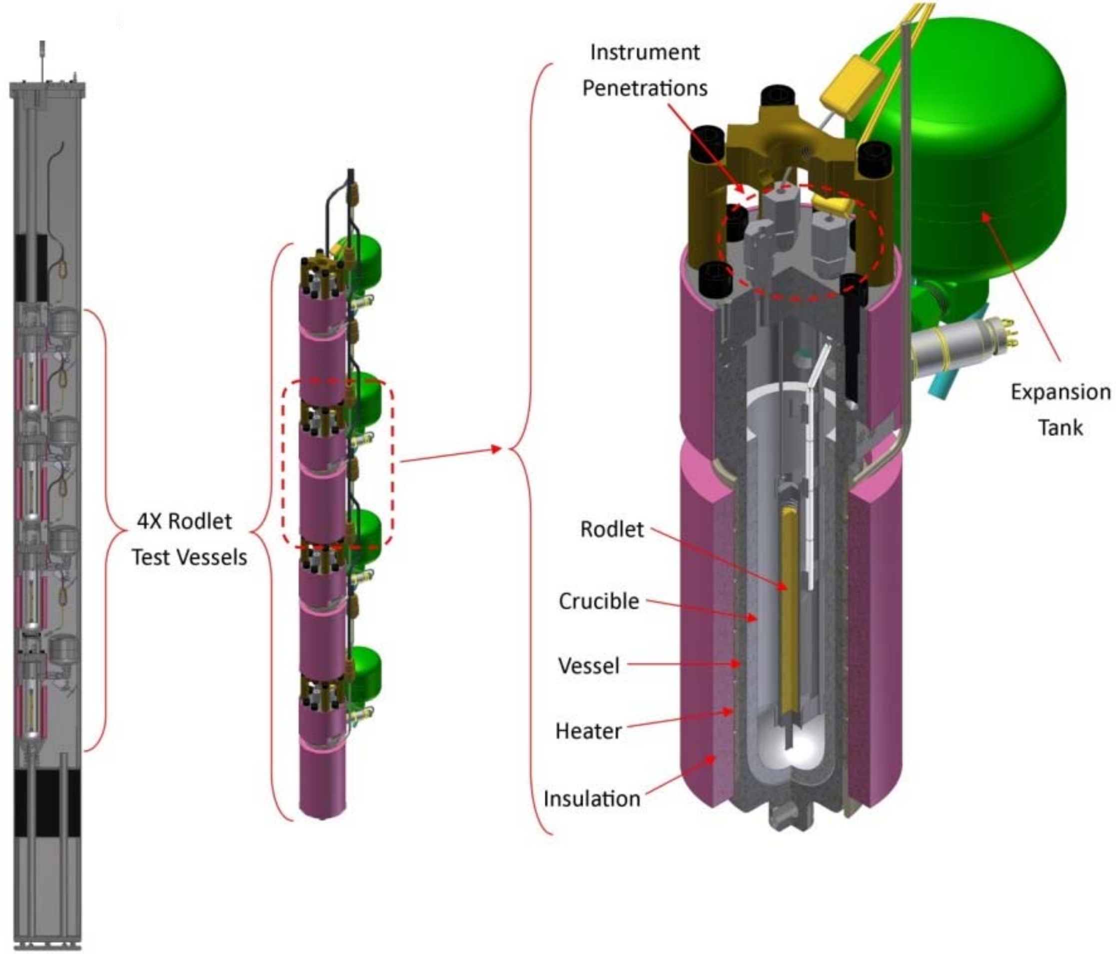
Planned Experiment Instrumentation



Primary Science
Fuel Rodlet Temperature
Enviroment Pressure
Enviroment Temperature
Vessel Temperature
Fuel Location/Movement
Totel Energy Deposition
Secondary Science
Cladding Expansion (radial, elongation)
Void Fraction
Cladding and/or Pellet Failure

Planned Experiment Instrumentation (continued)

- **Multi-SERTTA Instrumentation**
  - Thermocouples (sheathed and exposed tip) – vessel, environment, specimen
  - Fiber-based IR Pyrometer - specimen
  - Void detector - environment
  - Pressure transducer – vessel and expansion tank
  - Acoustic sensor – vessel
  - MPFD – in vessel
- **Next Experiment Vehicles (Super SERTTA, TWERL)**
  - LVDT – specimen internal pressure, cladding elongation, specimen elongation, flow meter
  - Turbine flow meters
  - Ultrasonics
- **Calibration vehicle/testing crucial for specimen power prediction**

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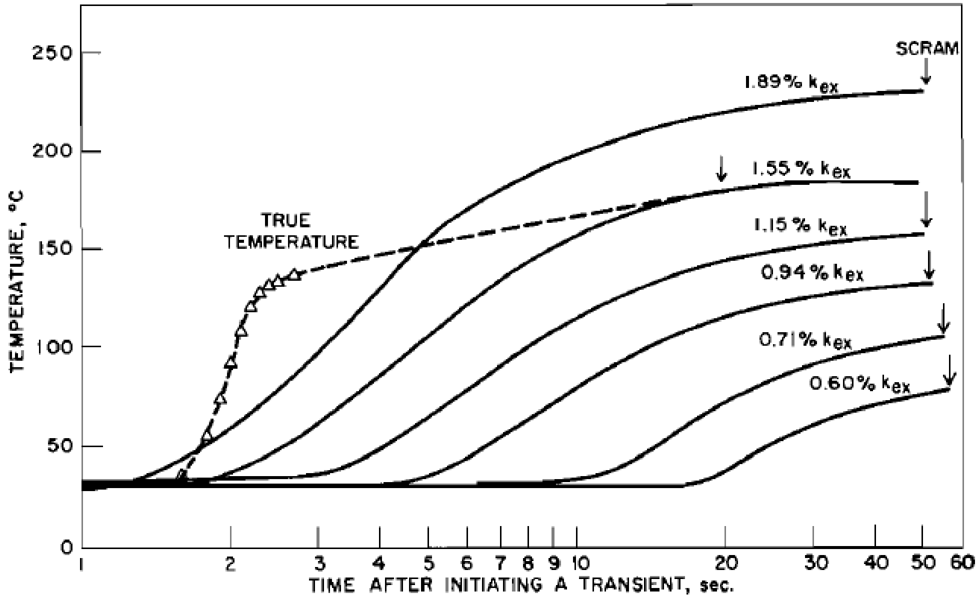
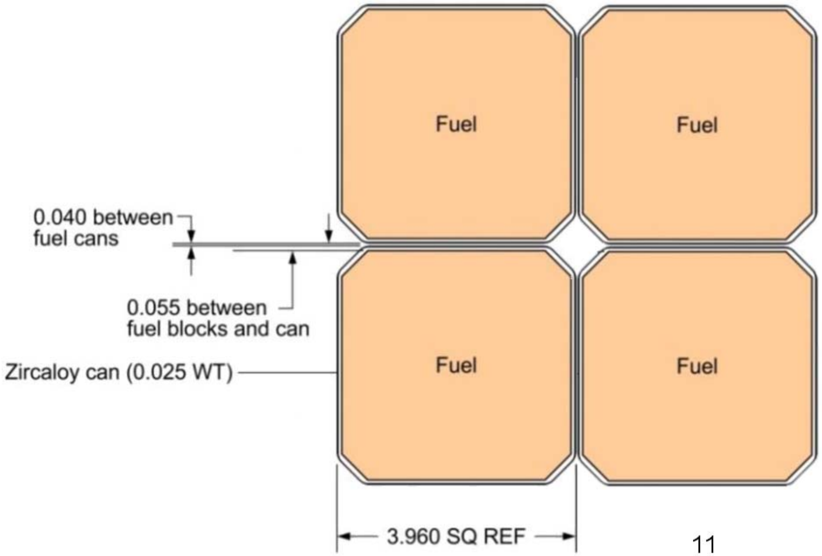
Needs to consider

- **Understanding of historical approaches including instrumentation strategy, selection, data interpretation, and modeling input**
- **Modern modeling validation data**
  - Never modeled to the level of detail currently underway
- **Transient characteristics of neutron flux magnitude, spectrum, and spatial distribution**
- **Transient thermal characterization – not known to have been done (~0.9 ms time delay from fuel particles to graphite, thermocouple delay ~ *below*)**
- **Open to good ideas…**



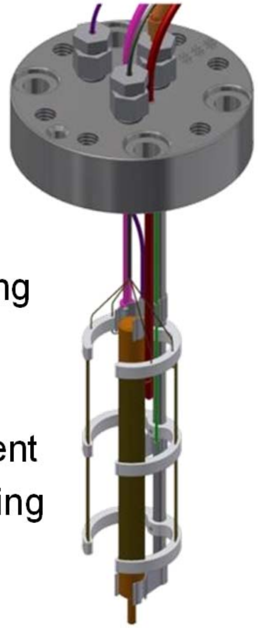
Instrument constraints and opportunities

- **In-core instrumentation (within the reflector)**
  - Additions or changes in core likely require some level of experiment safety analysis
  - Neutronic insignificance will simplify (small instruments, neutron transparent materials)
  - Variety of options for wiring, facilitated by “flexible wires” (fragile fibers difficult)
  - Provision needed to assure location and avoid dropping into the core
  - Gamma heating very high during big pulses, volumetric fission heating is enormous if sensor includes fissile material
  - Neutron damage nearly negligible
  - Some thermal heating should be expected (max fuel surface temp 575°C), polymers probably not the best choice
  - Gamma background rather low, except when close to pre-irradiated experiment specimens
  - Depending on instrument material and fluence, they could become radioactive enough to require shielded handling (storage, disposal)
  - Response time (and data capture time) very important during transients
- **Coolant channels at fuel assembly corners**
  - 0.625” square channels, seem like an obvious option for in-core instruments
  - Must be designed to avoid scratching fuel assemblies

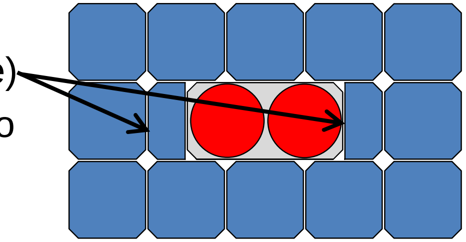


Instrument constraints and opportunities (continued)

- **In the fuel assemblies**
  - Existing driver fuel has a variety of thermocouple location designs
  - Outfitting (modifying) existing fuel assemblies probably a very difficult option to execute
- **In the experiment vehicle (e.g. SERTTA, TWERL, etc)**
  - Arguably the most difficult (and desirable) location for instruments
  - Must fit within the assumptions of a sizeable experiment safety package
  - Severely limited on space, wire routing difficult, must be workable in hot cell handling
  - Likely one time use instruments
  - Hermetic penetration for anything passing through the secondary containment
  - High-pressure/temperature penetration for anything passing into primary containment
  - Must negotiate for space with the main customer for the experiment (although nothing prohibits an instrument program can't be the owners of a dedicated experiment)
  - No shortage of "interested parties" already



- **Near to the experiment**
  - The 2" X 4" half dummy assembly is non-fueled (zircaloy and graphite)
  - Could be redesigned and fabricated rather easily (compared to fuel) to house instruments
  - Very close to the experiment but not subject to the same constraints



Instrument constraints and opportunities (continued)

- **Ex-core instrumentation (beyond the reflector)**
  - Very thermalized spectrum (unless slotted configuration like hodoscope)
  - Flux far reduced compared to in-core (signal to noise)
  - Cold positions (very little gamma heat and radiant heat from fuel)
  - Cannot displace instruments currently needed for plant operation
- **DAS**
  - TREAT currently expanding plant DAS***, could include some expandability for users
- **Quality Assurance**
  - Expect a little bit of “hassle” for things like instrument material traceability and test planning (INL team can help)

Known Complementary Efforts and Potential Resources

- **MOOSE TREAT modeling team**
- **TREAT restart team**
- **TREAT experiments team – developing and testing suite of experiment instrumentation (e.g. MPFD, pyrometer, boiling detector, thermocouples, pressure transducers…)**
- **FY14 NEUP IRP (UW) – Advanced Instrumentation for Transient Reactor Testing (advanced imaging systems, MPFD, optical fiber temperature sensor, diamond-diode temperature sensor)**
- **FY15 NEUP NEAMS (KSU) – A Transient Reactor Physics Experiment with High Fidelity 3-D Flux Measurements for Verification and Validation (MPFD)**

Task 3 Desired Outcomes

- **Identify gaps - what instruments are available now vs the past, what modeling needs exist that can be addressed, etc.**
- **Data for modeling benchmarks vs data for experiment coupling factors**
- **Focus on planning, testing, implementation, and interpretation of instrumentation for modeling and experiment needs (UW IRP has developmental role)**
  - Integrate with other complementary efforts
  - Uncertainty analysis
- **Encourage instrumentation (and other) testing in TREAT**
  - Possible opportunities in restart schedule
- **Possibilities for improved thermal measurements for characterizing core power**
- **Ultimately – the purpose of the core (and experiment vehicle) is to provide the experiment with the desired test environment**