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Comment Response for the Draft Combined TREAT-LOC & SATS Integral LOCA Experiment Plan

September 2022

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ABSTRACT

This document provides a detailed description of comments and responses, to the Advanced Fuel Campaign (AFC) loss-of-coolant accident (LOCA) experiment plan draft document shared in April 2022. Comments were provided from reviewers from U.S. nuclear fuel vendors, the Electric Power Research Institute (EPRI), the U.S. Nuclear Regulatory Commission (NRC), and the U.S. Department of Energy (DOE) all provided comments after solicitation. All comments have been carefully considered and responded to accordingly. Editorial and clarification comments are excluded from this writeup, but all have been addressed directly in the text of the revised plan document.

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ACRONYMS

AFC	Advanced Fuels Campaign
AGR	Advanced Gas Reactor
ANL	Argonne National Laboratory
ATF	Accident Tolerant Fuel
ATR	Advanced Test Reactor
BNGS	Byron Nuclear Generating Station
BWR	boiling water reactor
CEA	French Alternative Energies and Atomic Energy Commission
CRAFT	Collaborative Research on Advanced Fuel Technologies
DEH	decay energy heating
DOE	Department of Energy
ECR	equivalent cladding reacted
EOL	end of life
EPRI	Electric Power Research Institute
FFRD	Fuel Fragmentation Relocation Disperal
FGR	Fission Gas Release
FIDES	Framework for Irradiation Experiments
FOA	funding opportunity announcement
FOM	figure of merit
FPTTEG	Fuel Performance Testing Technical Expert Group
HBu	high burnup
HBS	high burnup structure
HERA	High Burnup Experiments on Reactivity Initiated Accidents
IB	intermediate break
INL	Idaho National Laboratory
JAEA	Japan Atomic Energy Agency
JEEP	Joint Experiment Programme
LB	large break
LED	light emitting diode
LHR	linear heat rate

LOCA	loss-of-coolant accident
LOC	loss of coolant
LWR	light water reactor
PCMI	pellet-cladding mechanical interaction
NEUP	Nuclear Energy University Program
NDMAS	Nuclear Data Management and Analysis System
NQA	national quality assurance
NRC	Nuclear Regulatory Commission
NSUF	Nuclear Science User Facility
ORNL	Oak Ridge National Laboratory
PCT	peak cladding temperature
PIE	post-irradiation examination
PWR	pressurized water reactor
QA	quality assurance
RCS	reactor coolant system
RIL	research information letter
RIP	rod internal pressure
SATS	Severe Accident Test Station
SB	small break
SCIP	Studsvik Cladding Integrity Project
SEH	stored energy heating
TC	thermocouple
tFGR	transient fission gas release
TREAT	Transient Reactor Test Facility
TRISO	tri-structural isotropic
TWIST	Transient Water Irradiation System for TREAT

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Comment Responses to "Comment Response for the Draft Combined TREAT-LOC & SATS Integral LOCA Experiment Plan

This document provides a detailed description of comments and responses to the Advanced Fuels Campaign (AFC) loss-of-coolant accident (LOCA) experiment plan draft document provided in April 2022. Reviewers included members U.S. fuel vendors, the Electric Power Research Institute (EPRI), the U.S. Nuclear Regulatory Commission (NRC), and the U.S. Department of Energy (DOE). All comments have been carefully considered and responded to accordingly. Editorial and clarification comments are excluded from this writeup but have been addressed directly in the text of the revised plan document. The source of each comment has been excluded from this document to provide anonymity to encourage open communication. Comments are included verbatim as provided, except only to modify where necessary to not reveal the source of a given comment.

The approach documented below has grouped comments by section where possible and combined comments by subject. The reader should refer to the acronym list in the front matter for text in the tables that follow.

1. Comments Regarding Overall Document

This may be a matter of semantics, but historically "integral" tests have been considered testing the combined irradiated clad and fuel pellets in the test sample, which has become commonplace in most laboratories. A distinction to consider today is that "integral" testing in this specific LOCA context involves the combination of in-pile LOCA tests of pre-irradiated fuel rodlets (e.g., TREAT, Halden Reactor (closed), MIR) and "semi-integral" testing involves out-of-pile LOCA tests of pre-irradiated fuel rodlets (e.g., ANL, Studsvik, ORNL-SATS, CEA, JAEA, etc.). Through this distinction, this test plan will best highlight the unique nature of this proposed research by leveraging both "integral" TREAT and "semi-integral" SATS along with the other separate-effects testing and characterization capabilities within AFC. We believe this will be critical to messaging these unique and highly complementary capabilities and technical leadership within the U.S. to further rally support of the U.S. Government.	We incorporated suggested change.
We understood the initial objective of the TREAT facility as compensation for the loss of Halden, expansion on SCIP knowledge, and a demonstration of hopefully more prototypical scenarios. Investigation into these areas would serve to demonstrate that the FFRD effect seen in SCIP and Halden is of lesser importance than current test results would indicate. We are concerned that the program as outlined in the test matrix shifts to a new technical focus (SEH) while	We understand the concern of testing new testing looking at SEH effects. It is important to highlight that the plan is intended to address both DEH conditions in addition to the SEH condition as described in the test matrix. A few clarifications were added in the text to better highlight this including a better description of SEH and DEH. Also, as the plan describes, it was developed starting from extensive evaluation of conditions important for FFRD and understanding the existing experimental database. The test plan will fill an existing gap related to prototypic conditions by

not providing the overwhelming value of TREAT to the major problem.	including SEH conditions, which are best suited to be studied with fuel internal heat generation (in-pile). TREAT is uniquely suited to do this while furnace testing will help keep the program grounded to the existing database..
What is meant by the term “fuel conditioning”?	This phrase was deleted.
Overall, I think this is a pretty good plan. I am glad that we are developing LOCA capabilities using advanced instrumentation and post-irradiation examination techniques, and I am particularly intrigued by the prospect of using the hodoscope to track fuel relocation during the transient. TREAT’s ability to provide novel power transients also offers the possibility to study the impact of rapid heatup rates characteristic of the stored energy heatup phase of a large-break LOCA. Finally, the ability to directly compare furnace tests to in-pile tests may help address the prototypicality of previous furnace tests at Studsvik, ANL, and ORNL.	No response needed.
A concern that it is not clear what problem it is attempting to solve. The test plan likely accomplishes part of objective 6, “Provide expanded LOCA datasets for model development and code validation on relevant HBu fuel material near important burnup thresholds”, in that it attempts to address the impact of things like heatup rate, axial gas communication, etc., on FFRD behavior. Certainly, these tests can help with model development. But what will such models be used to do? This depends on licensing strategy, and unfortunately, it is difficult to determine whether the test matrix is appropriate without some discussion of how it will address licensing issues. For example, the emphasis on stored energy heatup in the test matrix may be appropriate to address FFRD during a large break LOCA. But if the industry chooses to pursue a risk-informed approach to do away with FFRD in LBLOCA then it would be more appropriate to further study conditions that would be more characteristic of a medium or small break LOCA. Perhaps the tie-in to licensing is the purview of the General Guidance and Analysis Technical Evaluation Group, rather than the Fuel Performance and Testing TEG, but the two groups should be in alignment about what questions we are attempting to answer.	We agree that specific licensing strategies are not the purview of this plan. The high-level objectives listed in the introduction are technical in nature and have been developed based on identified gaps described in later sections and discussed in more detail the context of the test plan in Section 6. The plan does not address specific licensing strategies as they remain largely proprietary to prospective licensees. These inputs have been collected via extensive literature review, interaction with stakeholders, and development of capabilities consistent with current R&D needs. The plan should address the cross-cutting needs of stakeholders. The plan will be adapted as appropriate if an alternative licensing strategy, negates R&D need for FFRD during large break LOCA. Like this comment period, future review/revisions will allow for incorporation of potential missing items.
A concern is that the plan does not do much to address the impact of various dopants (e.g., chromia, gadolinia) on fragmentation behavior. We already have a fair	We agree that testing doped fuel is of high value and more tests may be desired to fully assess behavioral distinctions. The current strategy in the plan is due to

amount of data from Halden, SCIP, and the NRC-Studsvik LOCA programs on standard UO2. It may be more beneficial to study the impacts of dopants on fragmentation behavior than to simply gather more UO2 data. SCIP IV does have some tests on doped fuel, but it may be difficult to draw conclusions from these few data points (and of course the SCIP tests are performed in a hot cell).	the current unavailability of doped UO2 at relevant burnup but potential availability late in the described program/schedule. Testing ATF materials could be added to the plan if materials are available and fuel suppliers are willing to contribute to this DOE plan. The planned tests will add unique data/results/insights compared to the existing database on UO2, seen as a current priority.
It seems that the initial test series in TREAT are repetitive commissioning tests, some of which could be delayed or scheduled later to get more useful data once the impact of doped pellets with standard cladding can be demonstrated. Please consider the number of tests needed to really “shake-down” the LOC test rigs.	The test matrix has been developed with efficiency in mind. LOC-C is commissioning, and HBu-1 are “tieback” tests. We believe these represent minimum tests that should be done to have good confidence in the plan results.
A concern is that the plan does not necessarily address some of the gaps identified in the RIL. One of the biggest uncertainties is the burst opening size. A big burst opening can lead to significant dispersal, even if there is relatively little fine fragmentation. Thus, focusing the testing plan on better understanding the fragment size distribution does little good if there is still a large uncertainty in the burst opening size. Another significant uncertainty is the axial extent of the ballooning. Obtaining a better estimate of the strain needed for relocation does not do much good if we can’t predict the axial extent of the balloon. It will always be difficult to apply the results of balloon heights from 25-cm rods to the behavior of full-length rods, though perhaps the 50-cm specimen tests in TREAT can provide some information on this issue.	We agree that the plan does not highlight burst opening behavior as a primary target. Though, burst opening behavior will be an important data outcome from these tests. We think the data from these tests will best serve to complement existing and potential new data related to burst geometry obtained from out of pile experiments. As noted, the TREAT experiment design purposefully accommodates 50cm long fuel stacks to extend from existing furnace lengths of ~30cm and to “restore” length capability comparable at least to Halden IFA-650 experiments. Experiment designs are considering axial heating distribution carefully with an intent to provide more uniform heating conditions to the fuel length, expected to help better understanding prototypic heating impacts on balloon behavior.
Experimental test data will need to be generated using a stringent NQA-1 regime for both INL and ORNL activities, so a quality assurance plan should be developed. The AGR TRISO QA plan could serve as a basis for this test plan. Attention will need to be given to standardizing how characterization and PIE measurements should be made.	A section addressing data and associated QA has been added to the document in Section 8. In short, we agree testing will follow laboratory quality programs.
The results and experimental data will have to be evaluated statistically and available for future use, including NRC topical report submittals, for the generic results as well as the vendor-restricted results. The INL Nuclear Data Management and Analysis System (**NDMAS**) will need to be used to accumulate raw data, evaluate results, provide statistical data and to provide NQA-1 test information to one-to-one correspondence to summary figures, tables etc. The access to vendor proprietary data can be easily restricted using the NDMAS platform’s access	NDMAS has/is under consideration for data management. The final data management strategy(s) will ensure QA requirements are achieved.

procedures. It will be important to show how/when/where graphs' data points in ORNL and INL reports come from test data and will serve in future NRC licensing efforts. This test plan needs to explicitly state that NDMAS will be used for this program effort.	
It may be useful to appendix or even a separate report that gives the results of a literature review of fuel tests previously done vs what the new test plan can provide for high burnup fuel. The NRC RIL provides many references that could be used to show how the new TREAT and SATS tests will enhance our understanding. This may be a good exercise for a NEUP call or university collaboration.	This is a good suggestion. We believe several reviews (referenced in this plan) do a good job summarizing experiments and results that are publicly available. The test plan also provides key references and addresses direct connections to the existing database where appropriate. Some additional ties have been added in the detailed description of each test where appropriate.

2. Comments Regarding Sections 1, 2, & 3

Six different embrittlement mechanisms were identified in Section 1.4 of NUREG/6967, only 3 of which were previously understood. These findings underpin the 10 CFR 50.46c rulemaking.	No change made to document.
Figure 2 as currently presented is misleading. Stored energy only drives the initial heatup shortly after the break occurs; the cladding heatup during the remainder of the transient is primarily driven by decay heat. The difference in heat-up rate for a large-break LOCA transient post-blowdown versus a small-break LOCA transient is largely due to the timing of the core uncovery/cladding heat-up. Suggest modifying the figure appropriately.	The figure and section has been revised to better describe these conditions.
Referencing Figure 2: Not sure this properly illustrate the stored energy effect. Most of the excess stored energy are removed within 15 seconds when the average fuel temperature drops to ~575C for high burnup fuel. Further increase in temperature is due to decay heat. Decaying heat is largest at time zero rather than more than 100 seconds later. If I add up the two curves, it would not result in a stored energy peak typically reported in LOCA analyses	The figure and section has been revised to better describe these conditions.
Fig. 2 should be expanded to include evolution of temperatures for fuel pellet centerline and periphery to give a more complete picture of the combined impacts to pellet and clad	The figure and section has been revised to better describe these conditions.

"Some key aspects that are recently…" Please define what key aspects refers to (i.e., fragmentation? transient fission gas release? something else?).	The test is modified "Some key independent parameters and behaviors influencing FFRD that are recently…"
5th bullet: Is the differentiation pre-rupture versus post-rupture?	We added another bullet and modified for clarification.
Suggest adding a bullet relative to extent of axial cladding creep under a more prototypic axial temperature profile.	Bullet added noting axial temperature profile effects.
Information requests for pedigree information will likely require multiparty interfacing and agreements that are time consuming. Early identification of exact materials (rods and sections) for testing will be helpful. Resources required to gather data are significant.	Great point.
Details for ramp rates, temperature profiles, and test boundary conditions will need to be developed and will need to be matched for the TREAT test rigs and the SATS experiments. Since RCS thermal-hydraulic conditions during LOCAs and fuel phenomena depends on break sizes (small, intermediate, large break LOCA) a uniform and appropriate set of fluid conditions needs to be carefully evaluated to reflect accident conditions.	We agree. This work has been underway for some time and is a central focus of this plan. Final design details will be developed through formal design processes for the in-pile tests and will be developed with connection to the SATS. This plan provides primary targets and is oriented towards large break conditions as noted throughout. Other conditions could be considered.
The sentence on p. 1: "Measure key behavioral phenomena in-situ (cladding deformation, transient fission gas release (tFGR), fuel relocation and dispersal, cladding balloon surface temperature) to reduce…" needs to include burst dynamics in the parenthetical list. The bullet needs to include how these phenomena will be measured.	Added "burst dynamics" as suggested. Details on specific measurement strategies are provided in a later section.
P. 2. "While important considerations for LOCA evaluation, these phenomena are not the primary R&D issues for HBu fuel in LOCA addressed in this document." Why not? The NRC's FOM will need to be measured (17% cladding reaction, 1204 C) during these tests.	This point was written to highlight a focus on FFRD driving distinct testing targets. Data regarding PCT and ECR will be available from these tests. Tests could also be designed to evaluate these limits more specifically as noted in Section 6.1.
Another bullet is needed or amplify the 4th bullet on p. 5 to include balloon growth, burst expansion size growth and cladding hope stress and strain change during the LOCA as temperatures increase, and after the initial rod burst occurs.	A change was made as suggested.

I am not sure what conditions you refer to and if key elements vary widely how can we hope to develop useful tests. What reactor design are you assuming in your modeling and how representative of the PWR LWR fleet?	We revised this section for increased clarity and the requested additional information.
Referencing Figure 2 and related discussion: Why not show the corresponding calculations on fuel pellet response then? It is important to highlight how both clad and fuel centerline temperatures rise in either SEH and DEH scenarios to provide the bases for what is proposed in the test matrix. How are these ramp rates variable as the LOCA progresses and fuel clad leads or lags early on with the effect of fission- versus furnace-induced heating techniques. The SEH will likely be most sensitive to this effect early (<10s) whereas DEH will be less sensitive after relatively longer times (>100s). The next couple of sentences touch on clad deformation and rupture behavior, as well as tFGR, and how they all are affected by T ramp rate and the effect of T gradients (magnitude and “direction”) so do we know enough these effects to isolate them in the test matrix?	We updated the Figure 2 and the associated text to provide more details including more info on fuel temperatures. Regarding ramp rate/temperature gradient effects on performance phenomena, the test matrix is designed to provide explicit contrast with specific phenomena. For example, companion tests between TREAT and SATS provide a direct comparison that should be very helpful in distinguishing impacts. Some of the test variants will provide contrasting effects specific phenomena. Other examples for contrasting unique phenomena include purposeful differences rod length/plenum size/pressure (tFGR, balloon/burst) and heating profiles (balloon/burst) between TREAT and SATS as shown in the test matrix.
SCIP also investigating axial gas communication so this should be mentioned and coordinated with; also other effects are being investigated within SCIP	We don’t mention SCIP though we know they are doing something. Like you say they are working on several if not all of the bullets listed. We also address SCIP and the desire to collaborate in Section 2.

3. Comments Regarding Section 4

TREAT and TWIST device • Since no qualification tests were performed with the TWIST capsule in TREAT for now, it is rather difficult to evaluate the real capacities and limitation of the testing device. At this stage is therefore difficult to provide accurate feedback on the proposed testing conditions of the test matrix. • Provide more details on the capabilities of TWIST and TREAT– hard to comment on the test matrix without those. More details on the capabilities of TWIST and TREAT will enable more accurate comments on your test matrix. This may be best done later in the following qualification tests to know more realistic capabilities. The detailed testing conditions (e.g., inner pressure, free volume, rod length, initial power) should be discussed in the future in a step-by-step approach, taking benefits from knowledge acquired thanks to	• Experiment boundary conditions are known and can be provided for simulating conditions needed. INL can provide modeling results for desired information. • Specific parameters can be provided where needed. The test matrix provides nominal targets, but those can be adjusted where desired. TWIST device specifications are provided in Section 4. We agree the best approach to understand details will be through initial testing. However, we also point to the proposal in Section 10 for independent modeling of the system by stakeholders. We believe this would be an effective manner to obtain detailed understanding. • Specimen free volume can be adjusted as needed. References [20&21] also show the impacts of free volume, highlighting the impact described here.

the first tests and in other experimental programs, like SCIP. • Specimen length in TWIST is small compared to the free volume. Why is INL focused on 25cm long specimens? Is it possible to reduce the free volume? SCIP shows large free volume has a negative impact on fuel fragmentation (seems to increase the depressurization effect at cladding burst on FFRD). TWIST free volume is similar to Halden test but 25cm specimen is smaller (Halden were ~40 to 60cm). A systematic use of 50cm specimens would be recommended. TEST #1 is a comparison with Halden test, therefore a longer specimen would be required. • Are the companion SATS and TREAT tests identical for each test? These seems to be overly duplicative when so few tests can be performed withing cost and schedule. • Include tests for the investigation of inner pressure effects. • Need to know the temperature behavior of the test device (plenum, axial gradient, etc.). This is required to carry out modelling.	The free volume was selected to be consistent with the full length PWR rod, which we found to be 10-15cm from various reports. This volume is consistent with the IFA-650 tests and maybe slightly greater than SCIP tests. The size of the plenum in a subscale test could be selected in a variety of manners. It is difficult for us to justify a smaller volume for baseline testing while models for axial gas communication remain highly uncertain. We welcome an alternative recommended volume if a technical justification can be provided. The test matrix also includes tests with varied plenum size to evaluate this effect in these systems, and to add to the evaluations done elsewhere. Specimen length is selected as 25cm to target segments coming from between grid spacers. Longer length specimens are planned for later use but should come from a span without grid spacer or otherwise should include a grid spacer in the test design. The latter option is possible but not currently the nominal plan in the test matrix. • The companion TREAT/SATS tests are not identical from a heating perspective (in-pile vs out-of-pile) and (SEH vs DEH). This distinction is a crucial component of the strategy highlighted throughout the plan. Also the test matrix has been revised some to also alleviate this concern. • Inner pressure effects can be added to the matrix as another variable. The revised test matrix includes tests to explore different failure thresholds (#4-6), which are planned to be based on pressure variation. • All required boundary conditions will be provided in Appendix A (or as requested if missing there).
We would like to have more details about real-time monitoring in Figure 6 • Measuring FGR from the quartz tube (per the drawing) will only provide information after burst. We need information on FGR before burst as it could impact the ballooning + burst behavior. Is this possible with the pressure line connected to the rod? Pressure will be measured in the plenum, not at the burst location but pressure could vary locally.	The descriptions have been updated throughout. The pressure will be measured online and could be used to estimate the amount of fission gas released. However, it will not be possible to fission gas prior to burst unless a test segment gas volume is evacuated and measured at specific points during an experiment. Applicable to any LOCA test, no method is known for measuring pressure locally in a fuel segment. Plenum measurements are likely the best that can ever be done on integral fuel segments.

Have you assessed the maximum radial thermal gradient in SATS tests with the highest heating rate that can be achieved? Important to know this.	Assessments have been and will be made to achieve the goals of the plan.
Is there any constraint on plenum free volumes in TREAT/TWIST testing facility? Can we design any plenum size or are we limited to 15 cc and 5 cc ?	Plenum size can be adjusted within reason (accounting for practical fit up of components (space between cladding and fuel and fuel and rod endcaps). The values of 5 cc and 15 cc were selected based on testing done to date elsewhere and prototypic PWR rod free volume. There is likely a minimum size that can be accommodated due to practical limitations of putting the hardware together, some gaps are necessary between components. A minimum value has not been defined yet but is likely approximately a couple cc. A maximum size has also not been defined but could be relatively large.
Has the cladding heating rate in TREAT/TWIST DEH conditions been assessed?	Yes, the cladding heating rate has been shown to be controllable and able to match a variety of prototypic conditions used for reference. These heating rates vary over the transient but reach up to 100 K/s down to ~few K/s. This is illustrated in Figure 2 and the TREAT device is designed to match the full range of conditions of potential interest.
What is the range of initial rod linear power that can be achieved in TREAT LOCA tests?	TREAT is well suited to control fuel LHR over a wide range, spanning four orders of magnitude. In the TWIST configuration, the primary limitation for maximum power in the initial, full-power segment 1, portion of the LOCA test described in Figure 8, is limited mostly by programmatic thermal-hydraulic limits. We do not want to exceed DNB during this phase (but easily could if desired). The device is also designed to operate in a gas phase only condition, and could drive heating well beyond any reasonable level.
We fully support the proposed upgrades to the SATS facility described in this section. These updates will differentiate the capability of SATS relative to other existing facilities, and provide the capability to address certain questions within the existing experimental database. In order to achieve these benefits, the capability must generally be present for in-cell testing (not restricted to out-of-cell testing only).	We agree. In-cell capabilities are described in this document and some upgrades are in the works to be available for this plan. Updated information (such as exact testing conditions) will be provided when the information becomes available.
It is noted several places within the document that an upgrade is planned to SATS to allow for in-situ cladding deformation monitoring. Consider adding a paragraph to	Cladding deformation measurements will be measured continuously until burst occurrence using a non-contact laser device or LED device. The tests can either be tested under constant temperature and pressure conditions or under simulated LOCA conditions. Posttest measurements will also be performed at

discuss this capability similar to the other cited upgrades.	different axial locations, including at the burst opening, to supplement the in-situ measurements.
It would be preferable to end the re-irradiation with a reactor scram to capture fuel microstructure (bubble size and distribution). This can be lost in the normal shutdown after re-irradiation. How is this proposed to be done in ATR re-irradiation? What will be the shutdown protocol of the ATR irradiation positions? See previous comment re: importance of capturing ‘at-power’ fuel microstructure in re-irradiation of the test segment.	These proposed tests have been removed from the current test plan window and added to Section 6.1. The details of the referenced plan for re-irradiation are not described in this document. A separate work description has been developed under the NSUF project. However, the specific conditions for that work are still actively under development so the exact protocol for power control can be influenced.
Are the rodlets used in some (SATS) tests partially hollow? How does that compare to the initial conditions of the “cladding ballooning and burst” event?	The fuel tested in SATS have been standard PWR fuel pellets that do not include an annulus. However, tests can be performed on annular fuel provide material availability and value to the industry. Removing material by hollowing out or using annular fuel would increase the gas volume of the system. The increase in gas volume is expected to reduce the volume change ratio (delta V/initial V) thereby decreasing the burst temperature. This has been seen in analysis and closed valve vs open valve pressure test.
Are the heating rates shown (in Figure 3) consistent with the numbers in the Table? They don’t seem to be. Is current SATS limited to 25°C/s but TREAT can go as high as 100°C/s? Improved SATS may go even higher like 60°C. Please clarify on what is to be done or could this change as we learn from earlier test(s).	Figure 3 is updated to match with the table. SATS is currently limited to ~17 K/s while the upgraded SATS is expected to reach a heating rate between 45-60 K/s. This information will be updated once the system is tested. As noted in Figure 7, TREAT has great control over heating rate with practical heating rates of ~1 K/s to more than 10000 K/s. The rate of 100 K/s is referenced for TREAT as it has been found to be representative of the maximum seen during plant LB LOCA simulations. In reality, the ramp rate varies during a blowdown and is being simulated by the TREAT design. Near constant heating ramps are also possible in TREAT and planned in Tests #1 and #3.
Clad temperatures? If yes, what is the profile for fuel centerline and periphery temperatures? Have fuel temperatures been measured in SATS with an internal T/C, and will it be measured in the future LOC test matrix?	Yes, cladding temperatures. Analysis have been performed and will be performed for fuel temperature profiles in SATS. Internal temperatures have not been measured in SATS and would require removing fuel to insert a thermocouple. LOC-C commissioning tests will include centerline thermocouples. LOC-HBu tests are not currently planned to include centerline TCs, focus is on rod plenum pressure, but capabilities are

	under development now to allow this as an option on HBu segments.
Neutron power leads thermal power, I.e., the heat flow to the cladding is delayed by a small, but consequential amount. This affects how the blowdown and heat up ramps are placed relative to each other. Is that effect factored in?	Yes, heat input and blowdown can be controlled independently, and specific respective timing is considered in the design.
How was the quench temperature determined? If analytically, have they been cross checked with alternative analyses? LOCA phases vary among reactor designs, core design and operating conditions. Are the tests taking these variabilities into consideration?	The current proposed tests do not include a quench phase. The SATS system has this capability. The TREAT design does not currently include this capability, but it could be added with minor design change if desired. This second question is also addressed in other comments and throughout the plan. The plan focuses currently on PWR LB LOCA conditions. Relevant LOCA conditions were requested from fuel vendors and provided at their discretion. The DOE laboratories have also studied several cases. The plan is a result of those findings as pertains most directly on FFRD.

4. Comments Regarding Sections 5 & 6

As stated in the experiment plan description, up to now, the integral tests on HBU fuel rods were performed in DEH type conditions. Several gaps remain to understand FFRD in those conditions. We believe that AFC work should first aim at closing these gaps, rather than opening questions related to new testing conditions. Companion tests in SATS for all TREAT LOCA tests is likely not necessary. However, SATS tests are valuable to investigate the impact of nuclear heating on FFRD conditions and to evaluate the representativity of the out-of-pile tests. Once the impact of the nuclear heating has been clearly identified, the test matrix should be assessed to establish if SATS, TREAT or both are needed. The goal would be a more efficient utilization of the dual facilities.	This comment is largely addressed earlier. We agree with the need to continue to study DEH conditions. Tests #1 and a newly added #3 are both DEH tests in both facilities that should address nuclear vs furnace questions. We also believe that the impacts SEH conditions are a crucial gap in the database when considering prototypic conditions. This contrast can/will provide unique understanding of the DEH experiments performed to date. We agree a strict rule of companion testing is not necessary. The prescription of SATS tests has been changed to ensure more focus on DEH conditions throughout the matrix. A second TREAT test under DEH conditions has also been added. The test matrix is quite deliberate in the described strategy to ensure clear connectivity with the existing database that is exclusively in the DEH regime. The companion tests are, in part, with the objective of mitigating the previous concern about SEH testing and new capabilities coming in TWIST.
I am a bit skeptical of the heavy emphasis on the stored energy heatup phase of the LOCA. It makes sense to do one test (LOC-2 / SATS-2) under the rapid heatup	This comment is addressed in the previous and earlier comments. Additional information regarding future plan revision has been added to the document. As new

conditions to see how that impacts fuel behavior, but I'm not sure it's worth addressing in the other tests. I would note that while the Halden and SCIP tests have all been performed using slower heatup rates, some transient fission gas release and fuel fragmentation tests have been conducted at very high heating rates. Turnbull's tests come to mind, and his model is used to describe fragmentation in transients with slower heatup rates. I understand that these are separate effects tests performed on fuel disks, and the integral behavior of a fuel rod segment may be very different than the fuel disk behavior. However, I think it's worth reconsidering the focus on SEH conditions in the remaining tests (which the plan acknowledges is a possibility based on the results of LOC-2).	information is learned the plan will be adapted as needed with CRAFT concurrence. For example, if SEH conditions are found inconsequential then the heating prescription will be adapted as needed. More discussion on this point follows later.
Regarding test matrix and priorities: 1. We agree that the focus of the TREAT testing should be on the initial stored energy-driven cladding heatup since the cladding heatup rate and fuel temperature behavior during this period cannot be replicated via furnace testing. However, consideration should be given to a test in which the fuel rod survives the initial stored-energy driven heatup and then ruptures later. 2. Should a tie back to one of the Studsvik LOCA tests be considered, or is the tie back to a Halden IFA-650 test sufficient? *3.* We agree with the intent of the LOC/SATS HBu-3 & 4 tests, but notes that care must be taken in the rod selection. An adjacent metallography sample of the rod section to be tested, prior to refabrication, should be provided to ensure suitability for tests. *4.* We agree that experimentation regarding axial gas communication (tests LOC/SAT-HBu-5 & 6) is important but ranks the importance of this below some of the other proposed tests.	1. The test matrix has been updated to reflect this consideration especially by Tests #4-6. 2. IFA 650.15 had a sister segment testing in SCIP. Therefore, establishing experimental ties between four major test facilities is a goal of test #1. More tests could obviously be done with more coordination with SCIP and will be attempted in later tests to the extent possible. 3. We agree. Though, considering all feedback and current timelines these tests have been pushed back to the "potential" testing section, beyond the three-year program defined in the test plan. 4. The updated test matrix should better reflect received input on priority.
SCIP showed that the whole rod power history is important, not just the EOL power effect. According to SCIP III conclusions, the EOL power is not a sufficient criterion to determine the degree of fine fragmentation in high burnup fuel. The general objective of these tests should be the investigation of the link between power history, fuel microstructure and propensity to fuel fine fragmentation. • It is recognized that this investigation is a significant challenge, but the identified mechanism and challenge should be specified. At this stage, it would perhaps be best to identify the tests in the	As noted elsewhere, these tests have been moved to the future potential testing section, beyond the 3-year program defined by the test matrix. Overall, we agree with these comments as it is a complex issue to study. We also have limited knowledge of SCIP results to date. The principal investigators (NRC and EPRI) for the reirradiation project are familiar with the SCIP results and as addressed earlier, exact specifications for that reirradiation are not included in the scope of this plan and remain yet to be defined.

matrix as steps in a process to achieve the objective, then clarify how the matrix it is intended to work towards the goal. o .. and maybe clarify how you will communicate changes to the text matrix may change as we learn more about TREAT and collect data. • The number of tests within this program would not "solve it". We suggest strong coordination with other programs such as SCIP, for complimentary testing and examinations. Also, advanced modeling will be needed to complement the testing program.	• We agree with this concern. One change made in the document is to call it "pre-accident" vs "EOL" to make even clearer that the experiment is to address this specific condition. o Test plan changes are now addressed in Section 11. • We agree.
We are not providing extensive comments on the matrix. Without qualification tests to know the real capacities and limitations of TREAT, it is somewhat challenging to provide accurate feedback. We propose a step-by-step approach. The detailed testing conditions should be discussed in the future in a step-by-step approach taking benefits from knowledge acquired from the first tests and in other experimental programs, like SCIP.	This comment is addressed in Section 4 above and by additional information about planned review and revision to the test plan in Section 11.
From other experimental programs, it appears that plenum size and pressure have a significant impact on FFRD. SCIP-4 will have a strong focus on this topic. AFC work scope will need to follow those tests, and AFC may need to investigate these effects, especially in-pile conditions.	We agree. The test plan intends to address this for specific conditions to complement existing results.
Test matrix is highly focused on the new scenario: SEH, • Significant concerns about the being able to simulate SEH conditions, for example external pressure, highly variable coolant conditions • Significant concern about non-prototypical test conditions magnifying the fragmentation DEH still remains a large concern which would benefit from the advanced testing, additional understanding, and potential to demonstrate enhanced realism to minimize fragmentation. • TREAT is the only facility with nuclear heating. Nuclear heating produces representative radial thermal gradient, not reached with external heating. Therefore, the first critical step is to compare nuclear (TREAT) to non-nuclear heating (SCIP) experiment data.	• These comments are addressed earlier. The test design intends to ensure prototypically for fuel boundary conditions. Though likely imperfect, a documented plan with review/analysis/input from stakeholders will ensure this end. A significant experimental effort is underway to fully characterize the thermal hydraulic boundary conditions in the TREAT device using out-of-pile system mockups and a fresh fuel commissioning test series. • See previous bullet. An overarching goal of this plan is to evaluate relevant prototypical conditions. Similar comment addressed earlier. • Addressed earlier. Tieback testing is a goal of test #1 and test #3 and more, if better coordination with SCIP becomes possible as expected. Also, the companion testing of SATS and TREAT is an additional means

• The AFC scope of work should primarily build on SCIP knowledge before focuses on a new area	achieve this goal, with adjustments of the test matrix to better reflect DEH conditions • The SCIP relationship has been addressed in several other responses.
The benchmark on Halden IFA – 650.10/15 test is a good idea, since it will act as a suitable benchmark to SCIP OOP device. If AFC results are consistent, one could say the method is validated. If not, additional tests will be required. However, it is the 1st time a re-irradiation is proposed for a LOCA test, for which the impact unknown. There are many new features along with the inherent variability in the SCIP and Halden programs, and the phenomena in general. Thus, a single matching test may not be enough to convince the NRC that test protocols and databases are comparable. Consider adding a second benchmark with one of the tests that SCIP performed that also was very insightful to a desired mechanism of your choosing. For example, we were recently challenged by NRC that test results from a more realistic, multi-rod test (QUENCH facility) were “not credible” because the results were “too good”, especially compared to the larger database of “bad results” from a single-rod test facility.	Good comment. The test matrix has been updated to reinforce the goals stated here. Future test plan revisions and associated process are addressed by several other comments. IFA650-15 also had a sister segment tested under SCIP now specified more clearly in Section 6. A direct connection between the four facilities (Halden, SCIP, SATS, TREAT) is intended though results may indicate additional needs. Additional ties to SCIP tests are also desired as possible as DOE works towards increased collaboration with SCIP. The potential also exists to test an additional segment, currently at Studsvik, and from the same parent rod as IFA 650.15 and the SCIP test. This would need to be done in collaboration with Studsvik and working out shipping arrangements. A strategy for material exchange with Studsvik is under active discussion but availability is likely delayed a little from the initiation of this test program.
Test Matrix and SCIP III conclusions: EOL power has impact on FFRD, but the impact of power history is more relevant (microstructure changes). • Need to investigation of the link between power history, fuel microstructure and propensity to fuel fine fragmentation. • Detailed characterizations on fuel before test to understand the possible differences in behavior during the tests. • Large challenge, not achievable in this program alone. Larger coordination with testing facilities (e.g., SCIP) for complementary tests and examinations, advanced modeling, and even other labs/research/thesis may be highly valuable.	Good comments. See other responses regarding pre-transient power effects.
LOC-3 and LOC-4 are interesting in that they may shed some light on the impact of end-of-life power on fuel microstructure and its link to fragmentation behavior. However, there are a lot of practical difficulties with these tests. As the plan acknowledges, these tests require either receipt of rods with both high and low end-of-life power directly from a commercial plant, or reirradiation of rods in ATR. The former option is impractical since it requires vendors/licensees to provide two separate rods with very similar burnup but different end-of-life powers. The latter option is	This subject is addressed by other responses. We believe a commercial source may be viable for similar rods with similar burnup but very different power history. However, we are also concerned about uncertainty in power history from a commercial plant. Reirradiation provides opportunity for precise control and lower uncertainty.

perhaps more feasible but still complicated due to the additional reirradiation period. Based on these difficulties, it may be better to focus on other proposed tests in the plan	
Small-break / intermediate break LOCA scenarios would be valuable to understand full accident space scenario, globally these break scenarios are still challenging, and it would be valuable to conclusively demonstrate no FFRD. Considerations for standard BWR material should reflect industry need.	We agree. The section about potential future test objectives was reinforced in the plan, separated into a separate section, with specific mention of SB/IB LOCA consideration along with BWR. We welcome industry input on relevant LOCA scenarios for these conditions.
We agree with the proposed sample lengths. The shorter lengths correspond to approximately a grid span and allow for 1-to-1 comparison between TREAT and SATS. The longer lengths will provide insight into axial ballooning behavior since the axial power distribution in TREAT better represents a LOCA condition than has been previously achieved in furnace testing. Consideration should also be given to imposing a constraint representative of a spacer grid at approximately the same rod elevation at which a grid was present for the longer samples.	Good feedback on specimen lengths. Our plan is to incorporate a “grid spacer” constraint and manage local heating effects accordingly in segments that included a grid spacer on the parent rod in its base irradiation. Incorporation of a grid spacer into the experiment would still need design to ensure proper boundary conditions to the test rodlet. Longer lengths without grid spacer could potentially also be harvested and used.
We note that some of the proposed conditions are approximate or yet to be defined. This is expected as the results from prior tests supplemented by modeling and simulation can help inform the test conditions for future tests over time. We recommend that the Fuel Performance and Testing Technical Experts Group (FPT TEG) remain involved and continue to have future opportunities to review and comment as the experiment plan evolves.	Discussion was added to Section 11to discuss future changes to the plan and involvement of the FPTTEG.
The proposed burnups appear reasonable to us given currently available data. If fine fragmentation is observed during test LOC-1, then consideration should be given to a comparable test at lower burnup.	Lower burnup contingency is possible and included in the section on potential future test objectives.
Use of a single proposed peak temperature eliminates this as a degree of freedom across the different tests and is viewed as appropriate by us. We are also in agreement with the peak temperature proposed.	Good feedback.
We suggest targeting a higher rod internal pressure for a subset of the tests than currently proposed.	Rod internal pressure can be altered as needed up to ~20 MPa cold and will need to be specified via more detailed analysis and testing to define the temperature in the plenum region of the capsule. Tests 3-6 now reflect conditions that will include variation of pressure

	under a representative range. However, pressure specification has been removed from the test matrix in the final version to reflect this need.
If LOC/SATS-HBU-9 eventually becomes a reality, spacer grid(s) should be included at elevation(s) previously pinned by grids. The inclusion of grid(s) enables gathering of unique and important data relative to that which would be produced as part of the other experiments described in this document.	Good feedback. A bundle test has been moved to future potential testing, Section 6.1, beyond the 3-year test program described here. The TREAT experiment is capable of a small bundle test, considered a more complex configuration requiring some unique design adaptations and heating considerations.
Assumption of a shipment of Byron Nuclear Generating Station (BNGS) fuel in winter 2022/2023 is aggressive.	The plan has been updated to the most likely scenario based on current information.
Studsvik rods may be uniquely suited to address several of these tests. Suggest Idaho National Laboratory (INL) begin engaging with FPT TEG members on available rods from this resource.	We agree.
With the anticipated 2-3 tests per year schedule at TREAT and SATS (Figure 11) it will be important to get vendor supplied irradiated samples early enough for their preparations for testing specimens, and to prioritize the testing schedule, high burnup fuel rod selection and preparation, etc.	We agree.
I’m not sure how useful LOC-7 will be. It is true that there is little data available at such high burnups, but there would be very little fuel at a pellet-average burnup of 85 GWd/MTU in a core with a peak rod average burnup of 75 GWd/MTU.	We think it is logical to include a test just beyond the target burnup limit, the goal of this proposed test, though clearly it is not a primary target of the overall plan. Other feedback also indicated this is reasonable.
Although the NRC RIL mentions some possible threshold effects, p. 16 of this plan indicates that testing at a lower burnup near 55 GWD/t but this burnup level is too low to produce meaningful results. Instead of wasting time and resources on such lower burnup levels, the test plan should only test fuel at 62 GWD/t using incremental burnup steps.	Testing lower burnup specimen(s) is not currently planned. However, it is included as an option to be considered in the future.
It will be important to make sure that we have “sister rods” i.e., similar fuel samples for burnup conditions, enrichment, temperature history etc. for both SATS and TREAT so that the testing results can be evaluated and compared properly. The use of sister samples is the tie between enhanced traditional out-of-pile furnace tests (SATS) to the proposed unique pulse reactor tests (TREAT). This test plan should address what variables	Additional description with specific variables has been added at the beginning of section 6.

(burnup, fluence, fuel type, etc.) will be used to choose what makes "sister" specimens	
Doped pellet specimens should be tested sooner in the testing schedule as shown in Table 3, since it is anticipated that the doped fuel may provide better resistance to fuel fragmentation. If no vendor supplied doped fuel materials are available, we should consider making some standardized coated and uncoated cladding samples, and some doped versus undoped samples as soon as possible. When these are available, they should be incorporated in the test plan as soon as possible, and not be relegated to the later LOC-8/SATS-8 as shown on Table 3.	This comment is addressed in other responses. The primary limitation is availability of relevant high burnup doped fuel test materials. If doped fuels become available, the test plan could be revised as has been described in additions to Section 11.
Vendor doped pellets will need to be irradiated sooner to address the specific problem of higher rod growth because the doped pellets' densification is reduced because of the doping. Testing will need to be done at SATS and TREAT to determine the impact of densification differences on LOCA behavior on fuel performance. Please see the Westinghouse ADOPT fuel submittal ML21351A256 where Section 5.4 describes the rod growth model developed for ADOPT pellets in AXIOM cladding, where the doped ADOPT fuel shows higher rod growth.	See the previous comment response.
While the test plan focuses on higher burnup fuel testing, there is seems to be no direct link with the ATF program for the novel coated Zircalloy and FeCrAl cladding. Please specifically show when ATF specimens either irradiated in the ATR or in commercial reactors will be tested in TREAT and SATS.	Other responses address doped/ATF fuel. Material availability is a primary issue for the 3-year plan shown here, in addition to navigating proprietary concerns on novel materials owned by fuel vendors. The plan can be revised to incorporate such materials if opportunity arises. Also, while we prefer to test such materials as part of this AFC program in a joint fashion with industry, we expect vendor-specific testing will continue in parallel as directed by individual interests.
Please consider how to show the proposed tests in Table 3 interface with the international SCIP testing program (previous tests and SCIP-IV). This could be added in suggested appendix for international capabilities, and with another matrix table that shows FFRD related variables such as impacts to FFRD from: clad stresses and strains, burnup, thermal conditions, fuel cracking, gas pore structure, etc.	See other related comments on the DOE SCIP relationship.
For the Table 3 SATS and TREAT high burnup fuel test matrix: Can the doped fuel tests be done earlier in the schedule to show whether the dopants can reduce the amount of fine particle produced vs. undoped fuel, and how the dopants provide higher strength pellets? If	See other comment responses on doped/ATF materials.

doping the pellets can reduce pellet fragment formation, we need to know this sooner	
To support model developments at all length scales improved collection of the power/temperature histories of particular commercial samples are needed. This is also important for the experimentalists performing the experiments on the specimens. An example is the North Anna fuel rods being characterized at Idaho National Laboratory (INL) as well as being transiently tested at the Severe Accident Test Station (SATS) at Oak Ridge National Laboratory (ORNL).	We agree material histories are crucial to make this plan a meaningful success and distinguish more from testing to date at other facilities. Though not described in the plan, efforts are underway to obtain this information, facilitated by stakeholders/FPTTEG members.
Has the relationship between reactor power pulse—> power input to the specimen (with fresh fuel), which in turn is expected to achieve temps stated in 5th column of Table 2 been estimated or modeled yet? Please clarify	Modeling has been and continues to be performed with predictions in hand. The commissioning test series in the TWIST device, LOC-C, has this measurement goal for validation of these models as one of its highest priorities.
Do the tests use LOCA simulations to estimate the most limiting fuel location so that they are captured? If analyses are used, are they cross checked between at least two codes (or code suites?)	Extensive modeling work is performed to support testing and documented in a variety of calculations reports, etc. The modeling work is done using several computational tools including appropriate verification and validation basis, with a wide range of validation efforts underway. In all cases, the work follows institutional quality assurance standards. The proposed modeling benchmarking described in the document is also encouraged via participants in the FPTTEG. A specific benchmarking exercise is likely to be proposed to coordinate this effort within stakeholders and leverage such simulations to the extent possible.
How is axial gas communication (for that matter the plenum volumes) captured in the tests? Is rod growth, variable gap expansion along the total rod length l (where preset) represented? Test segments are only ~1.5 ft long (about 2ft in the new LOCA device) I am skeptical about the realism of gas communication aspects of the tests given the short length of the rodlets. There may be assumptions made on MPCI in the colder regions of the full-length rod. Could puncture tests be performed on the full-length, except the segment that is tested to have better info. on this and use that to get better estimate for RIP during tests?	Axial gas communication can be measured via plenum measurements of pressure and a first-of-a-kind gas composition sensor. Pressure data is available from the IFA-650 series. Most planned LOCA experiments are performed on ~1ft segments including the tests proposed in this test plan as it represents a common grid span length. However, including longer length as an option in TWIST, similar to Halden capability, with potential for grid spacer inclusion, may allow some extension of limited ability to measure this behavior under prototypic integral LOCA conditions. We do not expect these tests to answer all questions in this regard but to add unique perspective. We are also aware of a variety of separate effects approaches that have been used in the past or are under active investigation around the world that may complement the limits of rod length in these tests. Still, no perfect approach

	seems available to resolve uncertainties about axial gas communication. To the last question, puncture of full-length parent rods will be performed for RIP and could be used to set pressure in the segment prior to a test. Though, excluding the segment from the full-length rod puncture is not possible
Suggested Priorities of Tests: #1 – LOC-1 #2 – LOC-2 #3 - Contingency if 65 GWd/MTU samples in the first two tests show no FFRD, then should repeat LOC-2 at 70+ GWd/MTU #4 – If contingency test also shows no FFRD, then repeat test to confirm	This priority has been captured in an updated test matrix in the document.
How many repeats of each test (Because there can be high degree of variability among tests)	Repeats could be performed as needed. As usual, the challenge could be material availability to be adequately considered a repeat test.
I suggest build a contingency to test at 70+ rod if LOC-2 stay intact	Test matrix has been updated accordingly.
I understand LOC-1 you want to replicate IFA-650, but why keep on using large plenum volume? This is even larger than the plenum volume of a full std rod, which should be around 10 cc. Have you calculated the temperature in the plenum region in TEAT? Since there is no appreciable steam cooling, it would be good to know how the gas temperature relative to calculated LOCA plenum temperature.	The plenum volume can be adjusted as desired as described in earlier responses in this document. Some Halden tests had even larger plenum volumes. The values used in this plan were selected to roughly match full standard rod volume (on the high side). If 10 cc is more appropriate, it could be used. Though based on existing data, we don't expect much difference in results between 10-15 cc plenum volume. If other criteria are to be used, i.e. match plenum to fuel ratio, we believe a technical rational is needed to justify it since we have not found it to date. Characterization of thermal conditions of the plenum in TWIST is an active objective via modeling and experimental testing. We have calculation results available for detailed thermal conditions in the TWIST device available now.
Max in SATs is 30-60 K/s. Will each pair of LOC and SATS be matched in temp ramp rate? How exactly will it be achieved?	Temperature ramp rates for LOC and SATS tests are generally not planned to be matched as a point of experimental strategy described in the document. Test #1 and Test #3 are exceptions where both facilities will target similar "DEH" ramp rates. Ramp rate in most of

	the TREAT tests will vary according to prototypic LOCA stored energy effects combined with decay energy heating effects.
Gas volume in plenum and gap should be scaled for the length of the rodlet to the full-length PWR rod; volume of the internal instrumentation should be factored into free volume.	As stated in another response, we believe a technical rational is needed to justify this approach since we have not found it to date (and we welcome input on this). Using full standard rod plenum size seems most appropriate as the reference condition except for parametric studies of these effects, planned in later tests in the test matrix (and studied by SCIP and others as referenced in Section 3.3). Validated models of axial gas communication would likely be needed to support an alternate approach. A detailed evaluation of total free gas volume (including instrumentation) will be used in design of all experiments.
Please explain what can be gained in SATs tests since it is heated externally and the high ramp rate will result in unfavorable temperature gradient. Rather than replicating every TREAT test, it would be better to conduct some other tests the condition is better suited for, such as evaluate when does fuel-cladding debonding occur.	Other responses have also addressed this question. The test plan has been updated to maintain more contrast in ramp rate between the two facilities. It is important to have a DEH comparison to the SEH heat up planned in the TREAT tests, at least until the impacts of SEH have been fully evaluated. In short, the SATS tests are not replicates of TREAT tests, though Tests 1 and 3 are planned to be as similar as possible for more direct intercomparisons.
RIP should be prototypic of PWR rods and should be the same for both LOC-5 and LOC-6; same for SATS test too. RIP should be consistent with high burnup fuel designs which will exceed system pressure. Input from fuel suppliers is needed to establish a reasonable range.	This comment has also been addressed in other responses. We agree that prototypic RIP should be used. Initial specified RIP values were selected based on previous testing at Halden and SCIP, which have been focused in the ~8-12 MPa range. This specification has been removed from the latest test matrix as they will need to be fine-tuned during final design phase to achieve targeted prototypic thermomechanical conditions while considering a particular failure threshold. One reason for this is due to the current uncertainty in plenum temperature in the TREAT design, which will be resolved via ongoing out-of-pile experiments and design analysis. Overall, one should also consider system pressure as cladding wall pressure differential will be the primary target, especially during the higher temperature phases of an experiment. The goal is to drive representative thermomechanical conditions in the cladding and post-failure driving forces on the fuel. Pressure in remanufactured rods can be specified to beyond system pressure in a PWR system at room temperature (>16 MPa).

Bundle Effects Test is lowest priority at this point until capability is demonstrated	Bundle effects testing has been removed from the 3-year test matrix and added to future potential objectives in Section 6.1.
What other programs will be utilizing TREAT/SATS during this time? HERA JEEP will test for RIA	Several programs are necessarily utilizing TREAT for the foreseeable future as part of its mission to support DOE goals. Supporting the needs of the existing U.S. LWR fleet (via ATF/HBu) is considered a high priority, justifying facility restart and as a prime objective today. As noted, the FIDES JEEP HERA is using TREAT and is likely to use the TWIST device for RIA testing as well. DOE ATF FOA participants are also using/planning to use these facilities in parallel to the proposed LOCA plan. The proposed plan accounts for parallel activities.
Need input from fuel vendors for their topicals and NRC for their reviews of topicals	The collaborative engagement on this plan through the FPTTEG is a means to achieve this goal.
Not sure if Halden IF-650 can be simulated since test samples were pre-condition at 10 kw/m for 24 hours	This is a good point as a constraint related to TREAT testing. This caveat is added to the description of the test #1. IFA 650.15 was operated near 10 kW/m for more than 50 hours with another 45 hours at near zero power prior to LOCA simulation. Reirradiation interests could be met using ATR or HFIR.
What is the expected DEH phase heatup rate? Is it comparable to the 5 deg-C/sec used in traditional testing so isolation of the effects of the SEH phase ramp rate can be observed?	DEH is generally represented by the 5 °C/s used in all HBu LOCA testing to date. As noted, a goal is to isolate SEH effects.
The changes noted (grain structure, cracking, fission gas distributions) would seem to be more related to power during an extended period (ex: the last cycle of operation)? Using ATR would require an extended irradiation form moderate burnup fuel. Using commercial irritations will likely have other effects in the power history, such as differences in initial cycle exposure accumulation.	Based on inputs and schedule, experiments requiring reirradiation have been moved out of the current test matrix to beyond the initial 3-year test matrix. Other responses have also addressed this subject in more detail. The ATR experiment will have very well-defined power history and remains yet to be defined, but previous life history will need to be considered.
Plenum size is controllable. The extent of fuel pellet bonding may be subject to large and difficult to control uncertainties?	Fuel-pellet bonding is a challenge to characterize throughout the life of a test specimen.
(In reference to test matrix parameters) Listed at TBD at this point. Will SCIP be coordinated with when defining these levels?	The SCIP relationship is addressed by other responses. We plan to try to coordinate with SCIP and will

	continue to solicit stakeholder input as well, in addition to our own detailed analyses.
In reference to Test #7: This is about 5% beyond the target burnup when corrected for typical segment vs. pin average peaking. Seems like a reasonable upper limit at this point.	In agreement with this comment, the burnup target for this test is maintained at this level, though another comment noted the burnup as potentially too high.
In reference to test #8: Evaluating the impacts of these changes would seem to require multiple tests to address the variations in fuel performance. This would seem to be better suited for SATS initially and then TREAT if a difference is identified. A lower burnup TREAT test might be more valuable depending on the results of the first several tests.	We agree with the approach described here. For now doped fuel has been removed from the test matrix as described by other responses. Our general thinking is that an in-pile confirmatory test, potentially with SEH conditions, could be helpful to support broader testing. Lower burnup could be considered in the future as well as noted in Section 6.1.
In reference to test #9: Spacers impact fuel burnup, cladding temperature (axial and radial pellet effects) and potentially mechanical restraint on cladding. The test spacers should be aligned with the in core locations to account for the burnup impact. It is not clear that the temperature impact can be adequately simulated, starting from a steam environment. The simulated amount of entrained liquid in the steam/water mixture could be another complicating factor. A test which illustrates the interaction between balloon regions in different pins is useful.	We agree more detailed evaluations of bundle configurations would be required to design these tests adequately. As mentioned elsewhere, this test has been moved to the future potential objectives section out of the 3-year test matrix. The TWIST device is likely to be limited in its ability to create forced steam flow conditions (40-50 ft/s flow velocities). If this condition is deemed a requirement, a different test device may be needed. However, creating a test to match bundle thermal-mechanical conditions is likely feasible with minimal design adaptation.
Will AFC form an advisory team to track and evaluate progress, or will the CRAFT FPTTEG be considered for this role?	A description is provided in Section 11. We prefer FPTTEG to serve this role.

5. Comments Regarding Section 7

Need to add microstructural analysis (SEM, SIMS, EBSD, EPMA), especially to support the investigation of the effect of power history.	Parenthetical with advanced exams is added. It is important to note that Section 7 is unsatisfactory as written since a PIE plan is necessary and yet to be developed.
"quantification of potential fuel dispersal and overall fragment size distribution, metallography and …." Both the dispersed material and relocated, but not dispersed, material should be quantified and characterized, separately.	"Relocated fuel" has been added.

If LOC/SATS-HBU-9 eventually becomes a reality, additional thought should be given to instrumentation for that particular test which could provide value beyond the measurement capability described in Table 5 (which seems more geared to the other, single rod tests described).	As noted elsewhere, Test 9 has been moved outside of the 3-year test matrix.
It is noted several places within the document that an upgrade is planned to SATS to allow for in-situ cladding deformation monitoring; however, no indication of this capability is cited in Table 4.	The capability was added to table 4.
Over what axial length can the cladding deformation be measured in-situ during the experiment? What is the accuracy of the measurement? Does INL have anything more recent than INL/JOU-19-55264- Revision 0 that provides better information relative to current capabilities?	The current approach using an electroimpedance sensor will be semi-quantitative, basically a time-dependent measurement of relative changes in the cladding diameter and balloon length. The sensitivity of the sensor is not linear. It has strong potential for highly quantitative results with additional investments in detailed characterization and qualification. Post-test characterization will be important to interpreting its measurements. However, it is highly adaptable and can be tuned to target specific lengths and even azimuthal behavior through adding additional sensing plates. Currently this sensor is used for measuring 2-phase boiling conditions in TREAT with great success. Some characterization of its ability to measure radial deformation in tubes has been performed to date but is undergoing expanded laboratory characterization for this application. More publications on the sensor is forthcoming as the device is more fully characterized.
Will the pressure measurement capability allow for an assessment of impedance to gas communication within the rod?	Yes, it will provide some assessment similar to what was shown in Halden IFA-650 tests. Obviously it will not be fully prototypic due to shorter rod length.
The online FGR measurements in TREAT will be interesting, but it may be difficult to interpret the results, given that the rods are expected to burst and that measurements are taken in the plenum. If there is poor gas communication between the plenum and the balloon region, then transient fission gas release near the balloon region may contribute to ballooning behavior but not be captured by the online measurement system. Perhaps LOC-5 and LOC-6 can shed some light on this issue.	We agree that plenum measurements will be convoluted, especially by burst. The SATS FGR measurement system will provide a variety of options for addressing this question. The TREAT tests offer others. It seems no perfect solution is available to address local gas release routinely. The updated test matrix shows tests 4-6 as well as 8-9 to provide some variations to isolate specific conditions. For example, test 6 intends to balloon and not burst the rod similar to Halden 650.14 to capture all tFGR in the rod. Obviously, separate effects testing for tFGR should investigate broader conditions with integral testing providing confirmatory evaluation.

Integral fission gas release measurements during transients to validate transient fission gas release developments at both the engineering and mechanistic scales. If measurements on the irradiated fuel experiments in SATS could measure any fission gases released during the transient.	This is the goal.
It would be prudent—almost necessary for data interpretation—to perform fuel microstructure characterization at the vicinity of both ends of test segments to be tested in LOC and SATS.	We agree and the plan indicates this need as well.
Is there a way to image (radiography) the rodlets after refabrication so that before/after LOCA fuel fragmentation info can be obtained?	Neutron radiography can be done after refabrication at INL.
Will (metallography) be aimed to provide an estimate of rim (HBS) thickness?	Metallography will be done and should provide this information.
Close collaboration with Halden/IFE to transfer/adapt technologies to TREAT?	INL has had close collaboration with Halden/IFE for transferring technologies related to LOCA test design and related instrumentation, among other things.
Others have found that welding introduces too much complication in maintaining T/C adherence and causing a local clad anomaly. Have you reviewed past experience and concluded that welding is the best way to go? How will SATS attach T/Cs?	We have reviewed TC attachment methods in combination with understanding facility constraints in developing current strategies. In support of the SATS approach, welding vs strapped thermocouple attachment methods were evaluated to downselect to strapped methods to avoid debonding occurrence. For TREAT LOCA, an approach similar to that used in Halden IFA 650 is being targeted as it is consistent with the other methods used, the Halden experience was positive based on our understanding from conversations with their staff as well as related expressed opinions from the broader community. It uses a spot-welded strap over the thermocouple to the rod.
Will the capsule be epoxied post-test in its position in the capsule, as in IFA-650? So that 'additional' fuel relocation and dispersal doesn't occur as artifacts in post-test TWIST and segment handling.	To our knowledge, while perhaps attempted at some point, IFA-650 tests were not epoxied post-test due to challenges. We currently are not proposing any such approach due to concerns of efficacy. The TREAT strategy will rely on unique in-situ hodoscope data, neutron radiography at TREAT with minimal movement of the experiment from its post-test position,

	and final detailed neutron radiography at the hot cell that is ½ mile away from TREAT.
Will dispersed fuel from rupture opening be captured in the TWIST/SATS capsules for detailed characterization?	Quantification of both relocated and dispersed fuel is a data objective.

6. Comments Regarding Sections 8, 9, & Appendix A

In general, the RELAP5-predicted behavior looks consistent with desired transient behavior. However, we believe that valuable experimental data could be produced with a counterpoint experiment where cladding rupture does not occur during the initial "blowdown" period but does occur during the following "reflood" period. Can the experimental boundary conditions be setup to produce such a scenario?	This comment is more addressed to the test matrix. Test #4 now includes a specific point about failure timing to potentially target different conditions. Tests 3-6 should accomplish the goal described here.
Are drawings available of the TWIST capsule? If not, at a minimum, additional information is required regarding the upper capsule and the valve (plus associated piping) between the lower capsule and the expansion tank.	Drawings can be made available if needed. However, the description in Appendix A is recommended to communicate modeling input. If something is missing there, we want to be made aware so we can include it. A length associated with the hydraulic pathway between the capsule and blowdown tank has now been added to Appendix A.
Modeling and simulation that is necessary to define aspects of the experimental procedure and experimental boundary conditions should certainly be included in this program. Otherwise, it is recommended that any modeling be addressed separately from this experimental program.	Appendix A is included for this purpose. A separate document is currently planned to include even more detailed model description.
The modeling runs indicated on Table 6 of Appendix A should include doped vs. undoped runs, using vendor information if possible.	Table 6 may be expanded as additional test information is obtained. As described in Appendix A, additional information will for specific specimens will be sought after as detailed design and test specimen selection progresses. This information will be made available.
Another appendix should be added with a matrix table that shows international capabilities vs. SATS and TREAT test rigs considered for this test plan, with references for further reading. This would be useful for describing the TREAT LOC test series in Table 3, that are being used to benchmark historical test.	Several of the references in the plan point to good summary review documents that contain most (if not all) of this information. This could also be a good idea for future publications with potential new results.

A separate appendix with a matrix table should be developed to describe what LOCA test conditions will be used in terms of break sizes, important boundary conditions and fuel performance, and chapter 15 and DBA/BDBA transient analyses, and important FFRD issues to address issues given in the NRC's RIL 2021-013 which delineates "characteristics that evolve with burnup, such as porosity, stresses within the fuel pellet, grain growth, and subgrain formation, are more directly correlated with FFRD behavior. These fuel pellet features may in turn be influenced by operating history and perhaps the operating power just before the postulated transient. Further, some research has confirmed that transient characteristics, such as temperature ramp rate, peak temperature and burst pressure could also affect FFRD behavior	As stated in the document, this plan is primarily addressing LB LOCA conditions though smaller break conditions may be added later as more information comes available. We believe the break-size conditions should be addressed with specific experimental requirements developed specifically for those. To address some of these points, the test matrix and accompanying descriptions focus on specific characteristics under investigation. A detailed PIE plan will likely address more specific microstructural ties to these tests.
The overall schedule (Fig. 11) does not show when generic or vendor-specific licensing topical reports will be submitted to the NRC. Ultimately the NRC is the key "customer" to please, and topical reports are the ultimate deliverables for getting higher burnup limits, licensing advanced fuel, ATF etc. This plan needs to show how these tests in SATS and TREAT will be integrated into the overall licensing picture.	The ties to vendor-specific planning are not shown in this figure since the relationship of this test plan and vendor submittal plans likely could have some interdependency and only the plan is controlled by AFC. Obviously, those connections are very important and stakeholder input on schedule is solicited and will be incorporated as feedback is received. Integration with licensing strategies should be an indirect outcome of the consensus approach used to drive the plan.
Would BISON analytical results be compared to fuel performance analyses by one or more alternative codes?	Detailed fuel performance assessments are planned only via BISON by the AFC program. Some fuel performance information will also be calculated via RELAP5. As a goal, stakeholders will contribute their own evaluations for further code-code comparisons during the detailed design phase of the project.
There are 9 LOC-x tests in the matrix. Throughput is 2-3 TREAT tests per year so if TREAT tests start in late 2023, then the matrix would be complete as early as 2026. Is this correct?	The schedule has been updated in the latest revision. The stated conclusion is correct pending resource availability.