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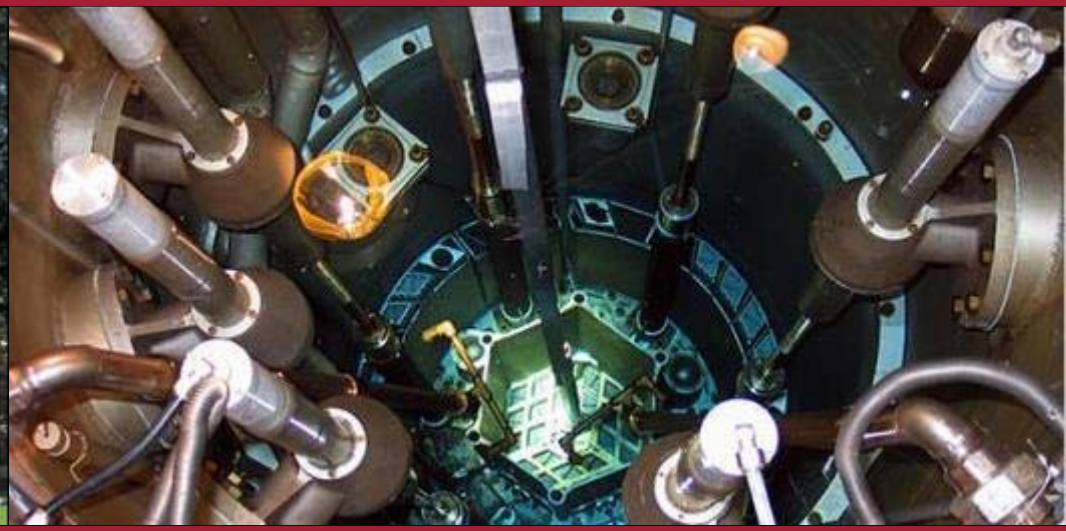

# Low Power Steady-State and Transient Tests for TREAT Core Instrumentations

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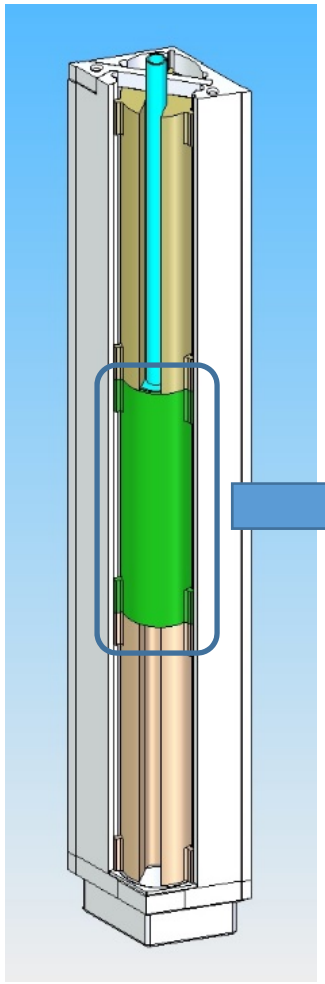
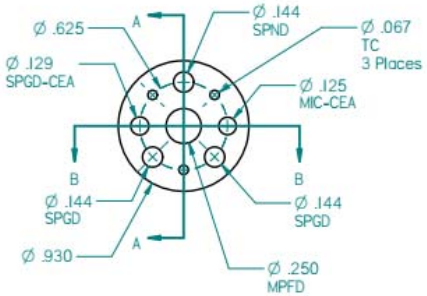
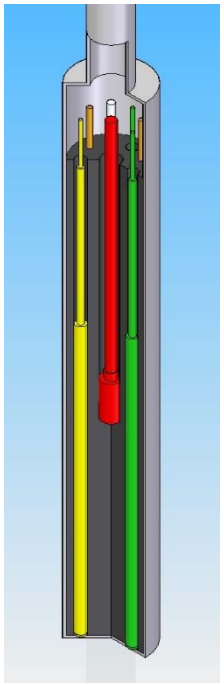
*Division of Research & Services*

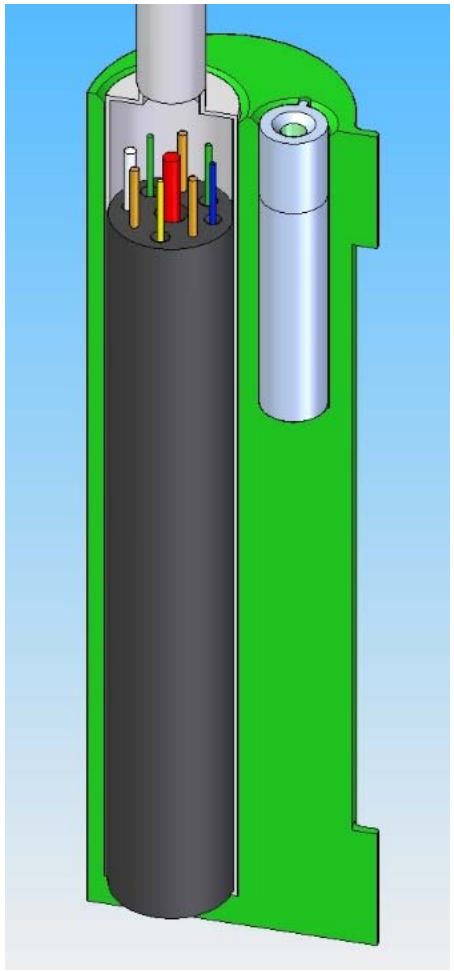
11/07/2017 – TREAT-IRP Workshop – OSU

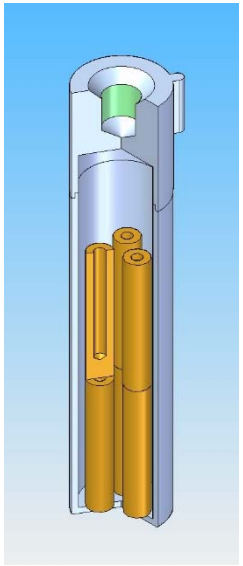
# Experiment Design









Experiment Assembly | Detector Container | Experiment Container | Flux Wire Container

# Test Plan (TP) Timeline

## 7/26/17 – TP0: Steady-state Calibration

| | |
|---|---|
| 1000 | RX **startup** |
| 1003 | RX hold for **10 minutes** at **10 kW, 20 kW, 40 kW, 60 kW, 40 kW, and 20 kW** |
| 1215 | RX **shutdown** via ARI (all rods/blades driven in simultaneously) |

## 7/27/17 – TP1: Slow-positive and Fast-negative Transients

| | |
|---|---|
| 1000 | RX **startup** |
| 1020 | RX hold for **10 minutes** at **10 kW** |
| 1030 | Drive **regulating rod** out for **2 minutes**, minimum 50s period (Slow-positive Transient) |
| 1034 | RX hold for **50 minutes** at **60 kW** |
| 1130 | **Drop one shim blade by releasing electromagnet** (Fast-negative Transient) |
| | **Wait 5 seconds**, then RX shutdown **via Minor Scram** (drop all blades) |

## 7/28/17 – TP2: Slow-positive and Fast-negative Transients

| | |
|---|---|
| 0900 | RX **startup** |
| 0930 | RX hold for **10 minutes** at **10 kW** |
| 0950 | Drive **one shim blade** out for **2 minutes**, minimum of 50s period (Slow-positive Transient) |
| 0955 | RX hold for 50 minutes at **60 kW** |
| 1045 | **Drop one shim blade by releasing electromagnet** (Fast-negative Transient) |
| | **Wait 5 seconds**, then RX shutdown **via Minor Scram** (drop all blades) |

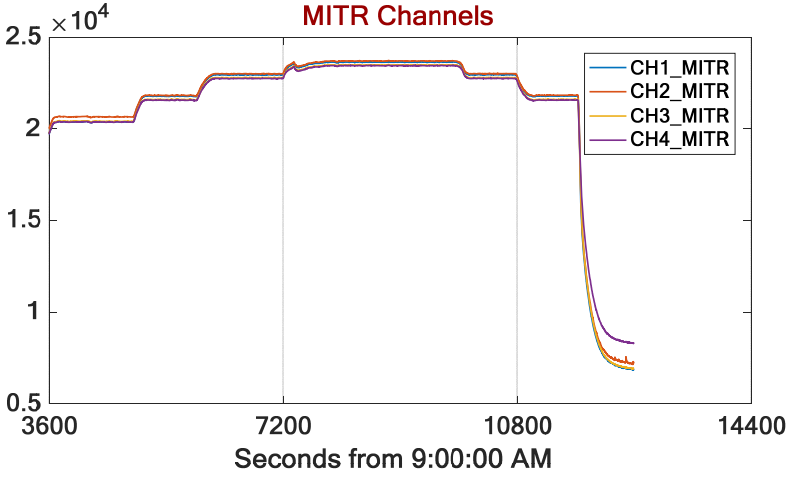
# Measurement Data Summary

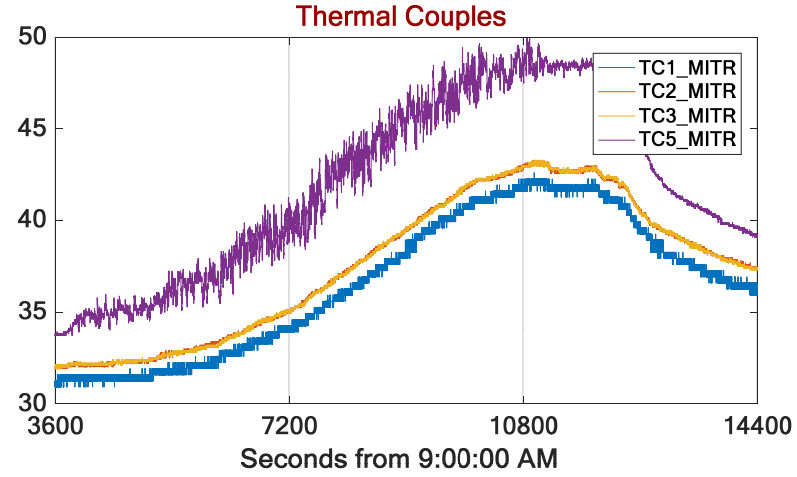
| | TP0 (7/26) | TP1 (7/27) | TP2 (7/28) |
|---|---|---|---|
| Gamma Detectors | | | |
| SPGD1_INL | 1 Hz (18,000 bins) | 1 Hz (18,000 bins) | 1 Hz (23,400 bins) |
| SPGD2_INL | 1 Hz (18,000 bins) | 1 Hz (18,000 bins) | 1 Hz (23,400 bins) |
| SPGD1_CEA | 2-4 Hz (60,000 bins) | 1-5 Hz (60,000 bins) | 20-100 Hz (280,000 bins) |
| SPGD2_CEA | 2-4 Hz (60,000 bins) | 1-5 Hz (60,000 bins) | 20-100 Hz (280,000 bins) |
| | | | |
| Neutron Detectors | | | |
| MPFD_KSU | N/A | ~ 4 Hz (60,000 bins) | N/A |
| SPND_CEA | 2-4 Hz (60,000 bins) | 1-5 Hz (60,000 bins) | 20-100 Hz (280,000 bins) |
| 4 × MITR Channels | 0.1-2 Hz (6,000 bins) | 0.1-2 Hz (6,000 bins) | 0.1-2 Hz (7,500 bins) |
| | | | |
| *4 × Thermal Couples* | *2 Hz (36,000 bins)* | *2 Hz (36,000 bins)* | *2 Hz (46,800 bins)* |

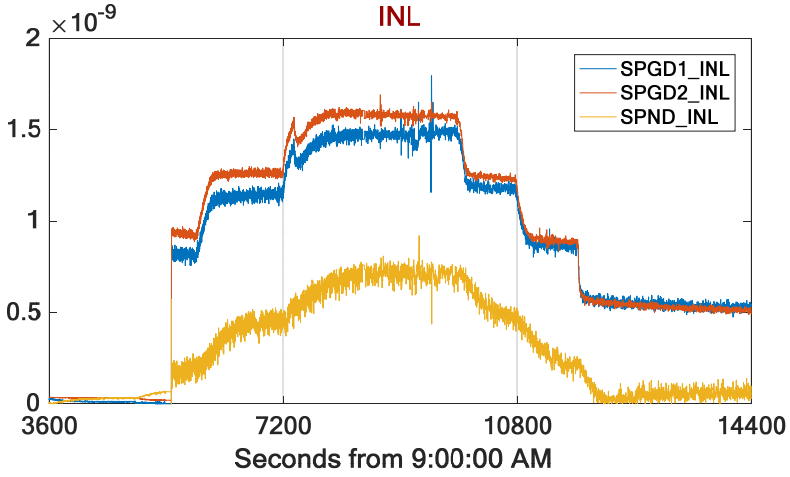
# Data Post-processing Methods

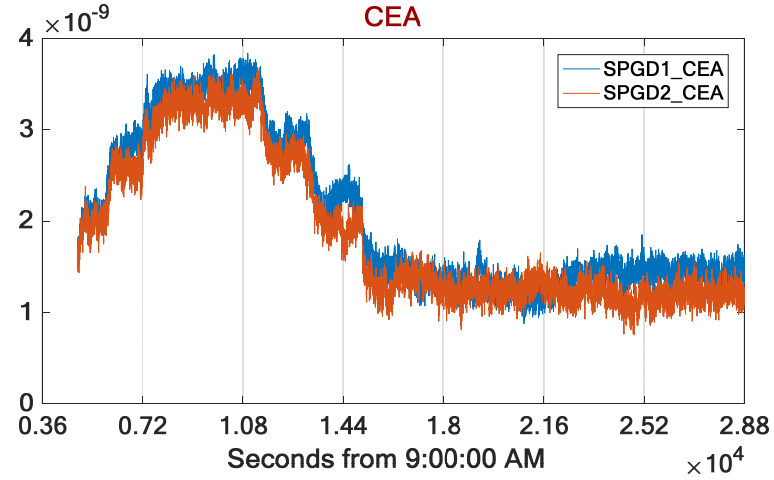
- Normalization
  - Avoid using zero power (background noise) level for normalization
  - Adopt two power levels (10 kW and 60 kW) from **TP1** for **linear extrapolation**
- Filtering
  - Remove statistical uncertainty due to different detector efficiencies and sampling frequencies
  - A moving average of ± 10 s is applied.
  - No filtering is applied to fast-negative transient (i.e., allowing maximum details). Exception is CEA's high frequency (100Hz) data at TP2. A moving average of ± 0.5 s is applied.
- Synchronizing
  - Different sampling frequencies (and intermediate changes) lead to synchronize difficulties
  - Featured power trips are adopted as key synchronizing characteristics

# TP0: Pre-processed Data

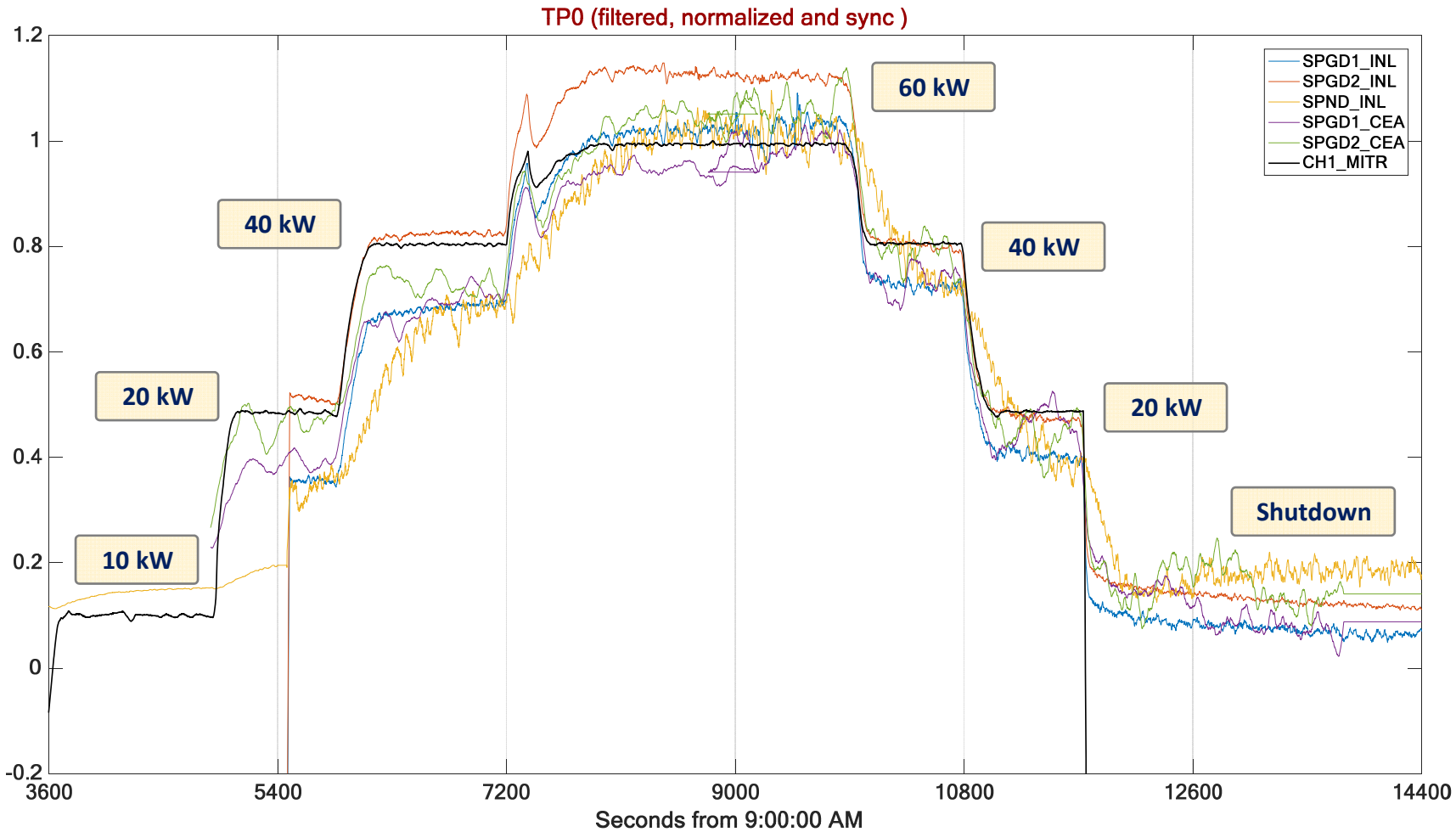


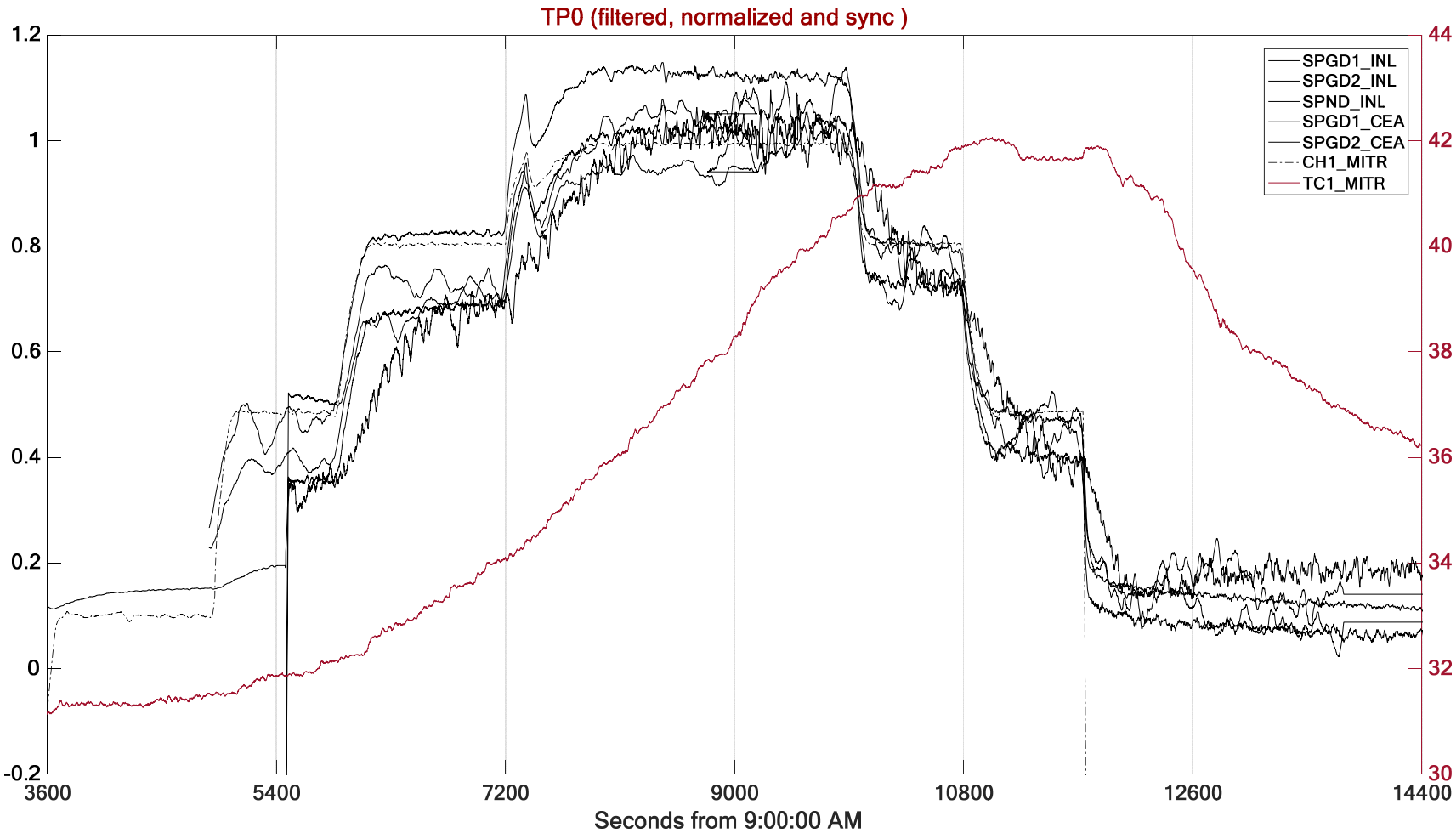



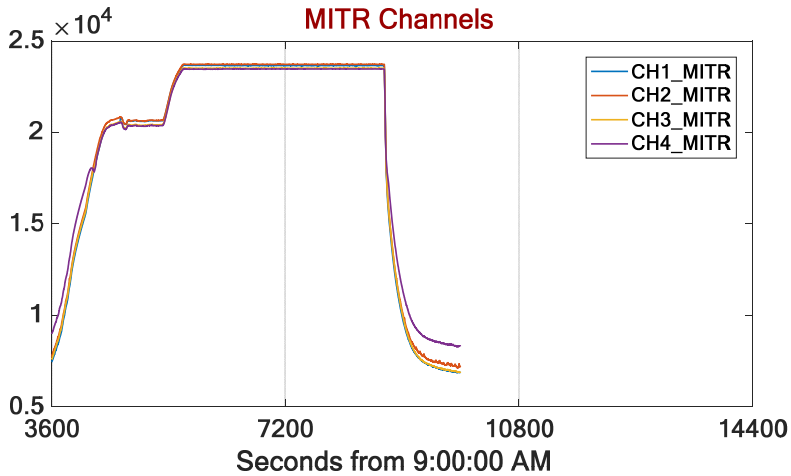
# TP0: Post-processed Data

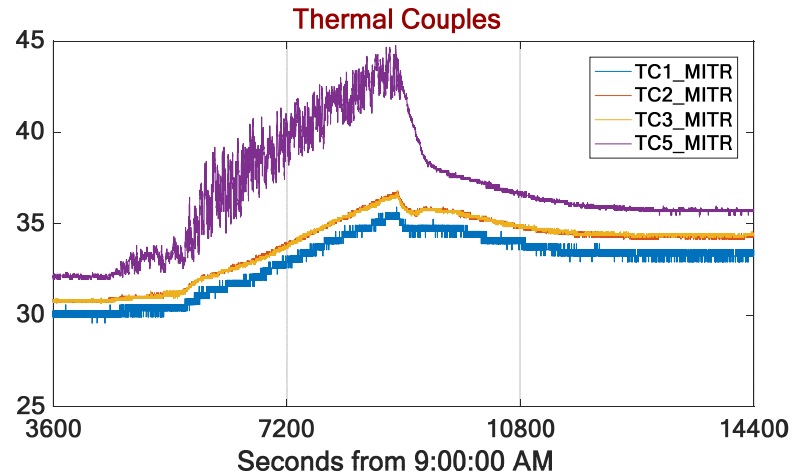


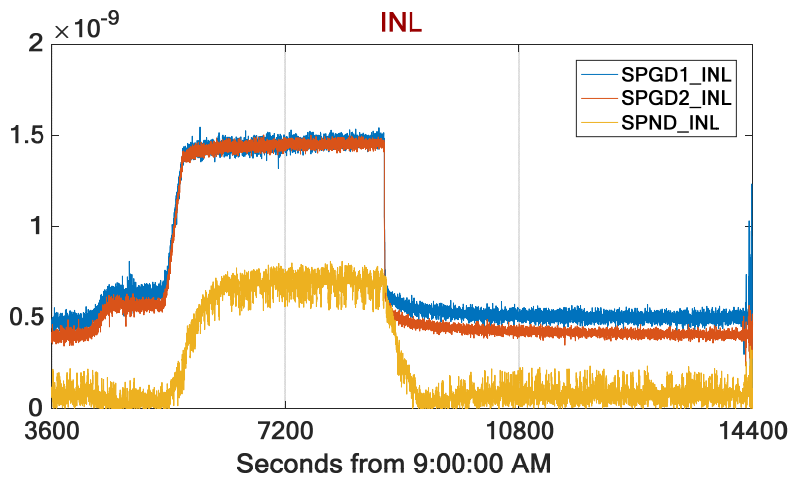
# TP0: Post-processed Data

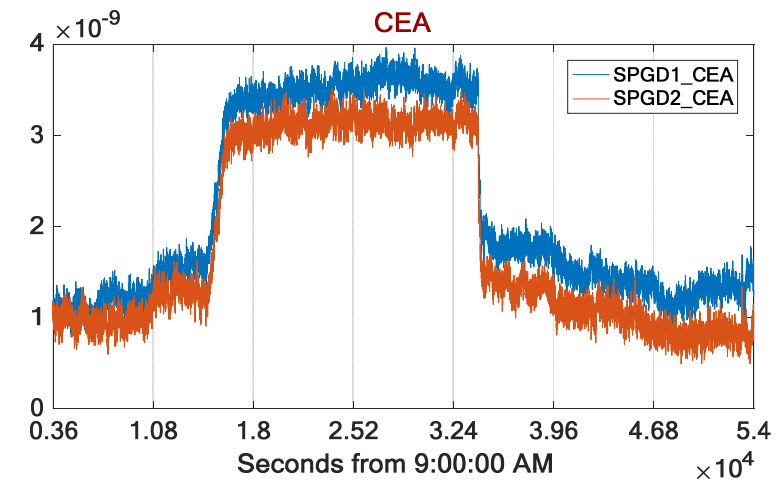


# TP1: Pre-processed Data

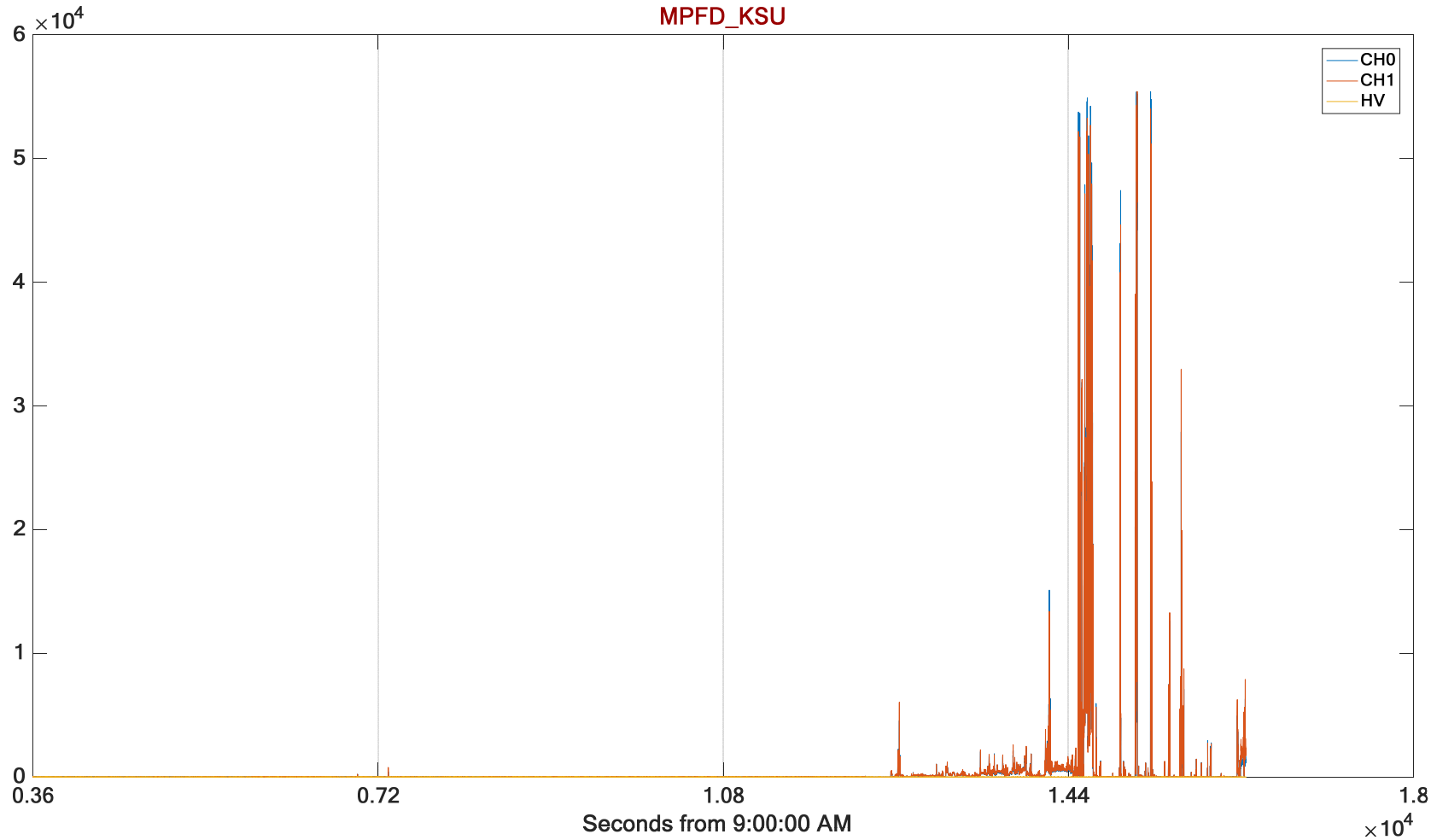


# TP1: (Unsuccessful) MPFD data



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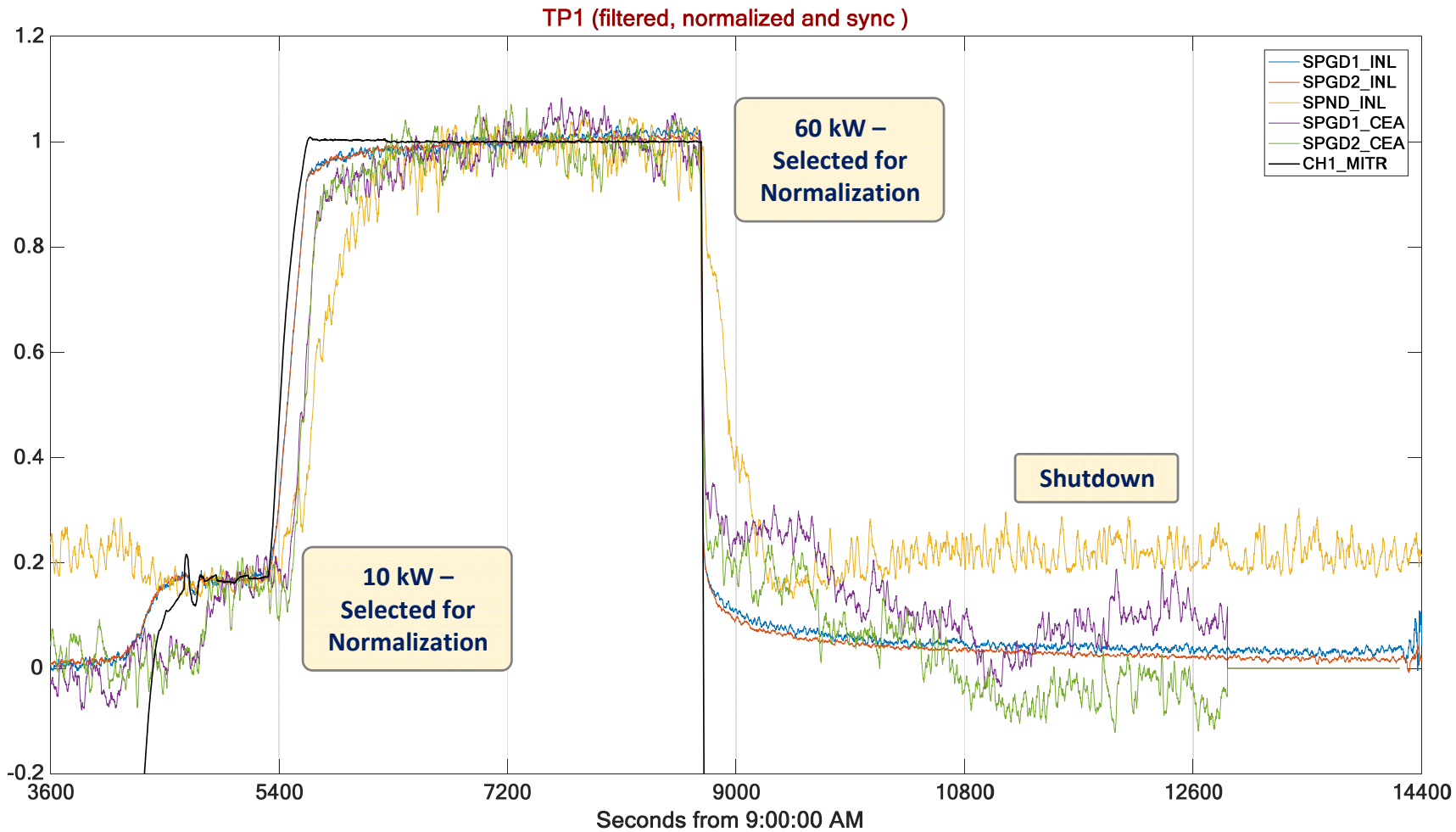
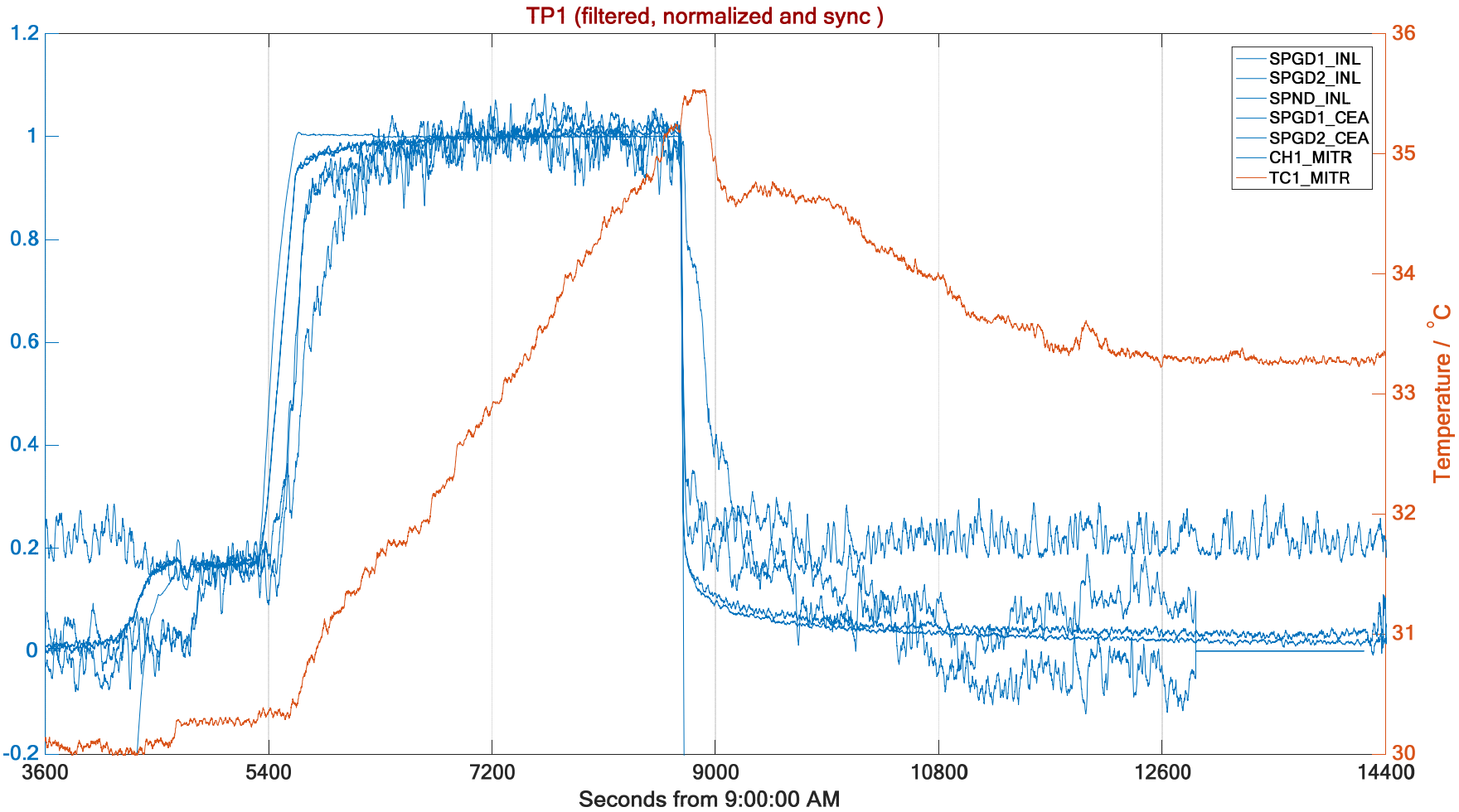
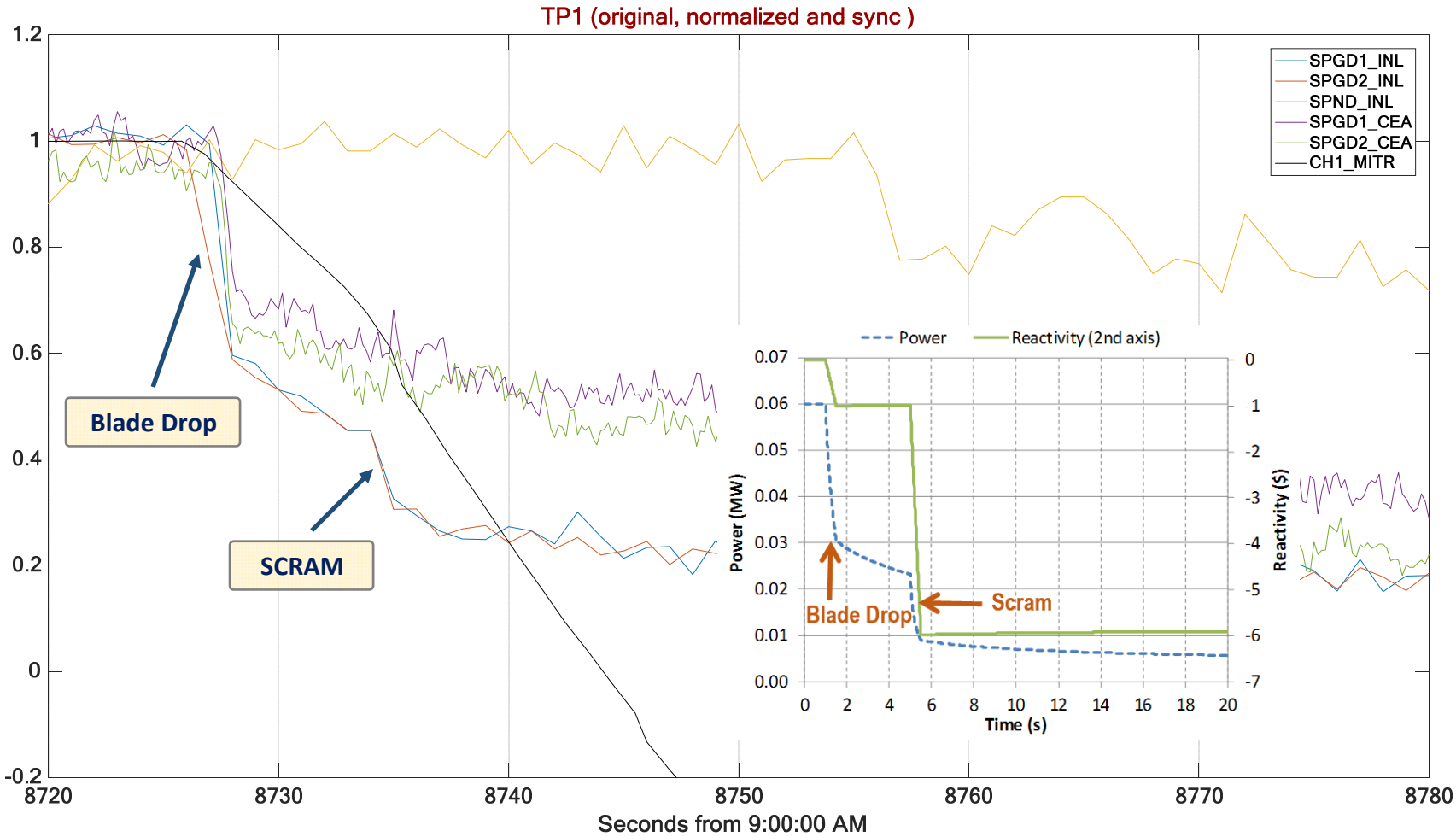


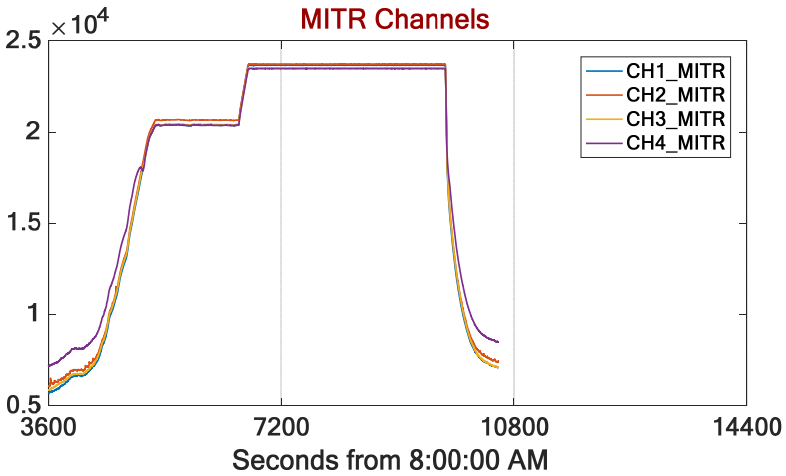
# TP1: Post-processed Data

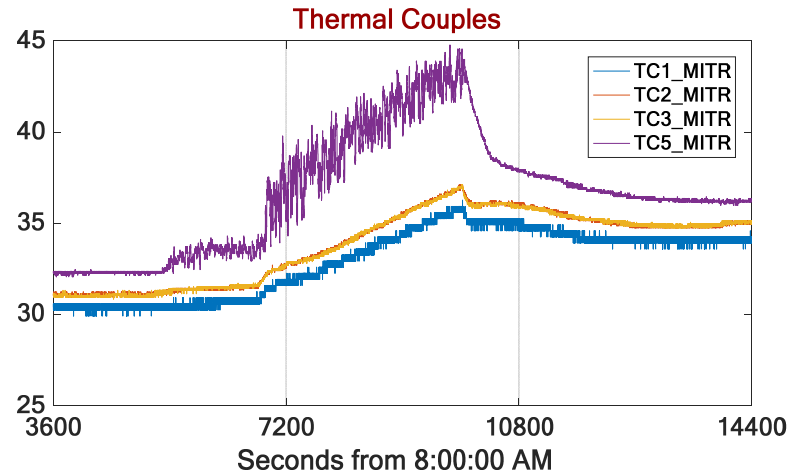


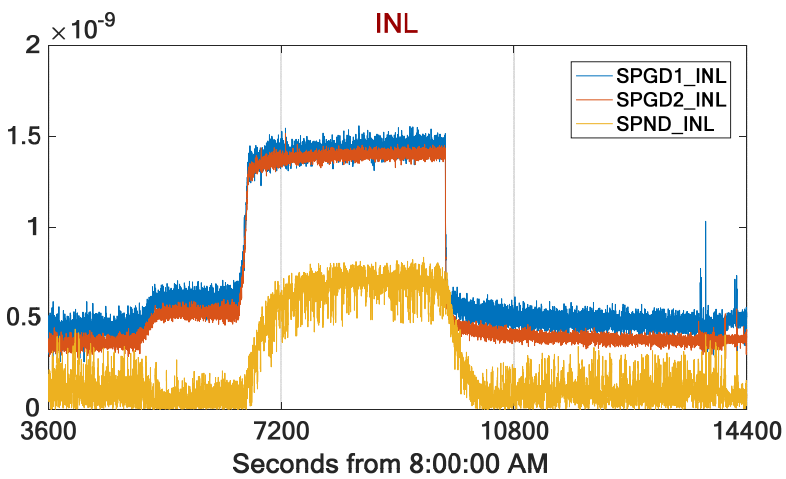
# TP1: Fast-negative Transient

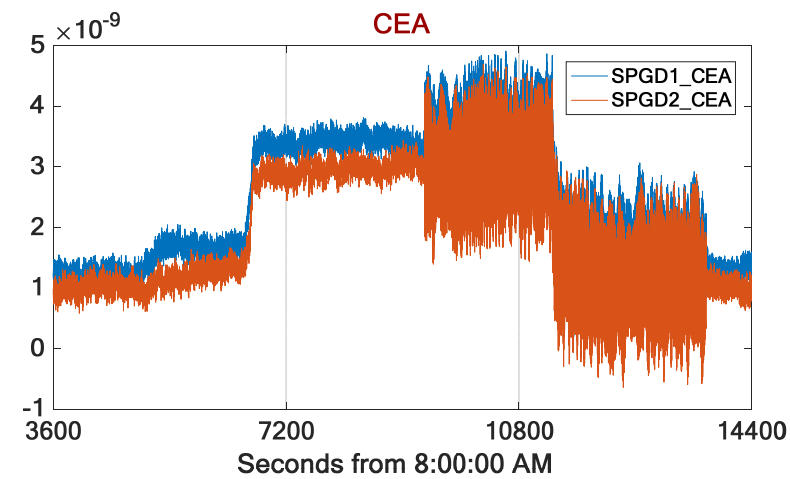


# TP2: Pre-processed Data

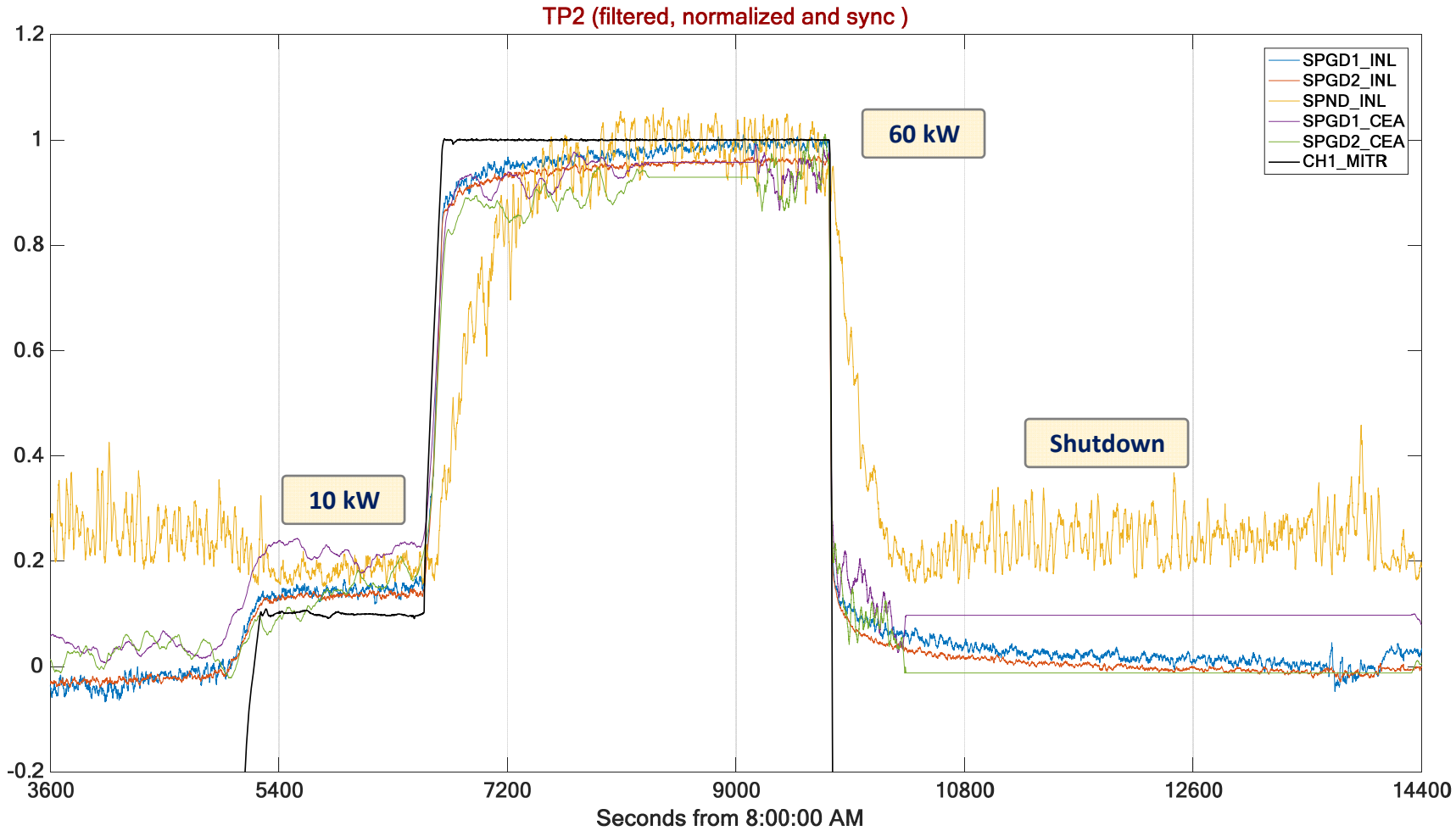


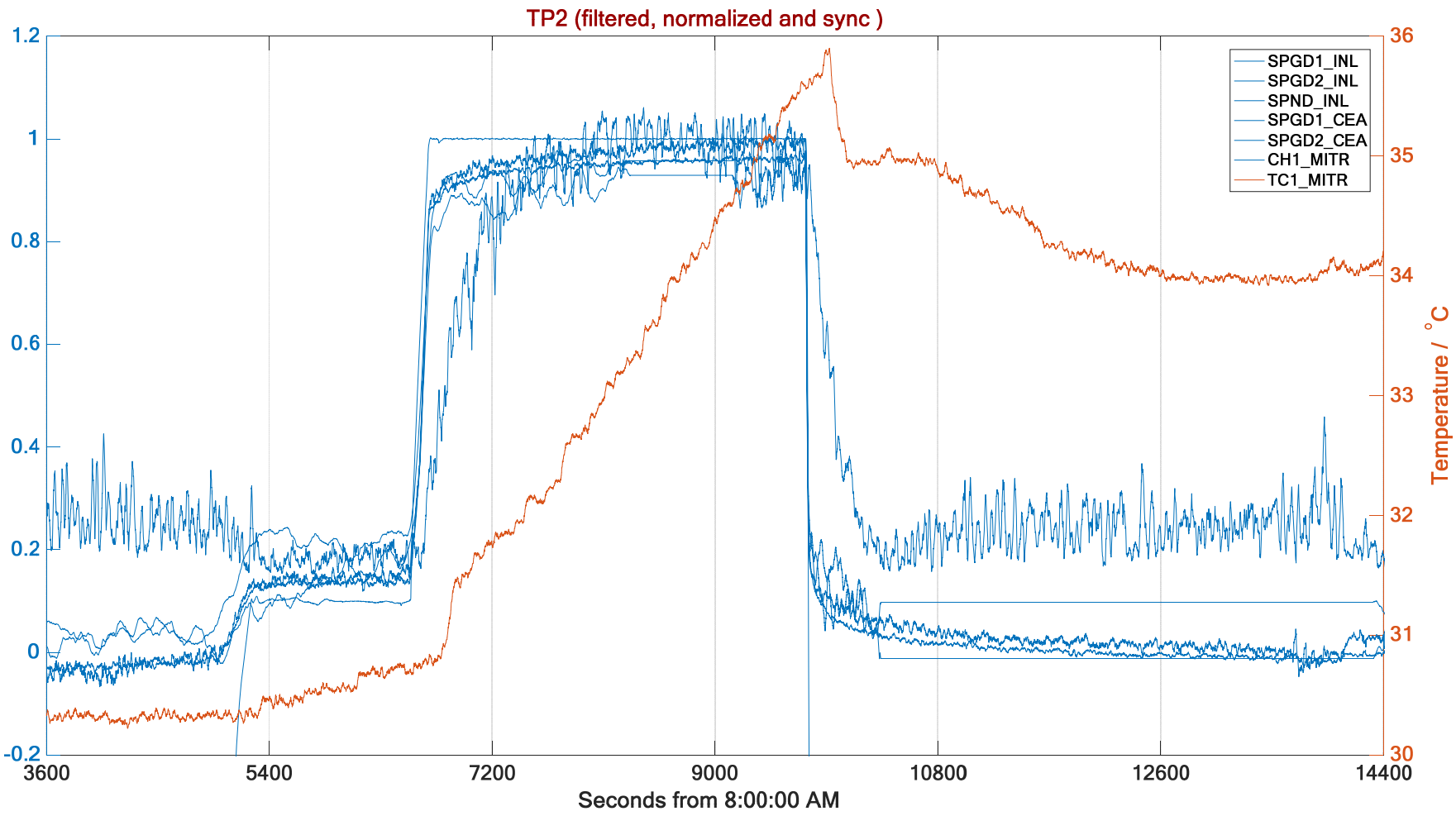



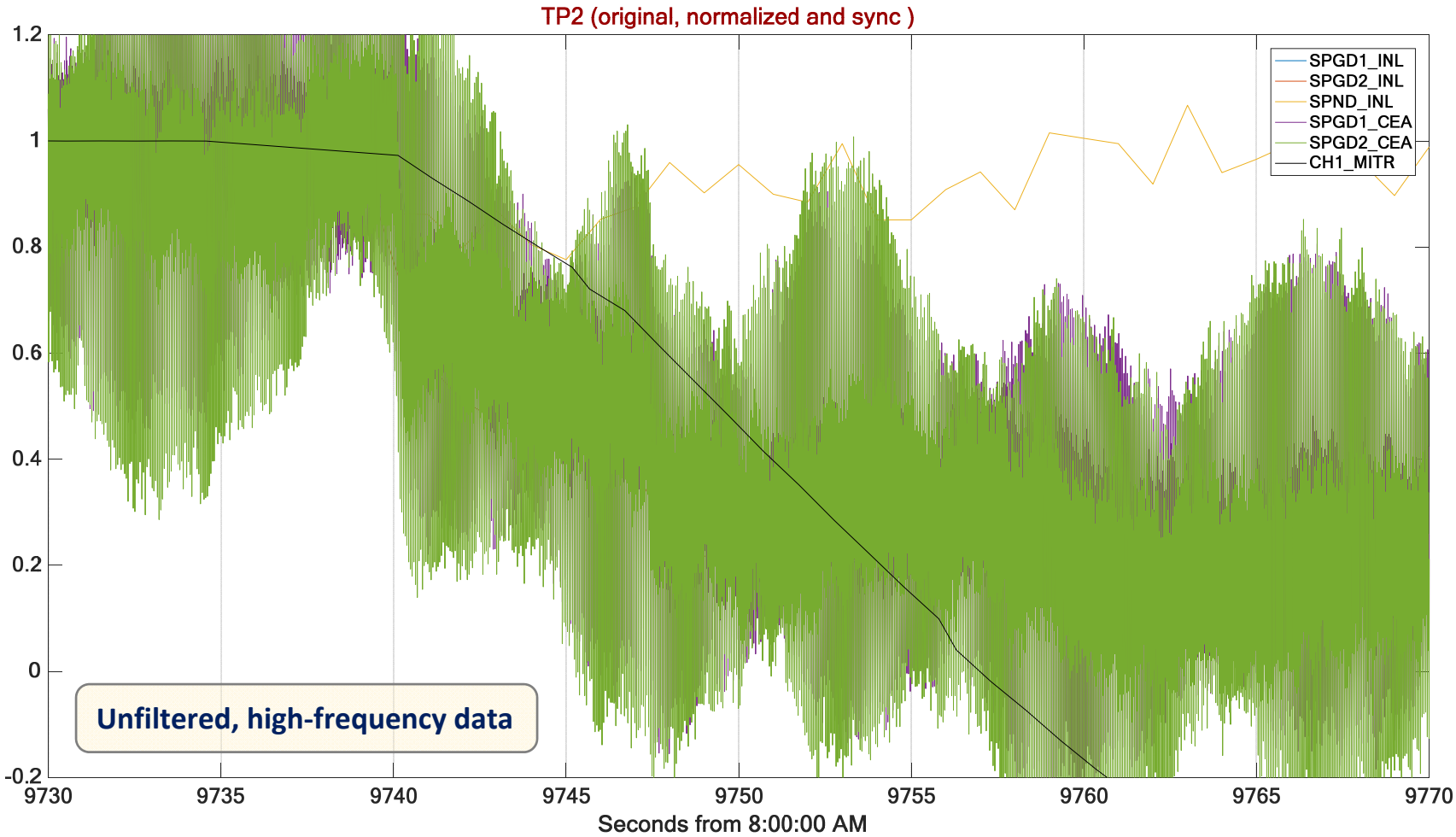
# TP2 Post-processed Data



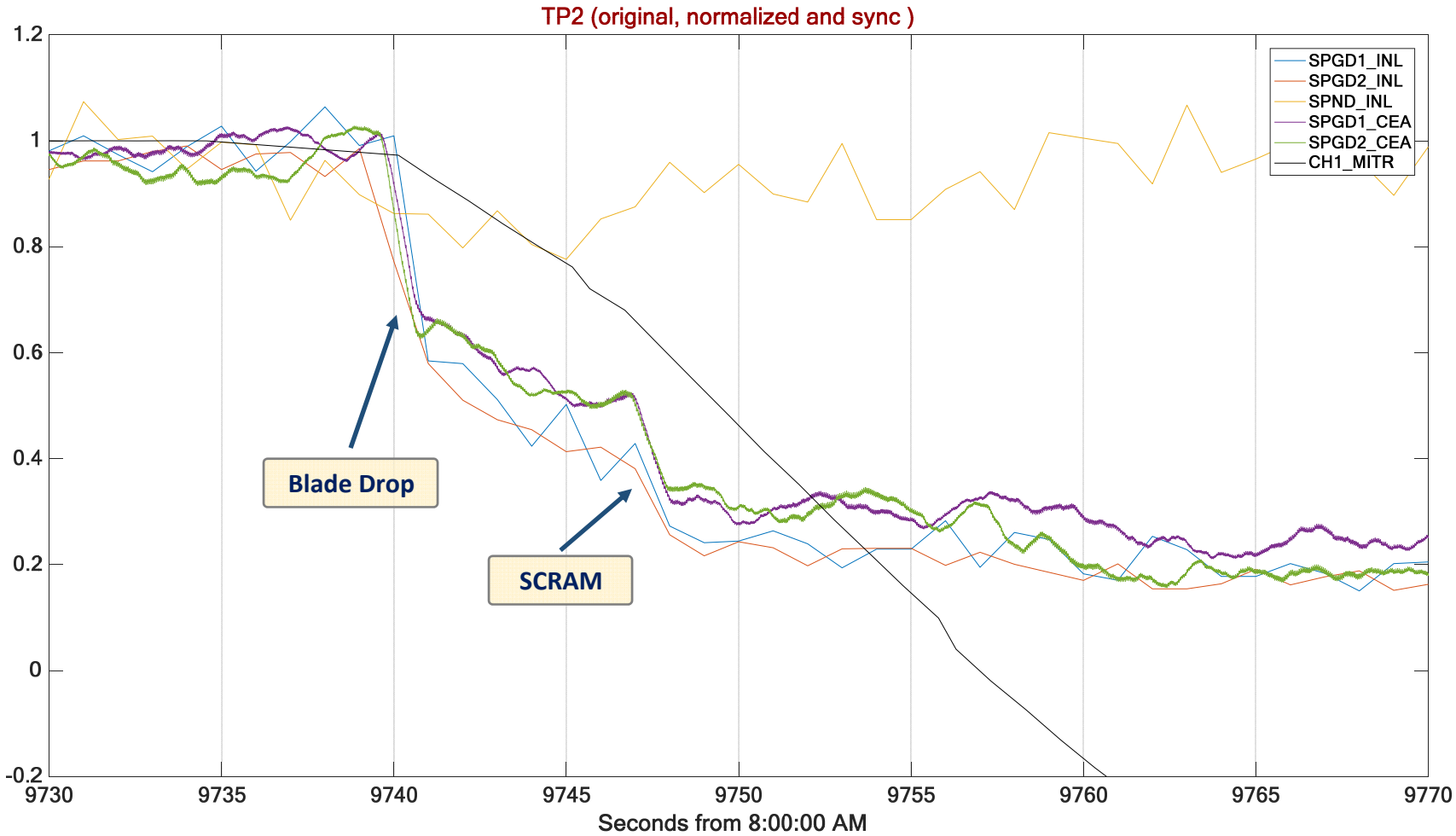
# TP2 Post-processed Data



# TP2: Fast-negative Transient

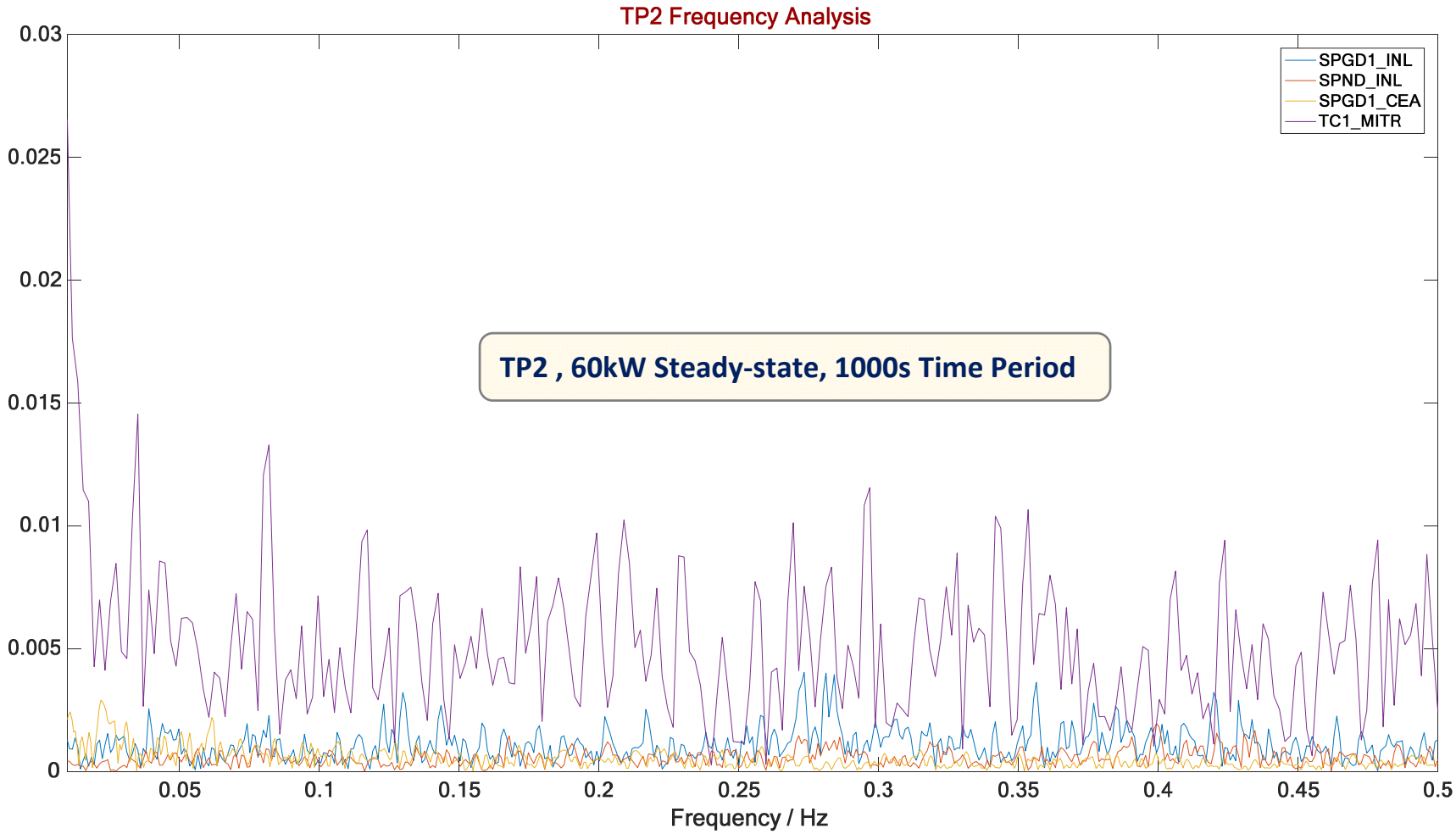


# TP2: Fast-negative Transient

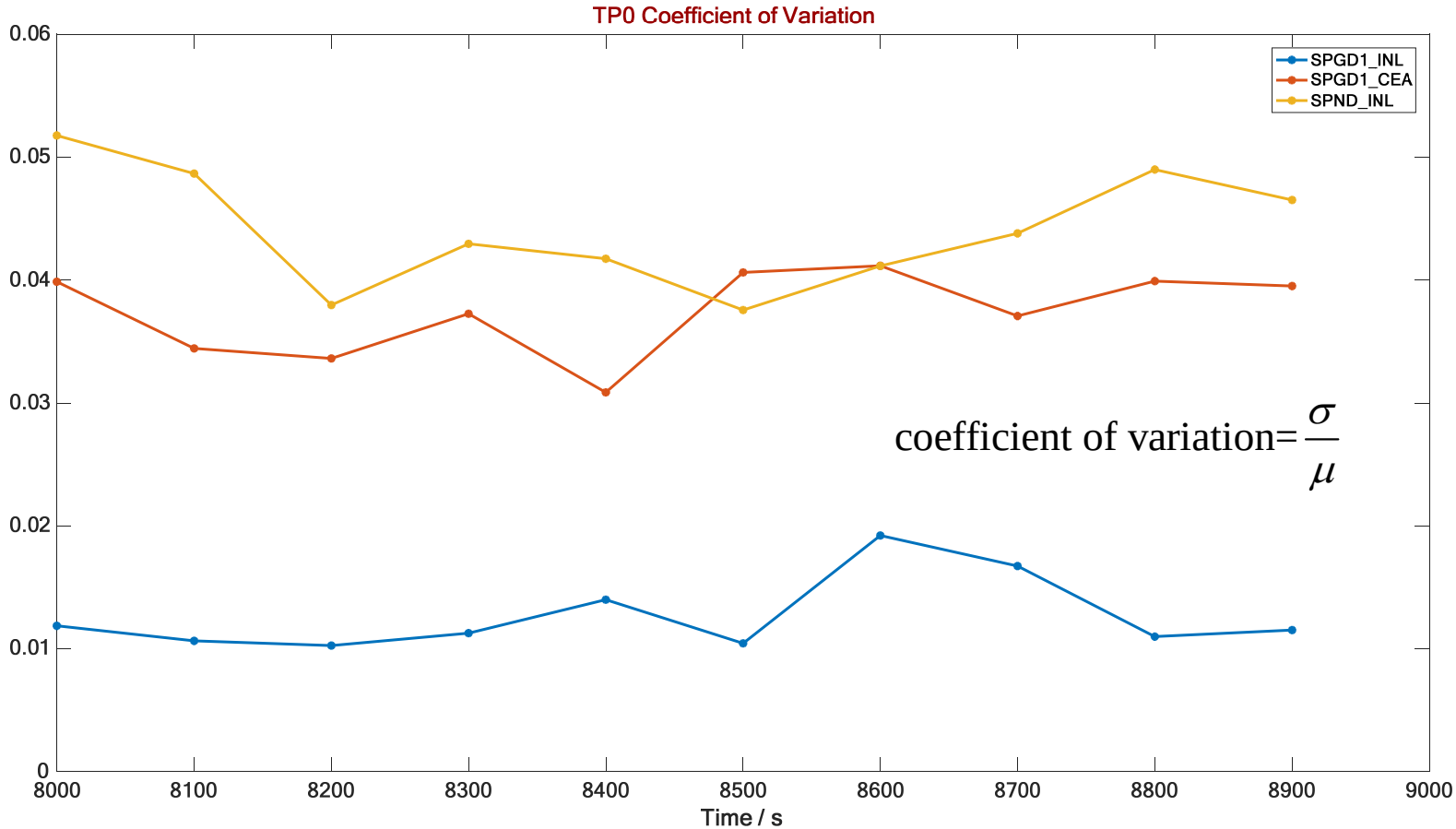


# Test Plan 2 -
# Fast-negative Transient

# Preliminary Frequency Analysis



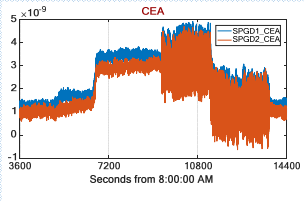
# Coefficient of Variation




$$\text{coefficient of variation} = \frac{\sigma}{\mu}$$

# Uncertainty Decomposition (attempt)

## Assumptions:




1. $\sigma^2 = \sigma_n^2 + \sigma_s^2 + \sigma_p^2$ ;

2. $\boldsymbol{\sigma_n^2}$ is the **detector noise** which is assumed to be approximately equal for one detector in the same physical process;

3. $\boldsymbol{\sigma_s^2}$ is the **particle statistical fluctuations** which just depended on the particle counts. For the same physical process, if the sampling frequency of signal 2 is k times that of signal 1, then $\sigma_{2s}^2 = k \cdot \sigma_{1s}^2$ ;

4. $\boldsymbol{\sigma_p^2}$ is the **physical process uncertainty** which is assumed to be **zero** for a short-term steady-state process.

## Mathematical Derivation:

for the same physical process, detector B's signal variances are $\sigma_{B1}^2$ and $\sigma_{B2}^2$ with two different sampling frequencies and detector A's signal variance is $\sigma_A^2$.

$$\because \ \sigma_{B2}{}^2 - \sigma_{B1}{}^2 = (\sigma_{B2n}{}^2 - \sigma_{B1n}{}^2) + (\sigma_{B2s}{}^2 - \sigma_{B1s}{}^2)$$
$$= 0 + (k-1)\cdot\sigma_{B1s}{}^2$$

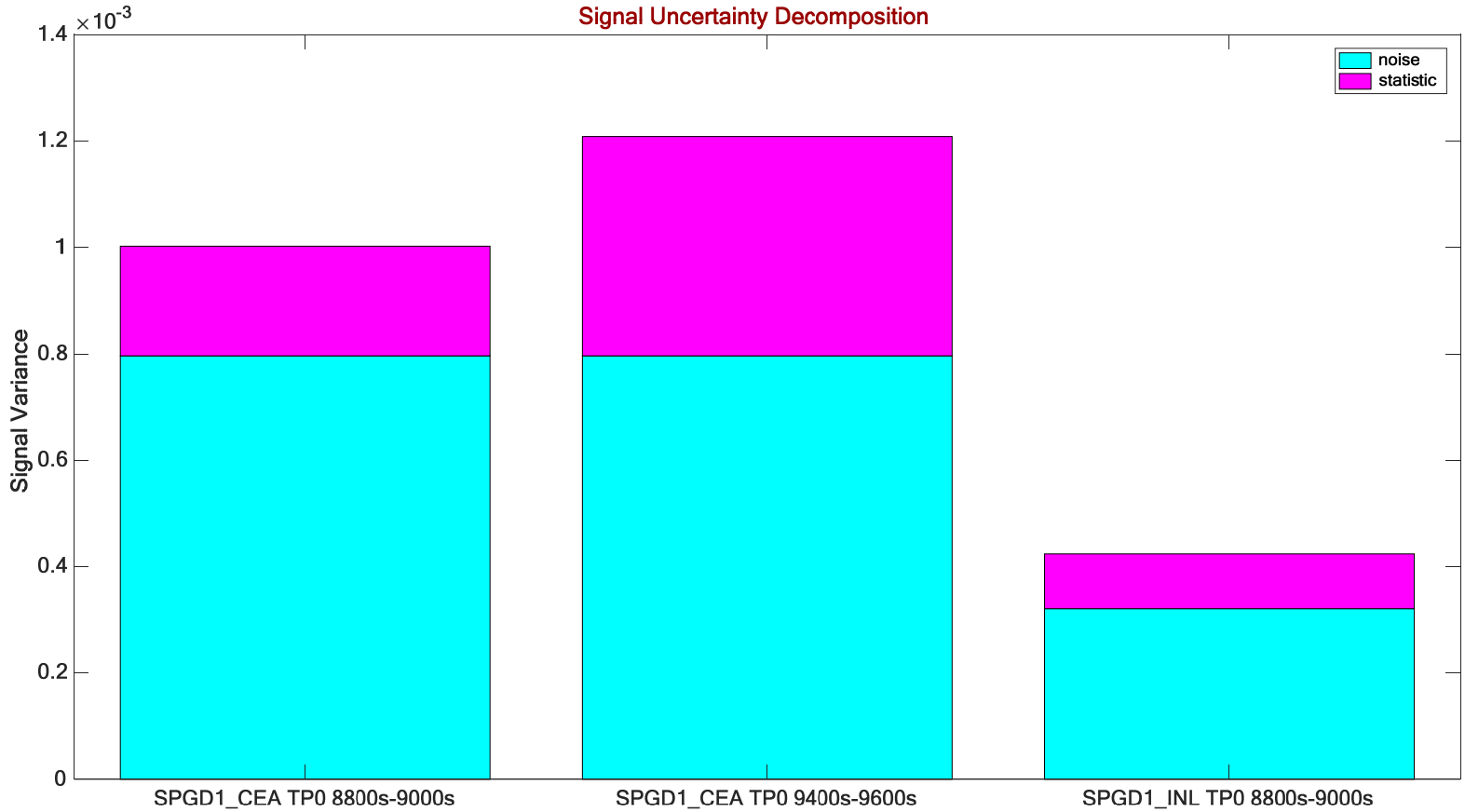
$$\therefore \ \sigma_{B1s}{}^2 = \frac{1}{k-1}(\sigma_{B2}{}^2 - \sigma_{B1}{}^2), \quad \sigma_{B2s}{}^2 = \frac{k}{k-1}(\sigma_{B2}{}^2 - \sigma_{B1}{}^2)$$

$$\therefore \ \sigma_{B1n}{}^2 = \sigma_{B1}{}^2 - \sigma_{B1s}{}^2, \qquad \sigma_{B2n}{}^2 = \sigma_{B2}{}^2 - \sigma_{B2s}{}^2$$

$$\because \ \text{frequencyA} = \text{m} \cdot \text{frequencyB1}$$

$$\therefore \ \sigma_{As}{}^2 = m \cdot \sigma_{B1s}{}^2, \qquad \sigma_{An}{}^2 = \sigma_A{}^2 - \sigma_{As}{}^2$$

# Decomposition Results




The reactor was at 60kW from 8000s to 10000s for TP0. While the sampling frequency of SPGD1_INL is 1Hz for the whole period, the SPGD1_CEA had two different sampling frequencies (segment 1: 8000s-9200s, 2Hz; segment 2: 9200s-10000s, 4Hz) .

# *Backup Slides*

# Background

- The projected MITR low power experiments are within the framework of Computational & Experimental Benchmarking for Transient Fuel Testing – FY15 Integrate Research Project (IRP) jointly organized by Oregon State University (OSU), University of Michigan (UM), and MIT.
  - *Neutronics Benchmark – led by UM (with contribution from MIT)*
  - *Thermal-hydraulics Benchmark – led by OSU*
  - *Instrumentation Benchmark – led by MIT*

- The Instrumentation Benchmark consists of two major tasks:
  - *Instrumentation Plan (completed in 09/16)*
  - ***Experimental Benchmarking (to be discussed today)***

# Experiment Plan

- Low Power Experiments at MITR
  - *< 100 kW operation – pump free (better radiation shield) and open lid (easier access and manipulation)*
  - ***Forced convection mode (< 100 kW operation ) is considered as backup option***
  - *Similar neutron flux level as TREAT instrumentation calibrations*
- Experiment Locations and Transient Selections
  - *3 in-core positions* ***(2 positions will be finally used.)***
  - *2 types of transient*
- Reactor Safety Analysis for Proposed Transients
  - *Safety Evaluation Report for Experiment Plan – Completed* ***(latest version distributed on June 27th 2017)***
- Final Safety Review for Low Power Experiment (by July 2017)
- Performing TREAT Instrument Test Experiment at MITR (July-August 2017)
- Flux wire and instrument data analysis (July-Dec 2017)
- Same instrumentation/thimble in TREAT reactor during first re-start testing (early 2018)

# Major SER Revisions

1. "Secured" category – 1.8% Δk/k reactivity worth (maximum of two aluminum spacers inadvertently ejected)

2. Multiple thermal couples will be attached along the outside of the guide tube, for temperature measurements above the reactor core.

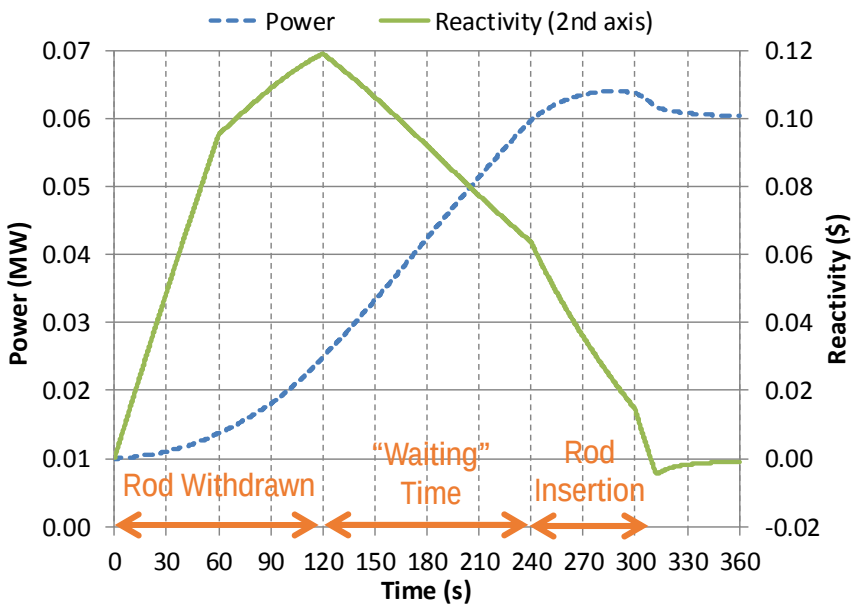
3. Temperatures in the detector capsule will be monitored by multiple thermal couples. High temperature scram will be initialized by one TC at 300 $^{o}$C. This is to prevent the aluminum fuel clad temperature softening temperature of 450 $^{o}$C. It also satisfies the Technical Specification requirement for "fueled" experiment.

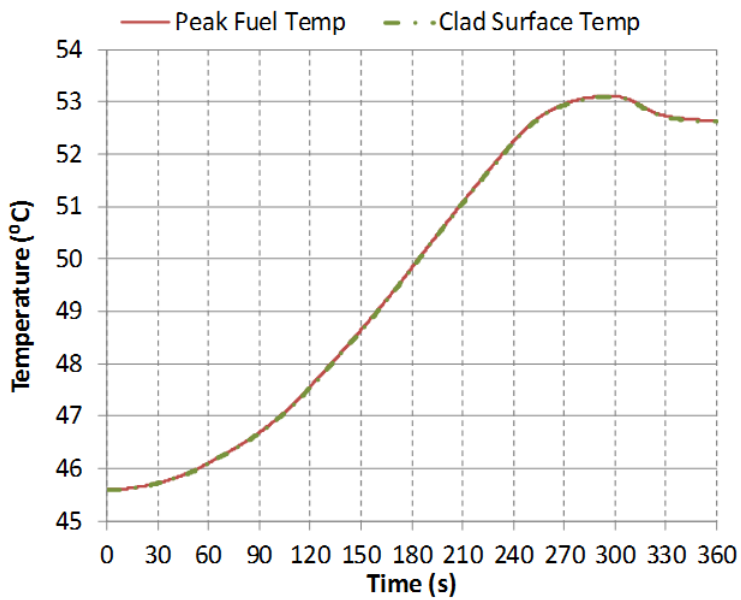
4. Three in-core positions (A-1, A-3, and B-3) are listed as experiment positions in the SER. However, in practice, A-3 will not be used due to grid plate latching concerns.

# “Slow Positive” Transient

- Established by withdrawing the regulating rod. Total reactivity worth of ~ $ 0.18 with maximum insertion rate of ~ $ 0.10 / min
- Prior-transient steady-state at 10 kW (natural convection) Post-transient steady-state at 60 kW (natural convection)
- Safety analysis performed by PARET/ANL-7.6 beta

- **MITR thermal flux level at 60 kW is similar to TREAT thermal flux level at 100 kW, i.e., its instrumentation calibration power level.**
- **Slow transient (regulating rod withdrawn) creates a positive period of about 50 s.**
- **Peak fuel centerline and cladding surface temperatures overlap each other.**
- **No safety concern for the MITR is expected.**

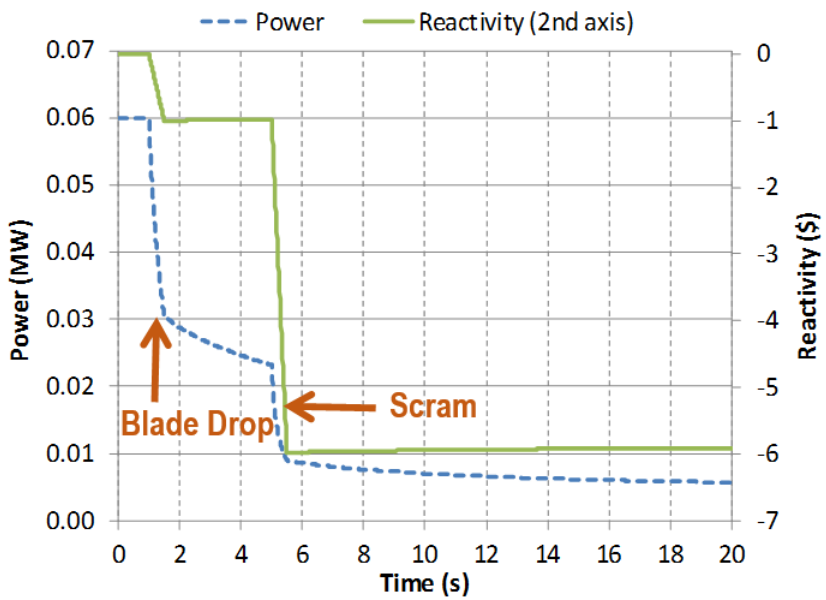


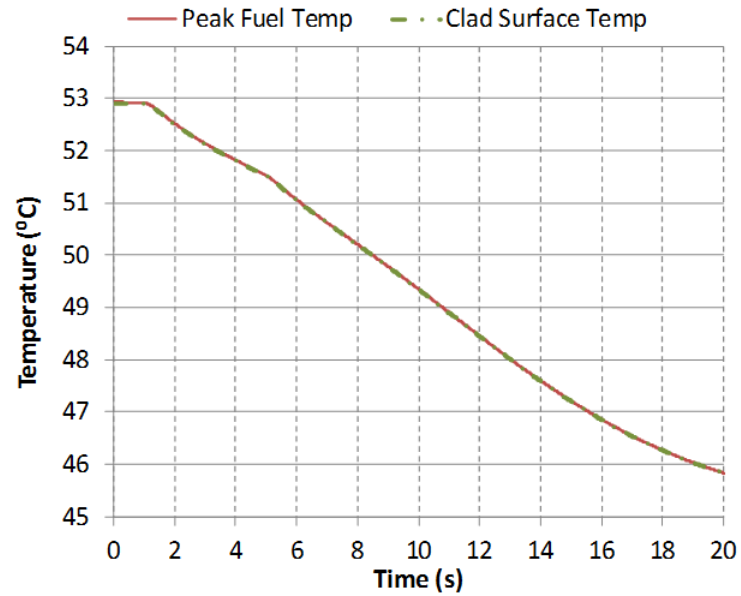



# “Fast Negative” Transient

- Established by a blade drop followed with a Scram.
  Blade Drop: $ -1.0 insertion within 0.5 s
  Scram: Additional $ -5.0 insertion within 0.5 s
- Prior-transient steady-state at 60 kW (natural convection)
  Post-transient after 20 s reach ~ 5 kW (natural convection)
- Safety analysis performed by PARET/ANL-7.6 beta

- **Fast transient (blade drop / Scram) creates a negative period in magnitude of -100 ms.**
- **The 100 ms period provides benchmark conditions for those “fast response” detectors.**
- **All temperatures are well below light-water saturation point. Thus, coolant boiling is not anticipated to occur at any forms, hence no MITR Limiting Safety System Setting violation.**



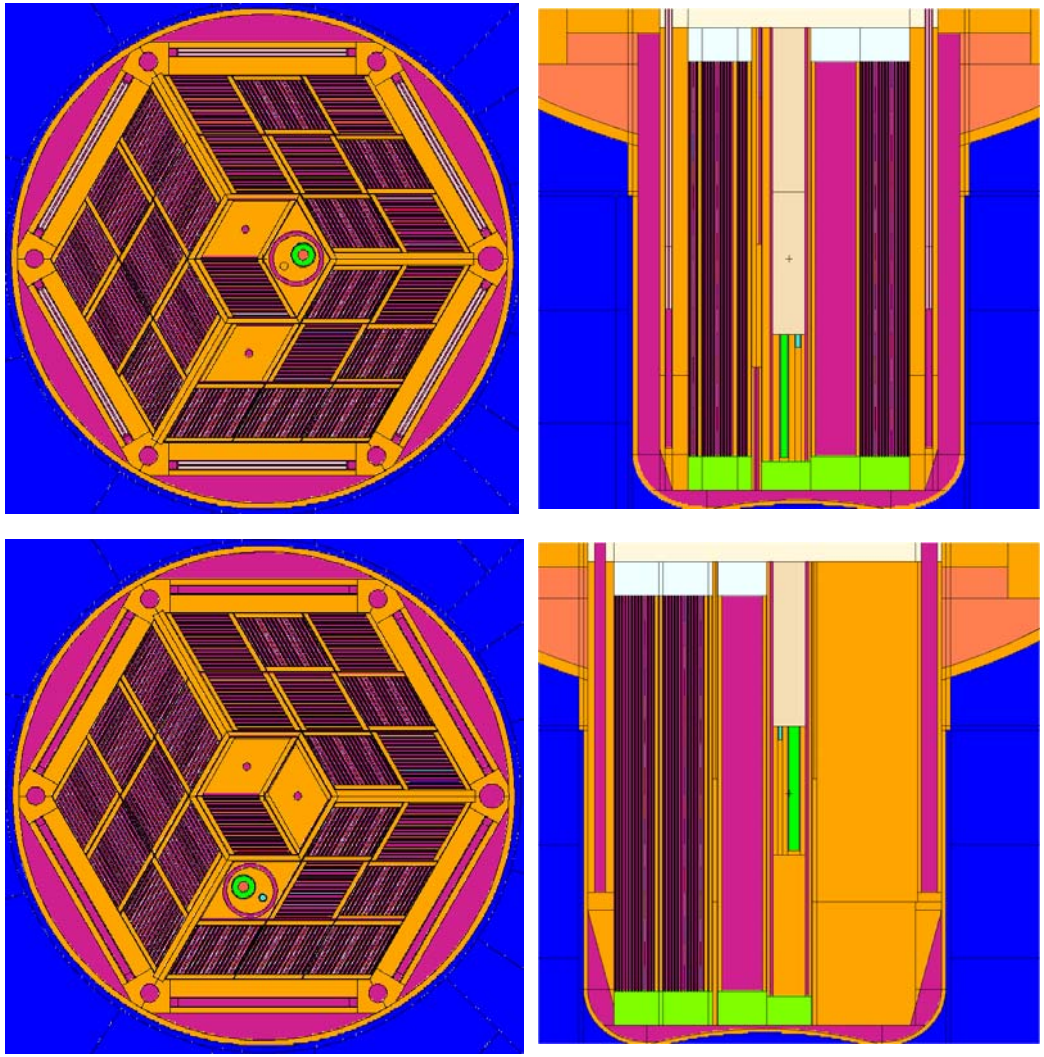



# Experiment Summary & Schedule

- Static Measurement at different power levels – 1 Location (A-1L)
- Temperature Measurements – 1 Location (A-1L)
- Static and Transient ("slow positive" and "fast negative") Tests – 4 Locations (A-1L, A-1U, B-3L, and B-3U)
- One-week experiment plan for the week of 07/24, the week of 07/31 as backup

| | Monday | Tuesday | Wednesday | Thursday | Friday |
|---|---|---|---|---|---|
| Experiment Setup | a.m. & p.m. | | | | |
| Test Plan #0 – Stepped Static Cases (A-1L) | | a.m. | | | |
| Test Plan #1 – Temperature Measurements Static and Transient (A-1L) | | p.m. | | | |
| Test Plan #2 – Static and Transient (A-1L) | | | a.m. | | |
| Test Plan #3 – Static and Transient (A-1U) | | | p.m. | | |
| Test Plan #4 – Static and Transient (B-3L) | | | | a.m. | |
| Test Plan #5 – Static and Transient (B-3U) | | | | p.m. | |
| Experiment Removal | | | | | a.m. & p.m. |

# Neutronics Summary



- All four test locations (A-1L, A-1U, B-3L, and B-3U) are preliminarily modeled and analyzed.
- Certain simplifications are made in the model, by preserving components mass.
- Due to considerable amount of water (~ 440 cc over the ~ 62.5 cm core region) between the dummy element and the experiments, a positive reactivity insertion (ranging from 0.15% to 0.25% Δk/k for different locations) is expected by implementing the experiments
- The effect is slightly stronger at B-3 position than A-1 position, because the former is surrounded with more fuel elements.
- The (highly unlikely) accident scenario for the "secured" experiment setting is determined to be, at "Lower Location", two (2) aluminum dummy spacer are inadvertently ejected and the space is replaced with water. The experiment holder and capsule will not be ejected at the meantime due to additional fixture for the hold-down tubing.
- The reactivity effect of the accident scenario is found no more than 0.35% Δk/k. This is well bounded by the 1.8% Δk/k for the experiment belongs to the "secured category".

# Summary

- The experiment is expected to operate the MITR with top lid open in natural convection (zero pump) mode. The experiment will be designed as "secured" category as many of our in-core experiments. The corresponding MITR Technical Specification (TS) requirements are as follows:
  a) *TS 3.1.4.5: The reactor shall not be operated at power levels of greater than 100 kW unless: primary coolant flow is established and reactor top shield lid is in position.*
  b) *TS 2.2: The Limit Safety System Settings (LSSS) for natural convection mode of MITR is "the maximum fuel clad temperature was calculated to be below incipient boiling if the pool temperature is maintained below the normal outlet temperature scram point of 60 °C, assuming MITR power level of 100 kW and a coolant height of 10 feet above the top of the fuel plate (4 inches below overflow)."*
  c) *TS 6.1.1: The reactivity worth of the experiment shall not exceed 1.8% Δk/k for "secured" category.*
- Sufficient safety margins will be maintained with existing the scram setpoints
  a) *High reactor power Scram at 80 kW*
  b) *Short reactor period Scram at 10-11 seconds*
  c) *High core coolant outlet temperature Scram at 55 °C*
  d) *Low level core tank at 4 inches below overflow*
  e) *An additional experiment Scram for temperatures in the sensor capsule at 300°C*
- Sample materials/weights well within scope of previous in-core experiments designed to operate at full-power. Fissile material weight is < 1 mg. Activities have been analyzed as part of final Safety Review.

# Neutronics Results

| Cases | Positions | keff | Reactivity |
|---|---|---|---|
| **No Experiment Insertion** | | **1.00832** | - |
| Reference TREAT Experiment | A-1L | 1.00984 | + 0.15% Δk/k |
| | A-1U | 1.01051 | + 0.21% Δk/k |
| | B-3L | 1.01030 | + 0.19% Δk/k |
| | B-3U | 1.01068 | + 0.23% Δk/k |
| *Hypothetical Accident Scenario* | *A-1L* | *1.01222* | *+ 0.23% Δk/k* |
| | *A-1U* | *1.01110* | *+ 0.06% Δk/k* |
| | *B-3L* | *1.01357* | *+ 0.32% Δk/k* |
| | *B-3U* | *1.01159* | *+ 0.09% Δk/k* |

- **All the calculated keff (by MCNP) have 1-sigma statistical uncertainty no more than 10 pcm.**
- **The (highly unlikely) accident scenario for the "secured" experiment setting is determined to be, at "Lower Location", two (2) aluminum dummy spacer are inadvertently ejected and the space is replaced with water. The experiment holder and capsule will not be ejected at the meantime due to additional fixture for the hold-down tubing**