April 22, 2015

MEMORANDUM TO: Victor G. Cusumano, Chief
Safety Issues Resolution Branch
Division of Safety Systems
Office of Nuclear Reactor Regulation

FROM: Ashley S. Guzzetta, Reactor Systems Engineer ***/RA/***
Safety Issues Resolution Branch
Division of Safety Systems
Office of Nuclear Reactor Regulation

SUBJECT: STAFF OBSERVATIONS OF BORIC ACID PRECIPITATION TESTING DURING A MARCH 30, 2015, TRIP TO THE TEXAS A&M UNIVERSITY IN COLLEGE STATION, TEXAS

On March 30, 2015, U.S. Nuclear Regulatory Commission (NRC) staff traveled to the Texas A&M University to observe testing associated with boric acid precipitation. The objective of this trip was to observe independent boric acid precipitation tests being conducted by the university. The participating NRC staff members were Ashley Guzzetta, Stephen Smith, and Victor Cusumano of the Safety Issues Resolution Branch in the Division of Safety Systems and Jeremy Dean and Leonard Ward from the Nuclear Performance and Code Review Branch. The staff interacted with graduate students and faculty of Texas A&M University.

The enclosure summarizes the staff's visit on March 30, 2015.

ENCLOSURES:
1. Trip Report
2. Appendix A - Test Procedure
3. Appendix B - Precipitation and Sedimentation Test Apparatus Presentation

CONTACTS: Ashley Guzzetta, DSS/SSIB
301-415-3201

Stephen Smith, DSS/SSIB
301-415-3190

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JDean, NRR LWard, NRR

ADAMS Accession Number: ML15112A149 **NRR-106**

OFFICE	NRR/DSS/SSIB	NRR/DSS/SSIB:	NRR/DSS/SSIB: BC
NAME	AGuzzetta	SSmith	VCusumano
DATE	04/ 22 /15	04/ 22 /15	04/ 22 /15

OFFICIAL RECORD COPY

OBSERVATIONS OF BORIC ACID PRECIPITATION TESTS AT TEXAS A&M UNIVERSITY

MARCH 30, 2015

Objective

On March 30, 2015, U.S. Nuclear Regulatory Commission (NRC) staff traveled to the Texas A&M University to observe testing associated with boric acid precipitation. The objective of this trip was to observe independent boric acid precipitation tests being conducted by the university.

The test witnessed by the NRC staff shows the basic visualization of boiling water with high boric acid concentration in a clear container. The test witnessed is just one test in a series of tests performed to assist in understanding the phenomena associated with boric acid precipitation (BAP) in nuclear reactors.

Overview of Facility

The test setup occupies a 5' by 10' area in one of Texas A&M University's offsite experimentation facilities. The building is used for experimental work and currently has a many experiments being carried out related to GSI-191.

Test Setup

In the current setup (see Figure 1), the Metering Pump draws a boric acid solution from the Reservoir to the top of the Test Section consisting of 41 heated rods simulating fuel rods in a reactor vessel. The heated solution actively boils and the vapor boiling off leaves the test assembly through the Vapor Exhaust. The experiment is held in a container with clear polycarbonate walls allowing easy visualization of the boric acid precipitation phenomenon. The maximum temperature of the experiment is 248ºF (120ºC). The fuel rods are 0.37 inch (0.95 cm) in diameter arranged in a square lattice. The rods are independently powered by power meters totaling up to 500 Watts each and totaling 20.5 kW.

ENCLOSURE 1

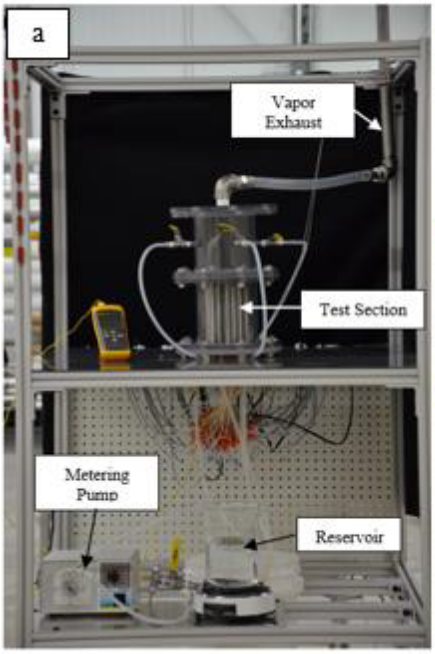


Figure 1. Experimental Test Setup for the Precipitation and Sedimentation Test Apparatus (PASTA)

Test Performance

The testing began by injecting one liter of boric acid solution to the Reservoir every 15 minutes. The heated rods were being powered with 4 kW. When the Metering Pump was stopped to add another liter of boric acid solution to the test assembly, all precipitate fell to the bottom of the test assembly as seen in Figure 2.

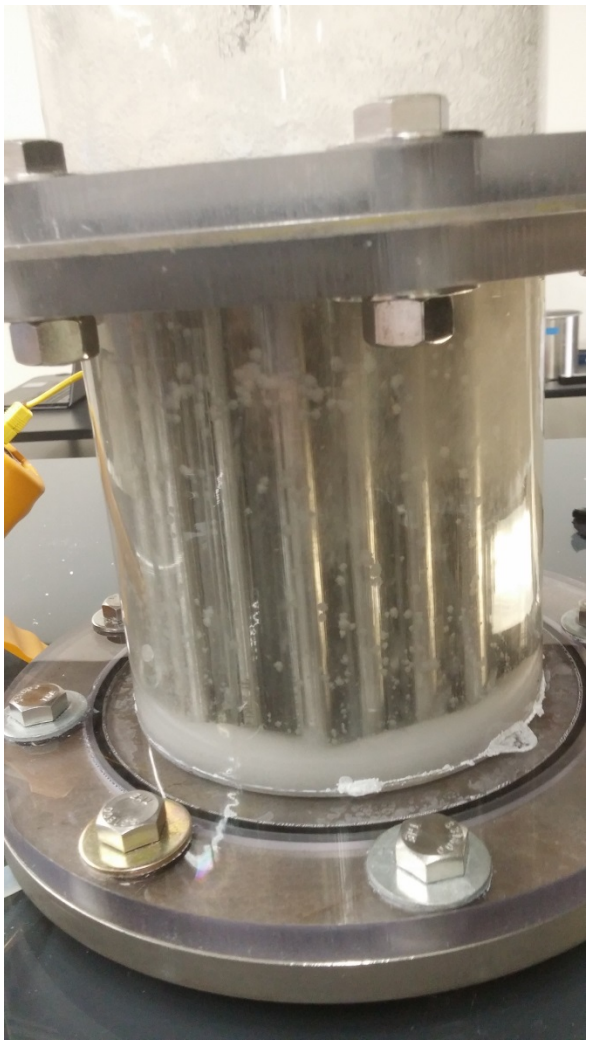


Figure 2: BAP on Bottom of Test Section when Metering Pump is stopped

Boric acid precipitation started to occur at about 75 minutes into the test after five liters of boric acid solution were added to the test assembly. It was observed that precipitation occurs on the walls of the test assembly and as agglomerations of precipitate of varying size. The boric acid solution and precipitate are vigorously mixed by the currents caused by boiling. This is seen in Figure 3. As a note, no precipitation was seen on the heated rods. This can be attributed to the temperature of the rods being greater than the precipitation temperature of the boric acid in the solution.

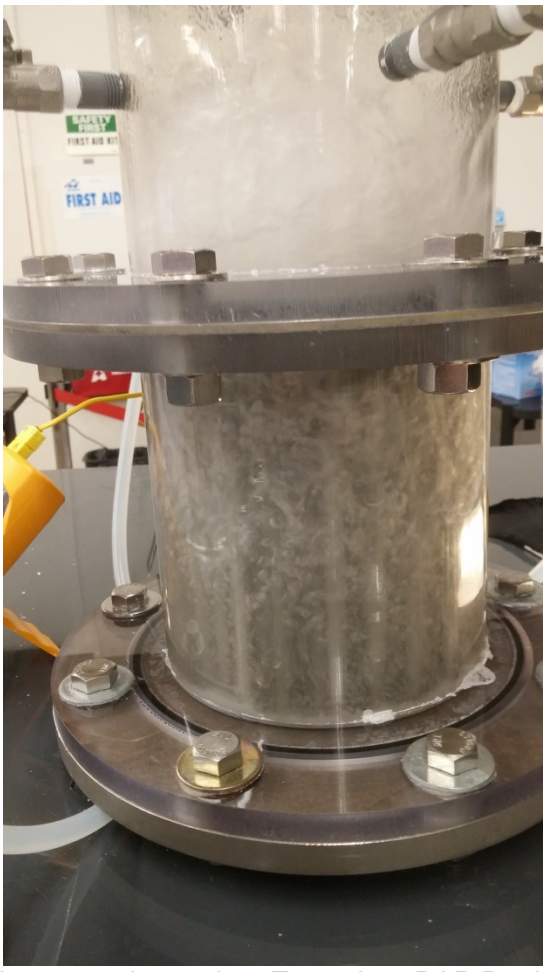


Figure 3: About 75 minutes into Test when BAP Begins to Occur

After about 2 hours of testing, boric acid solution was no longer added to the reservoir and the heater rods were continued to be powered. As vapor continued to boil off, the volume of solution in the test assembly decreased and the amount of precipitation and size of precipitate agglomerations increased as seen in Figures 4 and 5.

Figure 4: BAP in the Test Section after Boric Acid Solution Addition was ceased

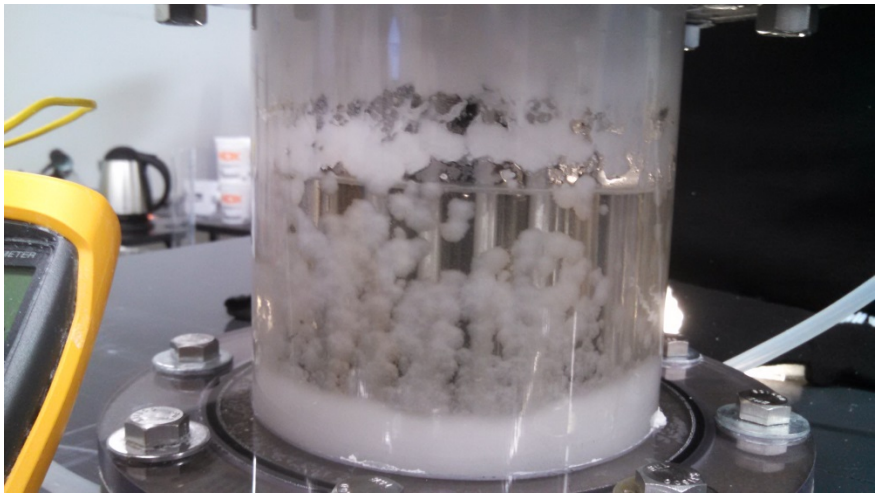


Figure 5: A Closer Look at BAP in the Test Section after Boric Acid Solution Addition was ceased

Summary

The NRC staff became more familiar with the BAP testing being performed at Texas A&M University as a result of witnessing the PASTA experiment. The testing was will assist in understanding the phenomena associated with boric acid precipitation in nuclear reactors.

ENCLOSURE 2
Appendix A - Test Procedure

TECHNICAL DOCUMENT COVER PAGE

Document No:	TAMU-PASTA-TPC	Revision: 1.0 Date: 3/28/15	Page 1 of 21
Doc Title: TAMU PASTA Test Procedure			
Project No: N/A			
Project Name: N/A			
Client: N/A			
Document Purpose/Summary: This procedure provides the instructions for preparation and operation of the PASTA test facility. Total Page Count: 21 pages.			
Continuous Use Procedure			

TECHNICAL DOCUMENT COVER PAGE

Document No: TAMU-PASTA-TPC	Revision: 1.0	Page 2 of 21

	Printed/Typed Name	Signature	Date
Prepared By:	Philip Jones		3-28-15
	Mason Childs		3/28/15
TAMU Reviewed By:	Rodolfo Vaghetto		03/28/2015

REVISION HISTORY LOG

Document Number: TAMU-PASTA-TPC Revision: 1.0

Document Title: TAMU PASTA Test Procedure

REVISION	DATE	DESCRIPTION
1.0	3/28/15	First release

TABLE OF CONTENTS

DEFINITIONS AND ACRONYMS

PASTA	Precipitation And Sedimentation Test Apparatus
DEGB	Double Ended Guillotine Break
GSI	Generic Safety Issue
LB	Large Break
LOCA	Loss of Coolant Accident
MB	Medium Break
NRC	Nuclear Regulatory Commission
SB	Small Break
PWR	Pressurized Water Reactor
TAMU	Texas A&M University

1.0 PURPOSE

The purpose of this document is to provide instructions to conduct boron precipitation experiments on the PASTA test facility at Texas A&M University (TAMU).

2.0 EXPERIMENTAL FACILITY

The facility was designed for high temperature tests in presence of chemicals. The facility consists of an acrylic cylindrical section (test section) with 41 heated rods. A variable speed metering pump injects boric acid solution through the injection lines into the test section to compensate the liquid water lost by evaporation, continually increasing the concentration of boric acid until precipitation occurs.

3.0 TEST PROCEDURE

3.1 GENERAL PROCEDURE

This section describes how to use this document. Sections 3.2 through 3.4 must be completed before the actual experiment can begin, outlined in section 3.5.

Section 3.2 describes how to prepare the general materials required, 3.3 describes how to prepare the PASTA facility, and 3.3 describes how to prepare the solution.

When initiating a step of the procedures, the step will be marked with an "O". The "O" will be crossed when the step is completed. Steps that are skipped, or do not apply to an experimental run, will be marked as N/A.

3.2 MATERIALS PREPERATION

The following steps provide instructions for preparing the materials that will be required during the experiment.

Prerequisite Materials

- 11 Plastic closed containers (Figure 1a)
- Minimum of 1260 g of boric acid
- Minimum of 5 gallons of DI water
- 10 glass vials with a 16 mL indicator mark (Figure 1b)
- 10 Trays with each containing 2 lab foils (Figure 1c)
- Safety masks for boric acid handling

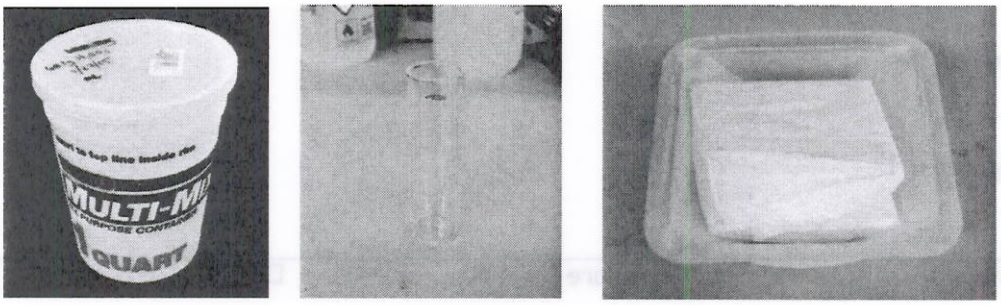


Figure 1a. Plastic container used for boric acid preparation. b. Glass vial for sampling with 16 mL indicator. c. Tray and foils used for sample drying.

Date: _____

1. _____ Ensure the 16 mL indicator on the glass vials is clearly visible
2. _____ Label the trays 1-10, and measure with the foil in the tray
3. _____ Record the masses of the trays in Table 3.2.1.
4. _____ Prepare 660 g of boric acid in a closed plastic container
5. _____ Prepare 10 x 60 g of boric acid in closed individual plastic containers

Tray Number	Measured mass (g)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Table 3.2.1. Test sampling tray masses

Signatures:

Test Operator 1

Name	Signature	Date

Test Operator 2

Name	Signature	Date

Quality Assurance Officer or Test Reviewer

Name	Signature	Date

3.3 TEST SECTION PREPARATION

The following steps provide instructions for setting up the facility to begin the experiment.

Prerequisite Materials

- 1 hot plate with stirring capability (Figure 2a)
- Water Heater – a tea kettle works well
- Stainless steel rod
- Syringe, minimum of 20 mL
- 2 Thermocouple readers
- 2 x 2000 mL clean glass beaker
- 1000 mL clean glass beaker
- 1000 mL clean graduated cylinder
- Stainless steel container, minimum of 2500 mL

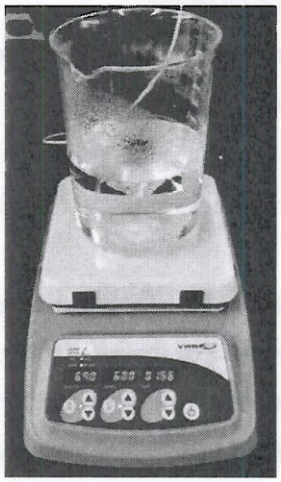


Figure 2a. Stirring hot plate used for boric acid batch solution preparation.

Date: _____

1. _____ Fill the test facility with DI water until the heater rods are completely covered – 2500 mL.
2. _____ Connect the thermocouple reader to the thermocouple inside the test facility.
3. _____ Turn on only a few of the rods, or a maximum of 400 W to slowly increase the water temperature until boiling.
4. _____ Add the 660 g of boric acid to the 2500 mL clean stainless steel container.
5. _____ Using the water heater, heat up an excess of 2800 mL of DI water to boiling.

6. _____ Add 2000 mL of hot DI water to the 660 g of boric acid in the stainless steel container and stir with stainless steel rod until as much of the boric acid is dissolved as possible.
7. _____ Place the stainless steel beaker with the 660 g solution near the PASTA facility and.
8. _____ Turn off the heaters in the test facility and open the valves to drain the DI water from the facility via the lower drain into the catch bucket located below the test section.
9. _____ Prepare a small amount (approximately 300 ml) of hot DI water in a clean glass beaker and connect to the suction of the PASTA metering pump.
10. _____ Open the selected injection port and turn on the metering pump to flush the injection with hot DI water.
11. _____ Turn off the pump and immediately close the injection valve to ensure that water remains in the injection lines.
12. _____ Close the drain valves used to drain the water from the test section.
13. _____ Pour the 2000 ml heated solution (step 7) from the stainless steel container into the test section.
14. _____ Use the remaining hot DI water container to clean any remaining boric acid from the container and add to the test facility. (Note the total volume of DI water injected in steps 14 and 15 must be 500 ml)
15. _____ With a syringe filled with DI hot water from the remaining 500ml, clean the walls of the upper test section with heated DI water.
16. _____ Ensure the liquid level is at the top of the steel plate.
17. _____ Close the top lid of the facility, confirming the O-ring is properly set.
18. _____ Install and hand-tighten the lid hold-down bolt.
19. _____ Connect silicon hose exhaust to the vertical exhaust pipe.
20. _____ Place video camera and adjust settings to view the experimental facility. Turn off audio recording.
21. _____ Take a final picture of the facility after test preparation.

Procedure notes:

Signatures:

Test Operator 1

Name	Signature	Date

Test Operator 2

Name	Signature	Date

Quality Assurance Officer or Test Reviewer

Name	Signature	Date

3.4 Batches Preparation

The following steps provide the instructions for preparing the boric acid solutions that will be injected during the duration of the experiment.

Prerequisite Materials

- DI water from section 3.2
- Boric acid from section 3.2
- Water heater
- Hot plate with temperature control and stirring device

Date: _____

Preparation of Batch 1

1. _____ Prepare 1000 ml of hot DI water.
2. _____ Add 60 g of boric acid in a 2000 mL glass beaker.
3. _____ Add the hot DI water prepared in step 1 to the beaker.
4. _____ Use the stirring hot plate, set at 69, to keep solution agitated and hot
5. _____ Place the beaker of solution on the injection reservoir heater.
6. _____ Place the suction hose from the metering pump into the solution.
7. _____ Place the thermocouple probe into the solution and turn on the thermocouple reader.
8. _____ Monitor the temperature of the solution and ensure it remains at approximately 70°C - 80°C throughout the entirety of the experiment.

Preparation of Subsequent Batches

1. _____ Begin preparing subsequent batch immediately after adding a batch to the injection reservoir.
2. _____ Follow steps 1-4 from the batch 1 preparation to make another 1 L solution of 100 g/L concentration.

Procedure notes:

Signatures:

Test Operator 1

Name	Signature	Date

Test Operator 2

Name	Signature	Date

Quality Assurance Officer or Test Reviewer

Name	Signature	Date

3.5 TEST EXECUTION: TEST #_____

The following steps provide instructions for operating the PASTA facility. The test initiation is outlined below. Throughout the experiment it will be required to check that the level of solution in the test section remains just over the plate. It will also be required to take samples during the experiment to later determine the concentration of the solution.

Prerequisites

- Prepared batches of boric acid solution
- Timer
- Camera
- Backlight
- Vials and trays
- Syringe
- Cold DI water

Date: _____

Test Initiation

1. _____ These steps are to be completed after Test Preparation procedures.
2. _____ Turn on the video camera and backlight.
3. _____ Record the time of test initiation and start timer. _____
4. _____ Turn on all switches for the electrical heaters.
5. _____ Calibrate heaters' power by adjusting the knob on the power supply while reading the output from the power meter. Fine tune the power supplies until each power meter reads 400 W (Each power supply will be approximately 40%).
6. _____ Check power after 5 minutes for stability.
7. _____ Record each reading from the power meters and total to determine total power output from the heaters.

   _____

   _____

   Total: _____ kW.
8. _____ Monitor the water as the temperature increases until complete dissolution of boric acid.

9. _____ Perform first **Solution Level Check** (see next section). If liquid level is below target, turn on pump until the appropriate level is reached.
10. _____ When all boric acid is dissolved and the solution is boiling and clear, begin injection by starting the pump and opening the injection valve (Pump should start at approximately 30-35%).
11. _____ Start pump and record the start time of injection. _____ m:s.
12. _____ When 300 mL solution remains in the injection reservoir, add the prepared solution batch to the injection reservoir beaker.
13. _____ Record the time of solution batch addition in Table 3.5.1.
14. _____ Record time of experiment termination. _____ m:s.
15. _____ Stop camera recording.
16. _____ Turn off experimental facility heaters and injection pump.

Solution Level Check

This is suggested to be repeated at each batch injection

1. _____ Ensure the experimental facility heaters and injection pump are turned off.
2. _____ Check the solution level in the test facility.
3. _____ Adjust pump rate with heaters off until more suitable level is achieved.
4. _____ Turn heaters and pump back on.
5. _____ Check power and fine tune if necessary.

Sampling

1. _____ Record the time of sampling in Table 4.0.1.
2. _____ Fill the vial with solution from the test section to the marked 16 mL level by opening the sampling valve.
3. _____ Immediately pour the solution into the tray without the lab foils in them.
4. _____ Clean boric acid from the vial with small amounts of DI water with the syringe.
5. _____ Pour any remaining DI water in the vial into the tray.

6. _____ Repeat steps 4 and 5 until vial is clean.
7. _____ Replace lab foils in the tray and allow to absorb the solution.
8. _____ Place the tray on the drying plate.

Batch Number	Injection time
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Table 3.5.1. Time of batch injections.

Procedure notes:

Signatures:

Test Operator 1

Name	Signature	Date

Test Operator 2

Name	Signature	Date

Quality Assurance Officer or Test Reviewer

Name	Signature	Date

3.6 TEST SECTION CLEANING

The following steps provide instructions for cleaning the precipitated boric acid from the test section

Prerequisites

- DI Water

Date:_____

1. _____ Turn on only a few rods to boil at a much lower rate than during the experiment.
2. _____ Remove the boric acid injection reservoir from the lower hot plate.
3. _____ Replace with a beaker containing hot DI water.
4. _____ Turn on the pump to a fairly high speed and inject until the water level is at the injection nozzles.
5. _____ Open the lower sampling valve and allow the solution to drain into the lower catch bucket.
6. _____ Close the valve when the water level reaches the plate.
7. _____ Repeat steps 4 through 6 until the water is completely clear and there is no longer precipitated boric acid on any of the test section interior surfaces.
8. _____ Turn off the heaters.
9. _____ Allow the facility to reach room temperature.
10. _____ Drain the facility.

Procedure notes:

Signatures:

Test Operator 1

Name	Signature	Date

Test Operator 2

Name	Signature	Date

Quality Assurance Officer or Test Reviewer

Name	Signature	Date

4.0 DATA ACQUISITION

The following steps provide instructions for measuring the samples to determine the concentration of the sample when it was taken during the procedure.

Date: _____

1. _____ Remove the samples from the drying plate and measure their masses with a scale (weight is assumed to be final when the scale reading is stable)
2. _____ Record their masses on table 4.0.1.

Tray Number	Acquisition time	Measured mass (g)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Table 4.0.1. Test sample acquisition time and masses

Procedure notes:

Signatures:

Test Operator 1

Name	Signature	Date

Test Operator 2

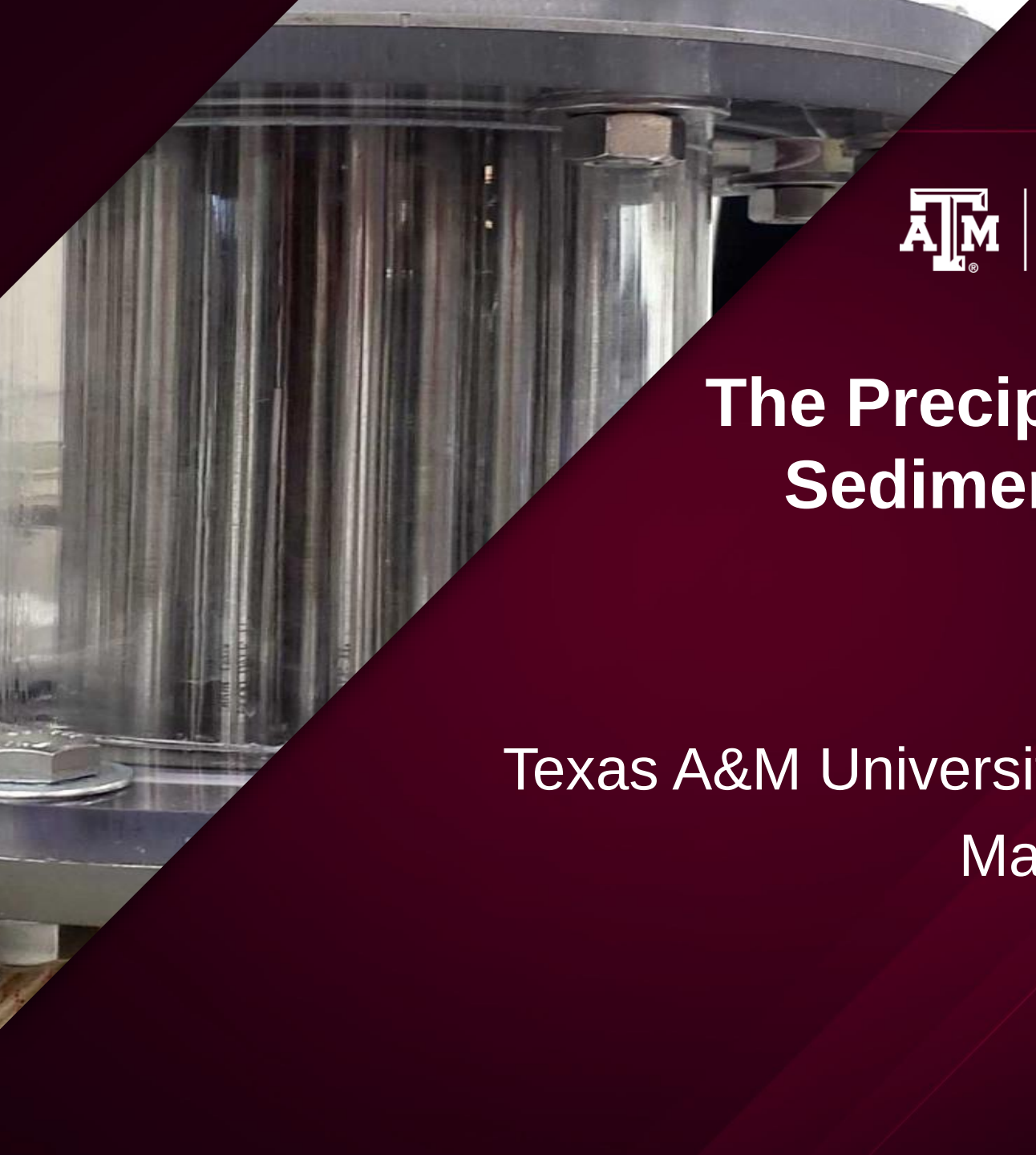
Name	Signature	Date

Quality Assurance Officer or Test Reviewer

Name	Signature	Date

ENCLOSURE 3

Appendix B - Precipitation and
Sedimentation Test Apparatus Presentation



NUCLEAR ENGINEERING
TEXAS A&M UNIVERSITY

The Precipitation And Sedimentation Test Apparatus

Texas A&M University Capabilities

March, 19th 2015

Table of Content

- Purpose
- The Beaker Experiment
- Questions Raised
- The Precipitation And Sedimentation Test Apparatus
- Timeline

Purpose

- Provide a description of recent research activity conducted at Texas A&M University on BAP
- Show the capabilities developed in the Thermal-Hydraulic Laboratory at TAMU and potential future research on BAP
- Establish Technical Communication between the NRC staff and TAMU for current and future research needs.

The Beaker Experiment

- Basic visualization of boiling water with high BA concentration
- Precipitation of BA in boiling water in an open clear container
- Basic learning and understanding of the phenomena involved

The Beaker Experiment

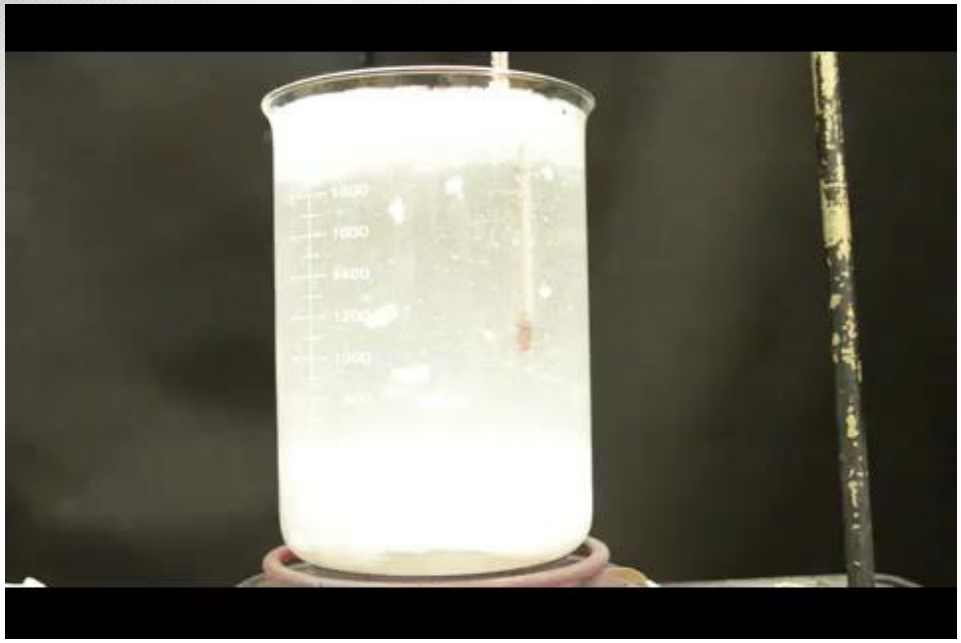
- 275 g of boric acid (Optibor ® Orthoboric Acid, H_3BO_3)
- 2000 ml of DI-water
- C_0 = 137.5 g/l

- Expected BA solubility limit (C_s = 275 g/l) to be reached at approx. 1000 ml water level

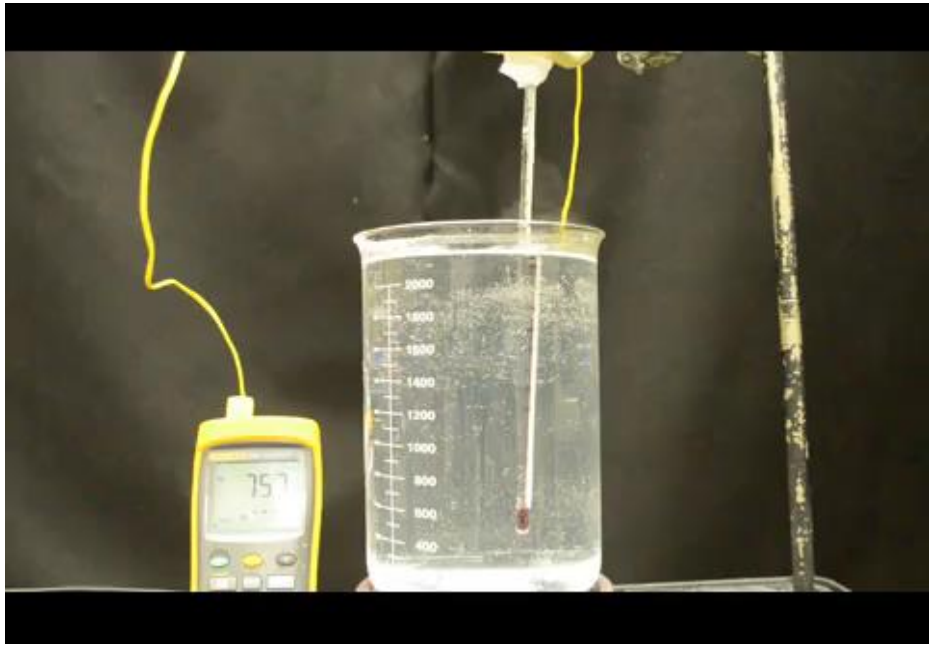
- No water addition during the experiment (water left evaporating over time)

K. P. Crapse, E. A. Kyser, III, “Literature Review of Boric Acid Solubility Data”, Savannah River National Laboratory report, SRNL-STI-2011-00578 (2011)

The Beaker Experiment



Early Stage - 1



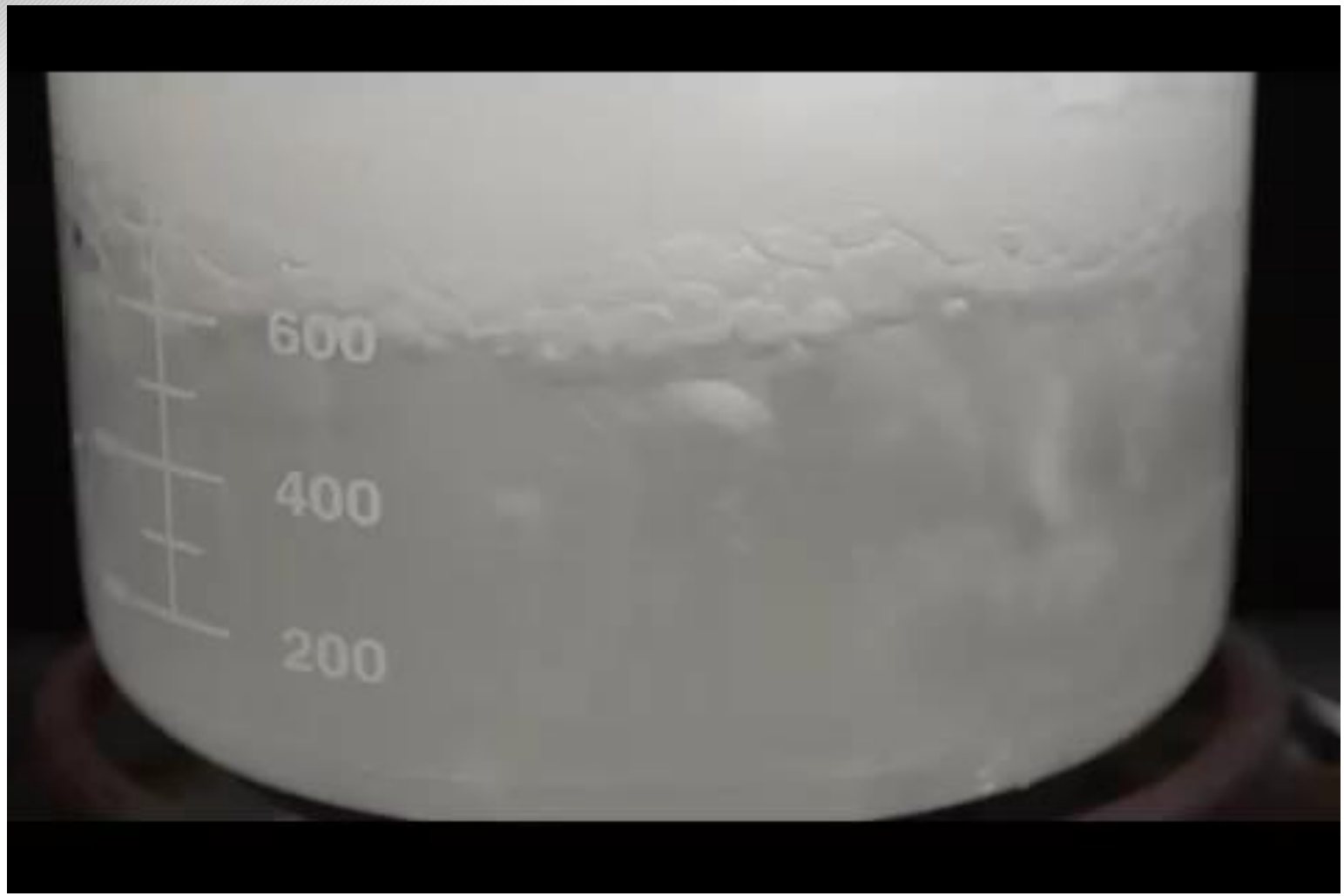
Early Stage - 2

The Beaker Experiment

Middle Stage

Later Stage

The Beaker Experiment



Final Stage

Questions raised after the Beaker Experimental Observations

- Differences and Analogies between Beaker and Pin Bundle
  - Geometry
  - Heat Transfer
  - Effect of Precipitation

The Precipitation And Sedimentation Test Apparatus (PASTA)

- Provide more realistic test environment than the beaker
- Supply larger power
- Allow controlled flow injection
- Allow flow visualization for qualitative analysis (including area between rods)
- Allow quantitative measurements of Boric Acid Concentrations

PASTA – Main features

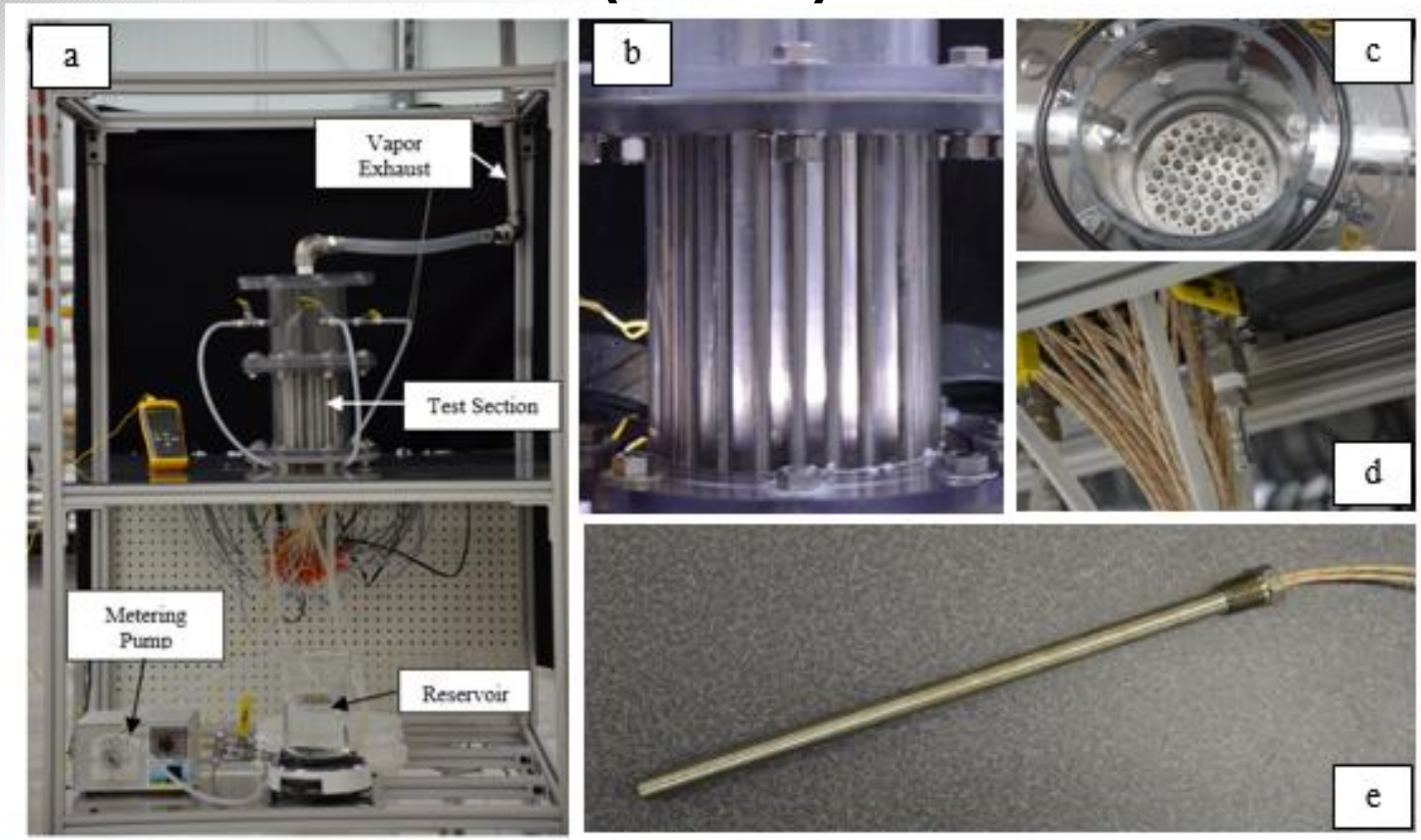
- **Clear Polycarbonate Walls**
  - 360° Flow Visualization
  - Max Temp = 120 °C

- **41 heated rods**
  - Square Lattice
  - 0.95 cm Diameter
  - 500 W each (total power installed = 20.5 kW)
  - Rods independently powered (power meters installed)

- Controlled Injection Flow Rate
- 4XTop + 2XBottom Injection Locations
- 2X Sampling Ports
- 2X k-type Thermocouples

- Easy to operate and clean

The Precipitation And Sedimentation Test Apparatus (PASTA)



a. Facility Overview
b. Test Section
c. Test Section (Top View)
d. Sampling Ports
e. Heated rod

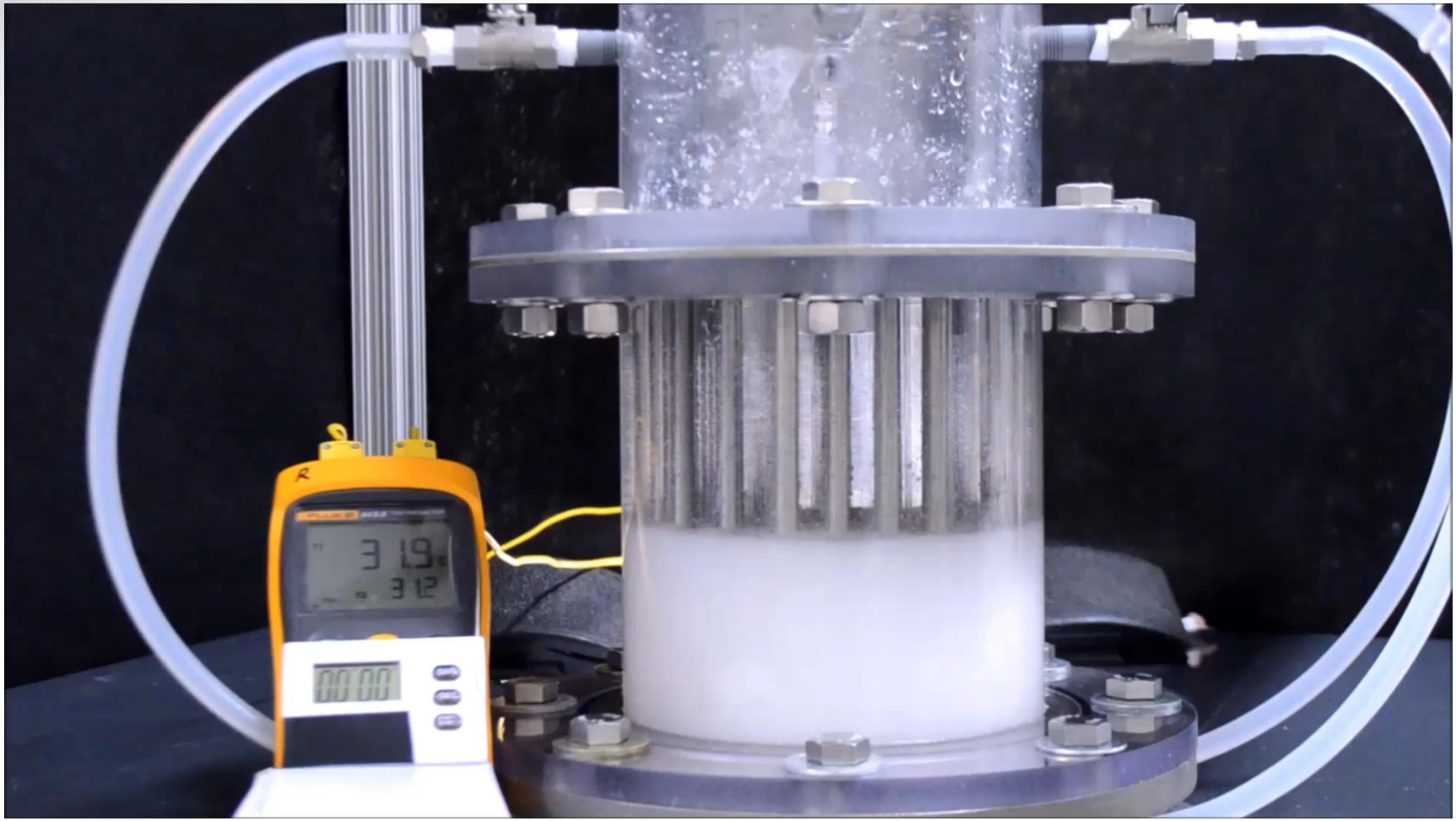
Experimental Activity Performed

- Shakedown Tests at ~2.5 kW
- Shakedown Tests at ~ 4 kW

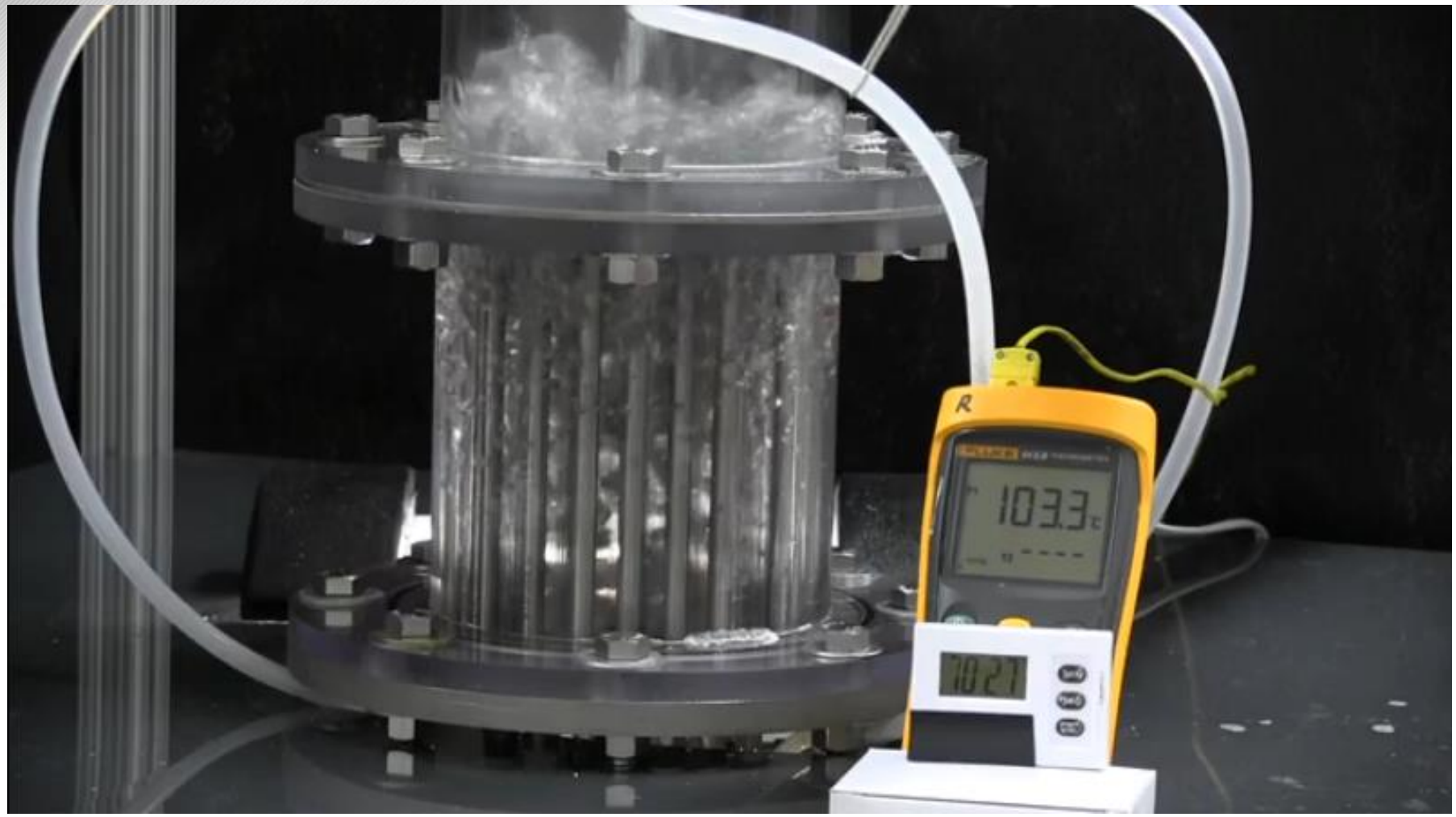
- Shakedown for Sampling Methodologies and Concentration Measurements

- BA Concentration Calibration (Calibration Curve and Error Estimation)

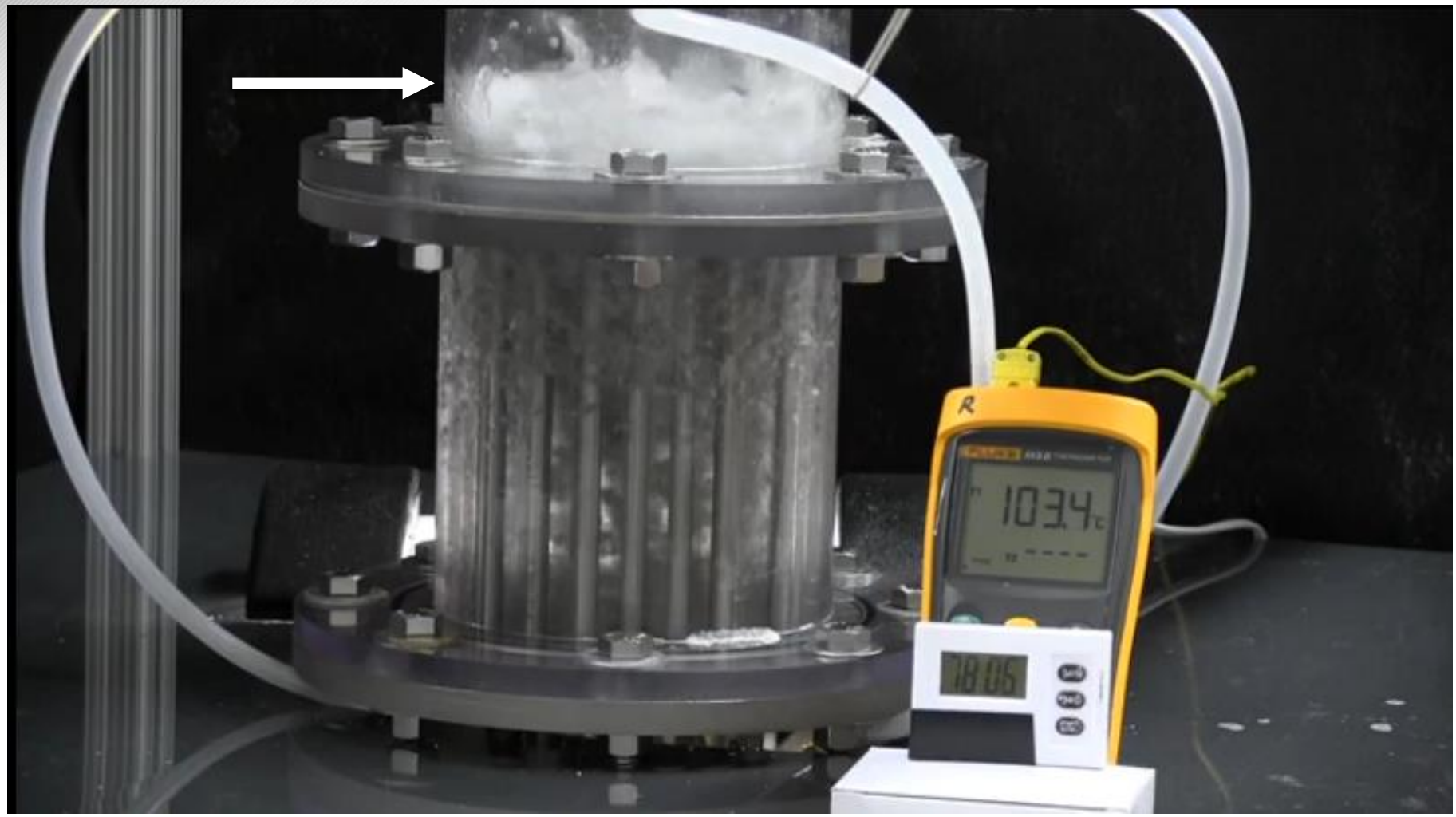
Video Sample



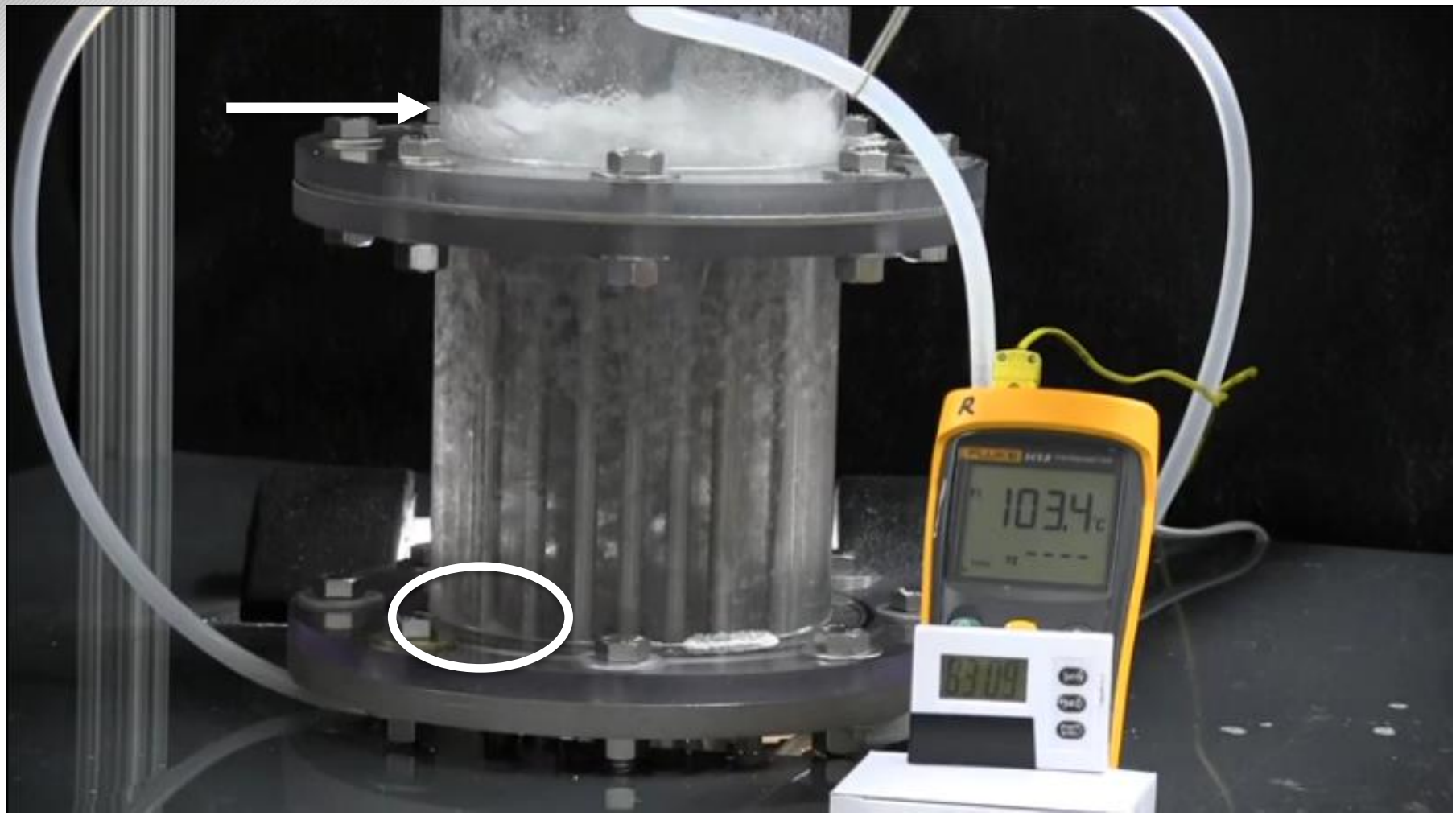
Shakedown – Snapshot 1/4



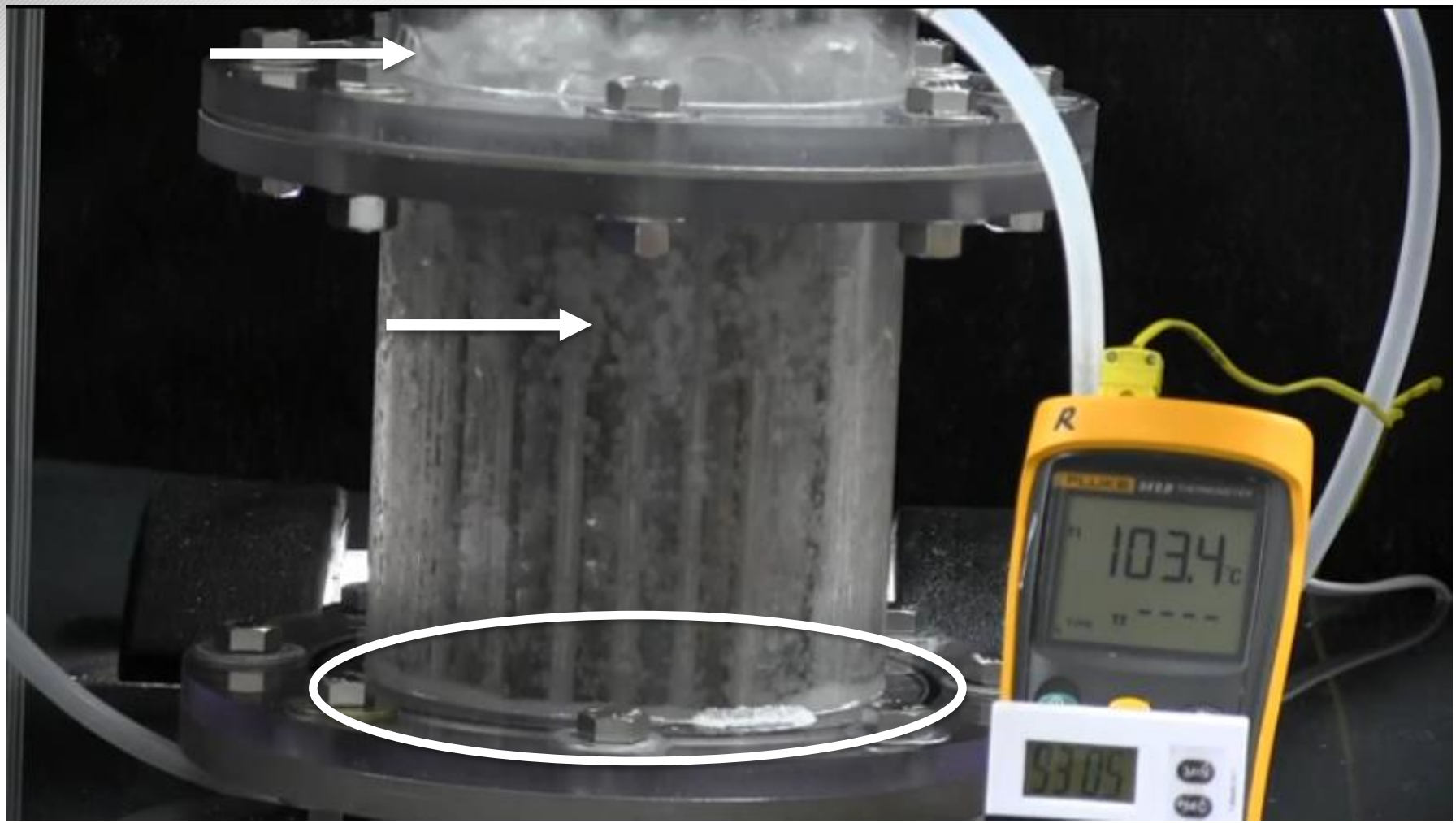
Shakedown – Snapshot 2/4



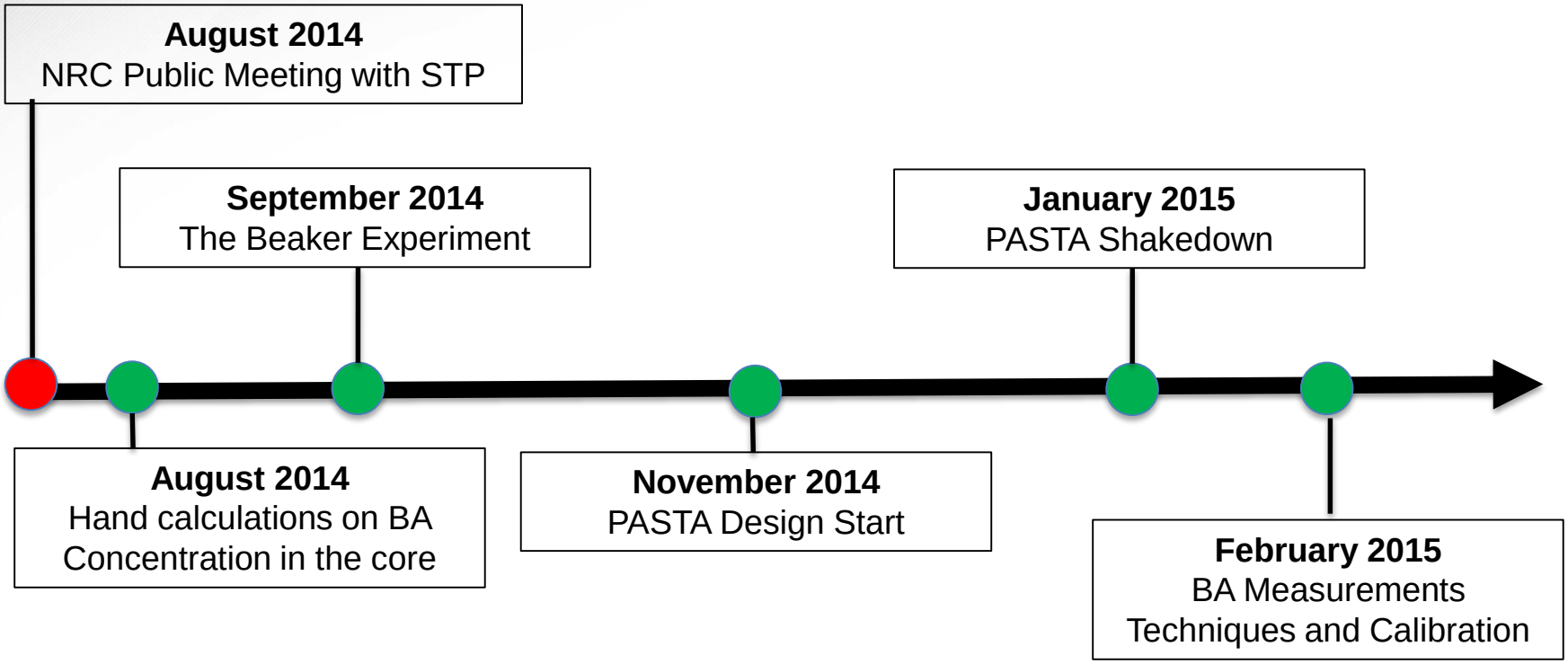
Shakedown – Snapshot 3/4



Shakedown – Snapshot 4/4



Timeline


August 2014
NRC Public Meeting with STP
September 2014
The Beaker Experiment
January 2015
PASTA Shakedown
August 2014
Hand calculations on BA Concentration in the core
November 2014
PASTA Design Start
February 2015
BA Measurements Techniques and Calibration

Discussion

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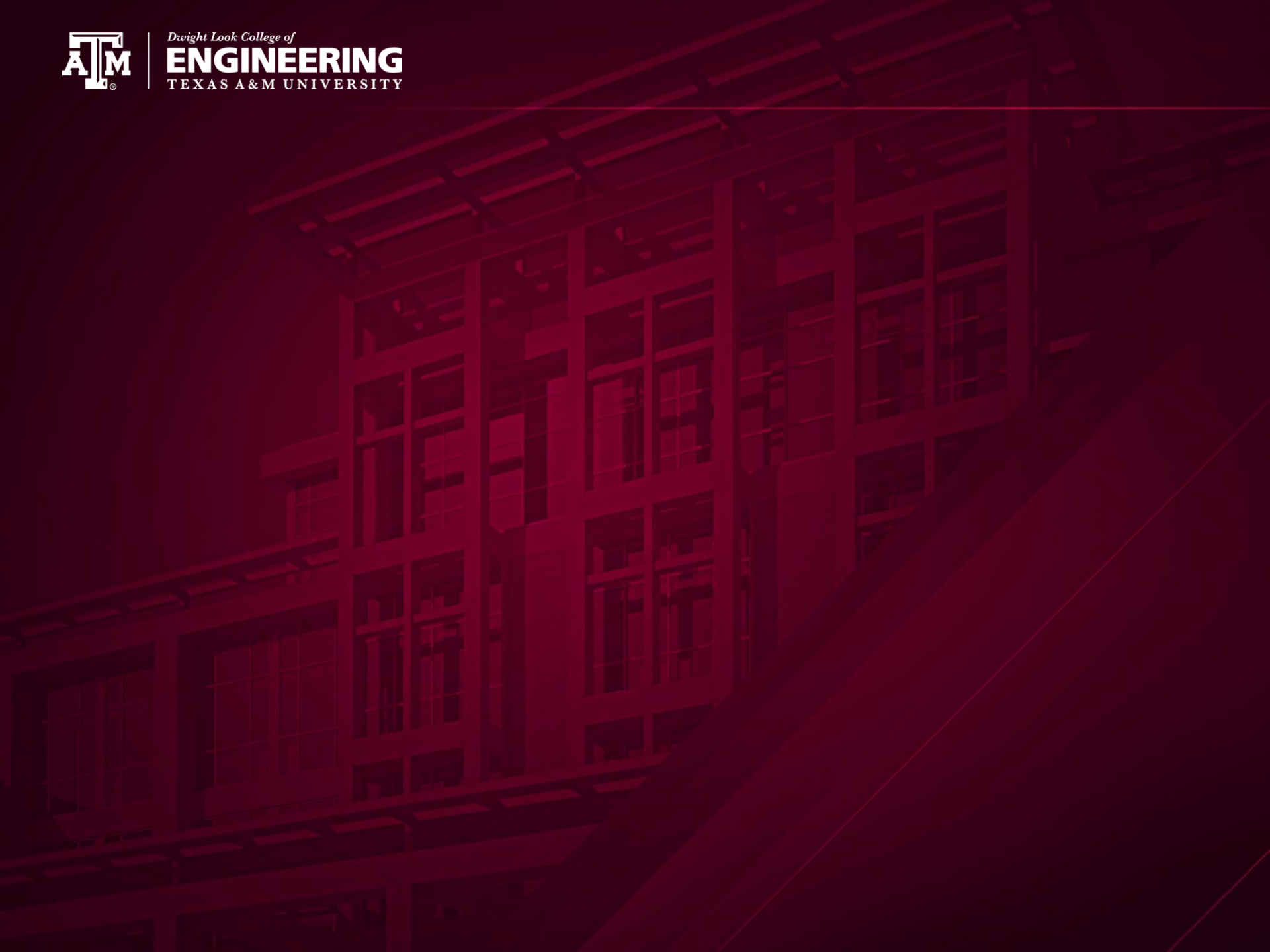
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