U.S. EPR™ Control Rod Drive Mechanism (CRDM) Test Results RAI 95 (Q 03.09.04-1b)

AREVA NP and the NRC

April 9, 2009

Introduction

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Agenda

- Introductions (R. Wells)
- Meeting Objectives (R. Wells)
- RAI 95 Question 03.09.04-1b Overview (R. Wells)
- U.S. EPR CRDM Test Program Description (F. Champomier)
- U.S. EPR CRDM Performance Test Results (F. Champomier)
- U.S. EPR CRDM Stability and Endurance Test Results (F. Champomier)
- Conclusions (F. Champomier)
- Inspection Findings (F. Champomier)

Meeting Objectives

- Discuss the basis for the response to RAI 95, Question 03.09.04-1b.
- Provide an overview of the testing that has been performed for the U.S EPR CRDMs being conducted in Germany at the KOPRA test facility for the U.S. EPR design.
- Discuss the test results for the U.S EPR CRDMs.
- Respond to NRC questions.

RAI 95 Question 03.09.04-1b

- **NRC Question:**
  - **Section 3.9.4.4 of the FSAR: Confirm that for mechanical adequacy of CRDS, a prototype testing program comprised of performance, stability and endurance tests was created. Provide status and results of the prototype testing program and the range of environmental conditions that supports it.**
- **AREVA NP Response:**
  - **Prototype testing for the U.S. EPR design is comprised of performance, stability and endurance tests. The performance tests verify the adequate performance of the equipment in a range of temperature, pressure and flow rate conditions. Stability tests ensure proper functioning is achieved over an amount of time in normal conditions. Both of these tests have been completed for the U.S. EPR design. The endurance tests quantify the amount of time and/or number of steps during which no appreciable mechanical damage possibly altering the correct mechanical behavior is to be expected. Testing is currently being conducted in Germany at the KOPRA test facility for the U.S. EPR design.**

U.S. EPR CRDM Test Program Description

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U.S. EPR CRDM Test Program Description

- **Testing conducted at the KOPRA test facility in Germany.**
  - **Objectives of the tests.**
  - **Description of the test setup.**
  - **Test program.**
  - **Results in various conditions normal or abnormal (performance tests).**
  - **Results in nominal conditions (stability and endurance tests).**

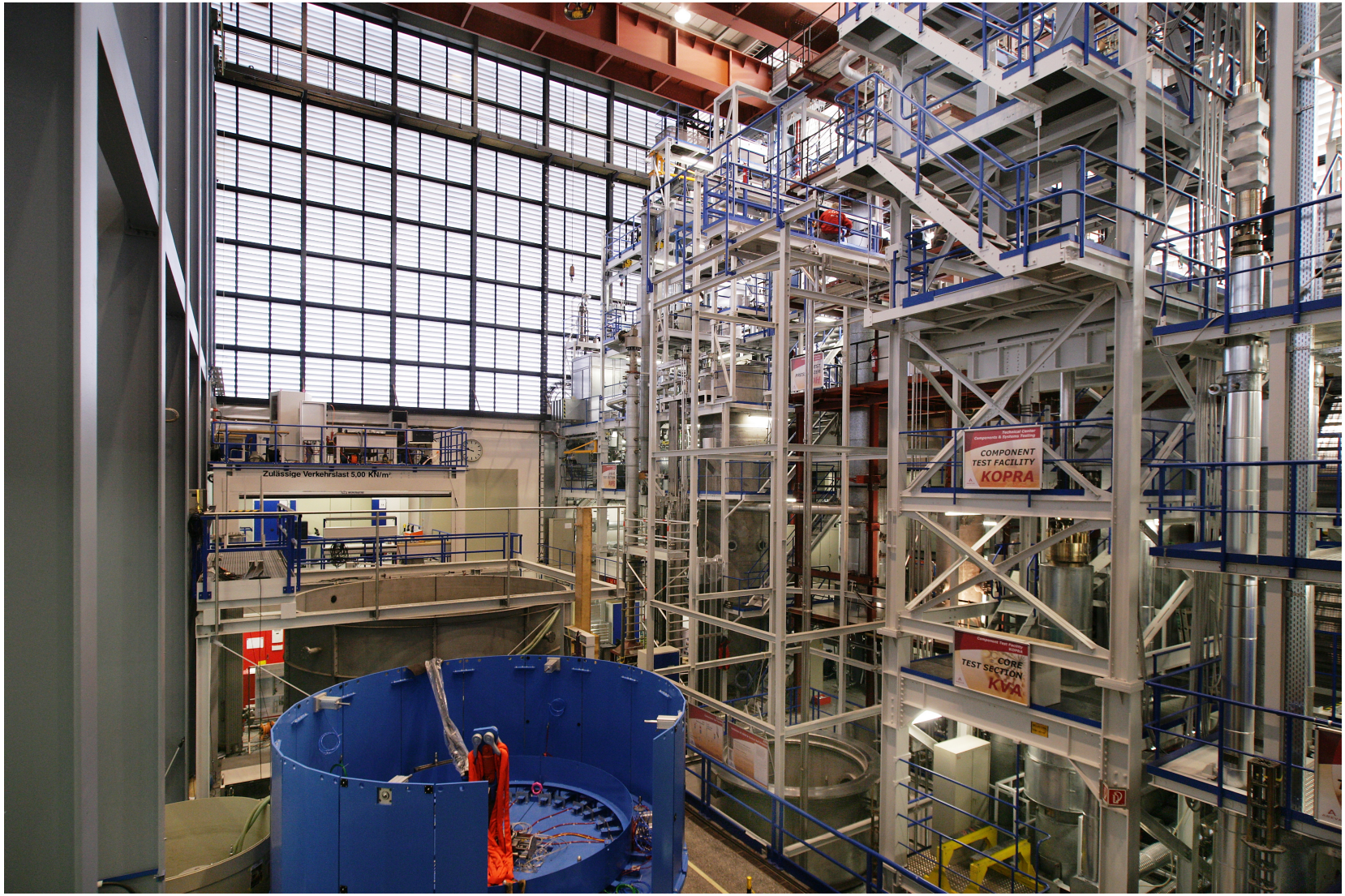
Test Objectives

- **Demonstrate the correct functioning of a prototype of the complete control rod line with CRDM pressure housing, coil stack assembly, latch unit, the control rod line (CRL), drive rod, control rod guide assembly (CRGA), rod cluster control assembly (RCCA), and fuel assembly (FA).**
  - **Performance tests to verify the adequate performance of the equipment in all conditions, whether normal or abnormal, in step by step operating mode with periodic drops.**
  - **Stability tests to ensure that proper functioning is reliably achieved over an appreciable amount of time.**
  - **Endurance tests to quantify the amount of time and/or the number of steps that can be performed with no unacceptable damage (notably wear).**

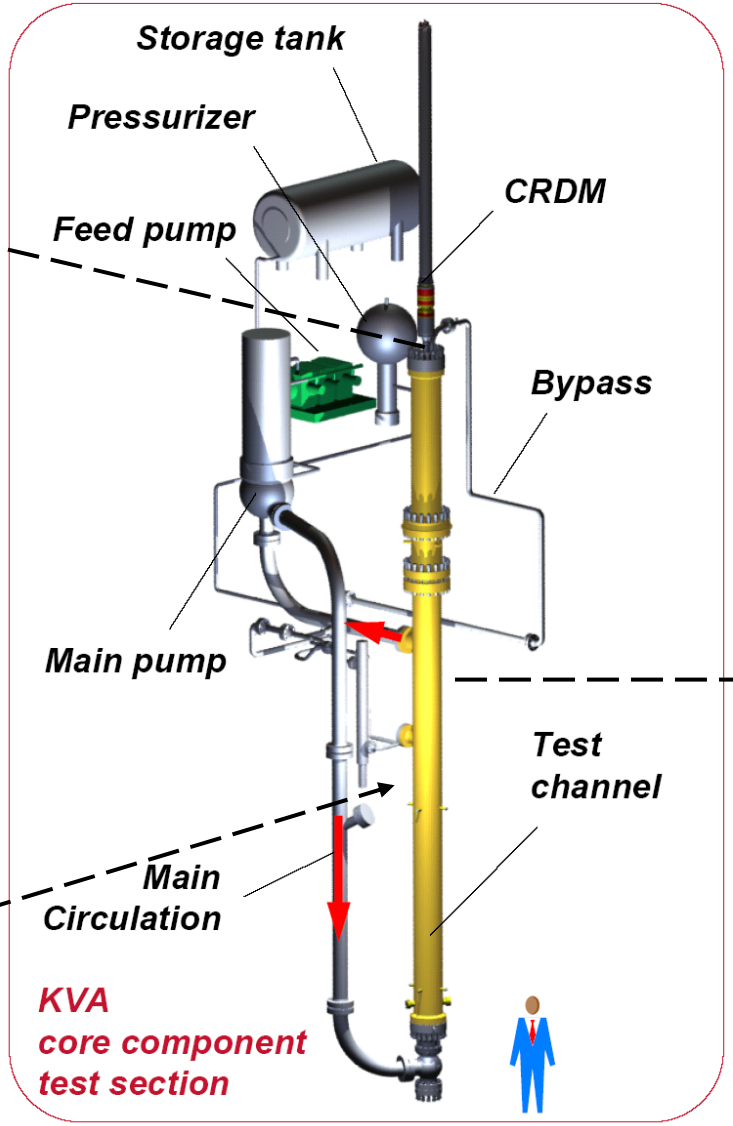
Test Objectives

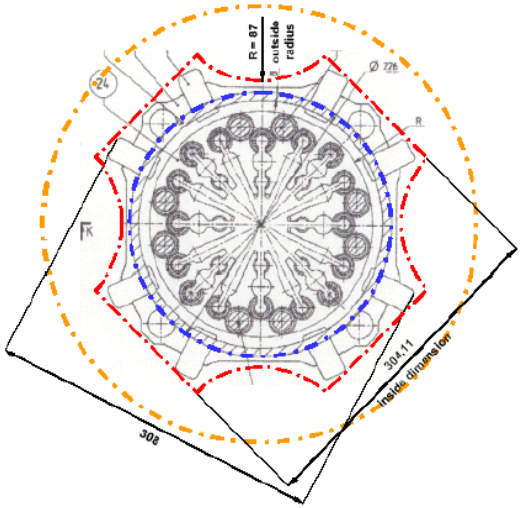
- Gather information on the behavior of the system in order to verify and/or improve available simulation procedures and codes. The rod drop time evaluation procedure is especially concerned (CIGAL software code). Specific tests have been dedicated to this objective.
- Contribute to the manufacturer qualification. For the demonstration, the full scale prototype is to be representative of the final component as it is to be manufactured.
- The fact that a complete scale 1:1 system is tested can only be fully meaningful if all items are tested together in their definitive and final configuration.

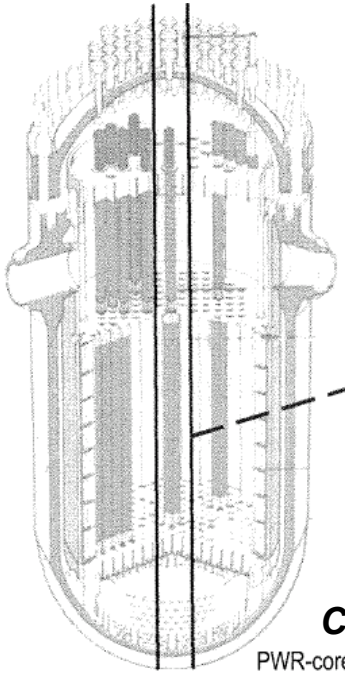
CRDM Test Setup



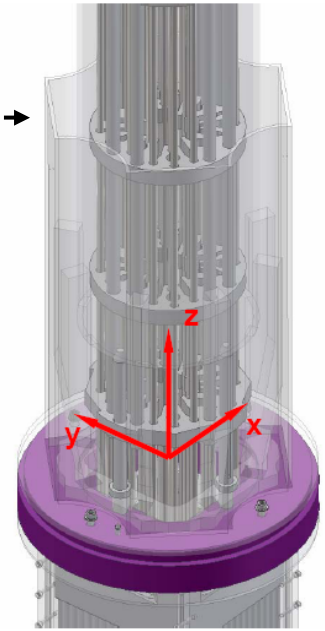
CRDM Test Setup







CRGA in central position

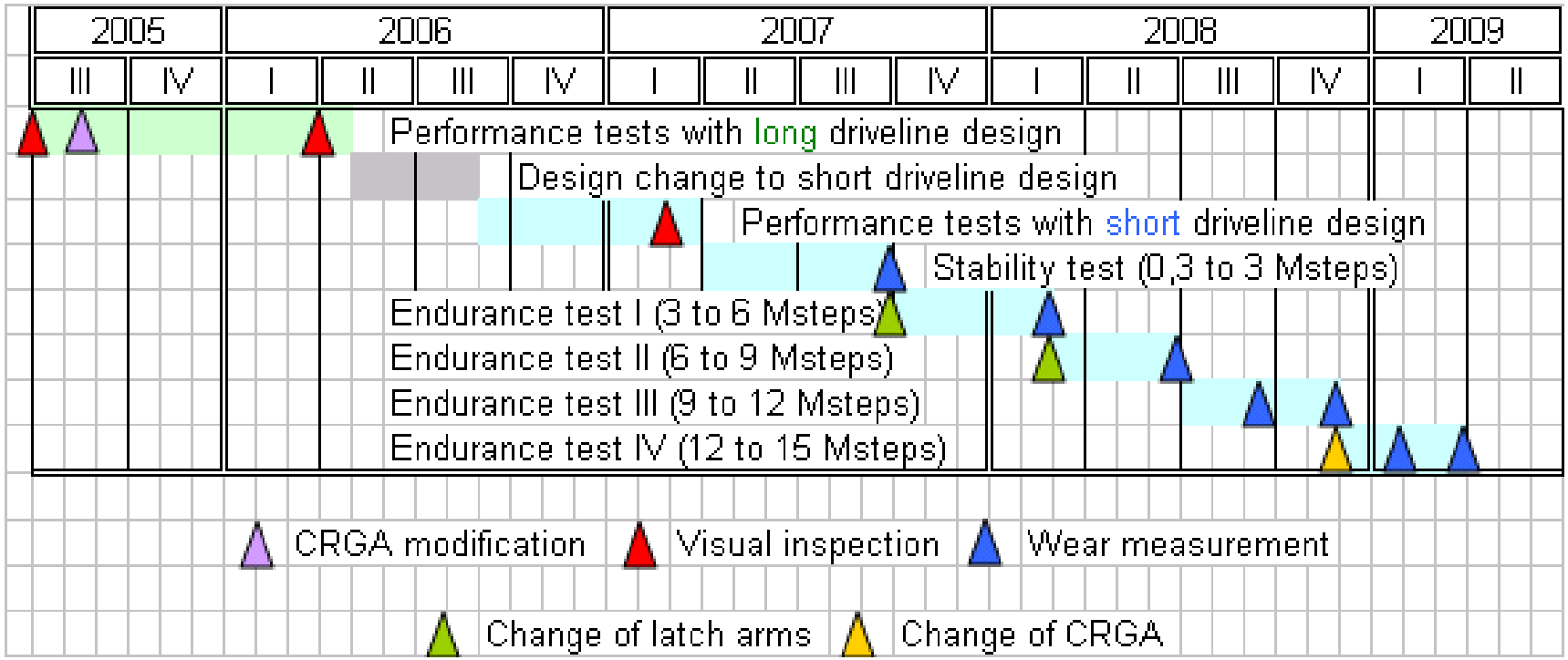


Maximum confinement

CRDM Description

Schematic of test setup

Test Schedule



Performance Tests: Hydrothermal Conditions

- Pressure and temperature varying from ambient to nominal values.
- Axial flow rate from FA, Q1, varying from 0 to 120% of nominal value.
- Auxiliary flow rate from or to the dome, Q2, (through CRGA cover plate), varying from minimal (negative) value to maximal (positive) value: -3 to + 7% of Q1.

Q_1/nominal Q_1		0%	60%	80%	100%		120%
Stepping frequency		nominal	nominal	nominal	nominal (+ lower)		nominal
Rod withdrawal		total except specified	total	total	total		total
Temperature	Q_2/ Q_1						
ambient (50 °C)	-3%				24		26
100 °C	0%				34		36
	0%	38 - 40(partial)	42-44	446-48	50-52		54-56
200 °C	7%		58-60	62-64	66-68		70-72
	-3%		74-76	78-80	82-84		86-88
	0%		90-92	94-96	98	100	102-104
320 °C	7%		106-108	110-112	114	116	118-120
	-3%		122-124	126-128	130	132	134-136

Performance tests ND-P3.x : x value for systematic drops in various hydrothermal conditions.

Performance Tests: Hydrothermal Conditions

- In contrast to reactor conditions, in the KOPRA loop, the FA is a dummy assembly and there is no heat transfer while the fluid goes through the core. Temperature and fluid flow are essentially unchanged with elevation along the FA (i.e. isothermal conditions). Comparison is necessarily made with mean on site core characteristics.
- In the KOPRA tests, the nominal Q1 value is 524 m^3/hr (18,505 ft^3/hr). This value is practically equal to the mean value expected on site: 24,925 kg/sec (54,950 lb/sec) or 530 m^3/hr (18,717 ft^3/hr) for a fluid at 312°C (594°F), mean core temperature. The 120% value also investigated covers variations associated to the position within the core.
- Maximal temperature is 320°C (608°F). This value is slightly higher than the expected mean core temperature at full power operation (594°F; CL=565°F; HL=624°F). This value is justified when associated to lower values (392°F, 212°F, and 122°F). The tests thus allow to verify that, in the temperature domain covered (122°F to 608°F), the physical phenomena governing drop times do not change.

Performance Tests: Drag Tests

- **Low pressure and ambient temperature.**
- **Axial flow rate from FA, Q1, varying from 0 to 120% of nominal value.**
- **Auxiliary flow rate from or to the dome, Q2, (through CRGA cover plate), varying from minimal (negative) value to maximal (positive) value: -3 to + 7% of Q1.**

	Q2 (%Q1)		
Q1 (%nominal)	**-3**	**0**	**+7**
0		1 drag up and down	
60	1 drag up and down	1 drag up and down	1 drag up and down
80	1 drag up and down		1 drag up and down
100	1 drag up and down	2 drags up and down	1 drag up and down
120			1 drag up and down

Drag tests allow measuring apparent mobile set weight versus elevation. For a given elevation, the friction force against fixed parts is derived.

Performance Tests: Displacement and Snap Back Tests

- **Low pressure and ambient temperature.**
- **No flow rate Q1 or Q2.**

Fixed/free (cantilever) mode			**displacement from top of PH**		
tests with assembled steel case (funnel)					
Number of tests	Measured parameter	Displaced condition	Mode	Driveline level	Displaced position
6	Force	PH top 0 to 100 mm	static continuous	low/middle/high	0/90 degrees
10	Drop time	PH top 10/30/50/75/100 mm	static/oscillating	high	
Fixed/fixed mode			**displacement from middle of PH**		
tests without assembled steel case (funnel)					
Number of tests	Measured parameter	Displaced condition	Mode	Driveline level	Displaced position
6	Force	PH middle 0 to 15 mm	static continuous	low/middle/high	0/90 degrees
6	Drop time	PH middle 5/10/15 mm	static/oscillating	high	

For comparison, the gap associated to the top displacement limiter is 38 mm.

Displacement and snap back tests allow estimating the influence of a distorted PH on drop times, contributing to the CRDM seismic behavior assessment.

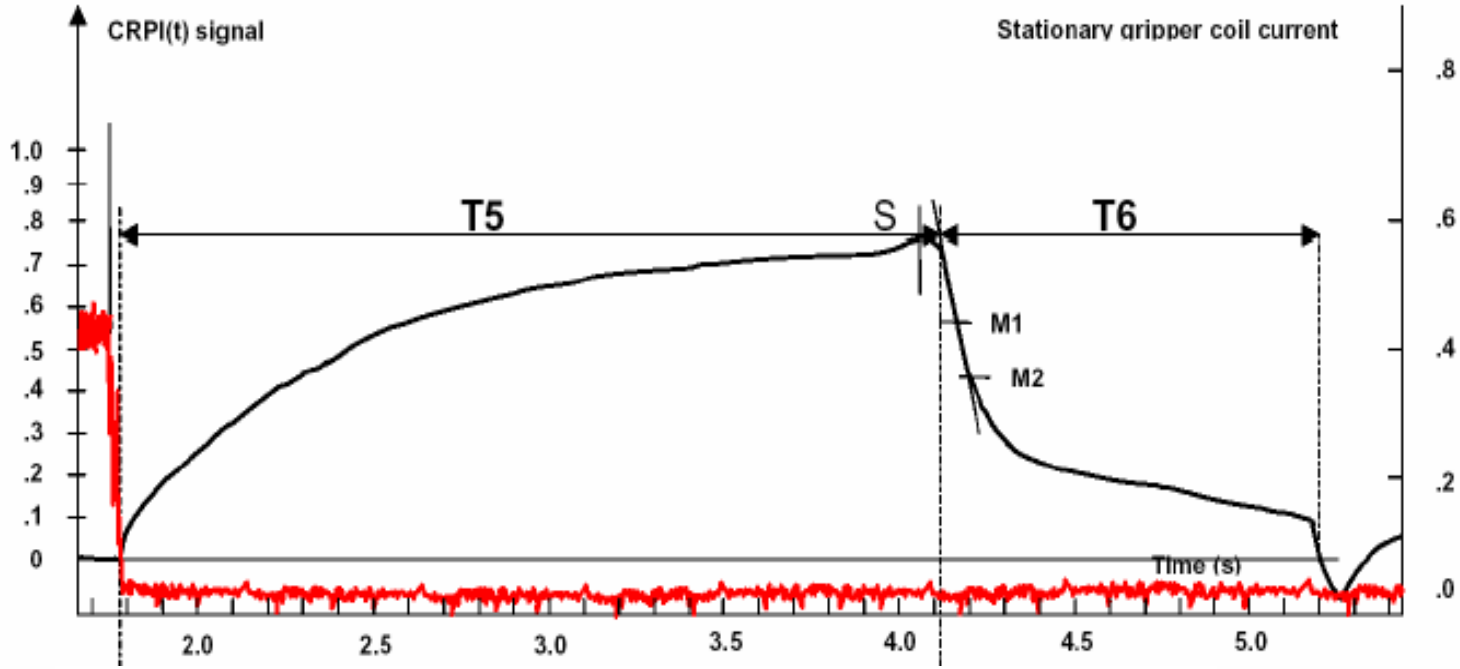
General Measurements

- Record drop times in order to:
  - Validate the computational model predicting drop times (i.e., CIGAL).
  - Justify the ability of the code to extrapolate (after penalization) and simulate additional conditions not experimentally tested.
  - Guarantee respect of the requirements regarding drop times.
  - Detect any drift indicating a state of degradation of the system.

General Measurements

- While performing a number of operations (up stepping, down stepping and drops) greater or equal to the number anticipated for 60 years of operating time.
- Periodically record operating parameters (coil currents, armature closing and releasing times) in order to:
  - Verify the stability of the electronic/mechanical behavior of the system.
  - Detect any drift indicating a state of degradation of the system.
- Periodically inspect for measurable degradation progress in order to:
  - Identify the weak points in the system (concerns endurance, wear but no corrosion or vibrational effects).
  - Detect any change in a degradation phenomenon.
  - Finally, demonstrate the adequate mechanical behavior of the system as regards the assigned endurance target.

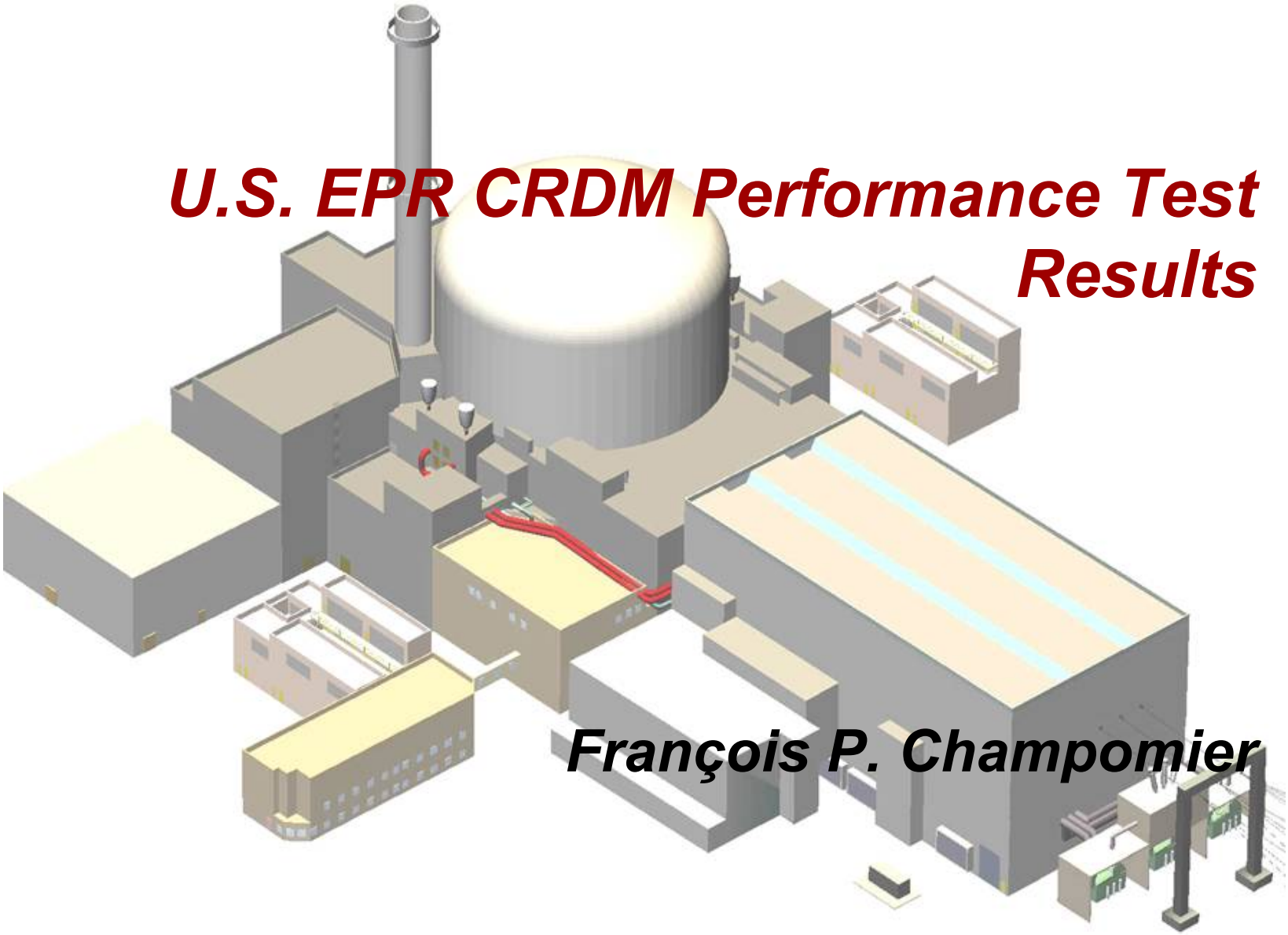
Test Program



Typical Rod Position Indicator signal (close to velocity) vs. time

- **Measured drop times.**
- **Drop time from beginning of motion (coil signal) to entrance of RCCA into the FA dash-pot (end of velocity plateau).**
- **Drop time between RCCA entrance into the FA dash-pot (end of velocity plateau) and first contact between RCC-A spider and FA top nozzle adapter plate (noise detection).**

U.S. EPR CRDM Performance Test Results



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Performance Tests

Drop times vs. flow rates, Q1 and Q2

- **In nominal conditions (320°C, 100% Q1), defined drop times are 2.0 and 2.8 sec, respectively .**
- **Drop times increase with Q1 (up to 3.3 sec with 120% Q1: axial overflow). Negligible effect of Q2.**

Performance Tests

Rod drop times decrease with increasing temperature.

Performance Tests

Drag force vs. DR elevation, flow rate Q_1 (Q_2 = 0), number of steps

4

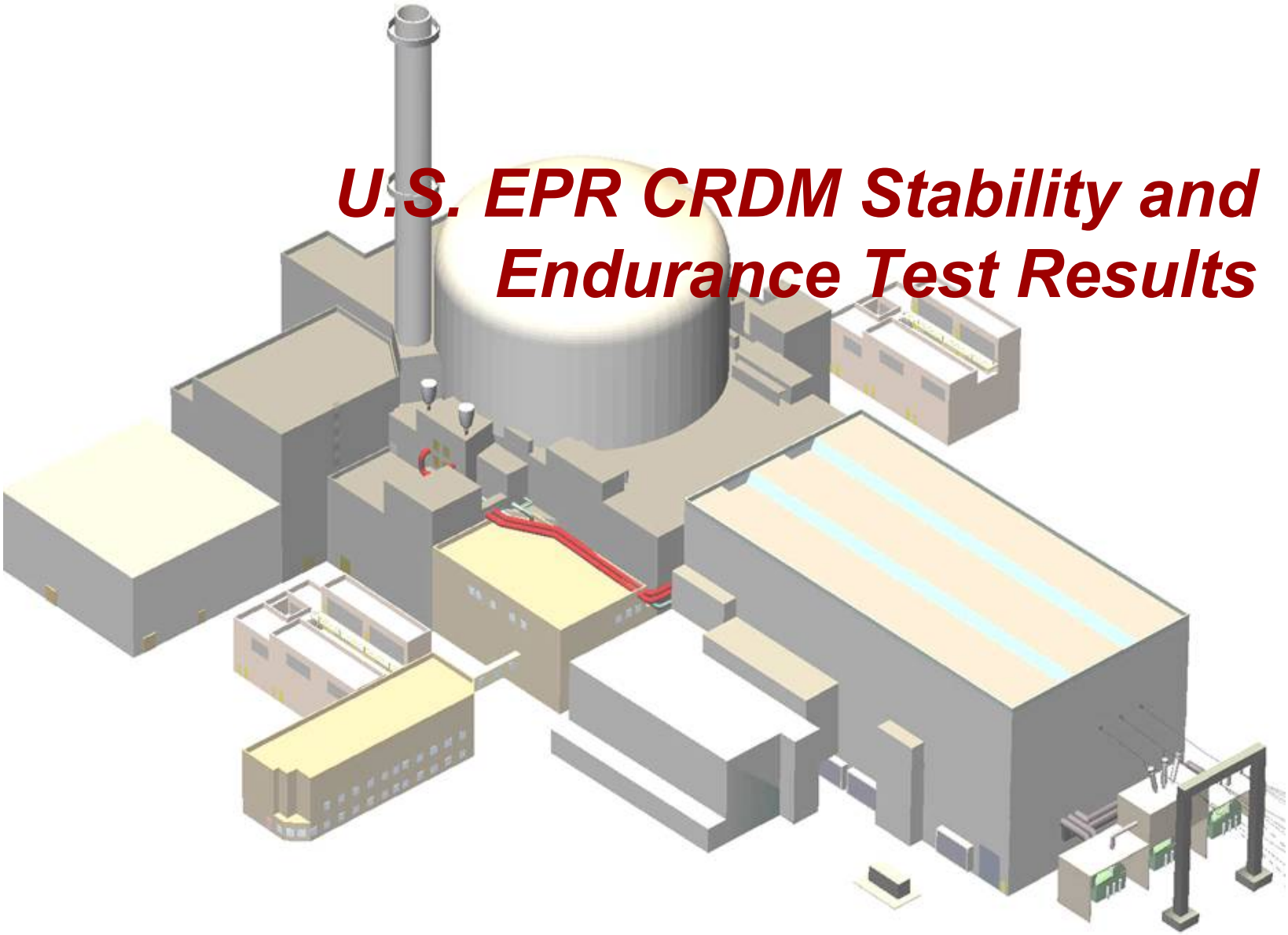
Drag force varies with Q1 and elevation and is reasonably constant with number of steps.

Performance Tests

Drop time measurements with a distorted PH
Cold conditions, no flow

- **The displacement range investigated covers that expected during earthquakes.**
- **Independence of dropping behavior from PH distortion due to seismic excitation is verified.**

U.S. EPR CRDM Stability and Endurance Test Results



Total operations

Total number of steps

Test step	Performed CRDM steps				
	Total	At 320°C	At 200°C	At 100°C	At 50°C
Sum	15,325,375	15,183,147	78,894	17,722	45,612

Total number of drops

Test step	Performed RCC-A drops				
	Total	At 320°C	At 200°C	At 100°C	50°C
Sum	1062	858	109	14	81

Stability and Endurance Tests

Main result: no significant evolution of drop times with number of steps.

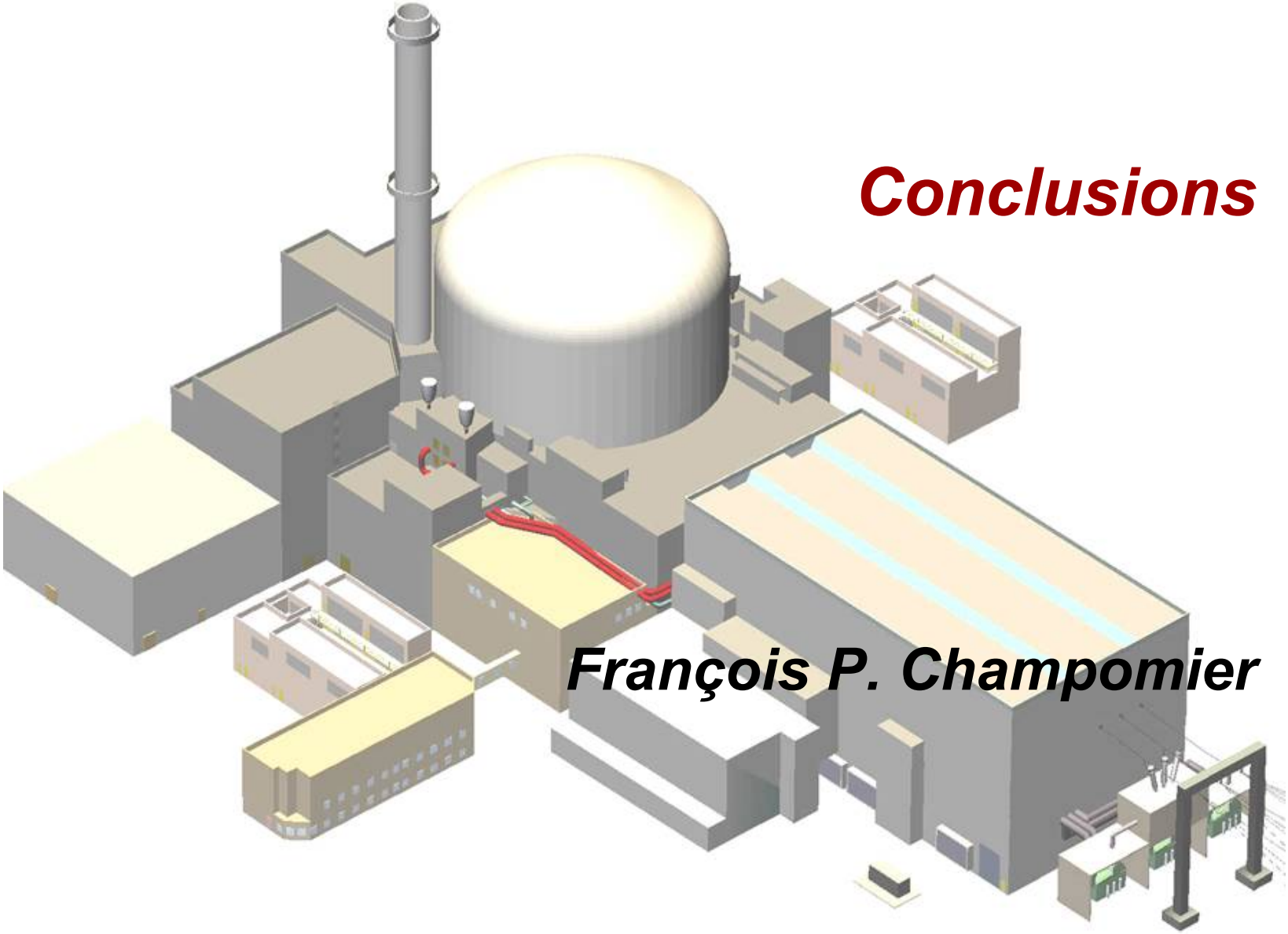
Stability and Endurance Tests

Main result: no evolution of switch times with number of steps.

Stability and Endurance Tests

Main result: evolution of armature closing and releasing times with number of steps remains well within limiting values.

Conclusions



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Conclusions

- The KOPRA simulation has successfully demonstrated the correct functioning of the entire Control Rod Drive System within a wide range of plant operating parameters covering normal and abnormal conditions.

- The entire test setup has operated for the complete extended testing period (15 Msteps).
  - No mis-stepping, no accidental drop occurred.
  - No drift in operating characteristics: practically constant operating parameters (electronic and mechanical) and drop times were recorded.
  - No sign of any alteration with time was observed in the system.
  - No signification degradation in any of the components was noted.

- Testing demonstrates that the system is adequately designed to operate correctly and reliably in the plant.

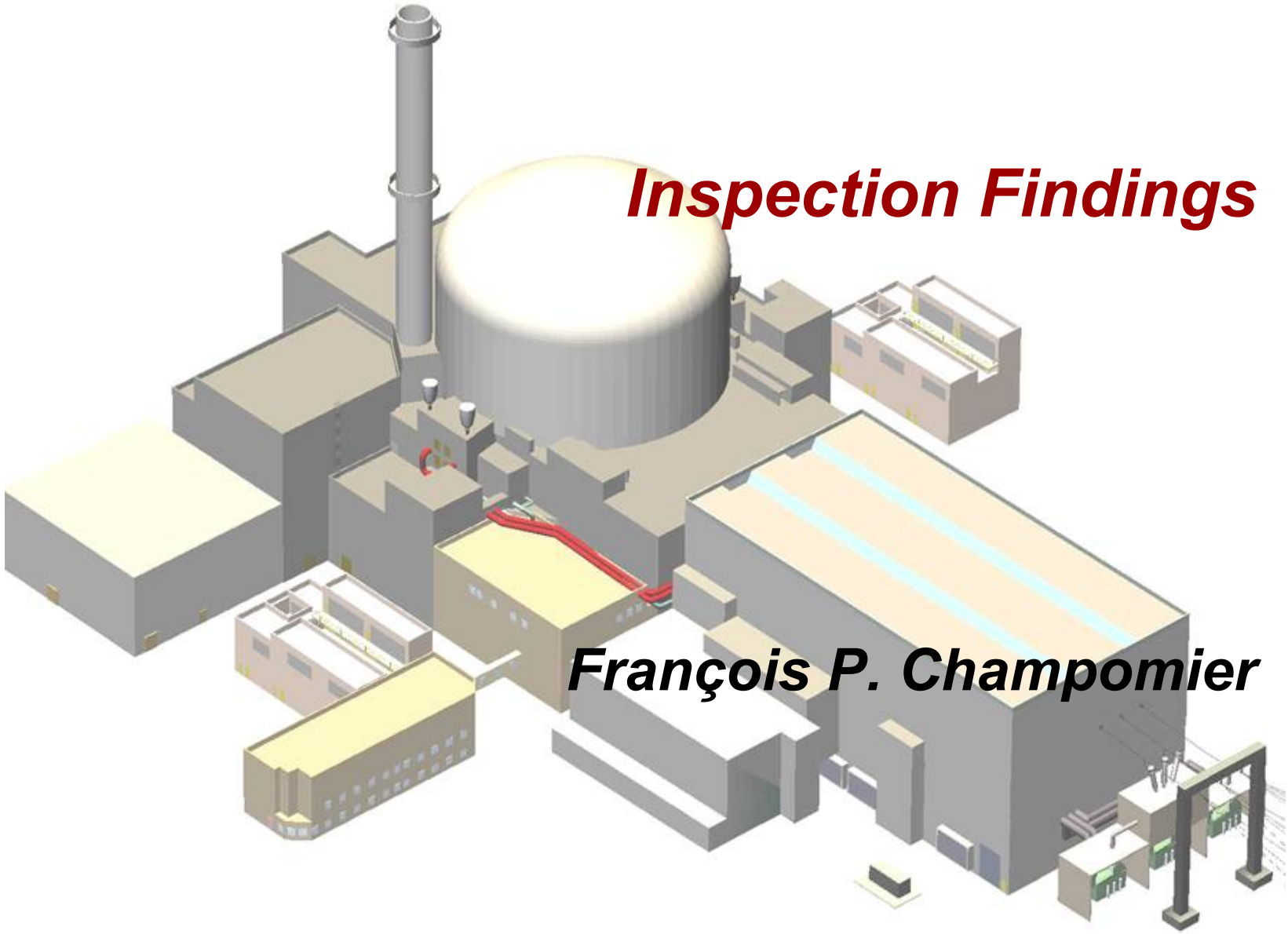
- Additional test performed under special conditions.

Conclusions

- The entire test set up showed little degradation in most of the parts.
  - The skeleton of the dummy FA was replaced at mid testing (having already seen a number of events largely exceeding that expected during operation)
  - The RCC-G (see following slide) was preventively changed after 12 Msteps to ensure the part would not need to be replaced during the final testing period (significant yet acceptable wear on lower cards was detected).
  - Originally, the first two sets of latch arms exhibited wear. The wear was related to the manufacturing practice used with the hardfacing of the latches. The latches were remanufactured with a different hardfacing technique.
  - The last set of latch arms successfully performed 9 Msteps with significant wear but with an essentially linear progression indicating a stable phenomenon.
  - Wear is found to affect essentially latch arm tips, latch arm holes and riveting pins: an increased lifetime target would need to reinforce those relatively weak points.

Test Program

Inspection Findings



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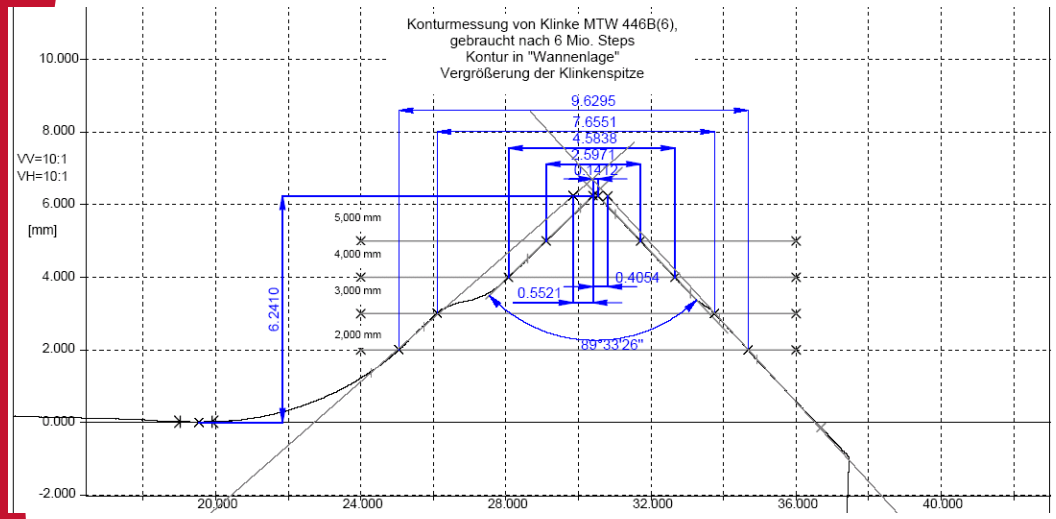
Inspection findings



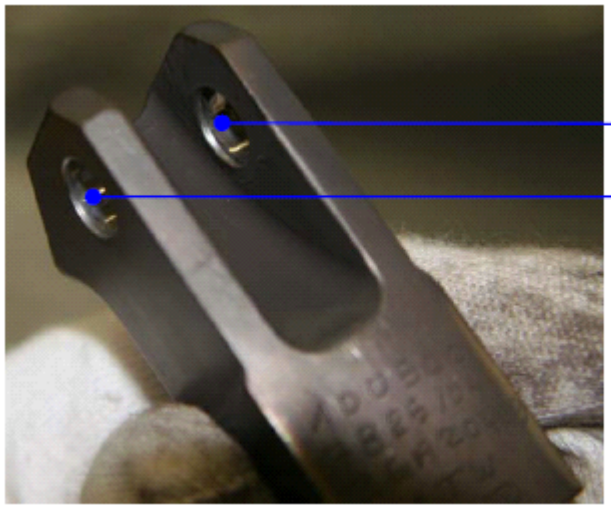


Abb. 1 : Klinke 547C

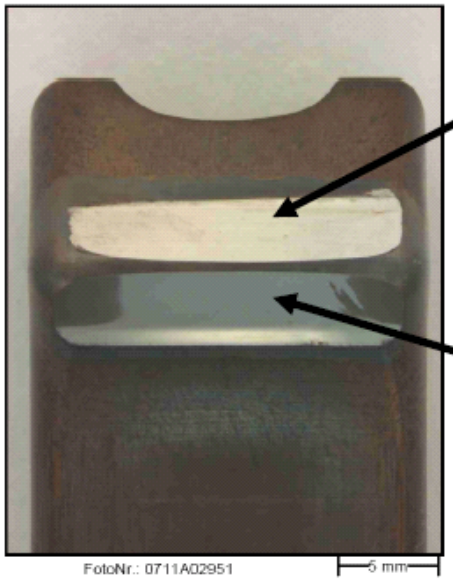


Abb. 2 : Klinke 549D

unten lower

oben upper

Wear pattern

Results in nominal conditions (stability and endurance tests)

Main result up to 7.5 Msteps: relatively stable wear, similar for all 6 latch arm tips