COMPREHENSIVE LIFE ASSESSMENT OF A COKE DRUM

NUCLEAR NDT RESEARCH & SERVICES, BUCHAREST, ROMANIA

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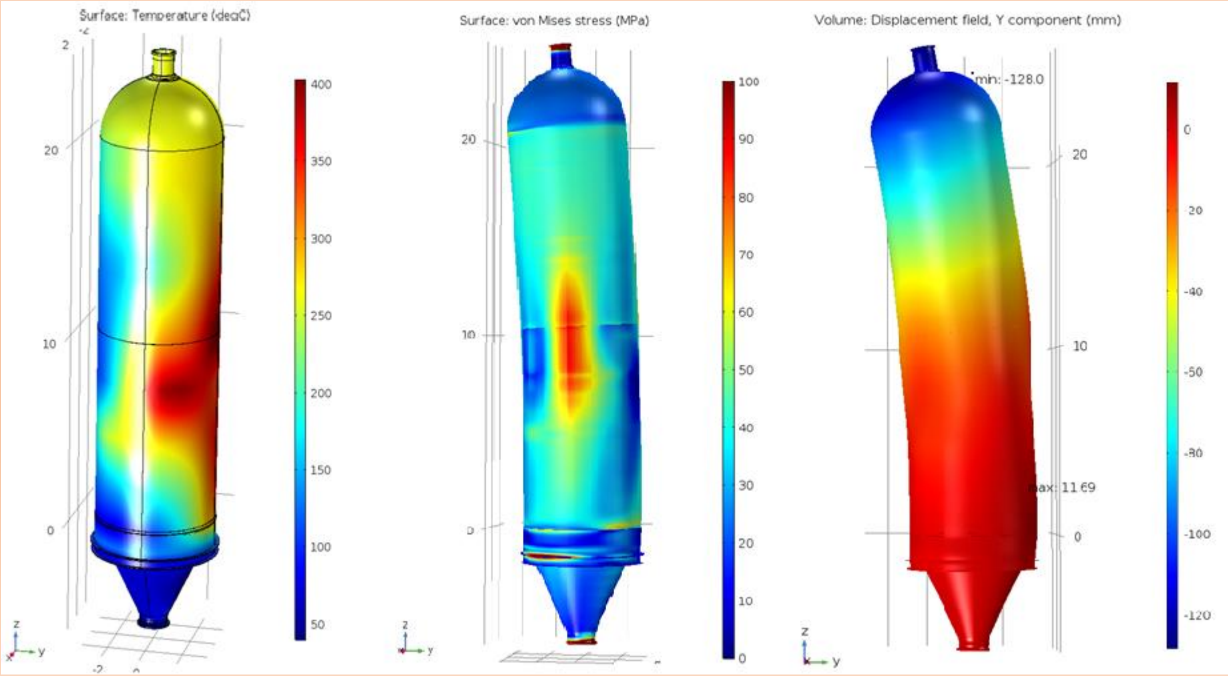

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COKE DRUMS ISSUES

- Coke drums are special pressure vessels subjected to strong and varied transient loads.
- They are expensive items with a long manufacturing cycle, therefore a realistic and accurate life prediction can save a lot of time and money.
- It is vital to know as much as possible their actual condition.
- The owner must have plans for:
  - Long term operation, Inspection, Repair and Replacement
- Usual questions:
  - How many cycles are there left?
    - To crack
    - To through wall crack
  - What is to repair and when?
  - How can we extend the lifetime of the drum?
    - Structural modifications
    - Operational optimizations

MAIN DAMAGE MECHANISMS

- Low-cycle fatigue from thermal transient
  - Large cyclic stress sources:
    - Thermal distributions generated by: coke bed interactions, random local flows through coke bed and around it near wall
    - Thermal heating and cooling rates
- Embrittlement – due to the long term exposure to high temperatures

FATIGUE ASSESSMENT PROBLEMS

- Low-cycle fatigue is the most important damage factor – a low number of high value stress range cycles add more fatigue than a high number of low value stress range cycles.
- Hard to assess the stress range over a cycle due to the non-uniform and continuously changing temperature map of the walls.

STRESS ASSESSMENT

In order to address these problems we developed a stress assessment method based on temperature monitoring using thermocouples.

- **Thermocouples advantages**
  - Able to provide a complete image of the temperature field on the entire coke drum surface
  - Through the mapping of the temperature on the drum surface we may:
    - Assess the stress in **<u>every</u>** point with a fair accuracy
    - … even in the points where a strain gauge cannot be set
    - Assess the intensity of thermal shocks
    - Study the coking process and the possibilities to optimize it

- **Classical method - Strain gauge**
  - Precise, in a single point on the outer face of the drum
  - No information about the stress state around the measuring point. On the other face it depends on the curvature of the wall, i.e. the temperature map
  - Impossible to set in some locations

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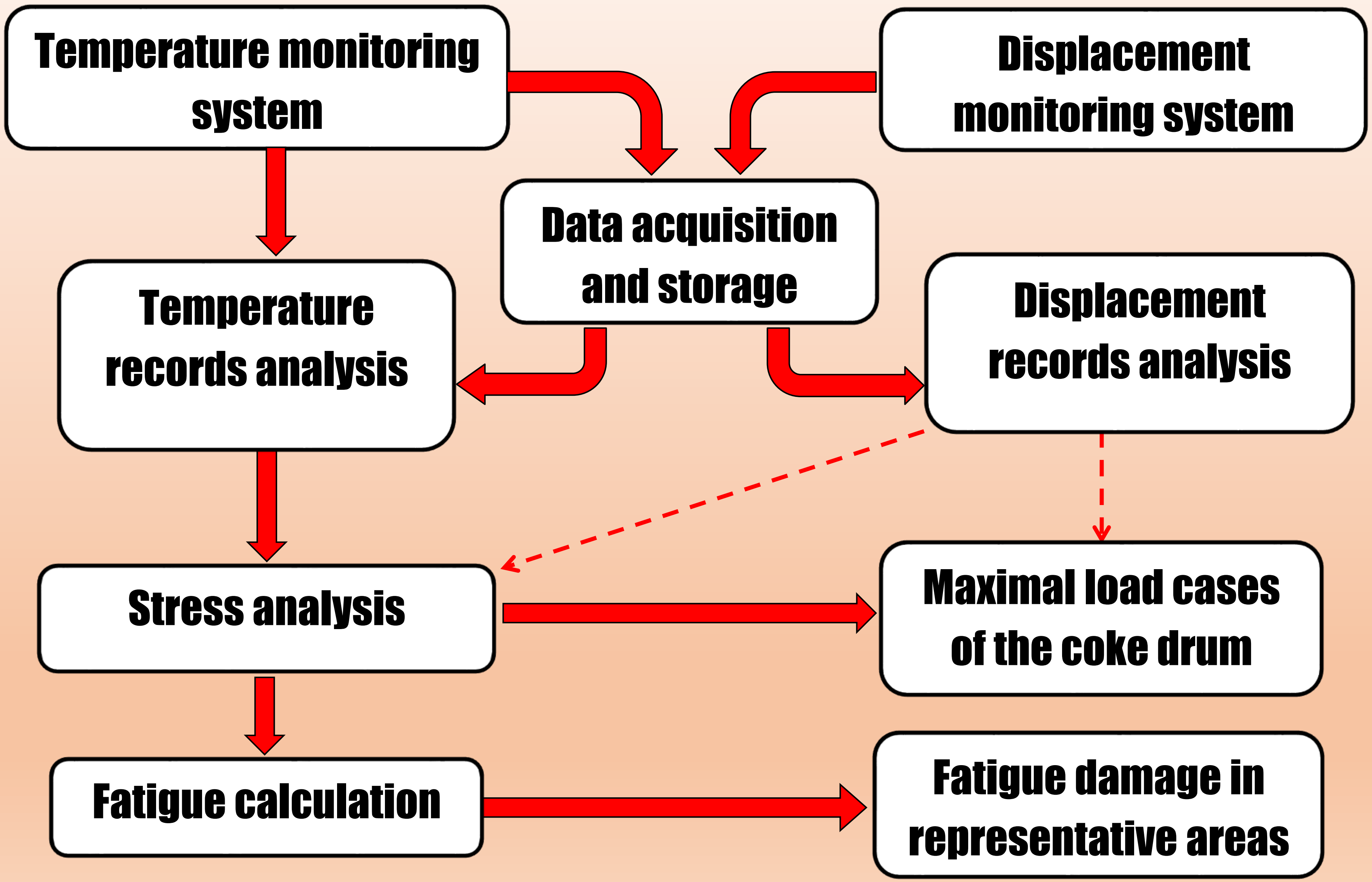
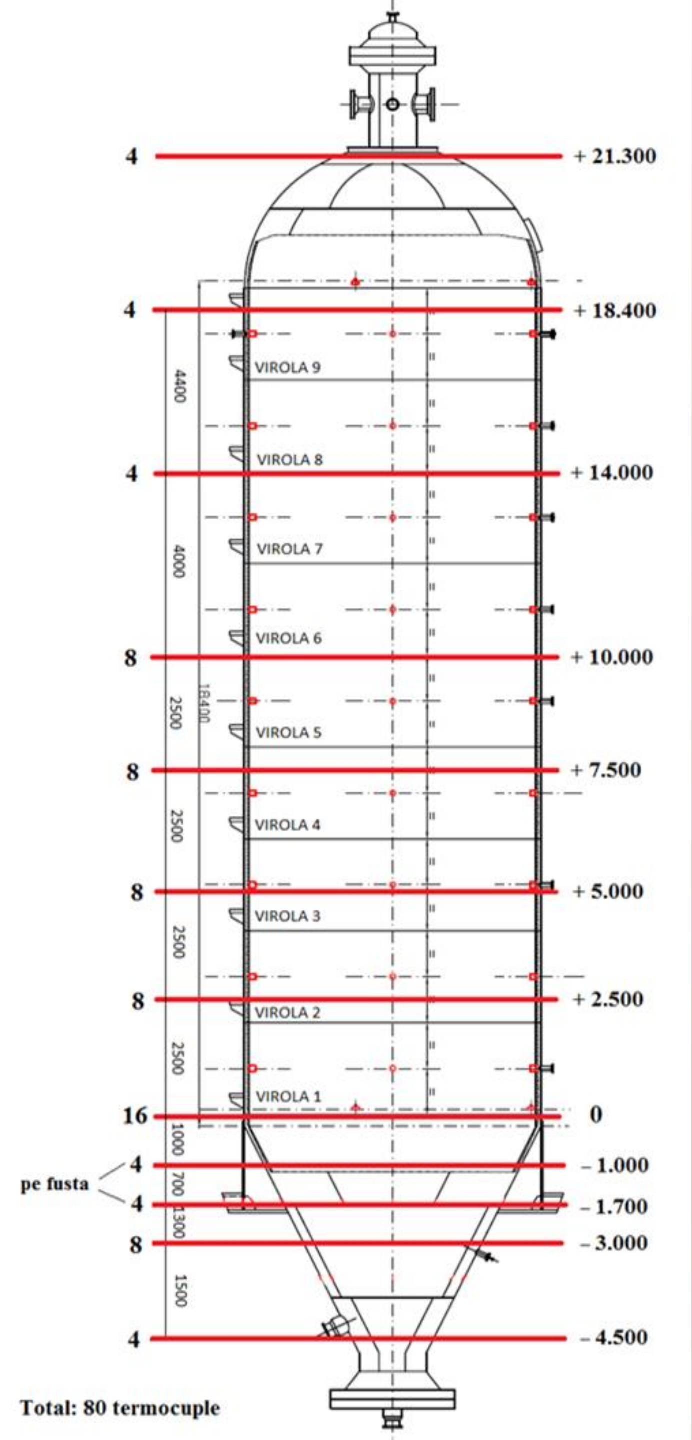
STRESS ASSESSMENT FLOWCHART

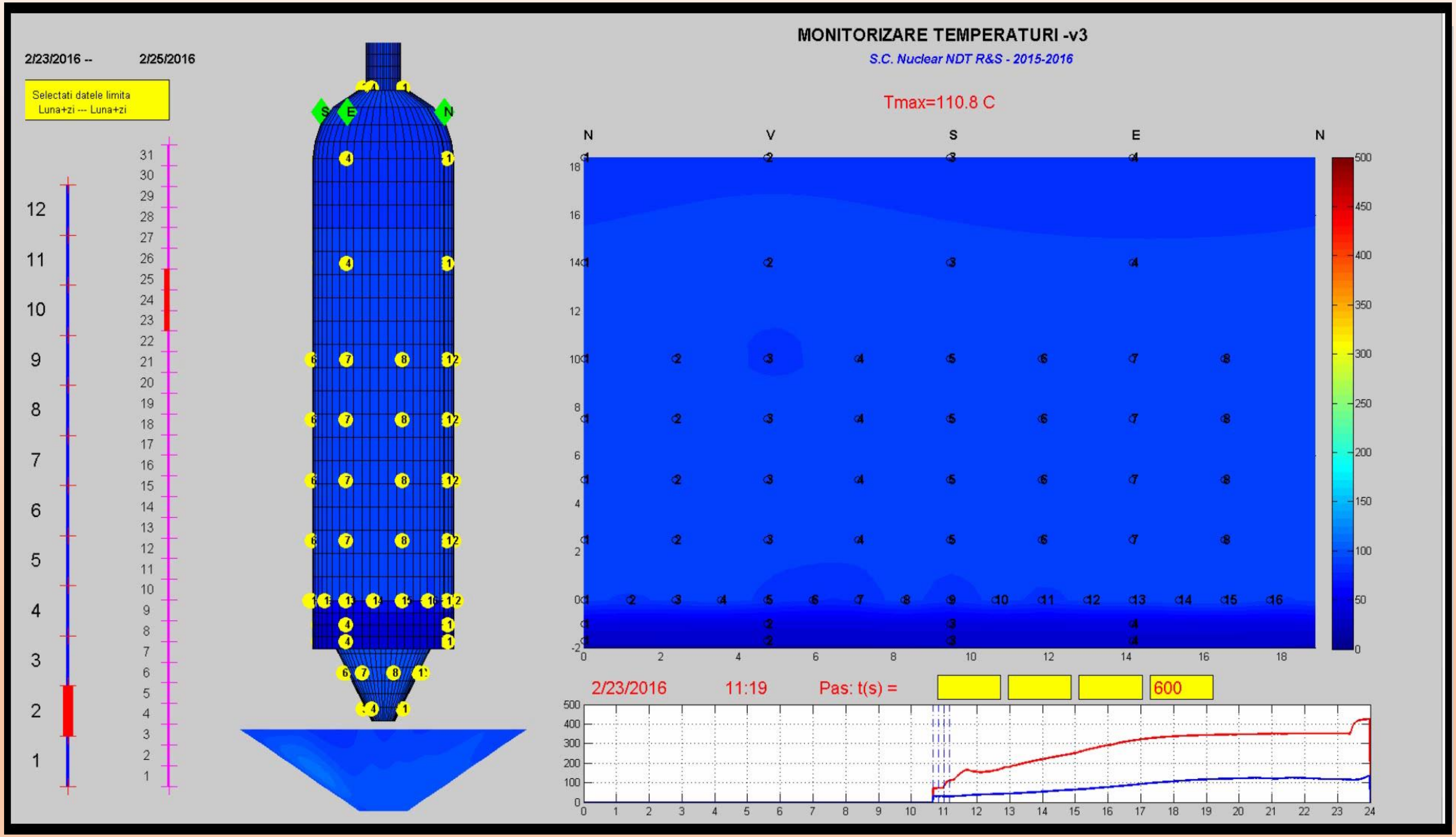


TEMPERATURE MONITORING SYSTEM

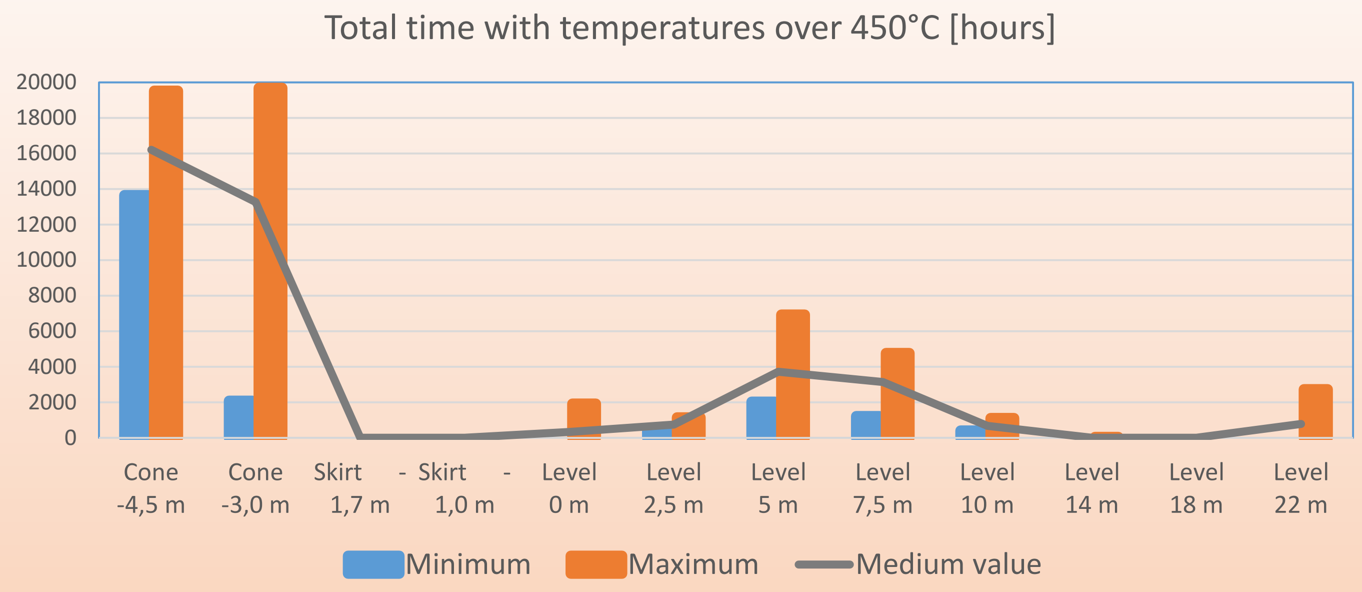


DATA ANALYSIS

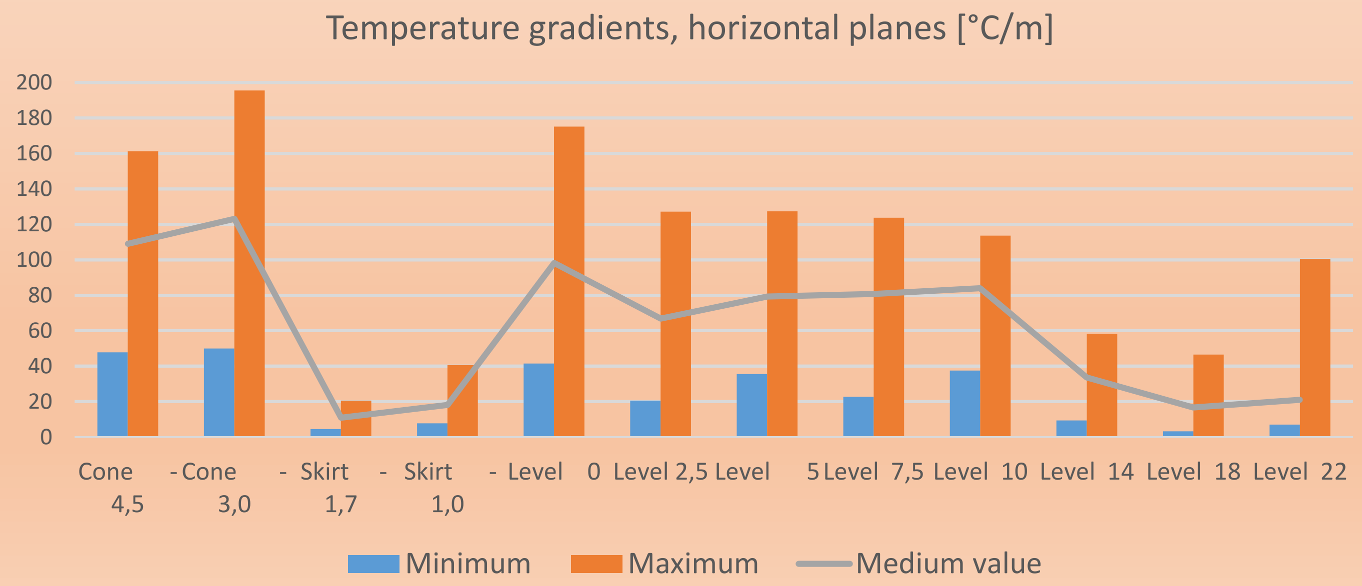
The recorded data are processed in order to estimate the temperatures in any point of the coke drum, using special **software developed by Nuclear NDT**



Atypical cooling cycle – the cooling fluid touches the wall at level +14

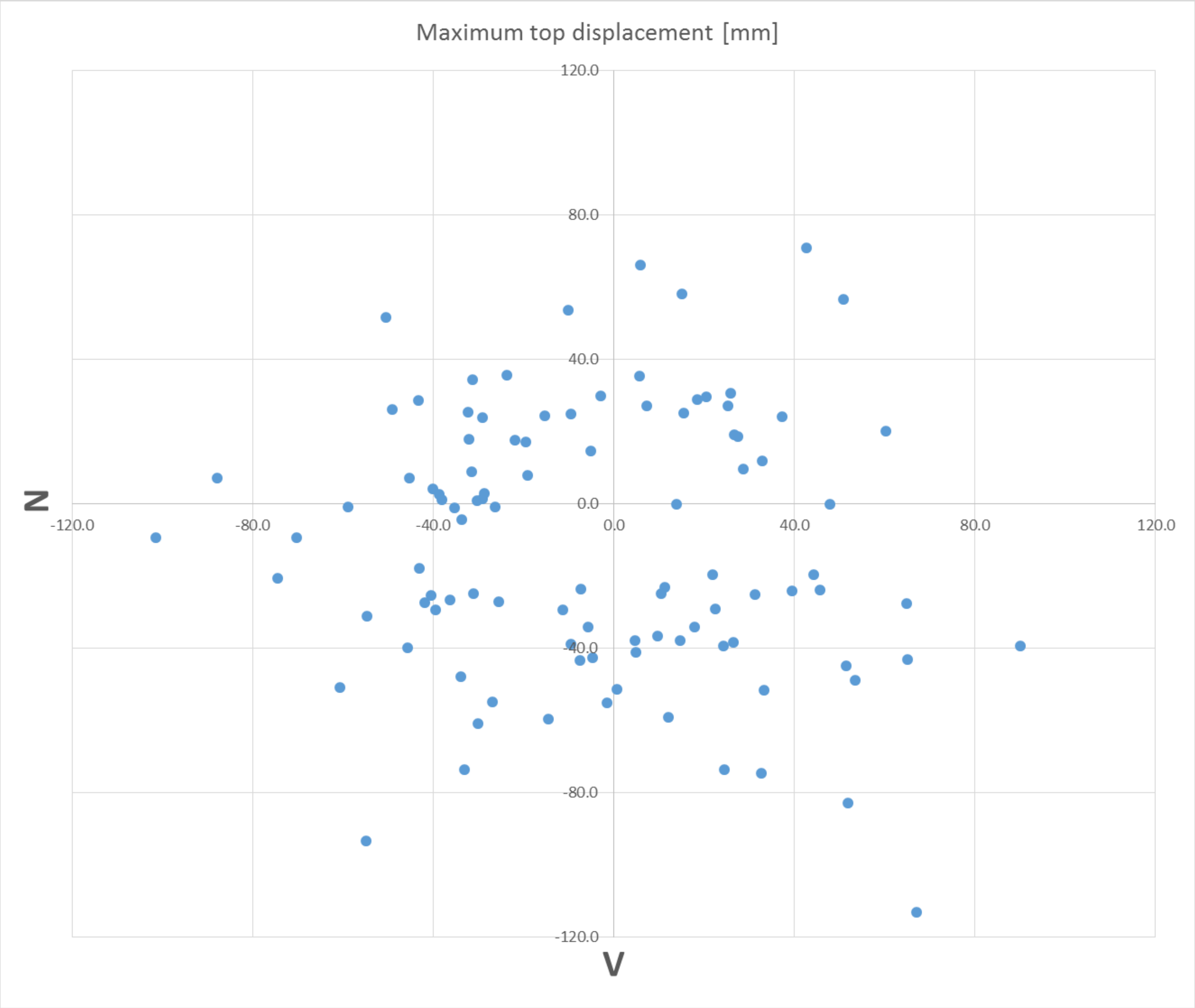


Total time at temperatures greater than 450°C, extrapolated from the temperatures measured over the monitored period.

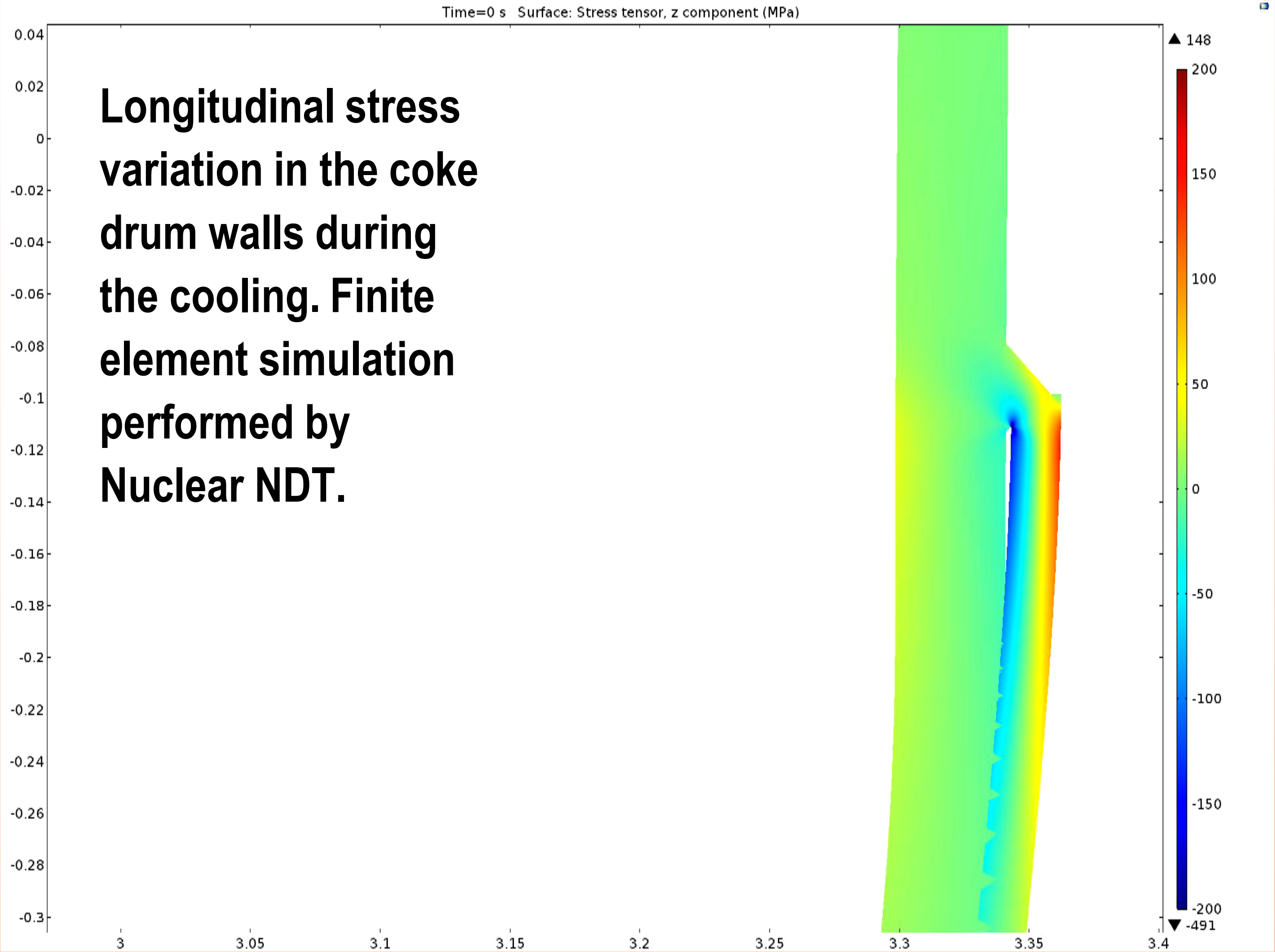


The highest temperature gradients are on the cone area, followed by the lower half of the coke drum.

COKE DRUM DISPLACEMENT



- Measured top displacement: 13,9 ÷ 131,6 mm.
- Maximum design value is 152,5 mm.
- In 3% of the monitored cycles the top displacement went over 100 mm.
- There is a preference for the directions N (55%) and V (59%).

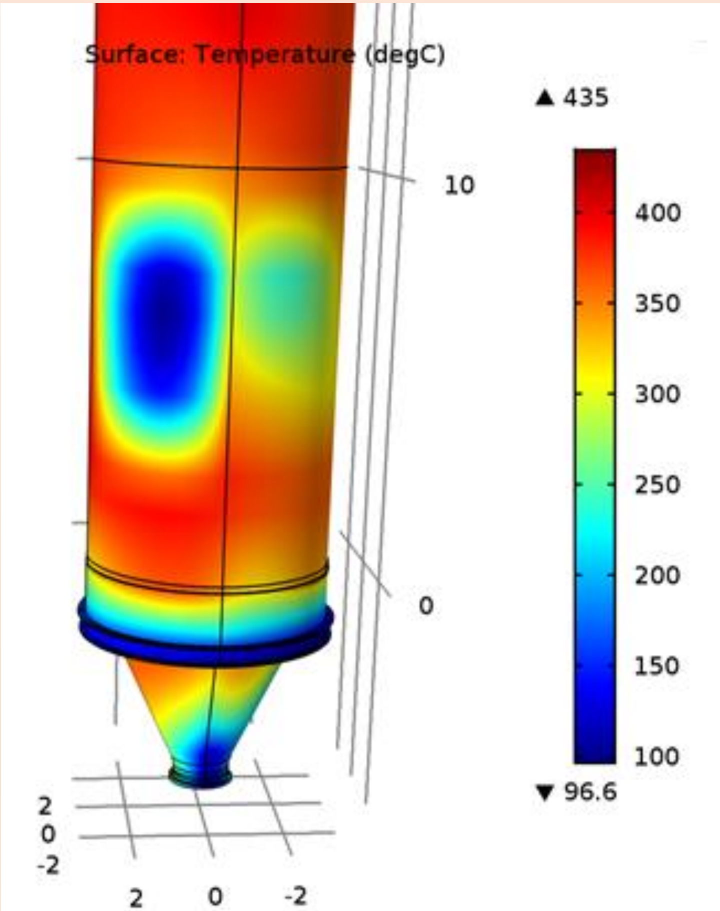


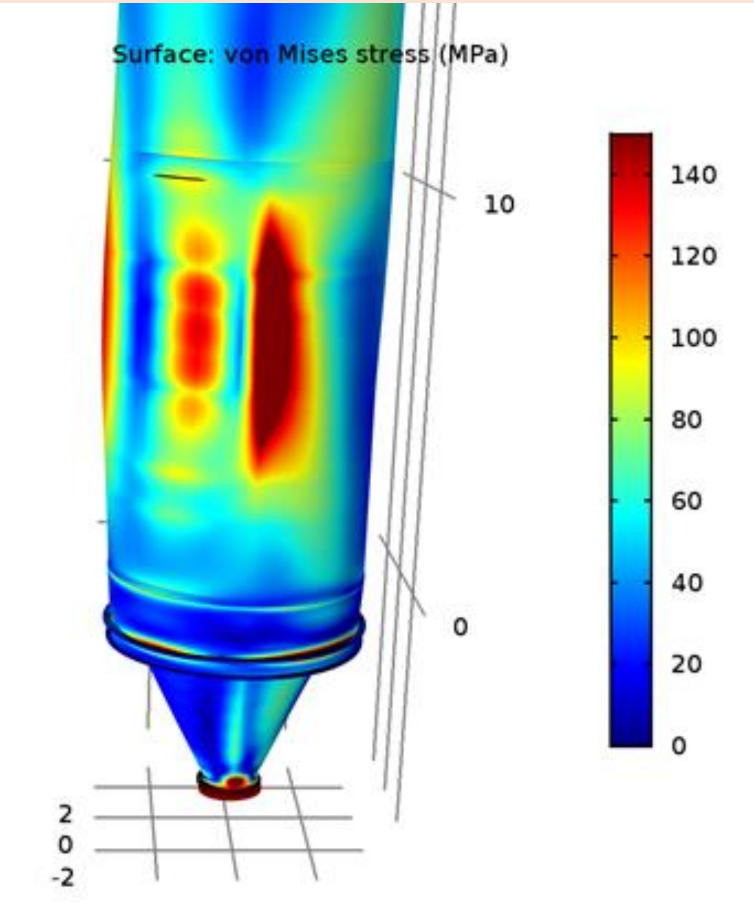
HOT SPOTS

- Skirt attachments,
- Tri-metal joint seams,
- Circumference seams in shell,
- Nozzles, Miscellaneous, attachments, Bulge peaks and valleys

FATIGUE CALCULATION

- We analyzed every cycle and identified the time moments when the temperature distribution leads to significant stresses (over the design allowable stress) in the structure of the coke drum.
- In each of this time moments we calculated the stress distribution in the coke drum generated by the temperature distribution.

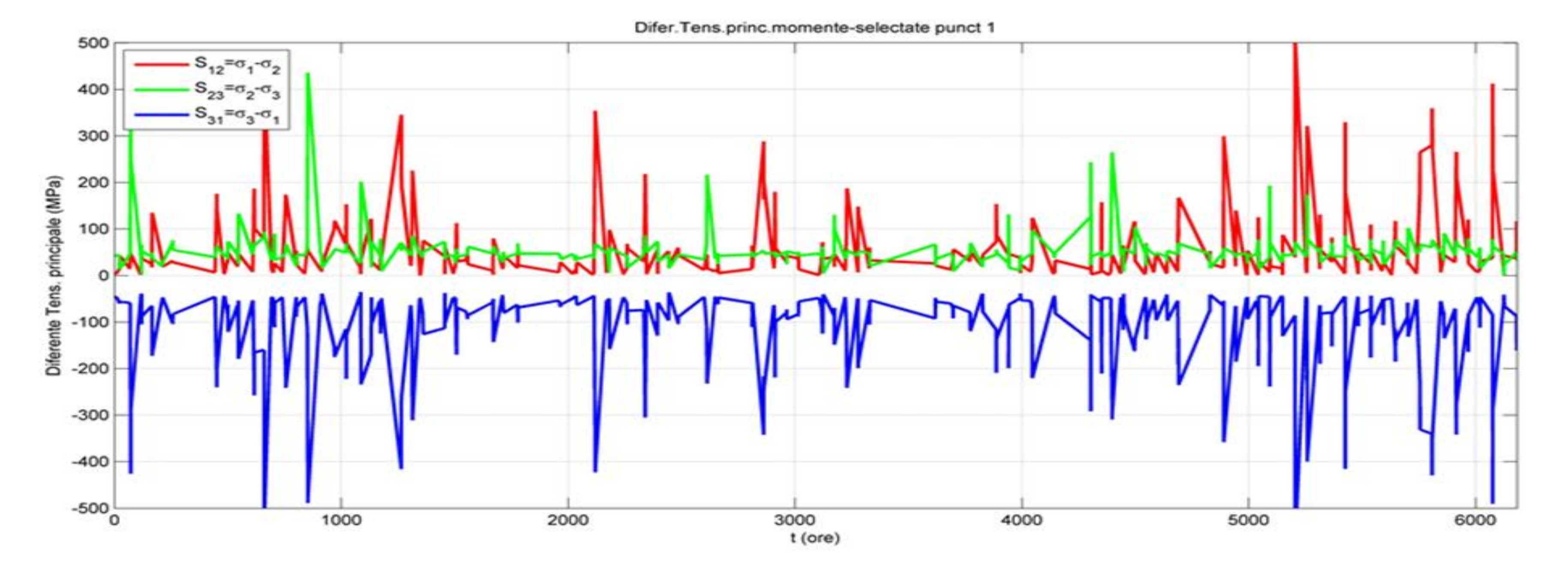




Example of a significant stress moment – Isolated cold spot

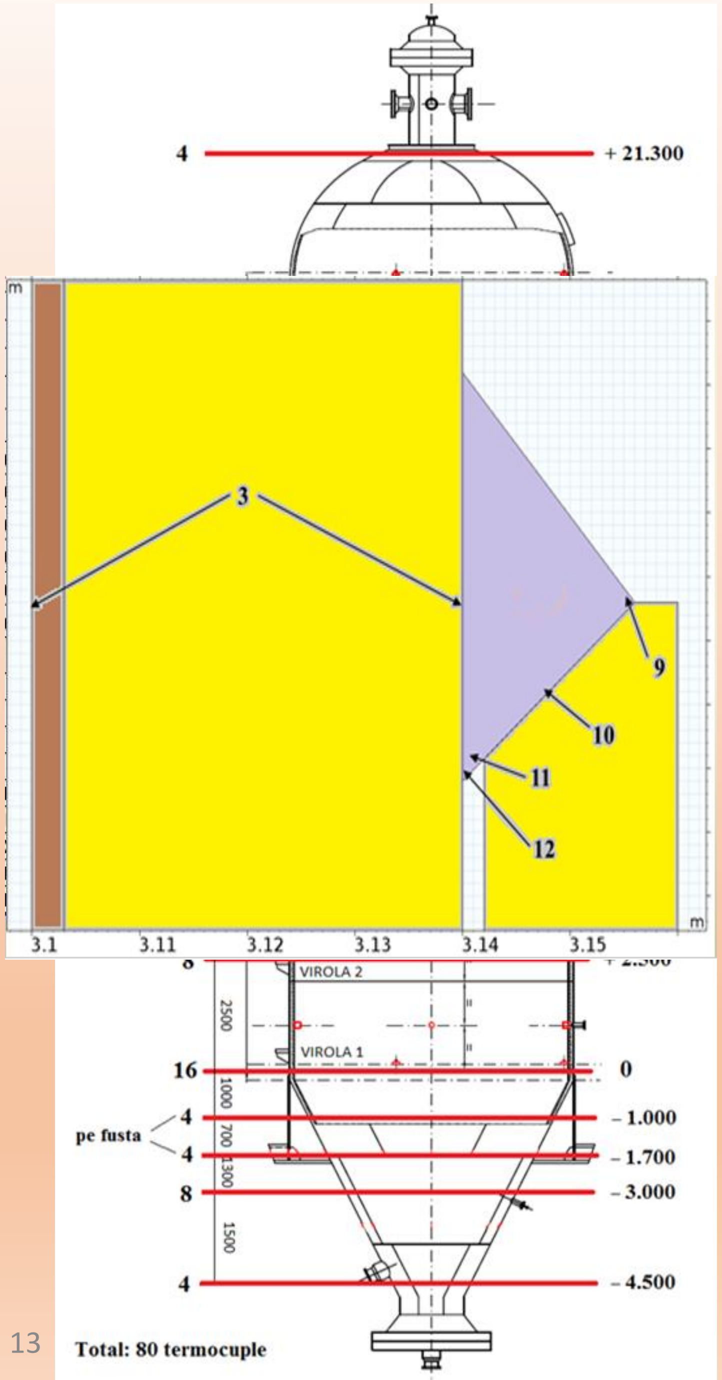
FATIGUE CALCULATION

- From the data base, gathered from the recorded cycles, we selected several hundreds moments with significant temperature gradients.
- In each of this time moments we calculated the stress distribution in the coke drum generated by the temperature distribution in 128 de points in 8 representative sections of the camera and in 64 points in 4 sections in the skirt welding.
- By organizing the results with respect to time we built the stress variation over the entire monitored period in all 192 points. For each point, based on this graph, we conducted the fatigue calculus according to EN 13445-3.



Variation of the principal stress differences in a point at level 10 m

Fatigue degradation, D (%), extrapolated for several thousands cycles, including the effect of random thermal events



Nr.	LEVEL	Circumferential position															
		0°		45°		90°		135°		180°		225°		270°		315°	
1	CONE -3,0 M EXT/INT	5	4	9	18	14	5	3	1	3	1	1	6	8	4	2	1
2	CONE -4,5 M EXT/INT	13	15	13	19	5	2	2	1	0	0	1	1	2	1	1	0
3	LEVEL 0 M EXT/INT	3	1	1	1	1	1	2	1	1	1	1	1	1	1	3	1
4	LEVEL 2,5 M EXT/INT	3	3	4	8	2	2	2	1	2	1	1	2	1	3	3	1
5	LEVEL 5 M EXT/INT	5	6	8	18	4	3	3	1	1	1	2	2	6	5	1	1
6	LEVEL 7,5 M EXT/INT	6	6	9	23	4	4	3	2	1	2	3	2	4	5	1	1
7	LEVEL 10 M EXT/INT	67	4	47	9	7	5	4	1	2	1	2	3	7	6	1	1
8	LEVEL 12,5 M EXT/INT	3	3	3	5	2	2	1	1	1	1	1	1	2	2	1	1

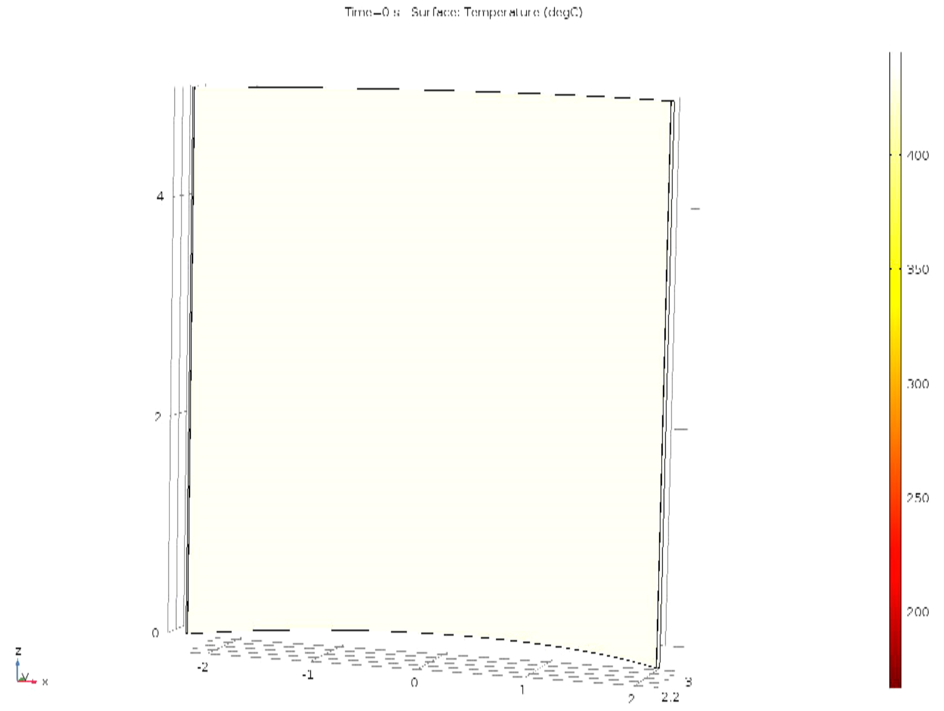
	SKIRT WELDING	0°	45°	90°	135°	180°	225°	270°	315°
9	EXTERIOR	2	2	2	5	1	3	2	8
10	MIDDLE	31	3	8	10	13	3	4	7
11	INTERIOR (LOWER CORNER)	52	58	74	179	44	57	50	135
12	WELDING CONCENTRATOR	153	194	237	696	137	185	138	468

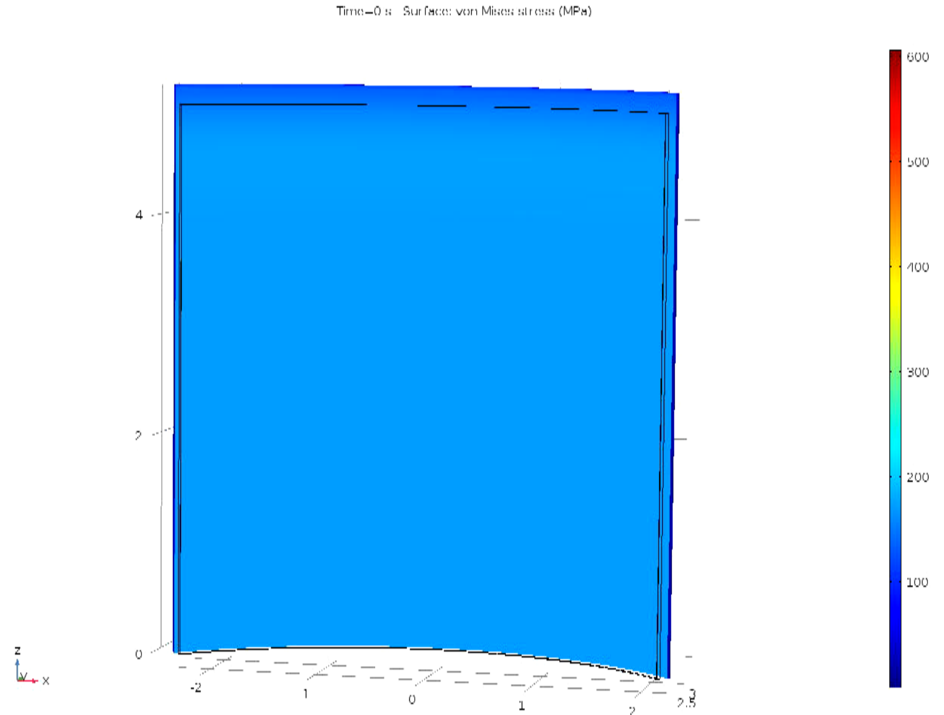
CLADDING FATIGUE

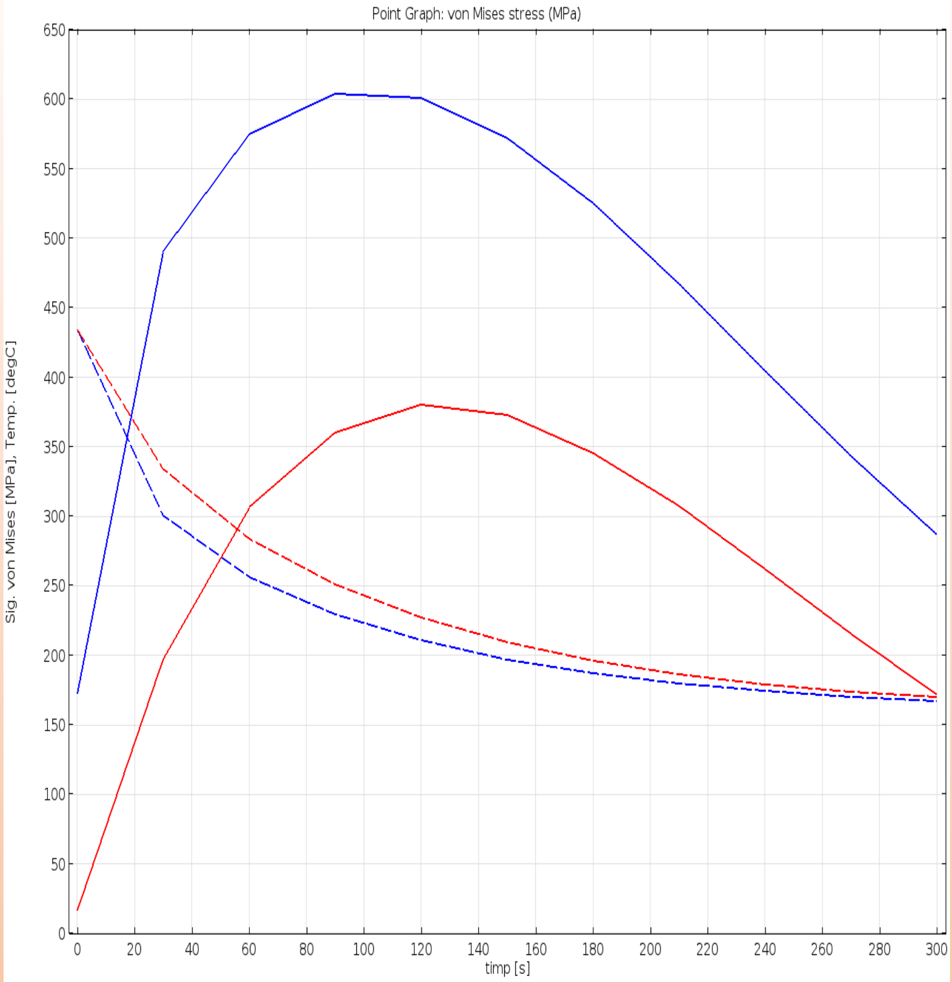
The fatigue calculation of the cladding was made at each level where thermocouples are set, taking into account the mean number of thermal shocks recorded by the thermocouples at that level.

Vmax	Medium number of thermal shocks at cooling over several thousands cycles									
[°C/min]	-4,5 m	-3,0 m	0 m	2,5 m	5 m	7,5 m	10 m	14 m	18 m	22 m
0 – 10	1163	1301	2644	1961	1489	1406	1245	1365	1950	1463
10 – 20	1403	1238	324	780	1009	1136	1080	1163	750	1365
20 – 30	315	379	36	150	296	311	379	368	255	188
30 – 40	90	79	21	71	143	113	188	105	68	15
40 – 50	38	26	2	19	53	38	79	23	0	0
50 – 60	23	8	2	19	23	4	38	8	8	0
60 – 70	0	0	2	4	19	11	19	0	0	0
70 – 80	0	0	0	11	0	4	0	0	0	0
80 – 90	0	0	0	11	0	8	4	0	0	0
90 – 100	0	0	0	4	0	0	0	0	0	0

Classification of the thermal shocks recorded during cooling at each level of the coke drum with respect to the cooling rate



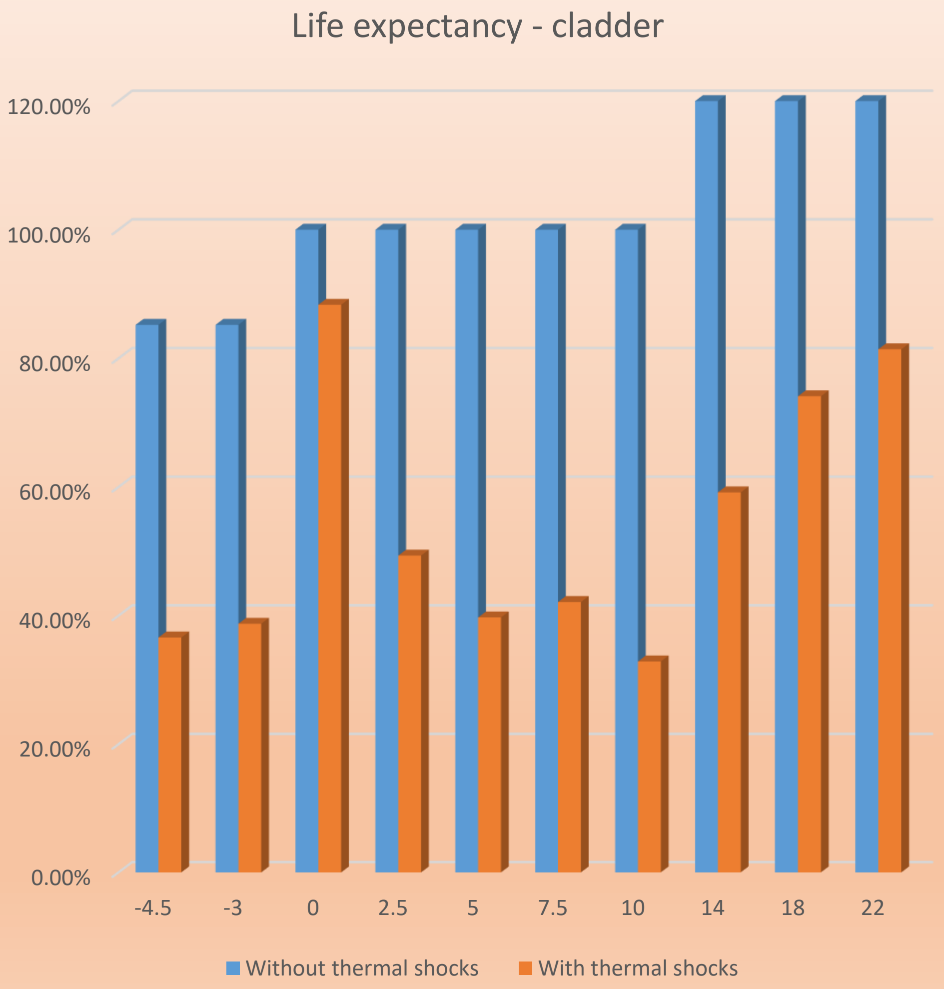


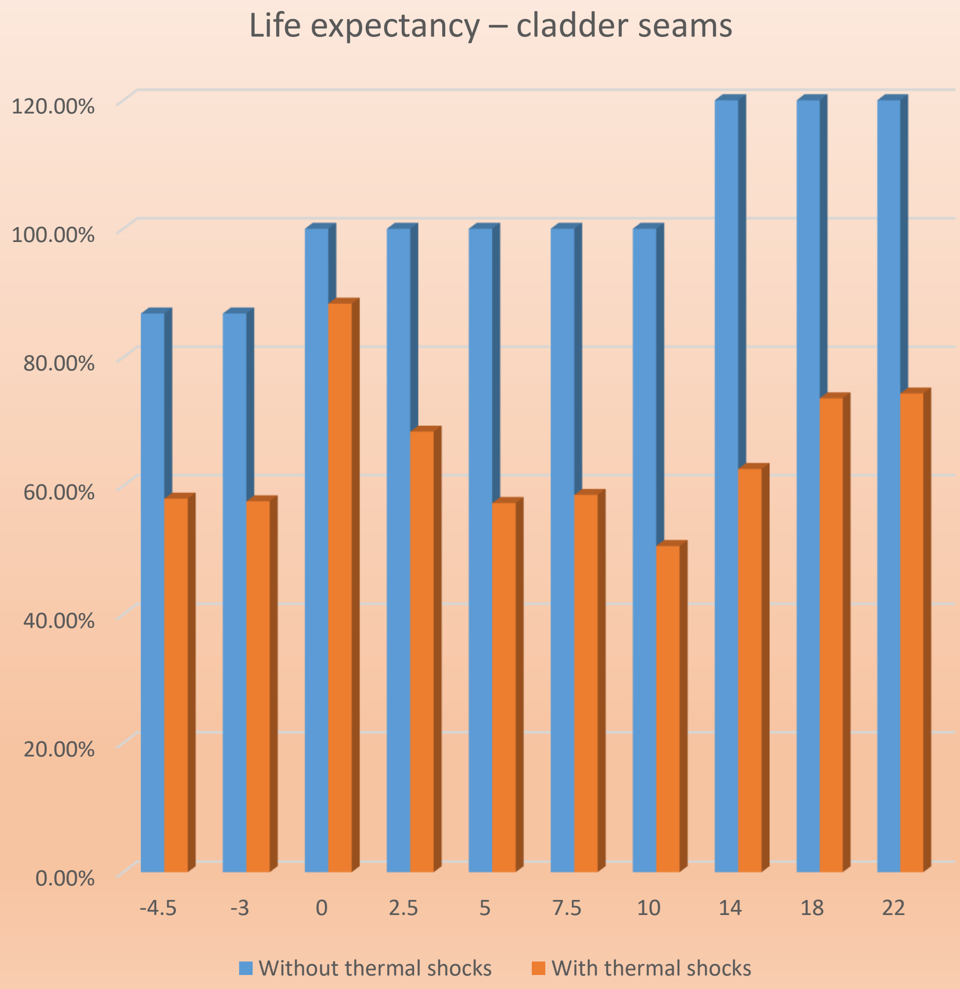


Thermal shock – Variation over time of the equivalent stress and temperature at the inner face of the cladding (blue) and in the base material at the contact with the cladding (red). Finite element simulation performed by **Nuclear NDT**

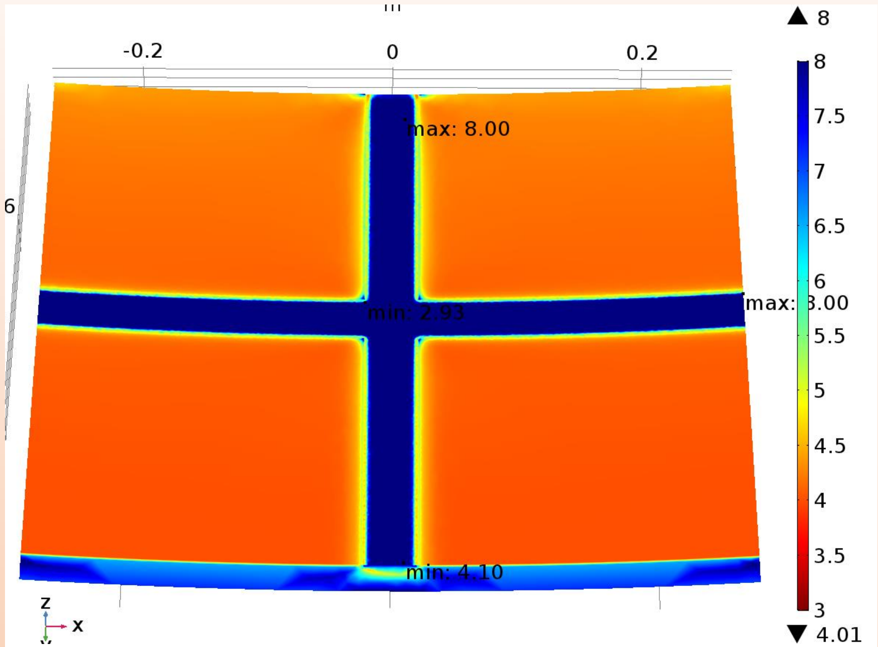
CLADDING FATIGUE

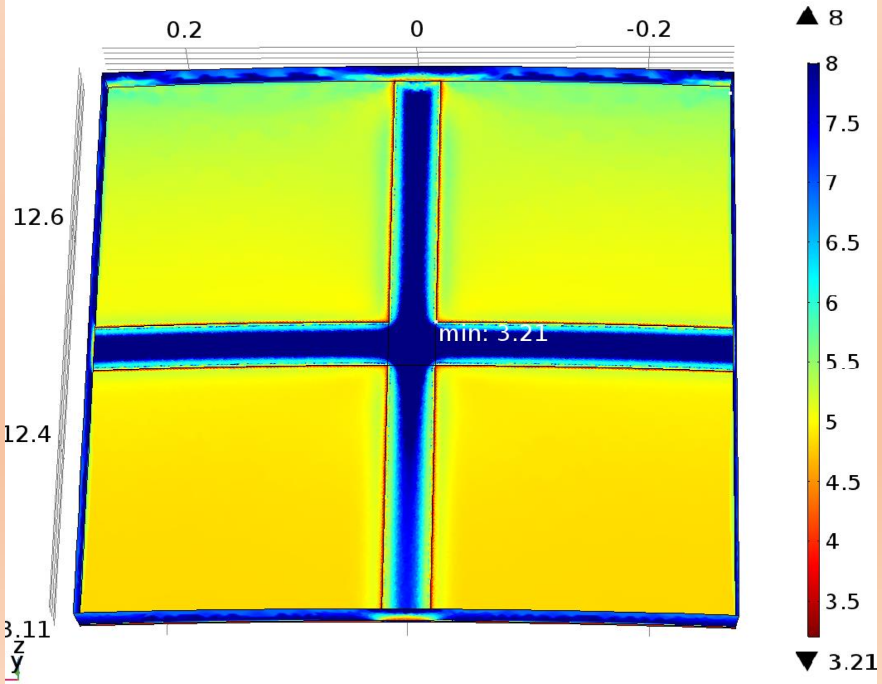
Life expectancy of the cladding when considering the effect of thermal shocks (red), compared to life expectancy without taking into account the thermal shocks (blue)





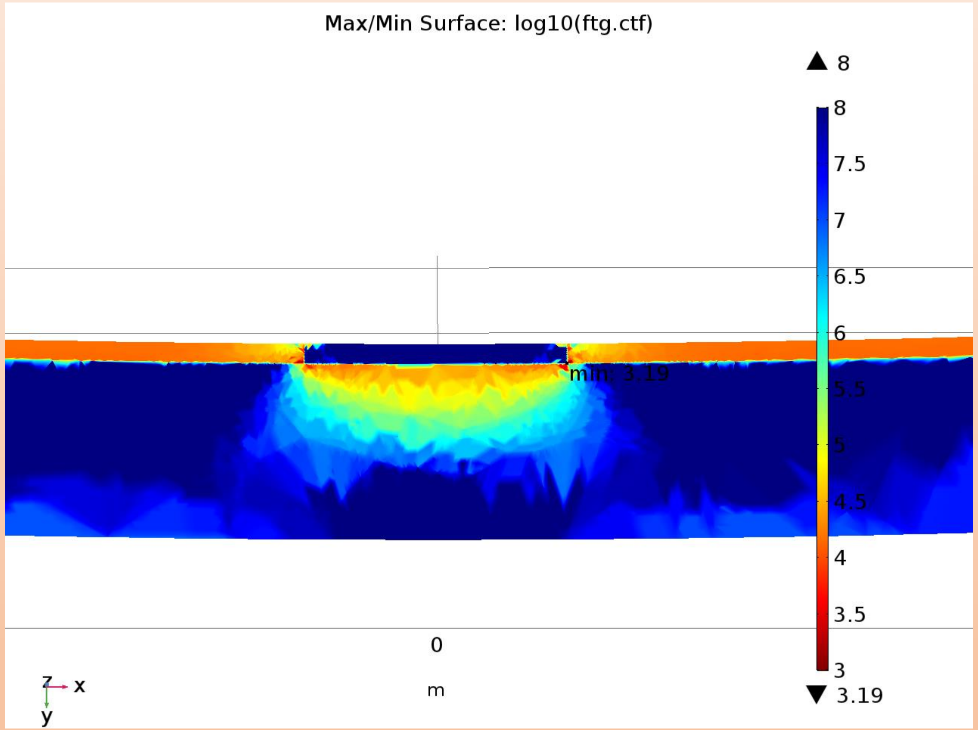
ELASTO-PLASTIC ANALYS performed by Nuclear NDT





Left up – Life expectancy of the cladding at the inner face of the wall. Minimum value ≈ 10500 cycles

Left down – Life expectancy of the cladding at the contact with the wall. Minimum value ≈ 70000 cycles



Right - Life expectancy of a tri-joint seam, in a horizontal section at level +12,6 m. Minimum value ≈ 1550 cycles in the contact line between the base material, cladding and the weld.

NOTABLE FACTS

1. The coke drum cooling process is highly irregular, the cooling fluid circulating through the coke and touching the wall at any level. The temperature differences between two measuring points are frequently exceeding 200°C, the maximum measured values being 374,3°C on the shell, 350,8°C on the cone and 282,5°C on the skirt.
2. The stresses in the lower edge of the skirt weld are frequently exceeding the yield limit. The toughness of the weld is a crucial factor in decreasing the fatigue degradation rate.
3. The fatigue degradation of the coke drum material is due in a great proportion to exceptional events. Such type of events, leading to very high stresses, occurred on average in 2 – 3% of the monitored cycles.
4. Using EN13445-3 we estimated that, on average, cracks will begin to occur in the skirt weld after 1630 cycles (in the most stressed two points the estimated number of cycles to crack drops down to **half**).
5. Between 12% and 67% of the total fatigue damage of the cladding (depending on the level) comes from thermal shocks, the rest is due to the cyclic warming at the vacuum residue temperature.

COMPLETED STAGES

1. We created a database of the coke drum temperatures recorded at 30 seconds interval, which may be used in subsequent analysis.
2. We performed the analysis of the temperature distribution corresponding to all the monitored cycles to extract the data needed in the assessment of stress levels and fatigue damage of the coke drum structure and cladding.
3. We assessed the fatigue damage of the material in the chosen points of the coke drum, based on the temperature distributions recorded during the monitored period of time.
4. We analyzed the thermal shock effects on the cladding at the heating, filling and cooling phases and evaluation of the fatigue damage of the cladding.

FUTURE DEVELOPMENTS

5. Optimization of the operating procedure (stripping and cooling) in order to increase the remaining life of the coke drums, based on the technological parameters which can be modified in operation.
6. Optimization of the skirt shape and joint with the coke drum.

*We would like to thank ROMPETROL RAFINARE - Midia / ROMANIA, member of **KazMunaiGas** Group, for the understanding and support to apply the methodology developed by "Nuclear NDT Research & Services" and described in this paper to analyze the thermo - mechanical behavior of a coke drum in operation.*

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