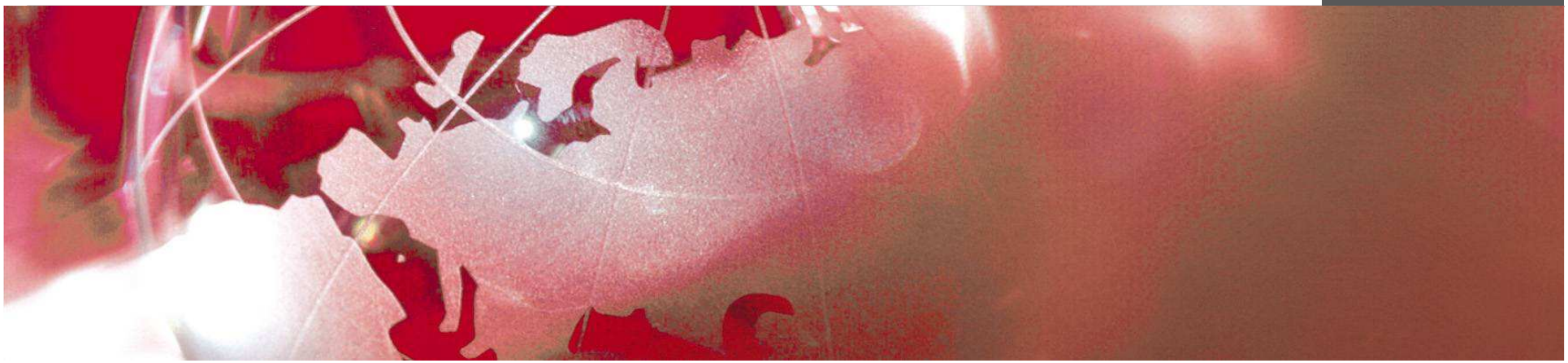
BAYERN-CHEMIE



Solid Propellant Rocket Motor Insensitive Munitions, Testing and Simulation

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MBDA MISSILE SYSTEMS

Content

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1. Overview

Customer: German DoD/BWB/WTD-91
Project Period: 06/2006 – 11/2009
Follow-on Project: IM Technology for Rocket Motors, 2010 - 2011, optional 2012

Major Goals:

1. Create a knowledge and data base on the IM behaviour of solid propellant rocket motors,
2. Improve and design new rocket-motor specific IM test set-ups and technologies and study the motor behaviour under different IM aggressions (15 full-scale IM tests were conducted at WTD91 proving ground),
3. Develop computer models that are able to predict the IM behaviour of solid propellant rocket motors in order to minimize the number of large-scale tests and to reduce motor development costs (focus on Slow Heating case),
4. Improve the IM characteristics of solid propellant rocket motors by studying the effects of motor design, propellant formulation, burn rates and mitigation.

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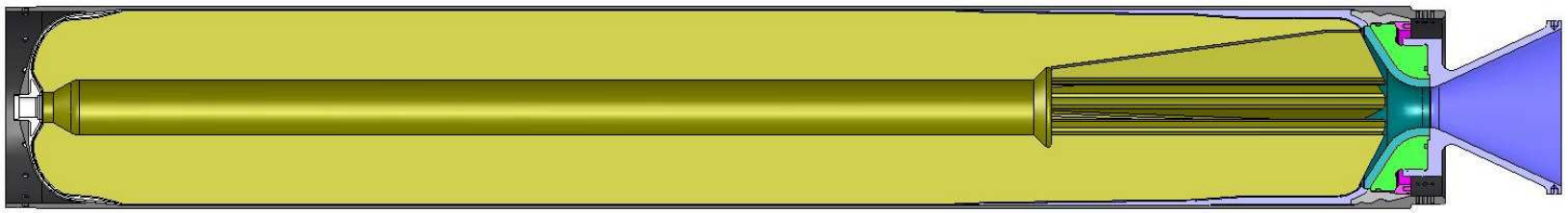
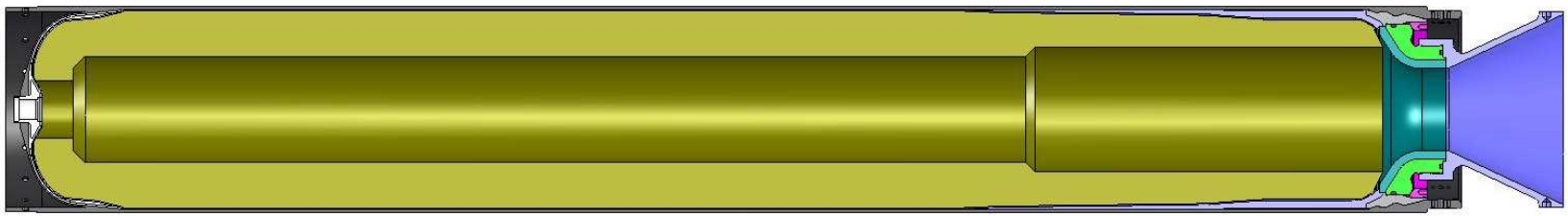
2. Motor Definition

- Carbon Fibre Composite (CFC) case,
- motor caliber: 168 mm, motor (case) length: 1180 mm (without nozzle),
- dummy nozzle made out of steel,
- „low“ burn-rate (LBR) propellant (20 mm/s at 100bar, +20℃), mTZ = 32 kg:



- „high“ burn-rate (HBR) propellant (40 mm/s at 100bar, +20℃), mTZ = 24 kg:



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3. Bullet Attack

A. Overview:

1. Test date & site: 10/06, WTD-91 Meppen

2. Number of tests: 4 Bullet Attack Tests (ambient soak temperatur)

3. Standard: STANAG 4241

4. Motor config.: Composite case with nozzle, no igniter, filled with

1x LBR propellant (single firing)

3x HBR propellant (single firing & triple salvo)

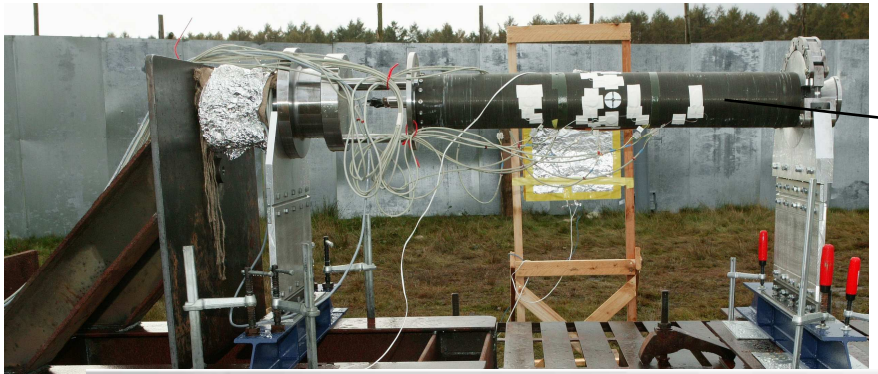
5. Equipment & measurements:

Motor level: Head-end pressure, thrust, strain sensors

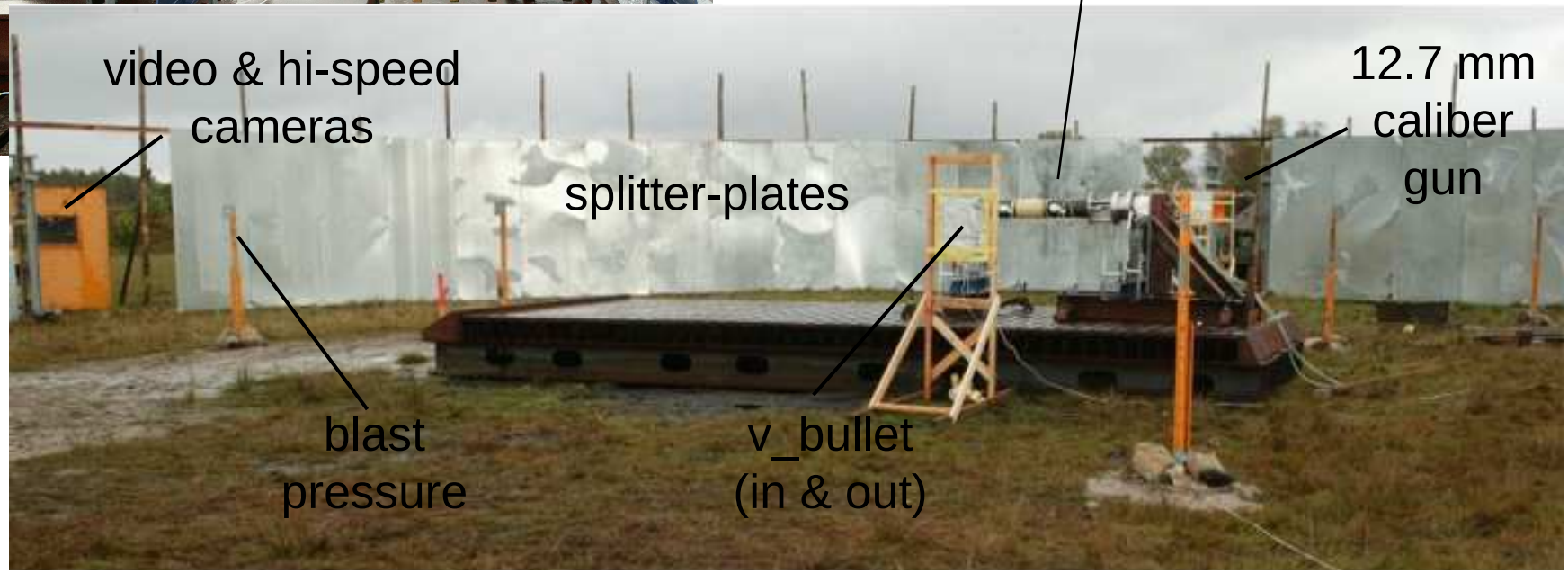
Test site: Blast pressure, bullet speed in & out, hi- & low-speed video

3. Bullet Attack

B1. Test set-up:



Rocket-motor on test stand:
- pressure & thrust measurement,
- CFC-case with strain gauges.



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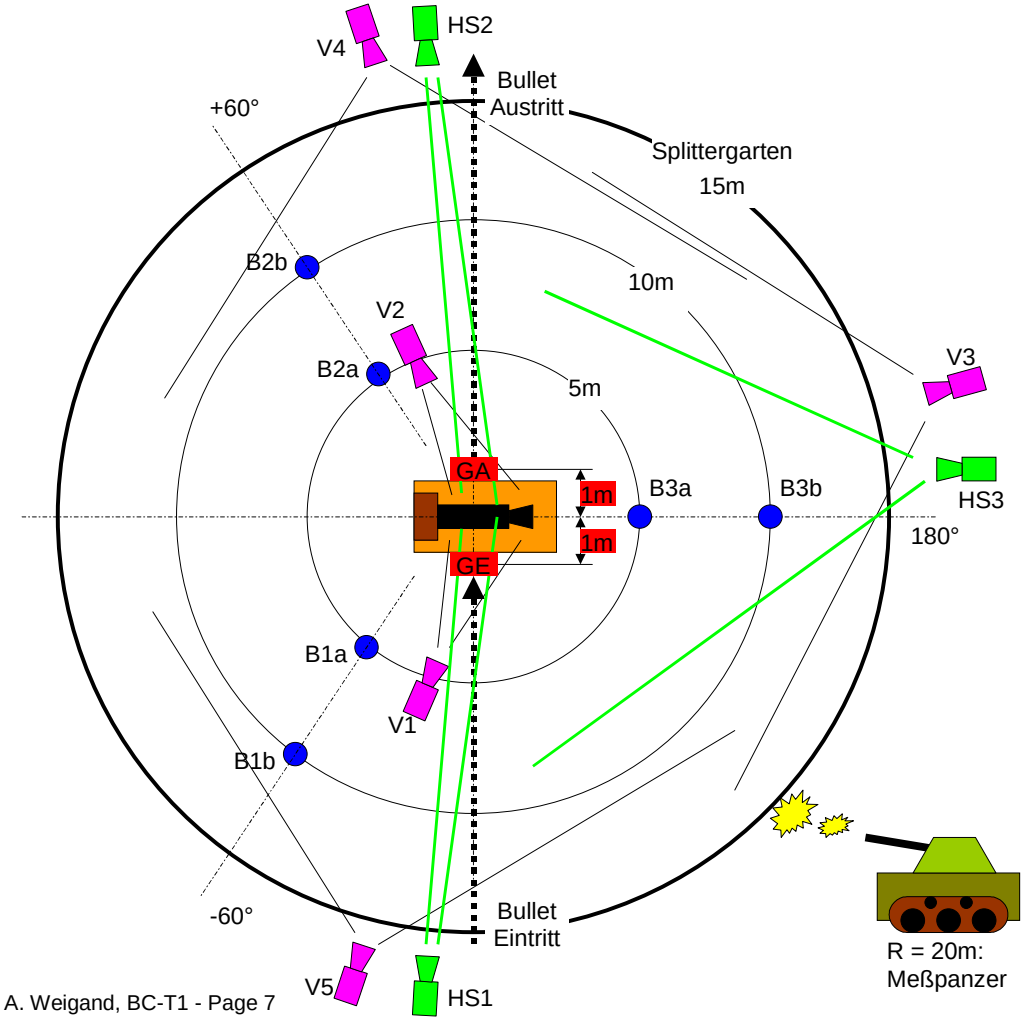
3. Bullet Attack

B2. Instrumentation:



Legende:

- GE — Geschwindigkeitsmessung Geschoßeintritt
- GA — Geschwindigkeitsmessung Geschoßaustritt
- Blastdruckmessung (Sensoren in Höhe der Motormittelachse)
- Videokamera
- Hi-Speed Videokamera

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3. Bullet Attack

C. Results and „failure“ mechanism:

- target pos.: center of motor
- target size: D = 50 mm
- bullet type: M2 AP-Bullet, 0,5 Zoll
- bullet speed: 810 to 830 m/s (meas.)
  850 ± 20 m/s (requ.)

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4. Fast Heating

A. Overview:

1. Test date & site: 05/07 and 06/08, WTD-91 Meppen

2. Number of tests: 6 Fast Heating Tests

3. Standard: STANAG 4240

4. Motor config.: Composite case with nozzle, no igniter

5. Fire type: 2x wood fire (1x LBR + 1x HBR propellant)

4x gas fire (3x LBR + 1x HBR propellant)

6. Equipment & measurements:

Motor Level: Head-end pressure, thrust & temperatures

Test Site: Blast pressure, hi- and low-speed video, IR-camera

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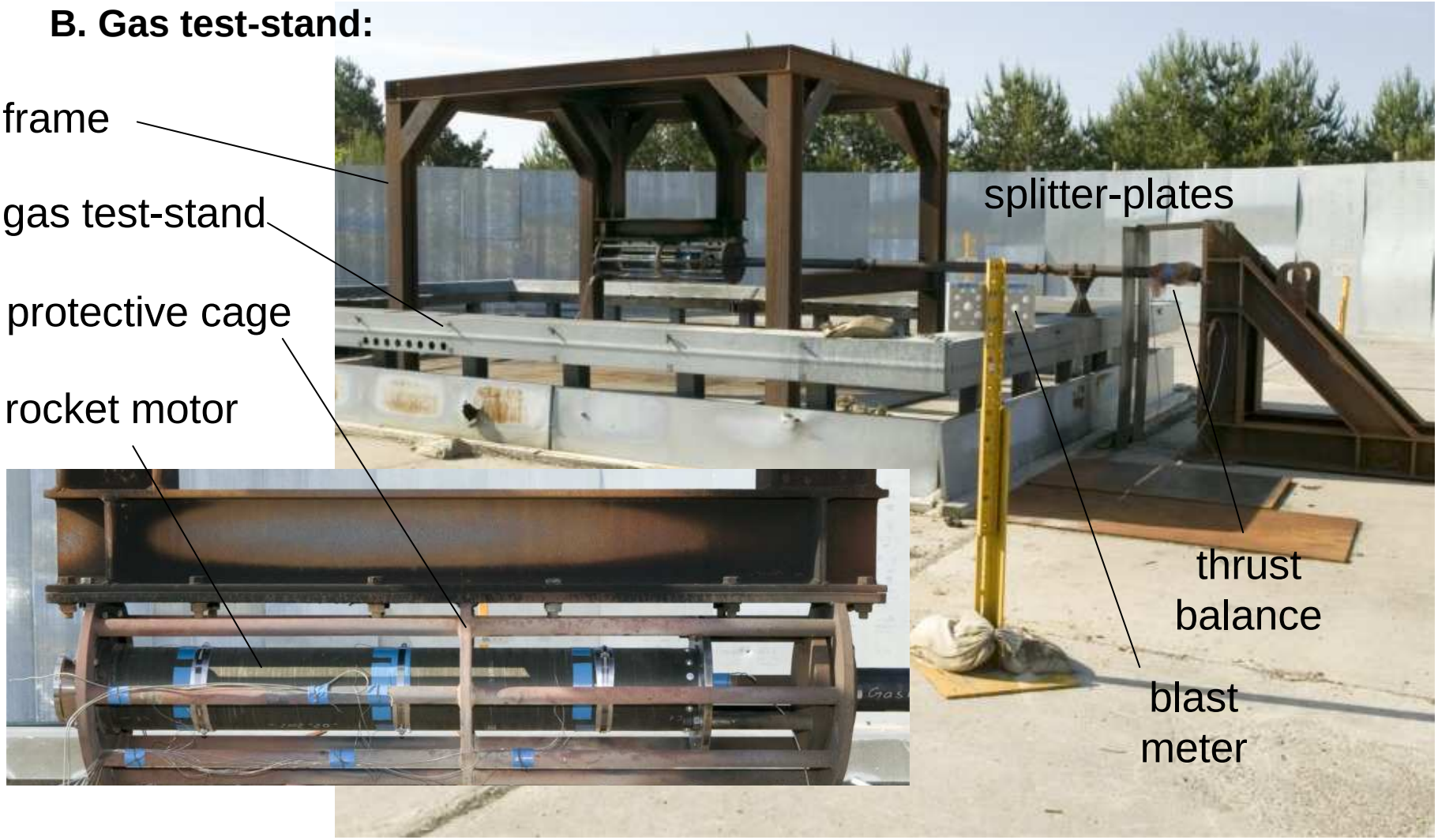
4. Fast Heating

B. Gas test-stand:



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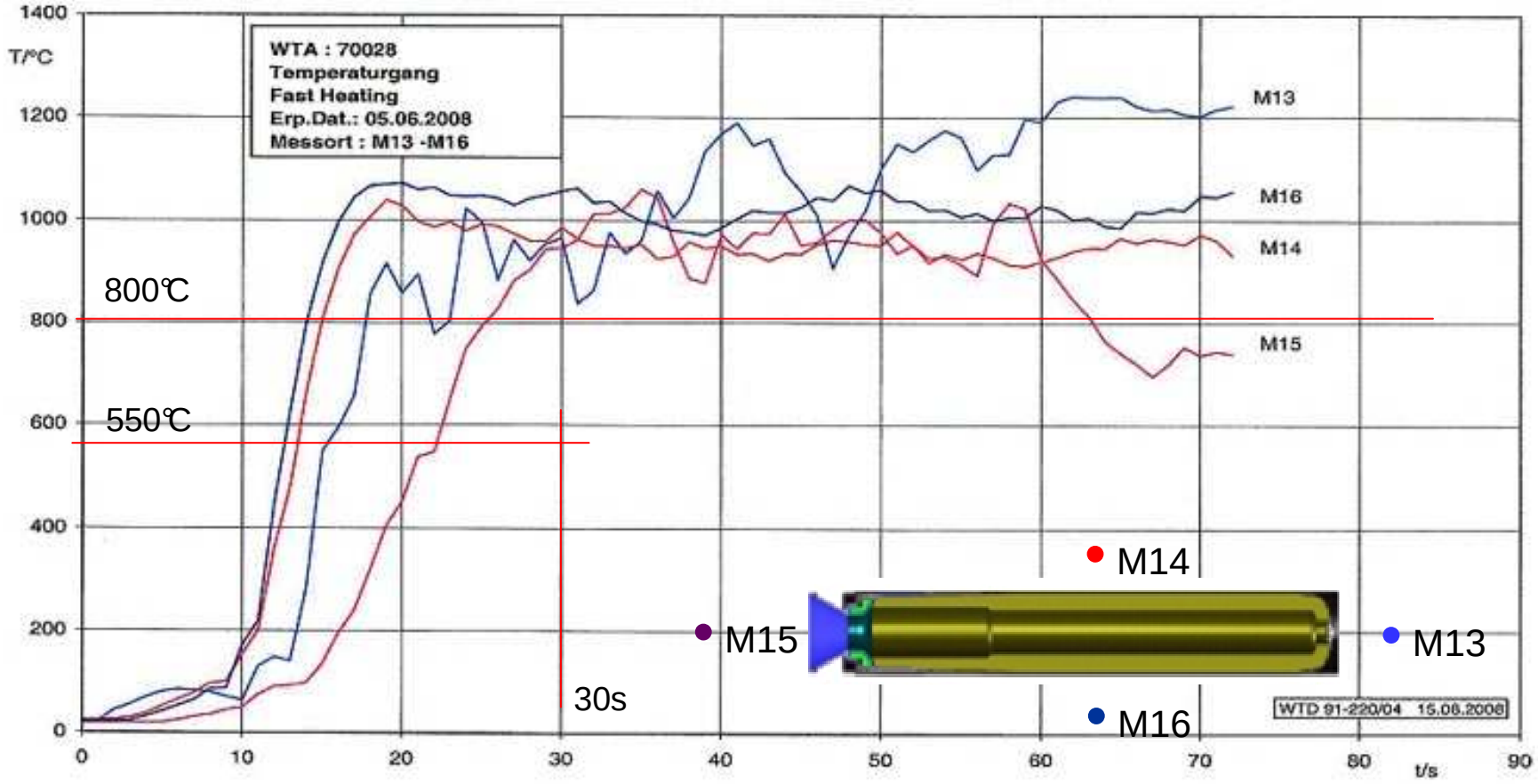
4. Fast Heating

C1. Measured fire temperatures (gas fire, LBR-motor IM-15, 05.06.08):



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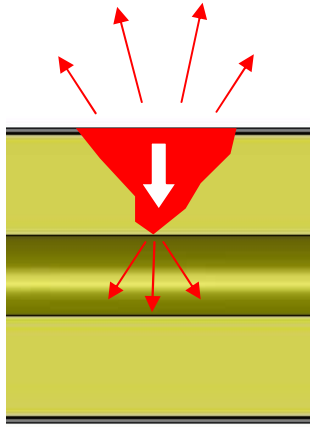
4. Fast Heating

C2. Results & Failure Mechanism: Two FH reaction-types!



1. Local & Slow Reaction: Two stages, relatively controlled burn, only small pressure & small axial thrust, no fragmentation.

- Stage 1: Local ignition at bondline burns a hole in the case from inside out, slow burn (atmosph. condition!) through web to bore, formation of radial cone.
- Stage 2: Ignition of bore surface, slow burn-off through hole (again, atmosph. conditions), formation of a side jet.

2. Global & Fast Reaction: Sudden pressure on-set, failure of case, fragmentation and weak, non-isotropic blast effects.

- de-bond due to outgasing of insulation/liner at high temperatures,
- ignition of a large part of the bond-surface -> sudden pressure on-set,
- failure of weakened case,
- global (i.e. spherical) fragmentation of case and grain,
- blast pressure recorded in extension of nozzle caused by motor start-up.

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5. Slow Heating

A. Overview:

1. Test date & site: 01/07, 09/07, 06/08, 06/09 and11/09, WTD-91 Meppen

2. Number of tests: 5 Slow Heating Tests

3. Standard: STANAG 4382 (3,3℃/h oven-temperature gradient)

4. Motor config.: Composite case with nozzle, no igniter, filled with

2x LBR propellant

3x HBR propellant

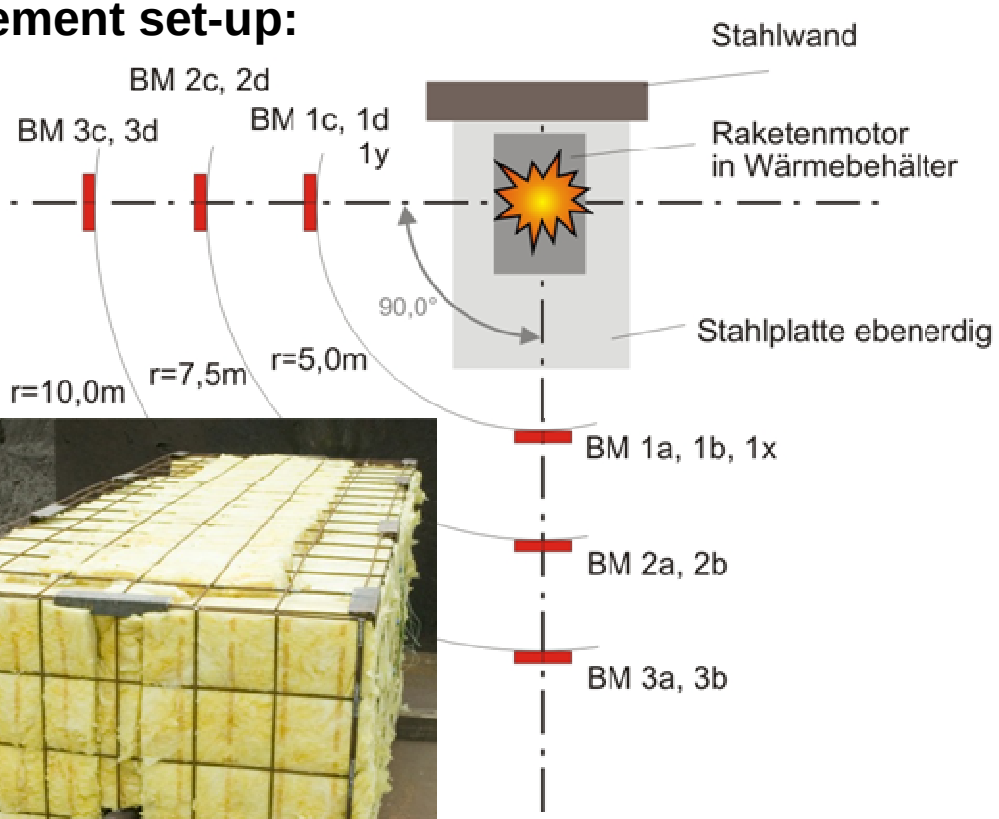
5. Equipment & measurements:

Motor level: Head-end pressure, temperatures

Test site: Blast pressure, low-speed video

5. Slow Heating

B. Test site with blast-measurement set-up:



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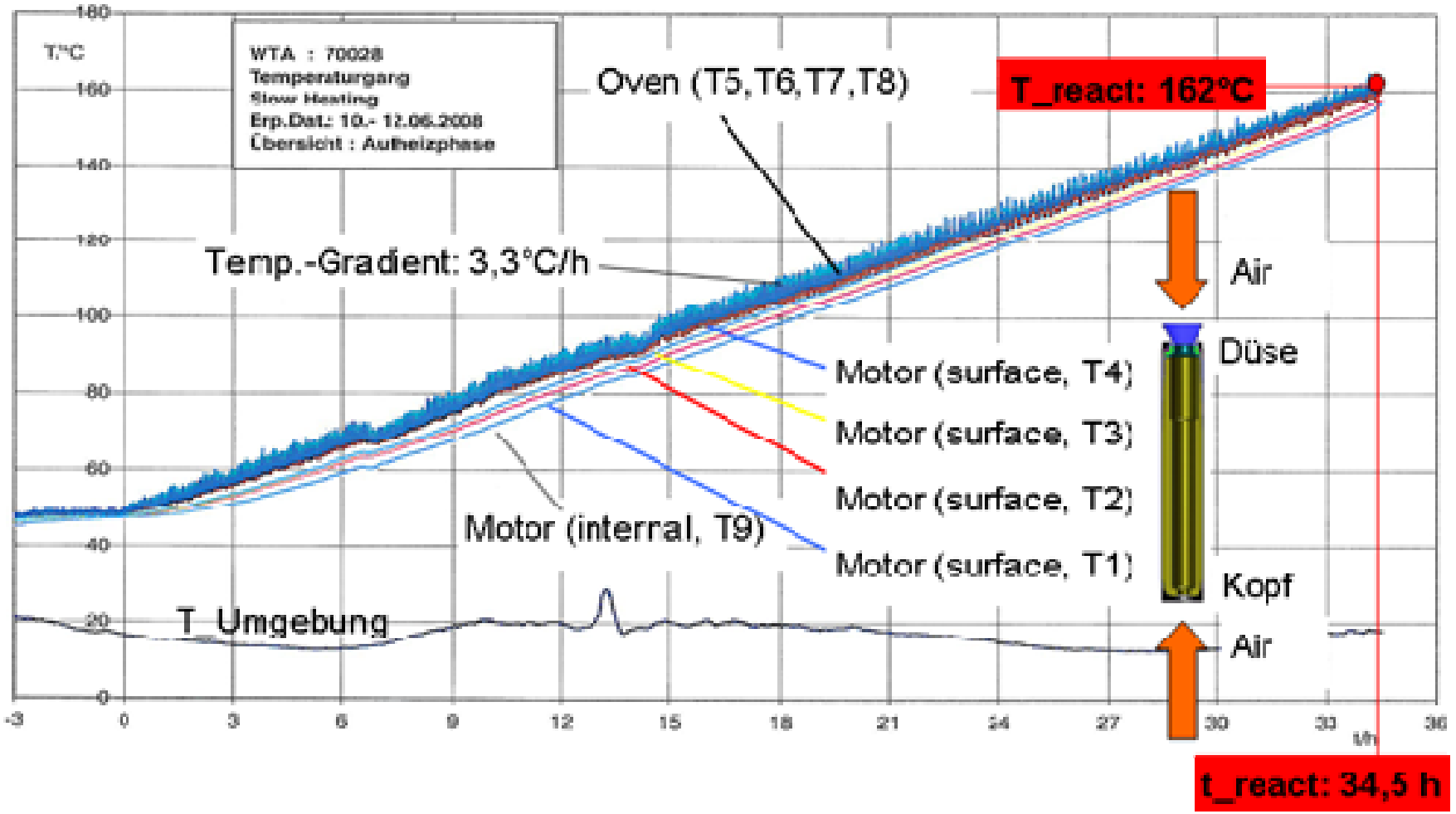
5. Slow Heating

C1. Oven-, motor- & reaction-temperatures (HBR-motor IM-18, 10.06.08):



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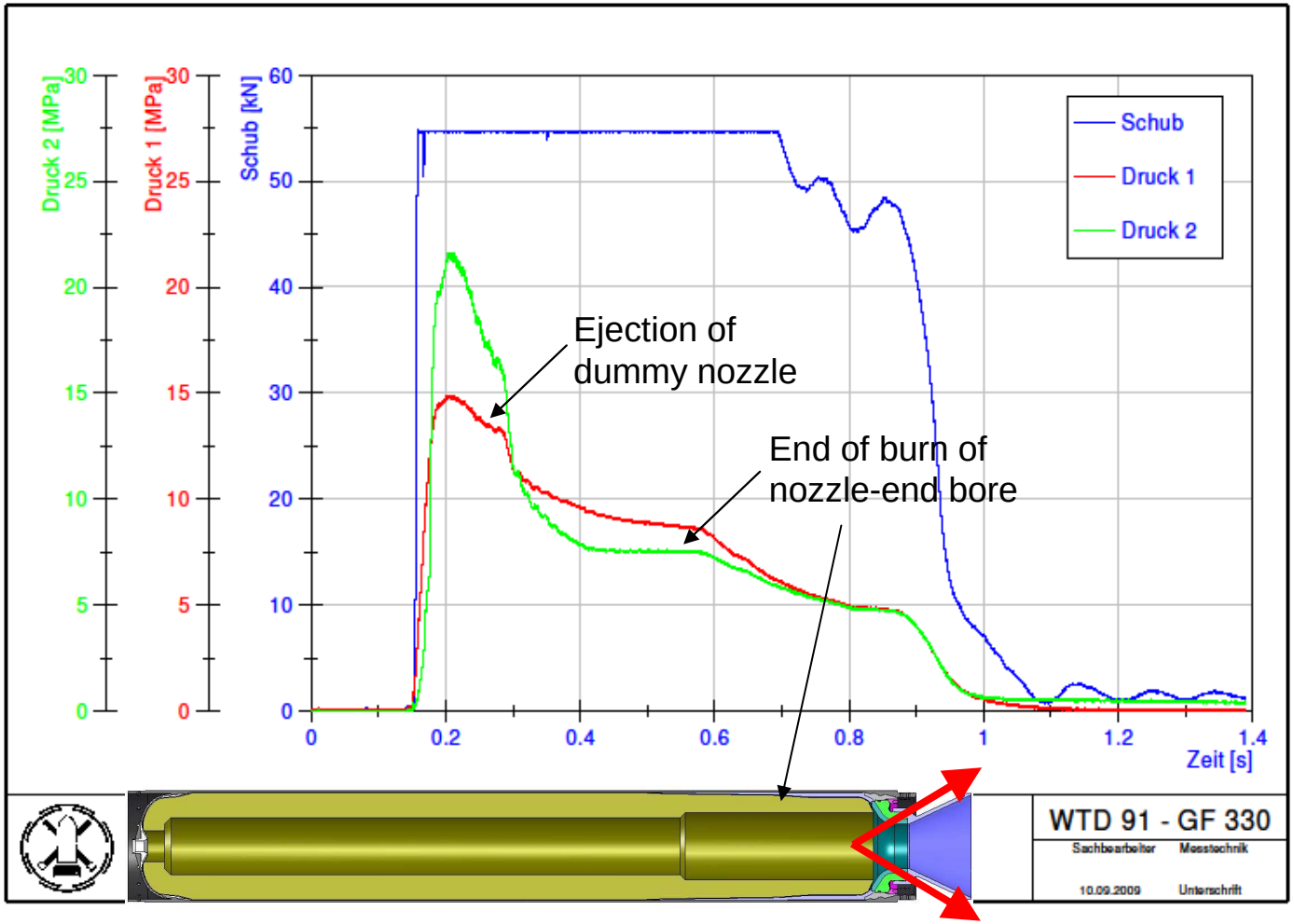
Slow Heating Mitigation:

Motor pressure and thrust measurements



1. Thrust was cut-off
2. Ejection of dummy nozzle after 150 ms -> thermal failure
3. p_max = 220 bar.
4. S_max = 80-100kN (internal ballistics)

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6. Simulation

A. Slow Heating, balance of heat:

$$-\lambda\Delta^2 T + \rho C_p \frac{\delta T}{\delta t} = \rho Q k_0 e^{\frac{-E_a}{RT}} - h\frac{S}{V}(T - T_0) - \varepsilon\sigma\frac{S}{V}(T^4 - T_0{}^4)$$

Conduction

Source
(Arrhenius)

Capacity

Convection,
Irradiation
(Environment)

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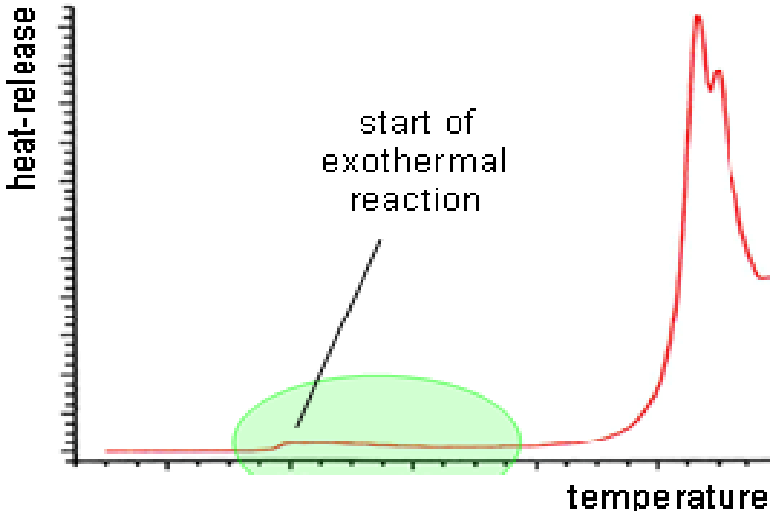
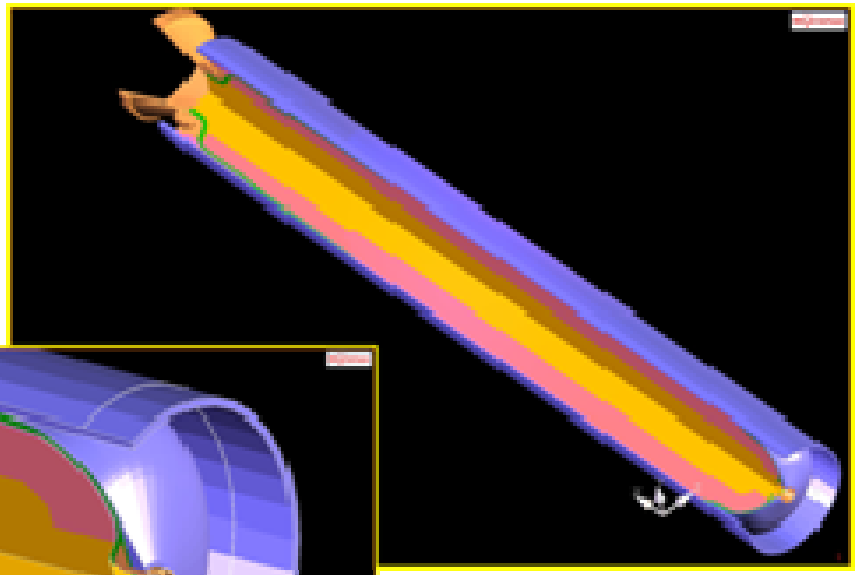
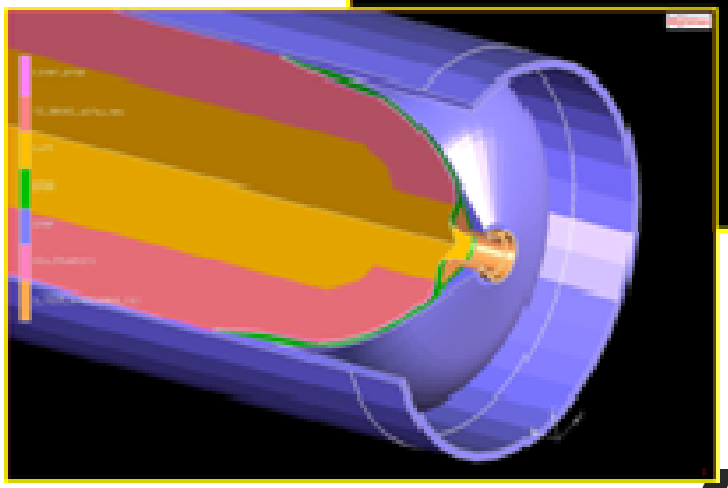
6. Simulation

B. Slow Heating, HBR propellant DSC measurements and FE motor-model:







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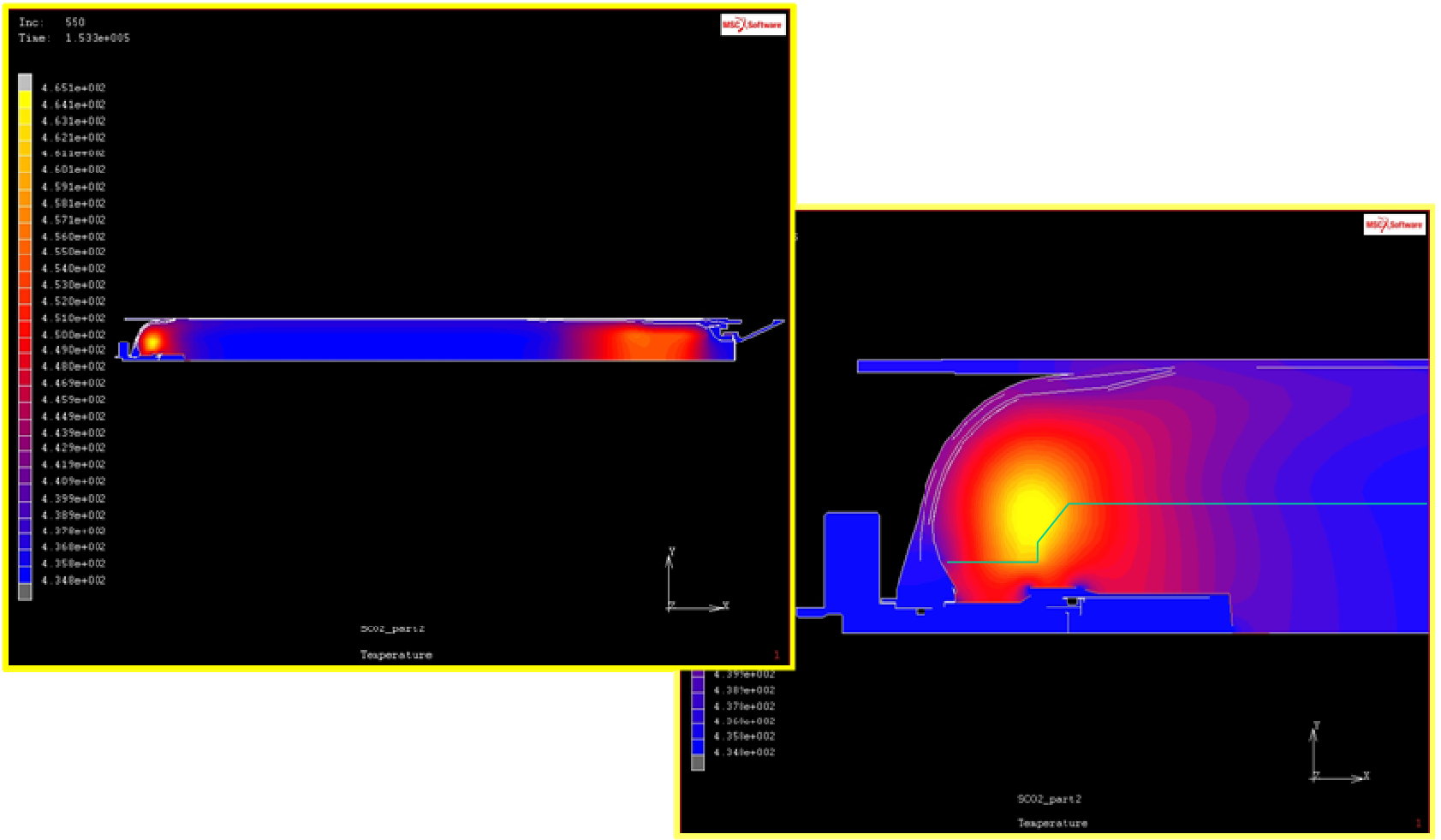
6. Simulation

C1. Slow Heating, computed temperature distrib. & hot-spot location (IM-18):



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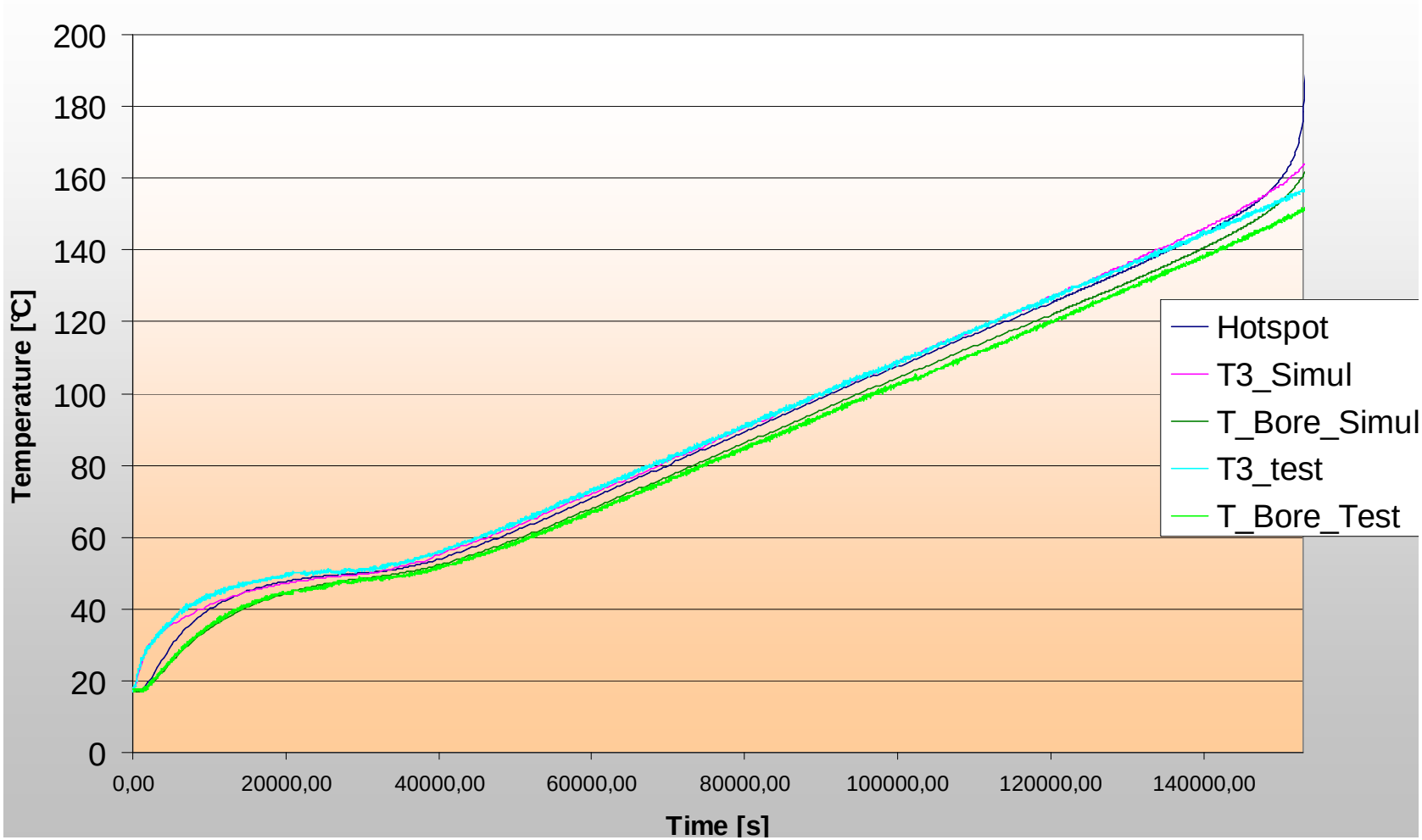
6. Simulation

C2. Slow Heating, computed and measured temperature evolution (IM-18):



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7. Outlook

1. Small-scale and high-temperature testing of
   - propellant burn-rates,
   - propellant reaction kinetics, and
   - material properties.

2. Fast Heating with Propane-gas and Kerosin:
   - fire boundary-conditions,
   - fire characteristics,
   - role of soot.

3. Simulation of dynamic reactions with fragmentation.

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