Bundesministerium
für Umwelt, Naturschutz
und Reaktorsicherheit

SCHRIFTENREIHE
REAKTORSICHERHEIT UND STRAHLENSCHUTZ

DURCHFÜHRUNG VON WEITERFÜHRENDEN KABELBRAND-VERSUCHEN EINSCHLIESSLICH DER PRÄSENTATION DER ERGEBNISSE IM RAHMEN DES INTERNATIONALEN PROJEKTES ICFMP

BMU - 2005-663

ENERGIE WIR STEUERN UM AUF ERNEUERBARE ENERGIEN.

BMU – 2005-663

„Durchführung von weiterführenden Kabelbrandversuchen einschließlich der Präsentation der Ergebnisse im Rahmen des internationalen Projektes ICFMP“

Prof. Dr.-Ing. Dietmar Hosser

Dipl.-Phys. Olaf Riese

Cand.-Ing. Mark Klingenberg

Institut für Baustoffe, Massivbau und Brandschutz

Beethovenstraße 52

38106 Braunschweig

IMPRESSUM

Dieser Band enthält einen Abschlussbericht über ein vom Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU) gefördertes Vorhaben. Verantwortlich für den Inhalt sind allein die Autoren. Das BMU übernimmt keine Gewähr für die Richtigkeit, die Genauigkeit und Vollständigkeit der Angaben sowie die Beachtung privater Rechte Dritter. Der Eigentümer behält sich alle Rechte an der weiteren Nutzung oder Vervielfältigung des Berichts vor.

Der Bericht gibt die Auffassung und Meinung des Auftragnehmers wieder und muss nicht mit der des BMU übereinstimmen.

Herausgeber:

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit
Referat RS I 2
Postfach 12 06 29
53048 Bonn

ISSN 1612-6386
Erscheinungsjahr: 2005

Abstract

As a part of the Fire Risk Research Program, the German iBMB (Institut für Baustoffe, Massivbau und Brandschutz) of Braunschweig University of Technology and GRS (Gesellschaft für Anlagen- und Reaktorsicherheit mbH) are participating in an International Collaborative Fire Modeling Project (ICFMP) to assess and validate fire computer codes for nuclear power plant applications. This assessment is being conducted through benchmarking and validation exercises. The tests are simulating cable fires scenarios in a single compartment.

The goal of the actual cable fire series is to investigate the effects of a natural fire to vertically routed cables (worst case) with different cable insulation material (PVC and FRNC). Another important aspect of cable fire is the risk of function failure. Therefore in the test series the short circuit and the conduction loss of cables are measured.

This report includes a first description of the experimental results for test 1 - test 4 of the International Collaborative Fire Model Project conducted in December 2003 at the iBMB in Germany. The experimental data are reported on the International Collaborative Fire Model Project - Platform. The measured data shall be the basis for fire simulations.

The tests show that the FRNC cables have significantly better characteristics in case of fire. No substantial flame spread takes place even in case of preheating. PVC cables could be ignited with a burner output of 50 kW, in contrary, the FRNC cables could be ignited at burner output of 150 kW. The preheating has a complex effect on the fire behavior of the cables. It may occur that gases are pyrolysed which are not ignited during the phase of preheating. These gases are transported from the cable surrounding and may leave the fire room.

Short circuits occur first in case “conductor to conductor” and later in case “conductor to tray”. The time periods until short circuits occur are strongly dependent on the preheating of the cables. In case of no preheating, the short circuit times are a factor two higher then in case of preheating. In one case, an I&C PVC cable already failed after nearly 100 seconds in case of preheating. A mean value for the time to loss of function of a PVC insulated I&C cable with preheating was estimated from the experiments to be 220 seconds. The short circuit times of power cables are nearly two times higher then those of I&C cables independent from the cable insulation material. FRNC cables have better characteristics in all tests although they are ignited with a substantially higher burner output as mentioned above.

Kurzfassung

Im Rahmen der aktuellen Aktivitäten zum Brandschutz in Kernkraftwerken nehmen von deutscher Seite die GRS (Gesellschaft für Anlagen- und Reaktorsicherheit mbH) und das iBMB (Institut für Baustoffe Massivbau und Brandschutz) der Technischen Universität Braunschweig am "International Collaborative Fire Modeling Project (ICFMP)" zur Validierung und Bewertung der Anwendbarkeit von Brandsimulationsmodellen für kernkraftwerkstypische Brandszenarien teil. Diese Arbeiten werden in Form so genannter Benchmark- und Validierungsaufgaben durchgeführt. Die aktuellen Versuche dienen der Simulation von Kabelbrandszenarien in einem einzelnen Raum.

Ziel der derzeitigen Kabelbrand-Versuchsserie ist die Untersuchung von Bränden auf vertikal verlegten Kabeltrassen bei natürlicher Belüftung (als worst case) für Kabel mit unterschiedlichen Kabelisolationsmaterialien (PVC und FRNC (*f*ire *r*etardant, *n*on *c*orrosive)). Ein weiterer bedeutsamer Aspekt dieser Versuchsserien sind Untersuchungen zum brandbedingten Funktionsausfall der Kabel. Dementsprechend werden bei diesen Versuchen sowohl mögliche Kurz- und Erdschlüsse als auch der Verlust der Leitfähigkeit der Kabel gemessen.

Der vorliegende Bericht enthält eine erste Darstellung der experimentellen Ergebnisse für die im Rahmen des ICFMP-Projektes im Dezember 2003 beim iBMB in Deutschland durchgeführten Versuche 1 bis 4. Die experimentellen Daten liegen auf der Internet-Plattform des International Collaborative Fire Model Projects vor. Die gemessenen Daten dienen dabei als Basis und Referenz für die Brandsimulationsrechnungen.

Die Versuche verdeutlichen ein im Brandfall erheblich besseres Verhalten der FRNC-Kabel gegenüber PVC-Kabeln. Selbst bei Vorheizung der Kabel findet eine nennenswerte Flammenausbreitung nicht statt. Während sich PVC-Kabel mit einer Leistung von 50 kW entzünden lassen, erfolgt eine Entzündung von FRNC-Kabeln erst bei einer Brennerleistung von 150 kW. Die Vorheizung zeigt komplexe Auswirkungen auf das Brandverhalten der Kabel. Einerseits kann ein Pyrolisieren von Gasen erfolgen, die sich nicht während des Vorheizens entzünden aber im Fall einer Flamme schlagartig verbrennen können. Andererseits besteht auch die Möglichkeit, dass Pyrolysegase aus der Umgebung der Kabel den Brandraum verlassen und sich gegebenenfalls an einer anderen Stelle sammeln und entzünden können.

Kurzschlüsse zwischen einzelnen Leitern eines Kabels treten zuerst auf, erst danach erfolgen Kurz- und Erdschlüsse zwischen Leitern eines Kabels und benachbarten Kabeln oder der Trassenbefestigung. Dabei hängt der Zeitpunkt, ab welchem erste Kurzschlüsse auftreten, erheblich vom Vorheizen der Kabel ab. Ohne Vorheizung sind die Zeitspannen, ab welchen

Funktionsverluste auftreten, ungefähr um einen Faktor zwei höher als mit Vorheizung. In einem Fall versagte ein Kabel der Elektro- und Leittechnik bei Vorheizung bereits nach nahezu 100 Sekunden. Als Mittelwert für die Zeitspanne bis zum Funktionsverlust eines PVC-isolierten Kabels der Elektro- und Leittechnik bei Vorheizung wurden 220 Sekunden ermittelt. Für FRNC-Kabel der Elektro- und Leittechnik wurde ein entsprechender Mittelwert für die Zeitspanne bis zum Funktionsverlust bei Vorheizung von 640 Sekunden gefunden. Die Kurzschlusszeiten von Leistungskabel sind nahezu zweimal höher als die von Kabeln der Elektro- und Leittechnik, unabhängig von der Art des Isolationsmaterials. FRNC-isolierte Kabel zeigen eine deutlich verbesserte Charakteristik bei allen Versuchen, obwohl sie, wie bereits beschrieben, bei den Randbedingungen der hier vorliegenden Versuchsreihe, nur mit einer deutlich höheren Brennerleistung entzündet werden konnten.

Aufgabenstellung im Rahmen des internationalen Projektes ICFMP

Im Rahmen des BMU-Vorhabens SR 2449 "Verbesserungen bei präventiven Brandschutzmaßnahmen - Auswertung von Brandereignissen und Kabelversuchen, probabilistische Betrachtungen für den SWR 69 im Rahmen der Level 2 PSA" nehmen die GRS (Gesellschaft für Anlagen- und Reaktorsicherheit) mbH und in ihrem Unterauftrag das iBMB (Institut für Baustoffe, Massivbau und Brandschutz) der Technischen Universität Braunschweig an einem gemeinschaftlichen internationalen Projekt zur Bewertung von Brandmodellen hinsichtlich ihrer Anwendbarkeit für kernkraftwerksspezifische Szenarien, dem so genannten International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications - ICFMP teil.

Im Rahmen dieses internationalen Projektes werden die Erkenntnisse und Erfahrungen diverser Fachinstitutionen genutzt, um gemeinsam den internationalen Stand von Wissenschaft und Technik bei Brandsimulationsmethoden und Computerprogrammen hinsichtlich der Anwendungen auf die besondere Situation in kerntechnischen Anlagen zu bewerten und zu verbessern. Dabei hat die Zusammenarbeit im Rahmen der Arbeitsgruppe ICFMP vorrangig folgende Ziele:

- Erfassung des internationalen Kenntnisstandes zu Brandsimulationsrechnungen einschließlich Validierung für kernkraftwerksspezifische Brandszenarien anhand von Experimenten,

- Prüfung von Anwendungsmöglichkeiten und -grenzen solcher Rechnungen für die Bewertung des Brandschutzes in kerntechnischen Einrichtungen und Einbezug derartiger Verfahren in kerntechnische Regelwerke,

- Erarbeitung von analytischen Hilfsmitteln für konkrete Anwendungen bei der Bewertung der Brandsicherheit von Kernkraftwerken,

- Beispielhafte Anwendung von Brandsimulationsrechnungen für ausgewählte Brandszenarien in Kernkraftwerken sowie Bewertung der Aussagesicherheit dieser Analysehilfsmittel für einen nationalen wie internationalen Einsatz.

Zur Umsetzung der unterschiedlichen Aufgabenstellungen des Projektes werden so genannte Benchmark-Aufgaben (Benchmark Exercises) und Validierungsuntersuchungen durchgeführt. Die Simulationsrechnungen werden hierbei von den teilnehmenden Institutionen aus verschiedenen Ländern mit unterschiedlichen Arten von Brandsimulationscodes zuerst "blind", d. h. ohne Kenntnis der Versuchsergebnisse durchgeführt, und später nochmals in Kenntnis der Versuchsergebnisse "offen" nachgerechnet, um schließlich die Ergebnisse untereinander sowie mit den Versuchen zu vergleichen.

Elektrische Leitungen zur Versorgung und Ansteuerung elektrischer und elektronischer Komponenten und Systeme können eine erhebliche Brandgefahr innerhalb der Kraftwerksanlagen darstellen. Einerseits beteiligen sich brennbare Isolierungen der elektrischen Leitungen direkt am Brandgeschehen, andererseits kann eine Brandausbreitung durch die ungeschützte Kabelführung über große Abstände erfolgen. Die Möglichkeit der Brandrausbreitung entlang der Kabel besteht insbesondere bei einer erhöhten Belegungsdichte, wie sie in Großkraftwerksanlagen gegeben ist. Mit Kabelbränden sind unmittelbare Gefahren wie anhaltend hohe Temperaturen, hohe Rauchproduktion, Freisetzung von gefährlichen toxischen Verbrennungsprodukten, Funktionsausfälle von Komponenten und Systemen oder auch langfristige Beschädigungen von baulichen Strukturen und der Ausrüstung durch korrosive Gase verbunden. Versuche am iBMB haben gezeigt, dass die Vorwärmung von elektrischen Kabeln einen erheblich Einfluss auf das Entzündungsrisiko und die Brandausbreitung haben kann.

In Kernkraftwerken älterer Bauart sind überwiegend PVC-Kabel eingesetzt. Die Kabelindustrie stellt jedoch seit geraumer Zeit eine Vielzahl an Kabelisolationsmaterialien mit verbesserten Eigenschaften im Brandfall bereit, die verstärkt in Kernkraftwerken zum Einsatz kommen [HOS 03]. Eine Gruppe dieser Kabel mit solchen verbesserten Eigenschaften sind die so genannten FRNC (fire retardant non corrosive)-Kabel.

Im Rahmen der vorliegenden Studie wurden vier großmaßstäbliche Raumbrandversuche mit vertikal angeordneten Kabelpritschen in einem Brandversuchstand des iBMB durchgeführt. PVC- und FRNC-Kabel wurden dabei getrennt untersucht. Die Versuche wurden je Materialart einmal ohne und einmal mit Vorwärmung durchgeführt. Als Zündquelle wurde ein Propangasbrenner eingesetzt, für die Vorwärmung ein in der Brandkammer angeordneter Ethanol-Flüssigkeitspool. Um den Einfluss des jeweiligen Kabeltyps zu berücksichtigen, wurden die Kabeltrassen in zwei getrennten Bündeln mit Leistungs- und mit Steuerkabeln praxisgerecht belegt.

Im Unterschied zu den bisherigen “Benchmark Exercises“ des ICFMP-Projektes wurden die Kabeltrassen in dem hier beschriebenen Versuchsprogramm der Versuchsserie 5 (Benchmark Exercise # 5 - Flame Spread In Cable Tray Fires) gezielt in Brand gesetzt, um das Entzündungsverhalten sowie das Brandausbreitungsverhalten zu untersuchen.

Eine weitere Gefahr bei Kabelanlagen ist der Funktionsverlust der Kabel im Brandfall. Dieser wurde in den hier vorgestellten realmaßstäblichen Versuchen mit untersucht.

In diesem Bericht werden die Ergebnisse der Kabelbrandversuche (Test 1 – Test 4) und der parallel durchgeführten Funktionserhaltversuche dargestellt. Um für die Teilnehmer des ICFMP-Projektes den Vergleich der Daten zu vereinfachen, wurden abgeleitete Größen (z. B. Heiß- und Kaltgastemperaturen, Höhe der rauchgasarmen Schicht, Massen- und Wärmeströme) aus den Versuchsdaten berechnet und als Datenfile zur Verfügung gestellt. Die hierzu benutzten physikalischen Gleichungssysteme werden dokumentiert. Die Spezifikation der Versuche und die Startbedingungen an den Versuchstagen wurden auf der ICFMP-Plattform vorgestellt und sind im Anhang zum vorliegenden Bericht enthalten.

Contents

List of Figures

List of Tables

1 Introduction

This paper gives information about the results of four real scale cable tray fire tests carried out at iBMB of Braunschweig University of Technology in the frame of ICFMP Benchmark Exercise No. 5. The specification of the tests is given in the Appendix A [RIE 03], last modifications of the tests are provided in the Appendix B of this document. For blind calculations a document containing environmental and burner output data after the realization of the tests is given in the Appendix C [RIE 03a]. The experimental data are provided in detail in the attached MS Excel file “BM#5-TestData”. All files have been included in the ICFMP web platform in 2003 and 2004.

The experimental results presented here can be used to assess and validate computational fire simulation models with the focus on cable flame spread. To study preheating effects, an ethanol pool was used at the beginning of test 2 and test 4. This phase of the experiments is also useful to validate computational fire models focusing on liquid fuel combustion.

2 Test Comments

A short overview of the main characteristics of the test series is given in the following comments.

Comments to Test 1 (FRNC, no preheating)

Ignition of both cables at 150 kW gas burner output, no continued flame spread, little blistering of the sheath surface, FRNC cables providing only a small contribution to the gas burner output.

Comments to Test 2 (FRNC, preheating)

Ignition of both cables at 150 kW gas burner output, no continued flame spread, strong blistering of the sheath surface, FRNC cables providing only a small contribution to the gas burner and the ethanol pool output.

Comments to Test 3 (PVC, no preheating)

Ignition of both cables at 50 kW gas burner output, continued flame spread on both cables.

Comments to Test 4 (PVC, preheating)

Ignition of cable A at 50 kW gas burner output with continued flame spread, no ignition of cable B at this output level. Ignition of cable B at a 100 kW gas burner output with following flash over. This phenomenon is discussed in the chapter 6.

3 Measurement Overview

3.1 Measured Values

The following parameters have been measured:

- Temperatures above the fire (plume) for 7 heights,
- Temperatures in the fire compartment at 4 locations for 7 heights,
- Temperatures 40 cm in front of the cable tray for 7 heights,
- Temperatures on the wall surfaces for 7 heights,
- Weight loss of the pool,
- Weight loss of the cable tray,
- Gas velocities and temperatures in the openings and in the plume,
- Pressure difference distribution for 3 heights of the fire compartment,
- Gas analysis (for O_2, CO_2 and CO) for 2 heights in the fire compartment,
- Heat flux densities before the cable bundles for 5 heights,
- Cable surface and inner cable temperatures for 9 heights,
- Gas velocity and temperature in the exhaust channel,
- Gas analysis (for O_2, CO_2 and CO) in the exhaust channel,
- Smoke gas density in the exhaust channel,
- Functional failure tests.

The different measurements are given in **Table 3-1**. The environmental data at test time, such as temperature and pressure, are taken from daily standard measurements from iBMB.

The fire compartment, which has been used for the test series is located in a large experimental hall with a floor area of 30 m x 16 m = 480 m² and 15 m height. The data are recorded with a data-logger every 10 seconds. The environmental data are recorded every 120 seconds. More detailed information about the configuration of the tests, the measurements and cable data are given in the Appendix A (Specification). There, also thermo-physical data from the cable insulation materials taken from tests, performed with the Cone-Calorimeter [ISO 99], can be found.

Table 3-1 Measurement abbreviations

Parameter	Abbreviation	Location	Unit
Temperature	TP TR TW, TWO TCI TCO TE TB TH	plume compartment wall, wall outside inside cable on cable surface ethanol bi-directional probes environment (hall)	[°C]
Mass loss	GVP GVC	ethanol pool cable tray	[kg]
Pressure difference	DP	openings, plume, compartment	[Pa]
Pressure	PH	environment (hall)	[Pa]
Gas analysis inside compartment	GA	compartment	[Volume %]
Heat flux density	WS	cable tray	[kW/m²]
Smoke production	SPR (RD)	exhaust duct	[m²/s]
Heat release rate	HRR	exhaust duct	[kW]
Gas burner output	GB	outside compartment	[kW]

( ) renamed

3.2 Location of Thermocouples on the Cable Tray

PVC coated cables as well as FRNC (Fire Retardant Non-Corrosive) cable insulation materials are used. Power cables as well as I&C (instrumentation and control) cables were investigated installed in two different cables bundles of the tray.

The vertical ladder type cable trays are filled with cables with the corresponding measuring equipment as outlined in **Figure 3-1**. The cables are mounted on the trays with cable clamps. The lowest series of thermocouples is installed approximately 70 cm above the lower side of the tray. The distance between the different measuring levels is 40 cm, the distance between the highest series of measuring devices and the upper edge of the tray is 10 cm. The measuring devices of each line have numbers starting on the lowest level up to the highest one (last digit in the number). The exact position of the thermocouples is given in **Figure 3-2**. **Figure 3-3** shows the position of the thermocouples “on” and “in” the cables.

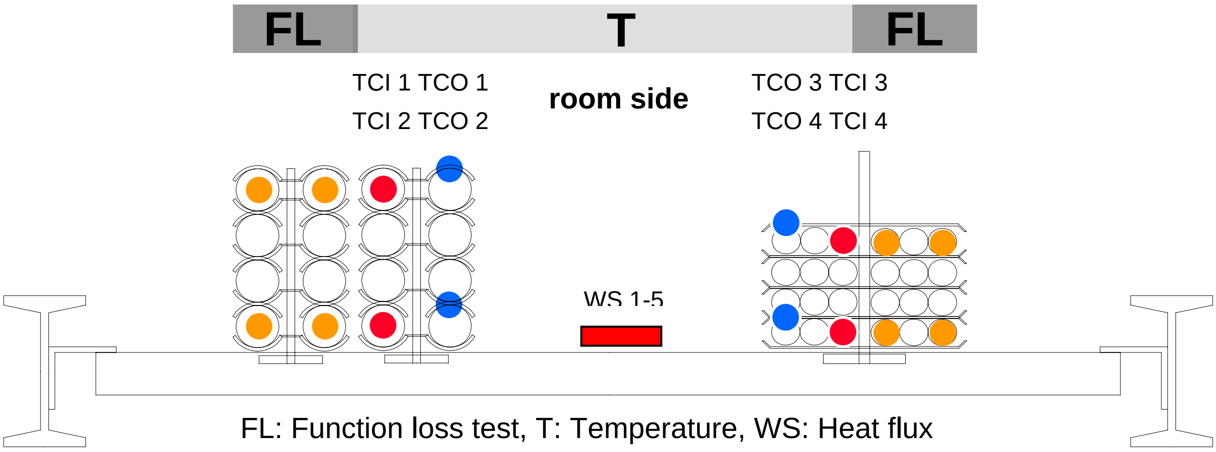


Figure 3-1 Vertical cable tray; two cable bundles; left: power cables, right: I&C cables

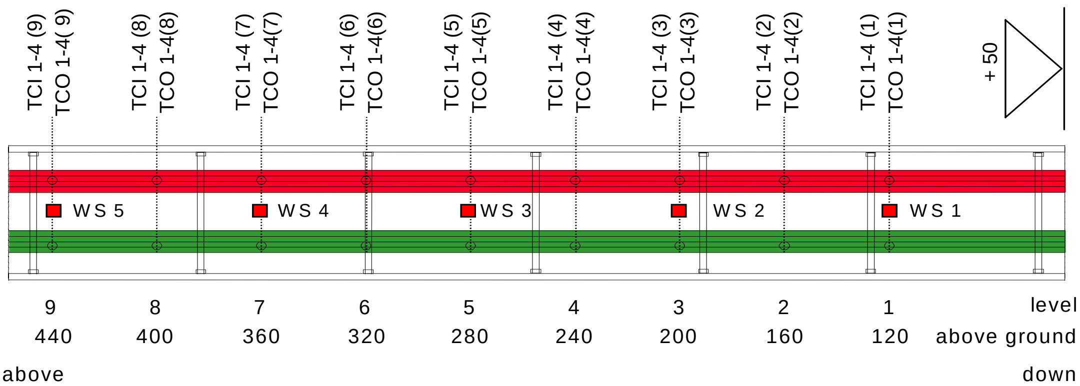


Figure 3-2 Temperature measurement positions on the cable tray, levels 1-9, and heat flux measurement positions at the cable tray

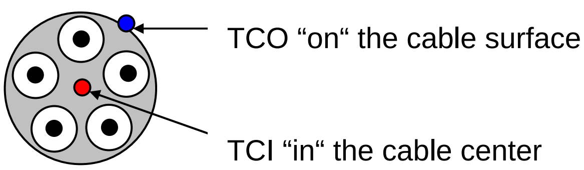


Figure 3-3 Location of thermocouples TCO “on” and TCI “in” the cable

4 Documented Results

The results of test 1 – test 4 are given in the attached MS Excel file 'BM#5-TestData'. Inside the comment line a comment is given for specific values. If no values have been provided, the respective lines are left free. In case of data error the number "9999.99" is used to indicate an irregular value. In the following **Table 4-1** the values being delivered and not measured directly are described in more detail. In chapter 5 the procedure for the computation of the derived values is presented. Some plots of interest for each test are given in the Appendices D-1 to Appendix D-4. With TR_M1-7 a mean value of the thermocouple trees TR1-4 (level by level) is given.

Table 4-1 Additional variables to be delivered

Description	Name	Unit	Comment
Velocity	V_EX	m/s	Velocity exhaust duct
	V_CP	m/s	Velocity centerline plume
	V_DO	m/s	Velocity door
Combustion	Comb_E	kg/s	Combustion rate of ethanol
	Comb_C	kg/s	Combustion rate of cables
	HRR	kW	Total combustion heat release
Layer temperatures and height	T_up	°C	Upper layer temperature
	T_low	°C	Lower layer temperature
	Layer_height	M	Layer height
Wall surface temperature	TW_up	°C	Wall temperature of the fire compartment in the upper layer region
	TW_low	°C	Wall temperature of the fire compartment in the lower layer region
Mass flow rates	Gin(Door)	kg/s	Mass flow rate through front door into the fire compartment
	Gout(Door)	kg/s	Mass flow rate through front door from the fire compartment
Heat flow rates	HeatLoss(Walls)	kW	Heat loss into the walls of the fire compartment
	HeatFlow(Door)	kW	Total heat flow through the door

5 Experimental Data

5.1 Gas Velocities and Volume Flows

5.1.1 Exhaust Duct [ISO 93]

According to [ISO 93], the flow rate $\dot{V}_{exhaust\ duct}$ is given by the equation (1.1), the velocity in the exhaust duct is given with equation (1.2):

$$\dot{V}_{exhaust\ duct} = A \cdot \overbrace{k_t \cdot \underbrace{\frac{1}{k_p} \cdot \frac{22,4}{T_{298}}}_{=0,07} \cdot \sqrt{T \cdot \Delta p}}^{corrected\ velocity} = A \cdot v_{exhaust\ duct} \quad (1.1)$$

$$v_{exhaust\ duct} = k_t \cdot 0,07 \cdot sign(\Delta p)\sqrt{T \cdot |\Delta p|} \quad (1.2)$$

$A =$	exhaust cross section area: 0.04 * π [m²]
$\Delta p =$	pressure difference bidirectional-probe [Pa]
$T =$	temperature [K]
$k_p =$	calibration constant for bi-directional probe: 1.08
$k_t =$	correction factor for velocity profile: 0.9 [-]

5.1.2 Centerline Plume and Door

The velocity $v_{plume,\ door}$ in the centerline plume and the door are calculated with equation (1.3)

$$v_{plume,\ door} = 0,07 \cdot sign(\Delta p)\sqrt{T \cdot |\Delta p|} \quad (1.3)$$

5.2 Combustion

5.2.1 Calculation of Heat Release Rate [ISO 93]

The heat release rate was calculated by using equations of [ISO 93]. With an appropriate measurement in the exhaust flow the smoke gas volume flow $\dot{V}_{298}$ (standardized to 25°C) is given using equation (1.4). With equation (1.5) the total heat release rate is given. For those one, who will determine the net heat release rate of the cables use equation (1.6). The data for the energy per oxygen consumed per volume of the propane gas and ethanol given here come from the Fire Dynamics Simulator database 3 [FDS 02].

$$\dot{V}_{298} = \frac{T_{298}}{T} \cdot \dot{V}_{exhaust\ duct} \tag{1.4}$$

$$HRR = E^{V}_{O_2,M} \cdot \dot{V}_{298} \cdot X^{a}_{O_2} \cdot \frac{\phi}{\phi \cdot (\alpha - 1) + 1} \tag{1.5}$$

$$\dot{q}_m = HRR - \frac{E^{V}_{O_2,M}}{E^{V}_{O_2,C_3H_8}} \cdot \dot{q}_b - \frac{E^{V}_{O_2,M}}{E^{V}_{O_2,C_2H_6O}} \cdot \dot{q}_e \tag{1.6}$$

with

T	gas temperature in the exhaust duct [K]
$\dot{V}_{298}$	standardized volume flow rate of gas in the exhaust duct [m³/s]
ϕ	”oxygen depletion factor with carbon dioxide filtering [-]
$E^{V}_{O_2,M}$	= 17200 kJ/m³ consumed oxygen (standard)
α	= 1.105 („chemical expansion factor“)
HRR	total heat release rate [kW]
$\dot{q}_b$	power output gas burner [kW]
$\dot{q}_e$	power output ethanol-pool [kW]
$E^{V}_{O_2,C_3H_8}$	= 16800 kJ/m³ consumed oxygen (propane)
$E^{V}_{O_2,C_2H_6O}$	= 12842 kJ/m³ consumed oxygen (ethanol)
$\dot{q}_m$	heat release rate of the material [kW]

5.2.2 Calculation of Mass Loss Rate Pool and Cables [ISO 99]

The mass loss rate [kg/s] from the pool and the cable on the tray is calculated by applying the five point numerical differentiation equations published in ISO 5660 part 1 [ISO 99] page 21. The mass loss was smoothed (sequential average over 8 values) therefore.

5.3 Smoke Production [ISO 93]

The smoke production rate SPR in the exhaust duct is calculated under consideration from the absolute volume flow:

$$SPR = \frac{1}{L} \cdot \ln\left(\frac{I_0}{I}\right) \cdot \dot{V}_{exhaust\ duct} \quad [\text{m}^2/\text{s}] \tag{1.7}$$

I_0 light intensity without extinction [-]

I light intensity with extinction [-]

L = 0.4 m, diameter of exhaust duct

5.4 Experimental Data Reduction [NIS 03]

5.4.1 Layer Interfaces Height

The lower layer temperature T_{low} is taken to be the average of the thermocouple readings of the lowest measurement points. The interface height and upper layer temperature were calculated from solving the integral equations, given in [NIS 03]. Combining these equations provides the equation for the interface height.

$$z_{\text{int}} = \frac{T_{low}\left(I_1 \cdot I_2 - H^2\right)}{I_1 + I_2 T_{low}^2 - 2T_{low}H} \tag{1.8}$$

z_{int} layer interface height [m]

T_{low} temperature of the lowest measurement point [°C]

H room height [m]

I_1 integral value – approximated by discrete summation

$$I_1 = \int_0^H T(z,t)dz \approx \sum_{i=1} T_i(t) \cdot \Delta h_i \tag{1.9}$$

$T_i(t)$ temperature at measurement point number i

Δh_i layer height assigned to measurement point number i

I_2 integral value – approximated by discrete summation

$$I_2 = \int_0^H \frac{1}{T(z,t)} dz \approx \sum_{i=1} \frac{1}{T_i(t)} \cdot \Delta h_i \tag{1.10}$$

5.4.2 Upper Layer Temperatures

The upper layer temperature was approximated as mean value of the temperatures of all measurement points located above the layer interfaces:

$$T_{up} = \frac{\sum_{j=1}^{n} T_j(t)}{n} \quad \text{for} \quad \mathrm{z_j} > z_{\mathrm{int}} \tag{1.11}$$

T_{up} upper layer temperature [°C]

T_j temperature of measurement point j

z_j temperature of measurement point j

n total number of measurement points above layer interface

5.4.3 Lower Layer Temperatures

The lower layer temperature was approximated as mean value of the temperatures of all measurement points located below the layer interfaces:

$$T_{low} = \frac{\sum_{k=1}^{m} T_k(t)}{m} \quad \text{for} \quad \mathrm{z_k} < z_{\mathrm{int}} \tag{1.12}$$

T_{up} lower layer temperature [°C]

T_k temperature of measurement point k

z_k temperature of measurement point k

m total number of measurement points below the layer interface

5.4.4 Wall Layer Temperatures

The upper layer wall temperature was approximated as mean value of the wall temperatures of all measurement points located above the layer interfaces:

$$TW_{up} = \frac{\sum_{k=1}^{n} TW_k(t)}{n} \quad \text{for} \quad \mathrm{z_k} < z_{\mathrm{int}} \tag{1.13}$$

The lower layer temperature was approximated as mean value of the wall temperatures of all measurement points located under the layer interfaces:

$$TW_{low} = \frac{\sum_{k=1}^{m} TW_k(t)}{m} \quad \text{for} \quad z_k < z_{int} \tag{1.14}$$

T_{up} upper layer wall temperature [°C]

T_{low} lower layer wall temperature [°C]

TW_k wall temperature of measurement point k

z_k temperature of measurement point k

n total number of measurement points above layer interface

m total number of measurement points under layer interface

5.5 Mass Flow Rates [EMM 02]

For a discrete measurement consisting of n (i = 1 to n) so-called ”bidirectional probes” and gas temperatures probes arranged in parallel the mass flow for the ith partial opening surface can calculated with

$$\dot{m}(z_i) = 16.79 \cdot b \cdot \frac{h}{n} \cdot \sqrt{\frac{\Delta p(z_i)}{T(z_i)}} \text{ [kg/s].} \tag{1.15}$$

A balance of the mass flows “in” and “out” the fire compartment must be determined as a function of the neutral height, which can vary time dependently.

z_i height in the opening [m]

b width of the opening [m]

h height of the opening [m]

n number of measurement points [-]

5.6 Heat Flow Rates [HAM 03]

The total heat loss through the door was calculated using the temperature and velocity measurements at the door opening. The energy was estimated from the following equation:

$$Energy = \sum \dot{m} C_p \Delta T = \sum \rho \bar{v} A C_p \Delta T \text{ [kW]} \tag{1.16}$$

ρ density was calculated from using the ideal gas law [kg/m³]

$\bar{v}$ mean gas velocity in the range of the opening [m/s]

A opening area [m²]

C_p $= 1.007 + 1.816 * 10^{-4} \cdot (T - 20)$ specific heat [J/kgK]

ΔT temperature difference between hall and opening [°C]

6 Discussion of the Results

Figure 6-1 shows the temperature 40 cm in front of the cable tray and **Figure 6-2** the measured heat flux in front of the tray for test 2 and test 4 during the phase of preheating. The temperatures and the heat fluxes in test 2 and test 4 in the environment of the cable tray are in good agreement. The boundary conditions for both tests are nearly the same.

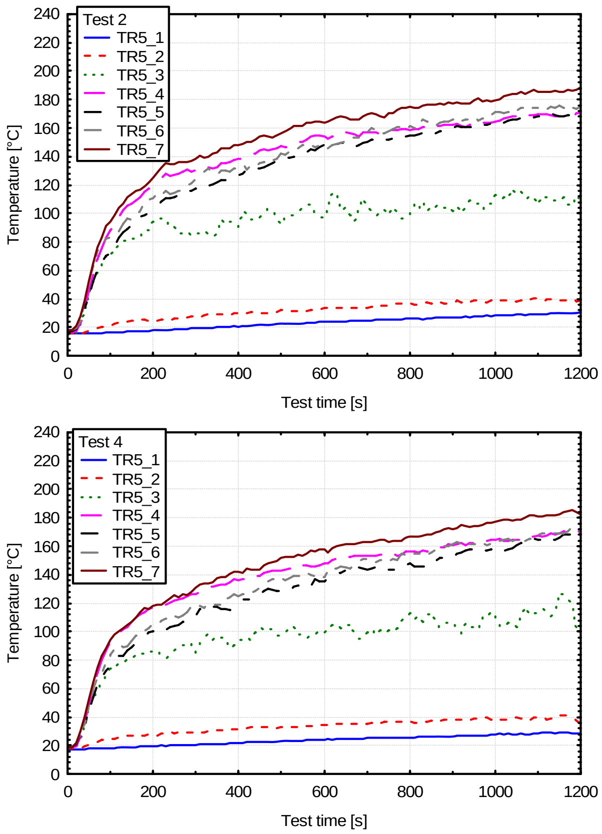


Figure 6-1 Temperature TR5, 40 cm in front of the cable tray levels 1-7, test 2 and test 4

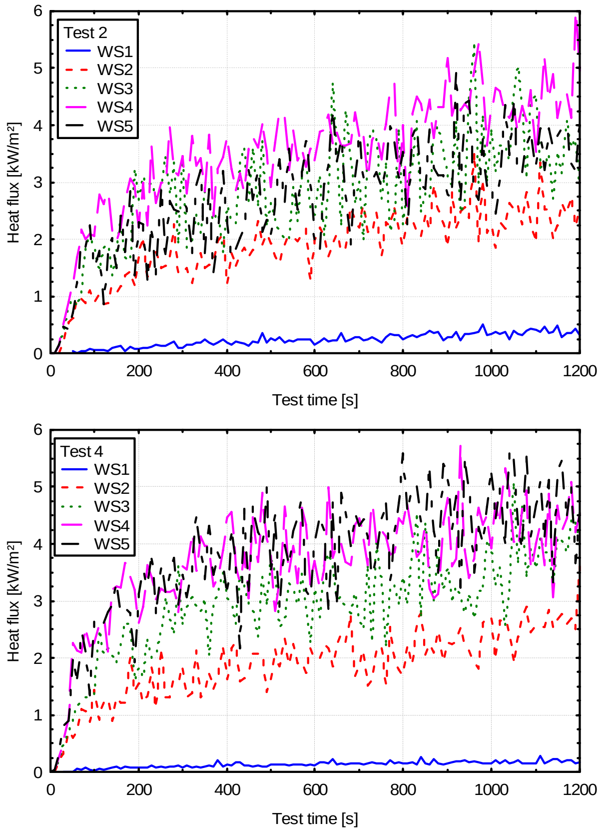


Figure 6-2 Heat flux WS, in front of the cable tray levels 1-5, test 2 and test 4

In **Table 6-1** the ignition times observed for tests 1 – test 4 are given. The ignition time is not accurately assignable because the gas burner fire and the fire of the cables themselves are superposed. The ignition times given here are an indicator for the fire behavior of the tested cable.

In case of test 4, the power cables are not ignited at a burner output from 50 kW and primary ignited when the burner is increased to 300 kW. This behavior has not been expected, because there was no problem to ignite the PVC power cables in case of test 3 without preheating and the same burner output. One possibility for the cause of this effect could be that the ethanol pool produced a flow field in which the flame of the gas burner is pulled away from the cable to the side of the pool. The consequence could be that the gas burner output is not large enough to ignite the power cables. On the other hand, the oxygen concentration in the room changes because of the oxygen consumption of the burning ethanol. This may represent another reason for the difficulty to ignite the PVC insulated power cables. During the preheating period of approx. 1200 seconds the cable insulation are pyrolysed, but the gases are not ignited. It is possible that the pyrolysis gases are taken away through the door. **Figure 6-3** and **Figure 6-4** show the ignition phase of test 3 and test 4. **Figure 6-5** to **Figure**

6-8 show the cable insulation materials after test 1 and test 3 in the lower and upper part of the tray.

Table 6-1 Ignition times observed

	Test 1	**Test 2**	**Test 3**	**Test 4**
Burner output [kW]	150	150 + preheating	50	50 + preheating
Ignition time [s] power cables	150	360	190	-
Ignition time [s] I&C cables	187	133	428	171

Figure 6-3 Ignition phase test 3, PVC I&C and power cable

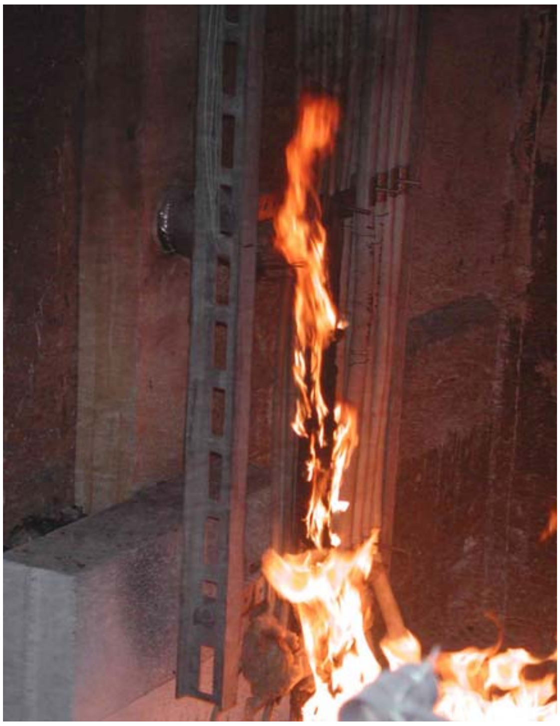


Figure 6-4 Ignition phase test 4, no ignition of PVC power cable

Figure 6-5 FRNC cable material after test 1, lower range of tray

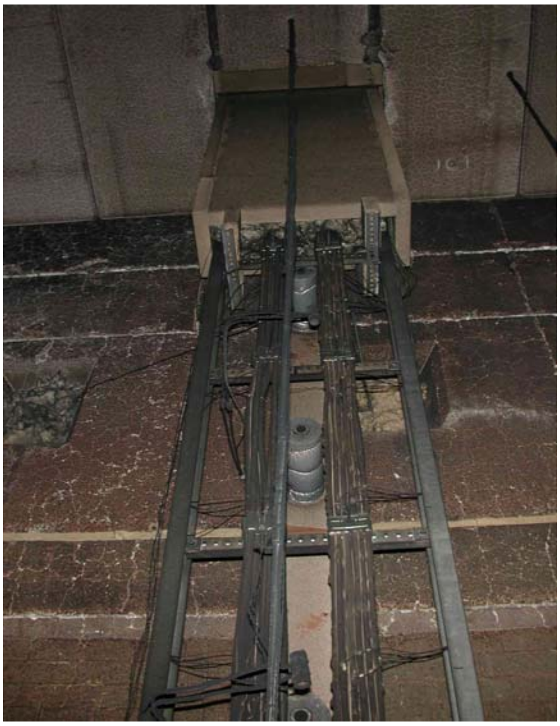


Figure 6-6 FRNC cable material after test 1, upper range of tray

Figure 6-7 PVC cable material after test 3, lower range of tray

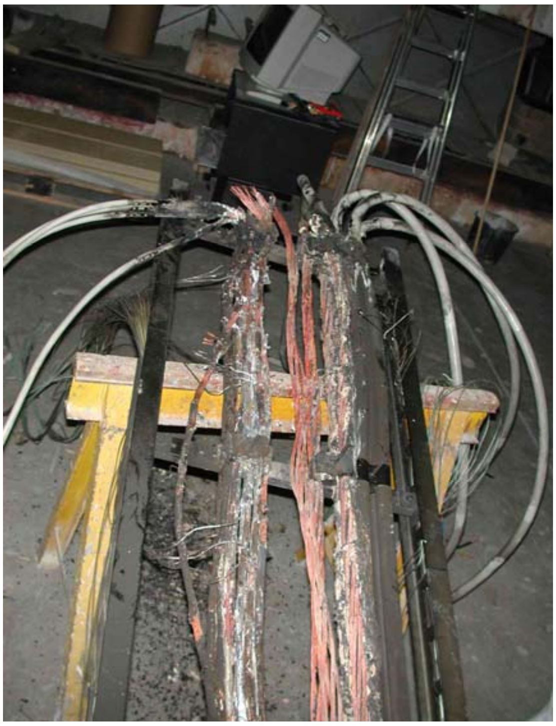


Figure 6-8 PVC cable material after test 3, upper range of tray

7 Functional Failure Tests

For the measurement of the current conduction and short circuits of electrical cables a measuring apparatus was developed according to the German non-nuclear standard DIN 4102-12 [DIN 95]. A parallel current conduction and short circuit measurement of in maximum 12 pairs of cable conductors is possible. Different from the German DIN 4102-12 the procedure works with a lower voltage of 9 Volt. This was necessary to allow parallel temperature measurements “on” the surface and “in” the centre of the cables.

Figure 7-1 shows the electrical scheme of the functional failure test equipment. The principle is shown for two conductors (1 and 2) from one cable. For each of the twelve pairs of conductors it is possible to measure the loss of the current conduction (for example 1.1 and 1.2 in the figure). Furthermore, the short circuit among each of the twelve cable wire pairs will be measured (conductor to conductor – for example K1). For one of each twelve pairs of conductors the short circuit is measured to the tray (conductor to tray – for example KR1). In the case of a functional failure, a light at the front panel of the test equipment will indicate the loss of current conduction or a short circuit of the conductors.

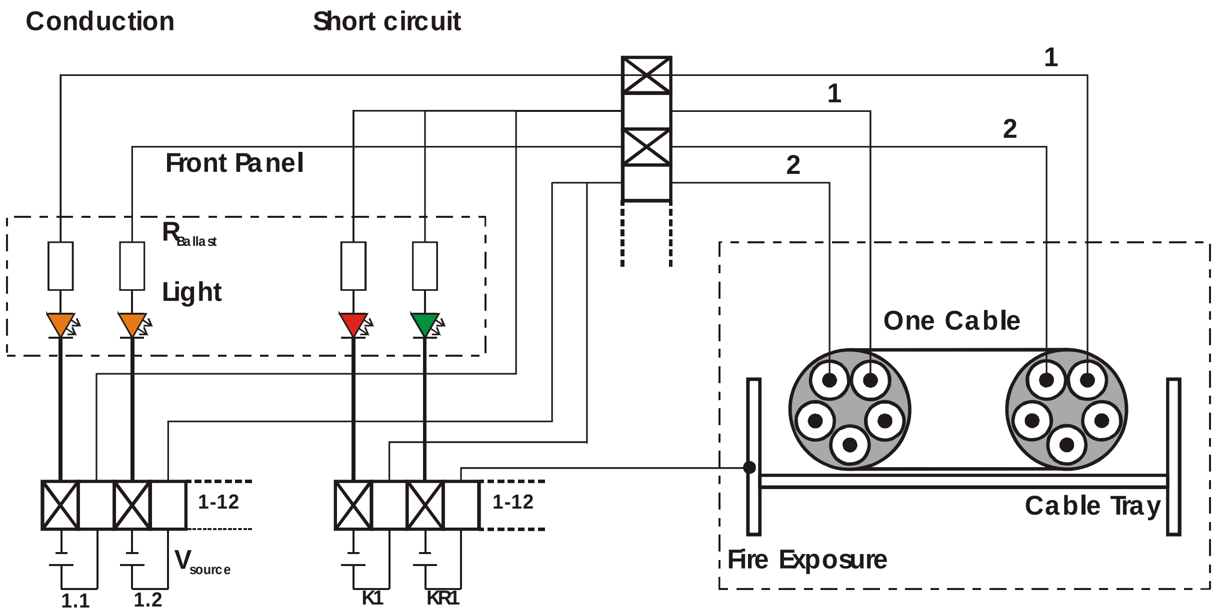


Figure 7-1 Electrical scheme of the functional failure (function loss) tests

Table 7-1 gives an overview on the abbreviations used in the context of the function loss equipment. A “K” indicates a short circuit between “conductor to conductor” and an “KR” indicates a short circuit between a cable conductor and the cable tray (“K” and “KR” are used therefore as failure indicator index). **Figure 7-2** to **Figure 7-5** shows the short circuit times for the tests 1 to 4.

Each plot involves a curve of the burner output during the test. In **Table 7-3** and **Table 7-4** data on the first short circuit, the mean value and the standard deviations of all short circuit times for the first burner output level are given. For test 2 and test 4 the preheating time of 1200 s is neglected.

Table 7-1 Function failure abbreviations

Number USNRC Failure Mode	**Conduction** Loss of conductor continuity	**Short circuit** Conduction to conduction	**Short circuit to cable tray** Conduction to external ground	**Cable type**	**Bundle side**
failure indicator	light out	light on	light on		
1	1.1 und 1.2	K1	KR 1	power cable	right side
2	2.1 und 2.2	K2	KR 2		
3	3.1 und 3.2	K3	KR 3		
4	4.1 und 4.2	K4	KR 4		
5	5.1 und 5.2	K5	KR 5		not used
6	6.1 und 6.2	K6	KR 6		not used
7	7.1 und 7.2	K7	KR 7	I&C cable	left side
8	8.1 und 8.2	K8	KR 8		
9	9.1 und 9.2	K9	KR 9		
10	10.1 und 10.2	K10	KR 10		
11	11.1 und 11.2	K11	KR 11		
12	12.1 und 12.2	K12	KR 12		

Cable failure modes and effects of risk analysis perspectives are documented in [NOW 03]. The author pointed out, that the issue of fire induced cable failure modes and effects continues to be an area of both technical challenge and regulatory focus. For practical reasons one cannot systematically consider the impact of all possible combinations. The cable failure modes reported in [NOW 03] are given in **Table 7-2**.

In the actual study the most important failure modes according to **Table 7-2** are considered. These are failure mode number A.1 (conductor to conductor), C (conductor to external ground) and failure mode D (loss of conductor continuity) as mentioned above. Furthermore, cable failure influence factors have to be considered.

Table 7-2 Cable failure modes as applied by Sandia National Laboratories [NOW 03]

Number	Failure mode	Special cases	Explanation
A	Intra-cable short circuits		This failure mode involves circuits formed between the conductor of a given multi-conductor cable
A.1		General conductor to conductor short circuits	As the cable insulation breaks down, various conductors may short to each other. The circuit impact depends on the circuit function of the shorting conductors
A.2		Hot short	A special case of the conductor-to-conductor short circuit where one of the shorting conductors is energized and, as a result of the short circuit, one or more other conductors become energized
A.3		Short to a grounded conductor	If one of the conductors in a shorting group is grounded b y design, then effects of the short will be the same as the short to an external ground
A.4		Insulation resistance degradation	This failure mode involves the formation of high-impedance short circuiting paths due to a breakdown in the insulation power of the conductor insulation
B	Inter-cable short circuit		This failure mode involves short circuits formed between the conductors of separate cables.
C	Conductor to external ground short circuit		This failure mode involves a short circuit between one or more conductors and an external electrical ground such as a metallic cable raceway support system
D	Loss of conductor continuity		This failure mode involves a physical break in the conductor that will prevent electrical energy from reaching the intended circuit

			destination

A list of cable failure mode influence factors is given in [WOO 02]. The list is based on a combination of SNL (Sandia National Laboratories) and USNRC (United States Nuclear Regulatory Commission) knowledge. The main factors are:

1. Cable physical properties and configuration factors (e.g. insulation properties),
2. Routing factors (e.g. cable tray type),
3. Electric function factors (e.g. I&C or power cables),
4. Fire exposure condition factors (Exposure mode, intensity and duration).

All these factors are relevant for the tests in this study. Because of the limited number of tests it is not possible to provide an exact analysis of the effects which have taken place and caused the functional failure of the cables. This report documents the functional failure times and the temperatures in the cable centre as well as in the surrounding of the cables at this time. Some effects are discussed that deals about the thermo physical properties of the cables, which are a main factor because of the different insulation material which is used. During the tests the failure mode C (loss of conductor continuity) does not occur. This means that the mounting and routing of the cables (routing factor having been chosen for the tests, could be neglected as a main functional failure influence in this work.

Figure 7-6 shows the functional failure results for I&C cables during all tests. A significant different in short circuit times is found between FRNC and PVC cable. The tests show a significant effect of preheating on the functional failure times of the cables. This behavior is a result of the effects of the thermo physical data from the PVC and respectively the FRNC cables, which are documented in [RIE 03]. The thermal inertia ($\lambda \cdot \rho \cdot c_p$) from the FRNC cables is higher than that from the PVC cables, so that the temperatures at the cable centre is lower in case of the FRNC cables (test 2) then in case of the PVC cable in test 4 after preheating time.

The temperature at the cable centre of the I&C PVC cable after 20 minutes preheating is approx. 30 - 40 °C higher. This effect is diagrammed in **Figure 7-7** for test 2 and test 4. It is remarkable that the PVC cables are ignited with a burner output of 50 kW, while in contrary, the FRNC cable are ignited with 150 kW.

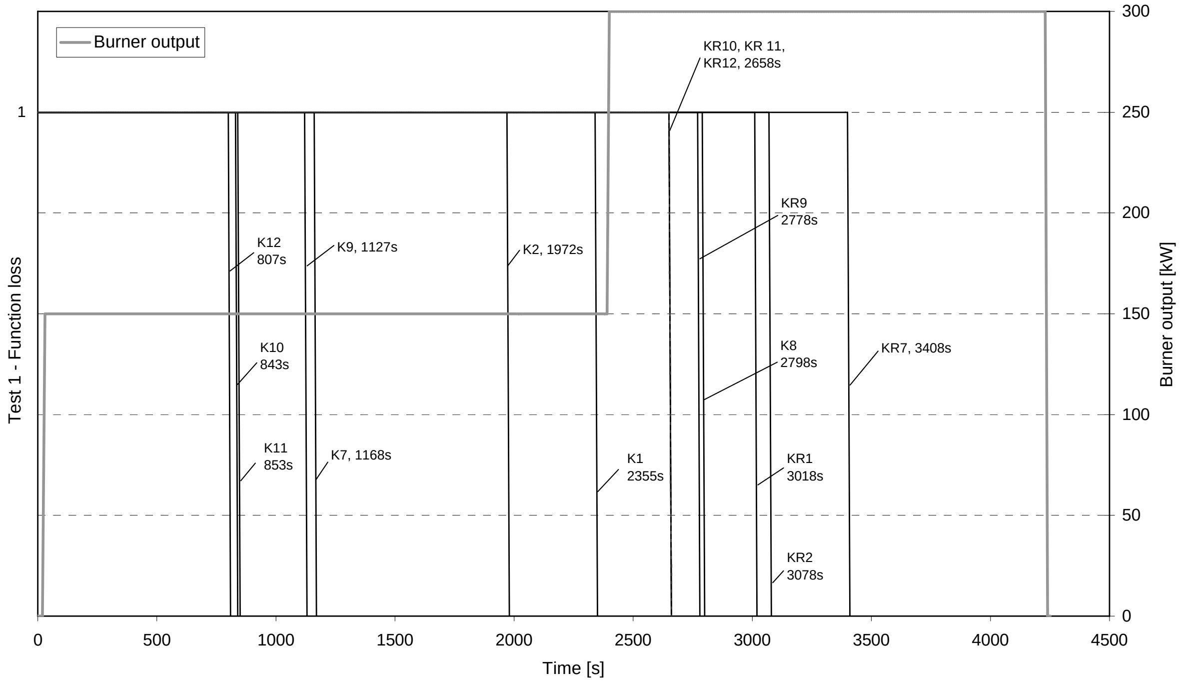


Figure 7-2 Burner output and short-circuit of FRNC cables (test 1, without preheating)

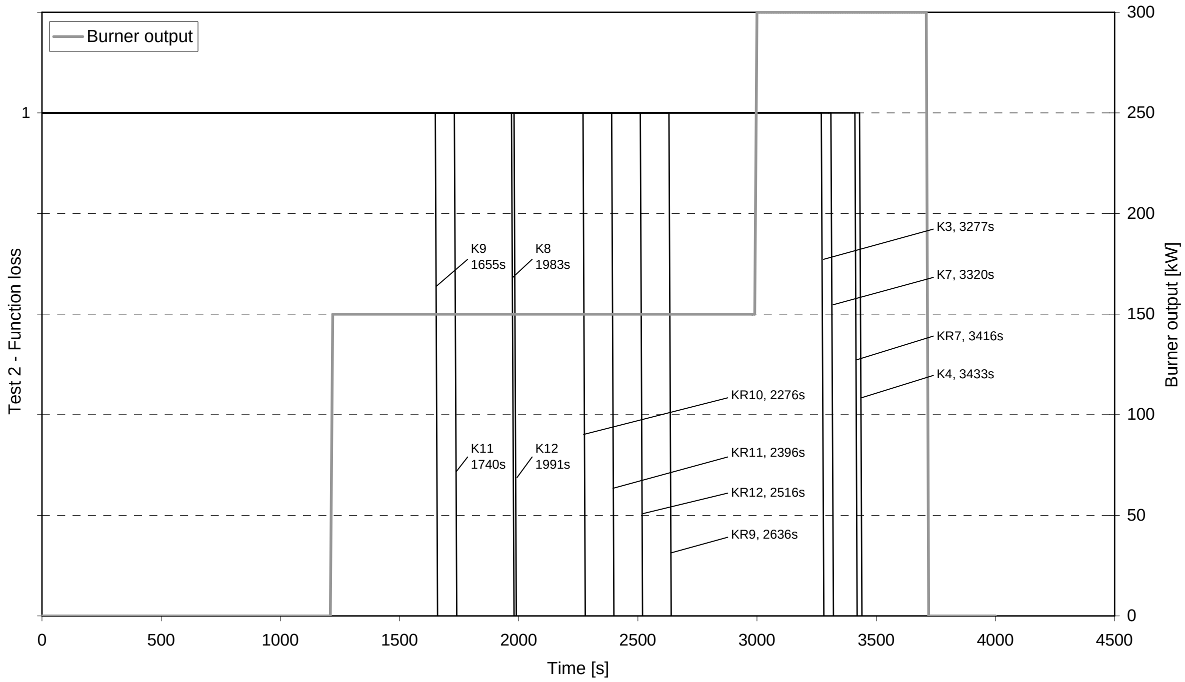


Figure 7-3 Burner output and short-circuit of FRNC cables (test 2, preheating 1200 s)

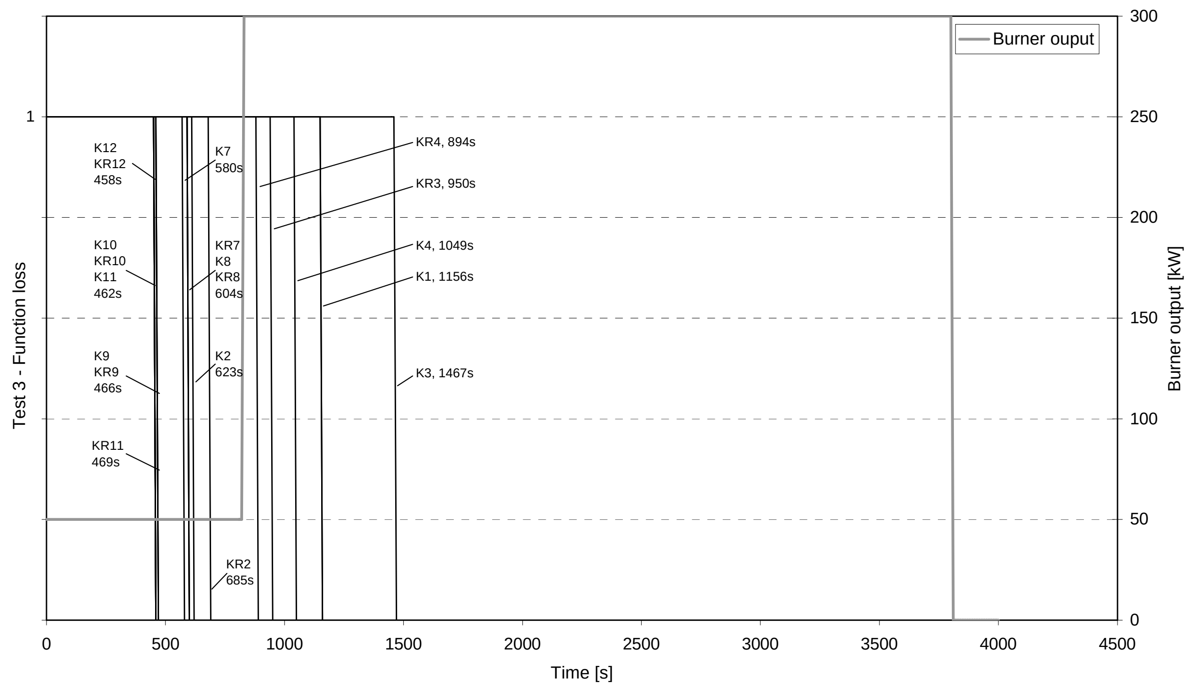


Figure 7-4 Burner output and short-circuit of PVC cables (test 3, without preheating)

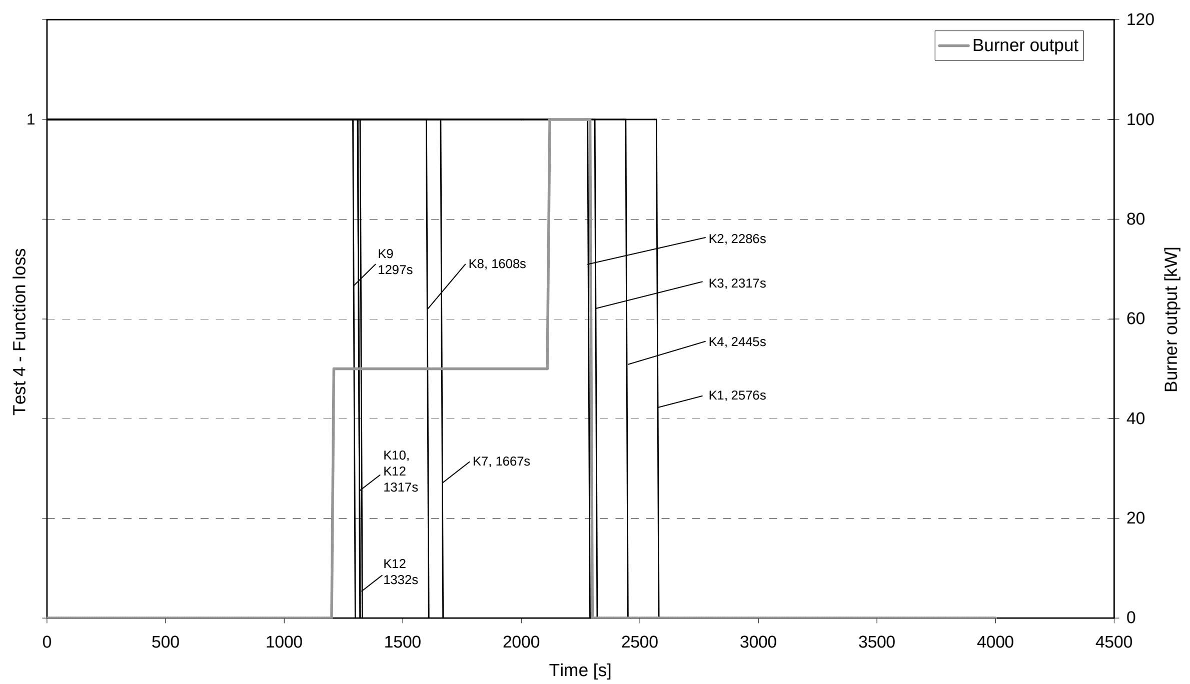


Figure 7-5 Burner output an**d** short-circuit of PVC cables (test 4, preheating 1200 s)

Table 7-3 Short circuit times test 1 & test 2, FRNC-Cables

Burner output [kW]		**Test 1 no preheating [s]**		**Test 2 preheating [s]**	
		I&C cable C	**Power cable D**	**I&C cable C**	**Power cable D**
conductor to conductor (K)					
150	minimum	807	1972	455	-
	failure index	K12	K2	K9	-
	mean value + standard deviation	959 ± 173	2163 ± 270	642 ± 171	-
conductor to tray (KR)					
150	minimum	-	-	1076	-
	failure index	-	-	KR10	-
	mean value + standard deviation	-	-	1236 ± 183	-

Table 7-4 Short circuit times test 3 & test 4, PVC-Cables

Burner output [kW]		**Test 3 no preheating [s]**		**Test 4 preheating [s]**	
		I&C cable A	power cable B	I&C cable A	power cable B
conductor to conductor (K)					
50	minimum	458	623	97	1117
	failure index	K12	K2	K9	K3
	mean value + standard deviation	547 ± 78	1074 ± 349	223 ± 158	1207 ± 134
conductor to tray (KR)					
50	minimum	458	685	-	-
	failure index	KR12	KR2	-	-
	mean value + standard deviation	531 ± 103	921 ± 194	-	-

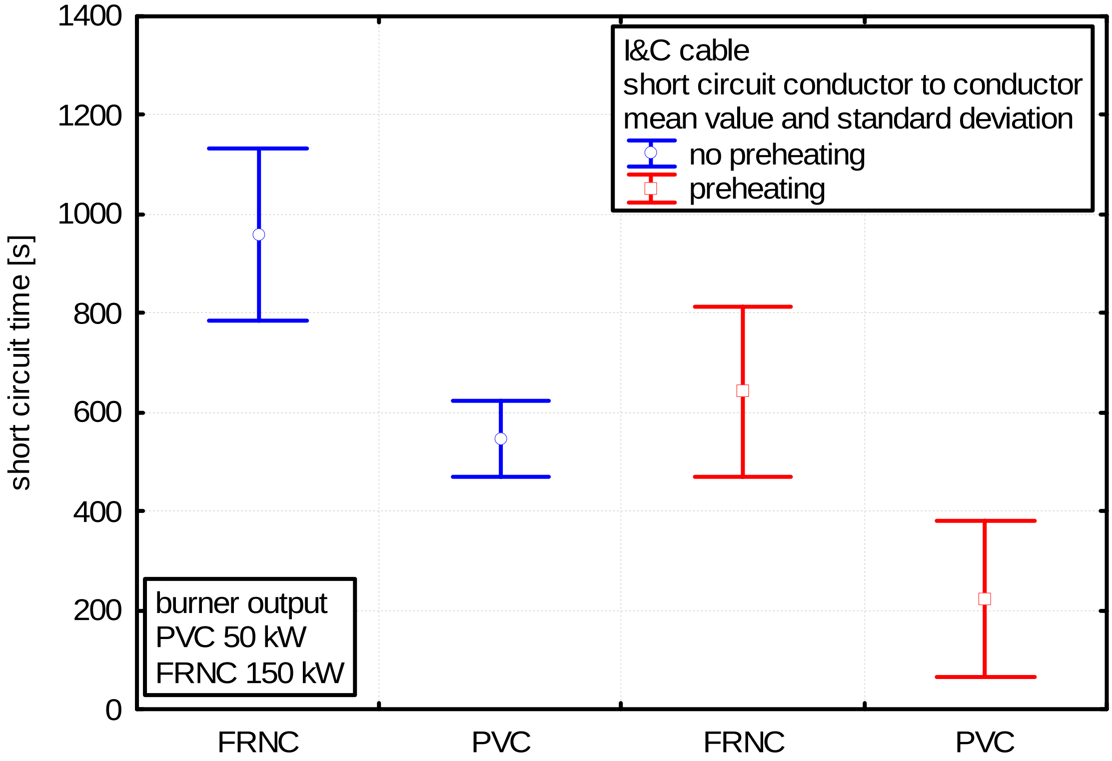


Figure 7-6 Short circuit times tests 1 – 4, I&C cables

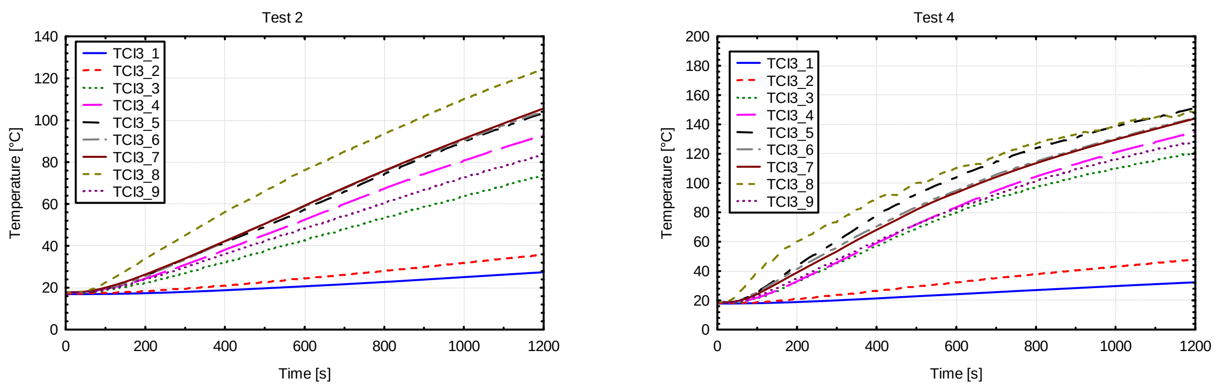


Figure 7-7 Test 2 and Test 4, Temperature in cable centre TCI3, Preheating time 1200 s

Figure 7-8 shows the results for I&C cables for both insulation materials in case of no preheating (test 1 and test 3). It is obvious that power cables have better fire characteristics than I&C cables of the same cable insulation material.

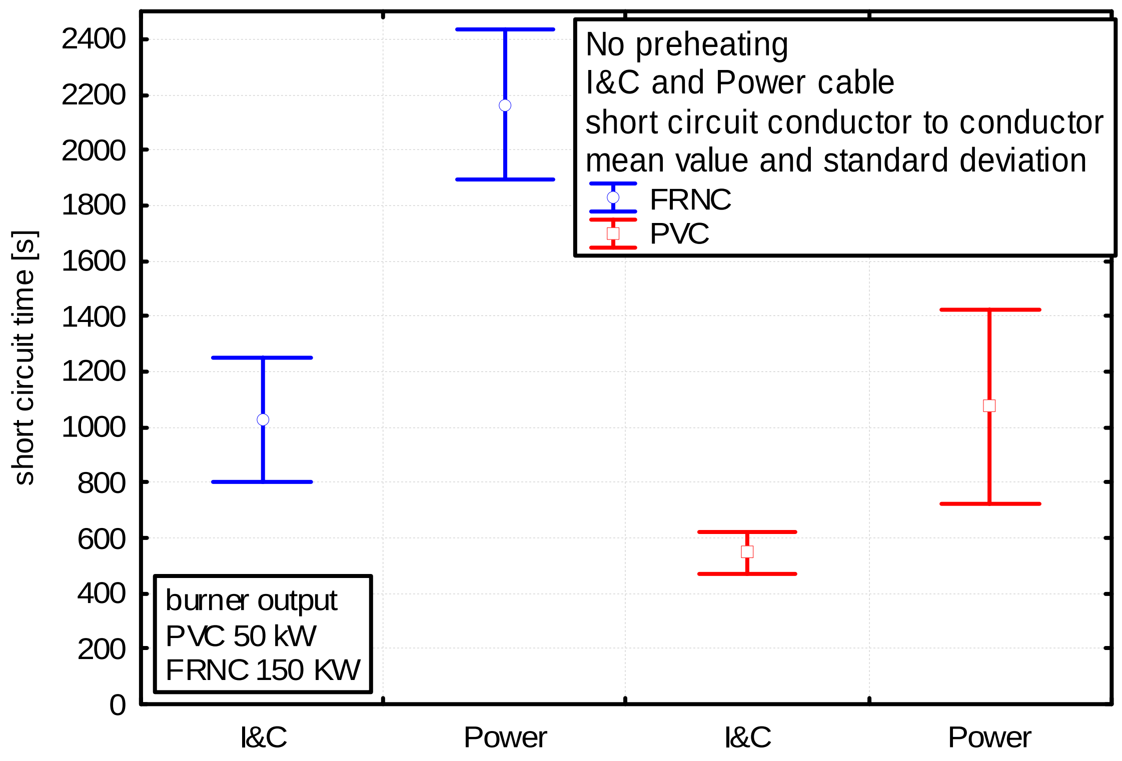


Figure 7-8 Short circuit times tests 1 – 4, no preheating

This effect is explainable with the higher fraction of metal in case of the power cables, so that heat could dissipate. This process resulted in later times of ignition. In [HOS 03] power and I&C cables from different cable insulation materials are tested with similar results.

In the same publication it was shown that a fundamental distinction between horizontal and vertical oriented cable has to be made. For the horizontal cable arrangement there is a significant dependence between the fire propagation, the cable quantity, the cable density, and the location in the fire area. For vertical oriented cables the influence of the quantity of the cables in a bundle on the vertical propagation is not so strongly pronounced. That means that it is not possible to derive the function failure results from the vertical to the horizontal cable tray arrangement. Nevertheless the vertical configuration lead to significant higher flame spread velocities [HOS 03]. This effect has great influence to the heat input to the room. As a consequence the temperatures in the surrounding area of the cable increase. In this case it is possible that vertical oriented cable trays have bad fire characteristics by comparison to horizontal oriented cable trays.

8 Conclusions

A series of four real scale vertical cable tray fire experiments in a naturally ventilated room has been conducted at iBMB of Braunschweig University of Technology in the frame of the “International Project To Evaluate Fire Models for NPP Applications” (ICFMP) to gain more insights on the consequences and effects of cable fires, in particular with respect to the functional failures of electric equipment, as well as for validation of state-of-the-art fire simulation codes. The test series consider preheating effects and includes time dependent electrical function loss measurements.

During the preheating phase of approximately 20 minutes, the temperature in the near vicinity of the cable insulation is determined to reach a maximum of 200°C. The main issue of the tests for the benchmark calculations is the flame spread on the cables. Two different cable insulation materials are used: PVC and FRNC. High voltage power cables as well as low voltage I&C cables have been investigated separately in two bundles on the cable tray. The preheating of the room has been conducted by means of an ethanol pool fire; a propane gas burner was used as ignition source.

The tests show that the FRNC cables have significantly better characteristics in case of fire. No substantial flame spread takes place even in case of preheating. PVC cables could be ignited with a burner output of 50 kW, in contrary, the FRNC cables could be ignited at burner output of 150 kW. The preheating has a complex effect on the fire behavior of the cables. It may occur that gases are pyrolysed which are not ignited during the phase of preheating. These gases are transported from the cable surrounding and may leave the fire room.

Short circuits occur first in case “conductor to conductor” and later in case “conductor to tray”. The time periods until short circuits occur are strongly dependent on the preheating of the cables. In case of no preheating, the short circuit times are a factor two higher then in case of preheating. In one case, an I&C PVC cable already failed after nearly 100 seconds in case of preheating. A mean value for the time to loss of function of a PVC insulated I&C cable with preheating was estimated from the experiments to be 220 seconds. The short circuit times of power cables are nearly two times higher then those of I&C cables independent from the cable insulation material. FRNC cables have better characteristics in all tests although they are ignited with a substantially higher burner output as mentioned above. A mean value for the time to loss of function of a FRNC insulated I&C cable with preheating was estimated from the experiments to be 640 seconds.

The tests have been prepared and conducted with high accuracy and by using instrumentation according to international standard. For a better understanding of the fire propagation on vertical cable trays in particular, more tests are necessary in different ways: for reproducibility a repetition of the tests is necessary to get fundamental validation data, which can be used for theoretical comparisons. On the other hand, the parameters have to be adjusted. A major parameter should be the preheating time and the burner output. Potential ageing effects of the cables and the variation of materials of the same type ("PVC is not equal PVC") are other parameters to be varied.

Because of continued flame spread, in particular the data of test 3 (PVC, no preheating) are appropriate to validate fire spread models. The flame spread models have to show that they can predict the results of test 1 and test 2 as well, because in case of FRNC-cables no flame spread occurs. This could mean that a computer code which just worked well if flame spread occurs is not adequate to handle complex materials. This proceeding will take place at the 8th ICFMP meeting in ESPOO - Helsinki in June this year and the results have to be reported subsequently.

References

[DIN 95] DIN Deutsches Institut für Normung e.V. (DIN):
DIN 4102 – Teil 12: Brandverhalten von Baustoffen und Bauteilen, Teil 12: Funktionserhalt von elektrischen Kabelanlagen, Anforderungen und Prüfungen, Berlin Februar 1995

[EMM 02] Emmons, H. W.:
"Vent Flows", SFPE Handbook of Fire Protection Engineering, Section Two, Chapter 3, National Fire Protection Association, Third Edition, March 2002

[FDS 02] McGrattan, K., et al:
Fire Dynamics Simulator (Version 3) – Database 3, National Institute of Standards and Technology, November 2002

[HOS 03] Hosser, D., Riese, O., Schmeling, M.:
"Durchführung von vergleichenden Brandversuchen mit unterschiedlichen Kabelmaterialien und Kabelschutzsystemen", VGB Kraftwerkstechnik GmbH, VGB-Kennziffer SA „AT" 11/00, Juni 2003

[HAM 03] Hamins, A,:
Report of Experimental Results for tests 2, 3 and 4 of the ICFMP Benchmarking and Validation Exercise #3, 015-028.pdf at ICFMP-platform, 2003

[ISO 93] International Standards Organization (ISO):
ISO 9705-1: Fire Tests - Full-scale Room Test for Surface Products (Room Corner Test), International Organization for Standardization,1993

[ISO 99] International Standards Organization (ISO):
ISO 5660-1: Reaction to fire tests – Heat release, smoke production and mass loss rate; Part 1: Heat Release Rate (Cone Calorimeter method), International Organization for Standardization, 1999

[NIS 03] National Institute of Standards and Technology (NIST):
International Collaborative Project to Evacuate Fire Models for Nuclear Power Plant Applications: Summary of 5th Meeting, NISTIR 6986, C-62-64, National Institute of Standards and Technology, September 2003

[NOW 02] Nowlen, S. P.:
Cable Failure Modes and Effects Risk Analysis Perspectives, Presented at: Structural Mechanics in Reactor Technology Post Conference Seminar 21 (SMIRT), Fire Safety in Nuclear Power Plants and Installations, August 25-28, 2003, Piestany, Slovak Republic, 2003

[RIE 03] Riese, O., Wolff, H.-J., Klingenberg, M.:
“Specification of international Benchmarking and Validation Exercise 5# – Flame Spread in Cable Tray Fires (Including Thermo-Physical Cable Data)”, published on the platform of International Collaborative Project Fire Model Project (ICFMP), 2003

[RIE 03a] Riese, O., Klingenberg, M.:
“Report of Experimental Results of International Benchmarking and Validation Exercise 5# – Flame Spread in Cable Tray Fires (Initial Conditions for test 1 – test 4)”, published on the platform of International Collaborative Project Fire Model Project (ICFMP), 2003

[WOO 03] Woods, H. W.:
Draft of the United (US) Nuclear Regulatory Commission (NRC) Final Report for the Fire-Induced to Electrical Cables and Circuits Working Group (FIDECC_WG) of the Cooperative PRA (COOPRA) International Effort, 2002

List of Appendices

APPENDIX A
(Specification)

“Specification of International Benchmarking and Validation Exercise # 5 – Flame Spread In Cable Tray Fires (Including Thermo-Physical Cable Data)”

APPENDIX B
(Last Changes)

“BM EX # 5: Information about last changes in the specification”

APPENDIX C
(Initial Conditions)

“Report of Experimental results of International Benchmarking and Validation Exercise # 5 – Flame Spread In Cable Tray Fires (Initial Conditions for test 1 – test 4)”

APPENDIX D
(Plots Test 1 – Test 4)

Plots of general values and derived data of test 1 – test 4

APPENDIX E
(Functional Failure Test 1 – Test 4)

Plots of results of functional failure measurements during test 1 – test 4

INSTITUT FÜR BAUSTOFFE, MASSIVBAU UND BRANDSCHUTZ

MATERIALPRÜFANSTALT FÜR DAS BAUWESEN - MPA BRAUNSCHWEIG

TU BRAUNSCHWEIG

APPENDIX A

”Specification”

“Specification of International Benchmarking and Validation Exercise # 5 – Flame Spread In Cable Tray Fires (Including Thermo-Physical Cable Data)”

to the

FINAL REPORT

“Performing of Recent Real Scale Cable Fire Experiments and Presentation of the Results in the Frame of the International Collaborative Fire Modeling Project ICFMP”

Contract SR 2449
Sub-contract UA-2298

Prof. Dr.-Ing. Dietmar Hosser
Dipl.-Phys. Olaf Riese
Cand.-Ing. Mark Klingenberg

June 2004

“This report represents the expert opinion and expertise of the contractor (iBMB). It is not necessary that this is in accordance with the expert opinion of the contracting party (Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH.“

Beethovenstraße 52 · D-38106 Braunschweig · Tel. (0531) 391-5431 · Fax (0531) 391-5900 · E-Mail ibmb@tu-bs.de · Internet http://www.ibmb.tu-bs.de

INSTITUT FÜR BAUSTOFFE, MASSIVBAU UND BRANDSCHUTZ

MATERIALPRÜFANSTALT FÜR DAS BAUWESEN - MPA BRAUNSCHWEIG

TU BRAUNSCHWEIG

SPECIFICATION OF INTERNATIONAL BENCHMARKING AND VALIDATION EXERCISE # 5

Flame Spread In Cable Tray Fires

Including Thermo-Physical Cable Data

Revision 3

October 31, 2003

Olaf Riese

Hans-Joachim Wolff

Mark Klingenberg

Beethovenstraße 52 · D-38106 Braunschweig · Tel. (0531) 391-5431 · Fax (0531) 391-5900 · E-Mail ibmb@tu-bs.de · Internet http://www.ibmb.tu-bs.de

Contents

List of Figures

List of Tables

1 Introduction

Electric cables for the support as well as for instrumentation and control (I&C) may represent a non-negligible fire risk inside buildings. The electric cables themselves can cause a fire on the one hand. On the other hand the fire propagation along cables over longer distances can be supported by the cable routing. The possibility of fire propagation along cables is particularly given in case of a higher amount of cables. Cable fires may result in severe consequences, such as longer lasting high temperatures, high smoke production, the release of toxic combustion products endangering humans, functional failures of systems and components, or long-term damage to structures and equipment by corrosive particles.

The cable manufacturing industry has meanwhile developed a variety of cable materials with improved characteristics in case of fire. In a first large scale fire test series performed at the "Institut für Baustoffe, Massivbau und Brandschutz" (iBMB) of Braunschweig University of Technology in Germany cable fire experiments with different types of cable types and insulation materials as implemented typically in German nuclear power plants (NPP) have been performed from 1999 until 2002. It could be shown that a pre-heating of the cables strongly increases the fire propagation risk so that high fire spreading velocities can be reached even in case of cable insulation materials with improved characteristics in case of fire.

By means of the actual cable fire series the effects of a naturally ventilated fire of vertically routed cables (as worst case) with different cable insulation materials shall be investigated, in particular, the functional failure of equipment in case of such a cable fire. The measures data shall be the basis for fire simulations. One of the major goals of these analyses is the applicability of various fire models of different types, such as zone models, lumped parameter codes and three-dimensional computational fluid dynamics codes (CFD models), for such cable fire scenarios with and without pre-hearing of the fire compartment.

In the frame of the test series it is intended to carry out special measurements with respect to the functional failures and deteriorations of electric equipment as a consequence of cable fires.

2 Test Specification

In the fire compartment of iBMB four large scale fire experiments with realistically routed vertical cable trays will be carried out.

The actual cable fire experiments are performed considering the results of cable fire experiments with different types of cables carried out in the frame projects for the German authorities as well as for nuclear industry in the past. They take into account additional relevant aspects, such as mixed compositions of different cables on the tray and potential functional failures of electric/electronic equipment. The primary fire and the operation mode of the ignition source will be different from the earlier tests. Instead of the oil burner used up to now, a pool fire shall be used for pre-heating the compartment and the cable surface. To be able to compare the results of the tests with former test results, all the other boundary conditions will be the same as for those tests (fire compartment geometry, ventilation conditions, wall for separating the cables from the pool, ignition time).

2.1 Fire Compartment

The cable fire experiments will be carried out in a special fire compartment (iBMB test facility) with a floor area of inner 3.6 m × 3.6 m. The inner room height is 5.7 m. As primary pilot fire for pre-heating the cables a pool fire of 1 m² pool area is assumed. For measuring the burning rate of the liquid pool, the pan with the liquid is mounted on a weight scale. The cable tray is directly ignited / inflamed by means of a propane gas burner. The pre-fabricated trays filled with are mounted on a special cable rack. Details on the pool fire are given in paragraph 2.2, details on the burner in paragraph 2.3. Table 2-1 gives an overview of the fire compartment data.

The gas exchange takes place through an opening of 0.7 m width and 3.6 m height, which is reduced by a wall of 1.4 m height to an area of approx. 1.5 m². Smoke gases released are collected in a hood with a exhaust duct located over the opening and lead to a smoke gas cleaning system. The measuring section for the gas analysis as well as the optical measurement is located in the horizontal part of the exhaust channel. The layout of the gas analysis measurement meets the requirements of ISO 9705. In addition, a filter with lime-soda (carbon dioxide trapping) is located inside the way to the oxygen analyzer, which has to be considered for determining the "oxygen depletion factor". By this procedure, the off-gas volume flow, the amount of oxygen, carbon monoxide and carbon dioxide, as well as the optical absorption inside the off-gas flow are measured. The rate of heat release can be estimated by means of the oxygen consumption method. The calibration (precision of the system and system response) is performed by pretests with the liquid (ethanol) pool. A second small opening is placed in the side wall near by the pool.

Table 2-1 Fire compartment data

	Fire compartment		
Floor area	3.6 m x 3.6 m (inner area)		
Height	5.7 m (inner height)		
Opening - Door	0.7 m x 2.2 m, 1.4 m above the floor		
Opening - Side wall	0.6 x 0.7, 0.7 m above the floor		
Cable tray	0.5 - 4.5 m above the floor		
	Thickness [mm]	**Material**	**Insulation [mm]**
Walls	250	light concrete	50
Floor	300	concrete	-
Ceiling	200	light concrete	-
Walls, 1.4 m height	200	aerated concrete	-
Material	**Heat conductivity λ [W/mK]**	**Heat capacity c_p [J/kgK]**	**Density ρ [kg/m^3]**
Concrete	2.1	880	2400
Light concrete	0.75	840	1500
Aerated concrete	0.11	1350	420
Insulation	0.05	1500	100

For measuring the smoke gas levels, four vertical measuring chains with seven thermocouples each and one vertical measuring chain in the plume are foreseen. The temperature development in the vicinity of the cables is measured by an additional measuring chain 40 cm in front of the vertical tray. Details of the experimental setup can be found in Figure 2-1 to Figure 2-7. Table 2-2 gives an overview of the data for the fire compartment environment. The abbreviations of the measuring points and types of measurements are given in paragraph 3.2. Details on the cables tray itself and the corresponding measuring equipment on the cables are given in paragraph 2.4.

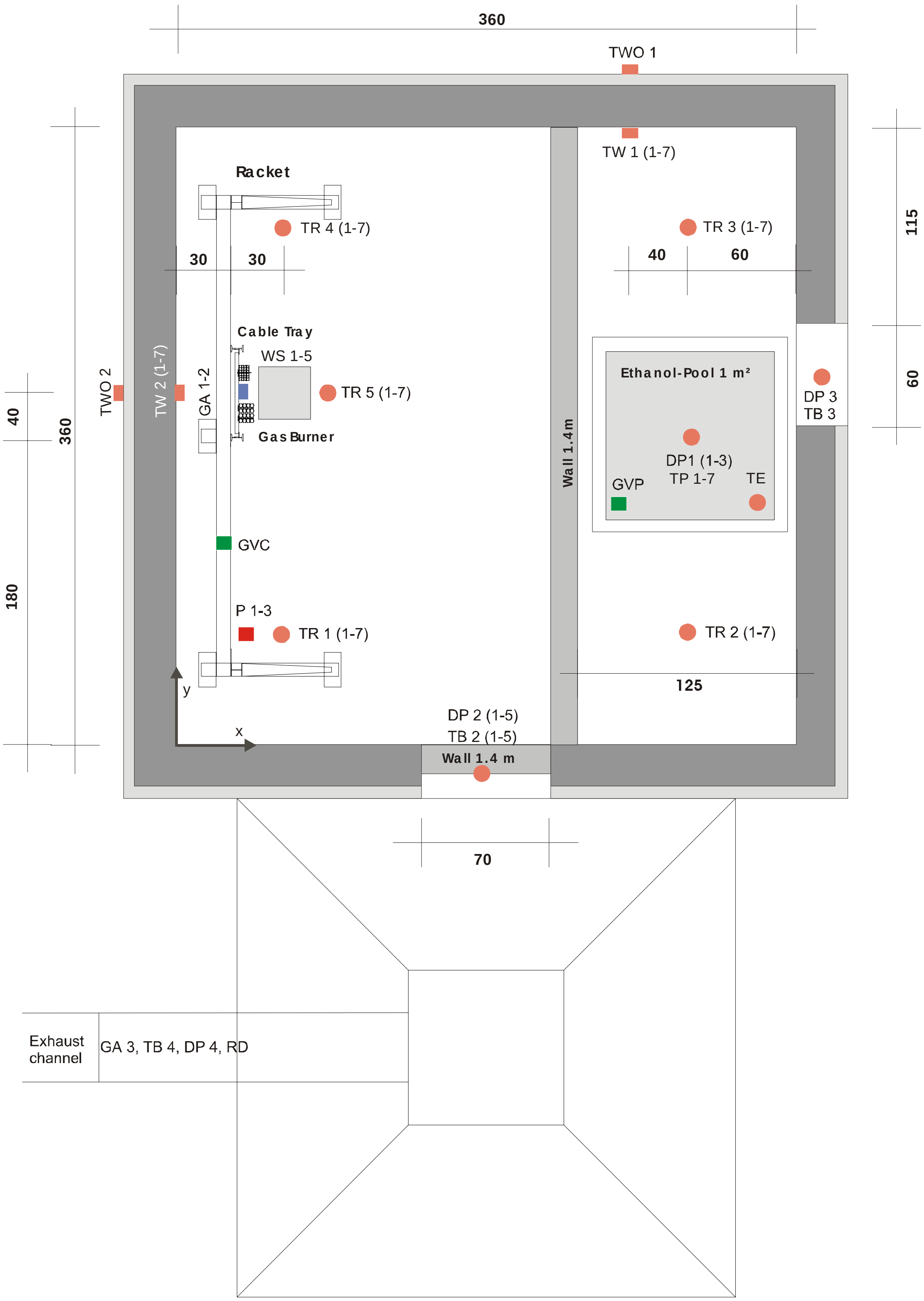


Figure 2-1 Top view of the fire compartment for the cable fire tests

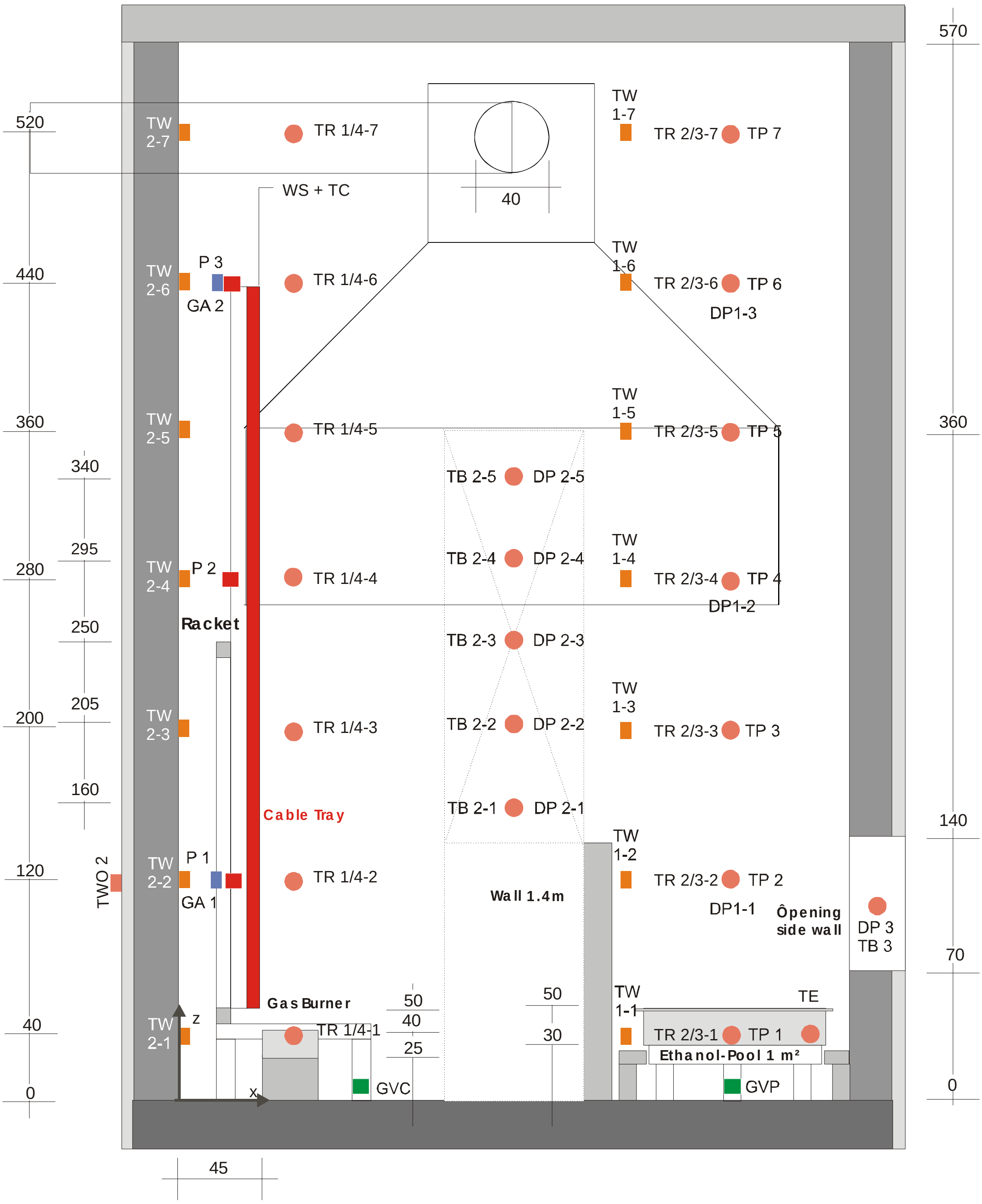


Figure 2-2 Side view of fire compartment (in +y direction)

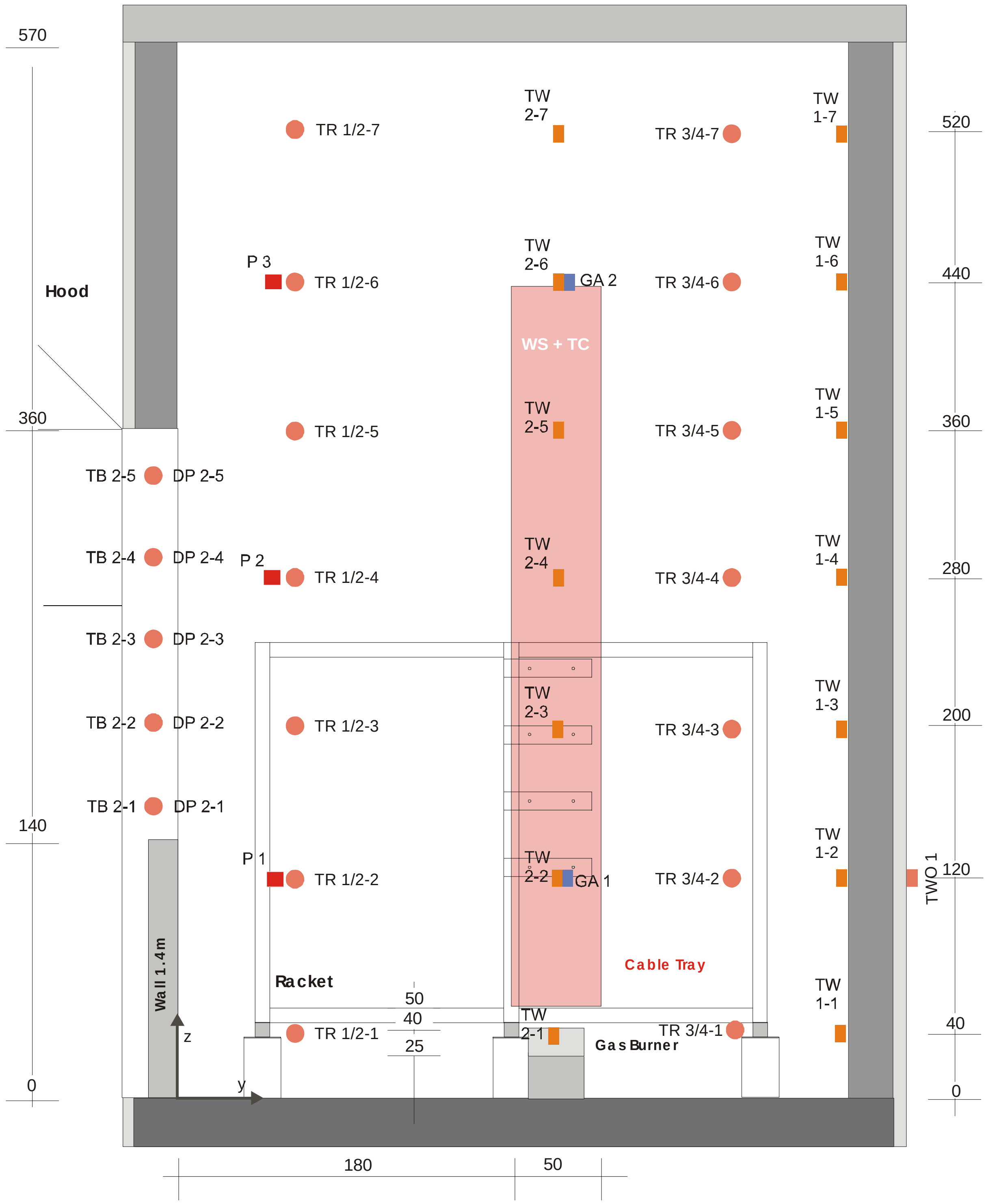


Figure 2-3 Side view of fire compartment (in -x direction)

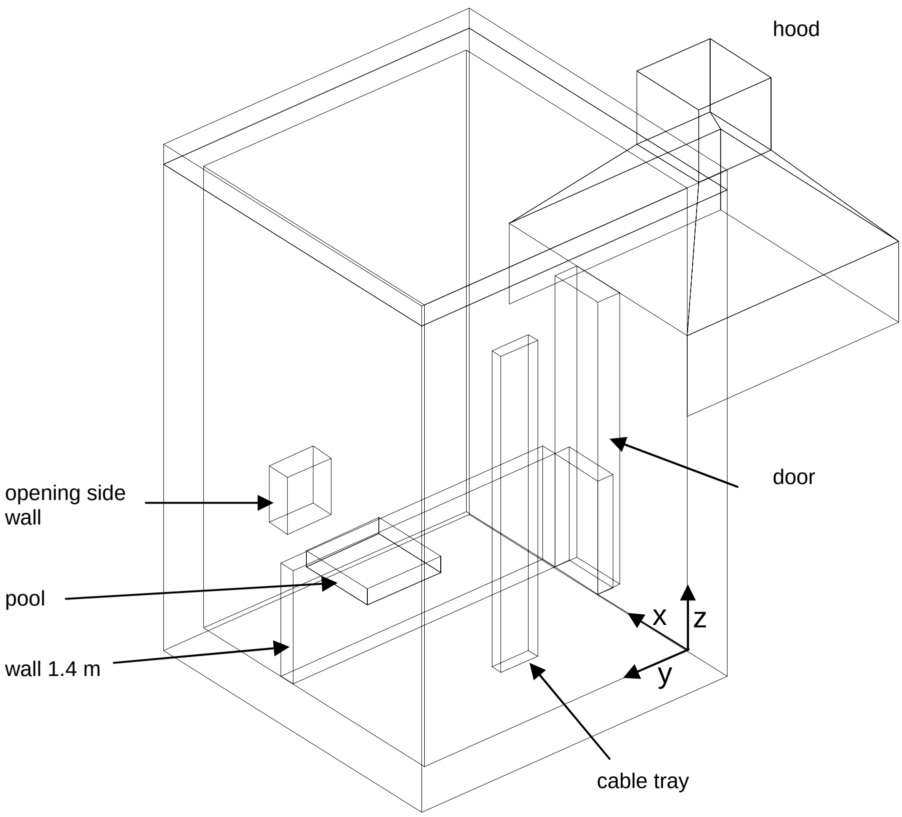


Figure 2-4 Three dimensional view of fire compartment

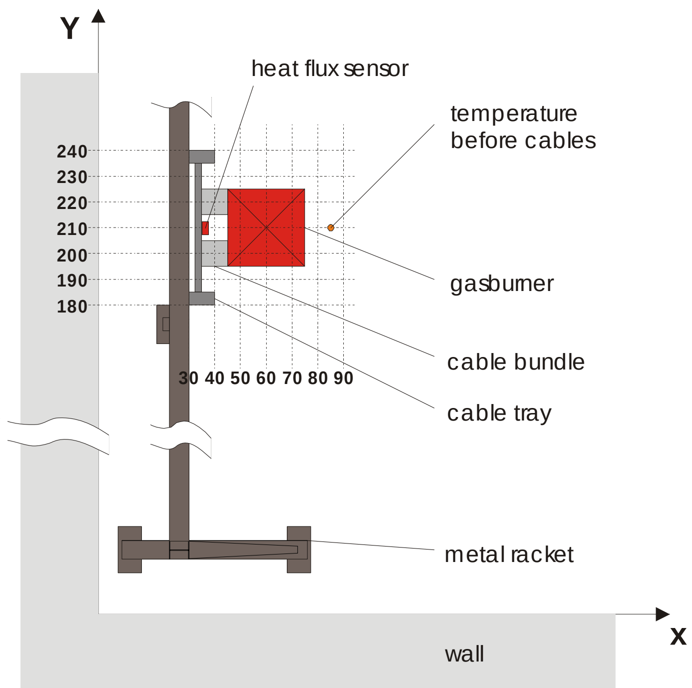


Figure 2-5 Layout plan cable tray, bundles and burner

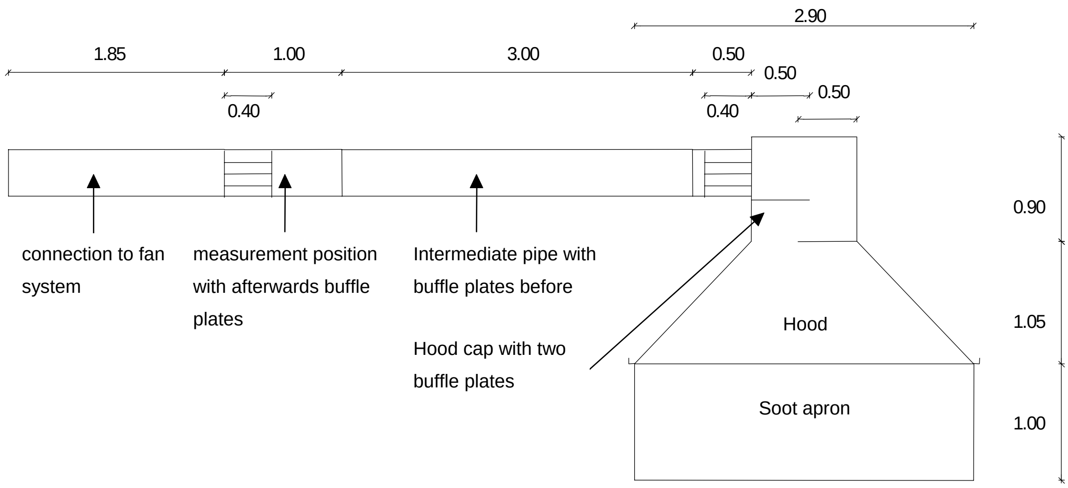


Figure 2-6 Scheme of the hood above the front door

Figure 2-7 View onto the hood above the front door

Table 2-2 Environmental data

	Fire compartment environment	
Hood with exhaust duct	5 maximum, approx. 3.5 intended *)	m³/s
Temperature	20 *)	°C
Pressure	101300 *)	Pa
Height	0	m
Wind	0	m

*) depending of the day

2.2 Pre-heating

A pool 1 m² floor area filled with ethanol (ethylene alcohol) is used as pre-heating source. For estimating the filling level pre-tests and simulations are planned to be carried out. The tests aim on pre-heating the cable surface on a maximum temperature level of 250°C. In case of temperatures exceeding 250°C - 300°C, a flashover of the flame spread has to be assumed for PVC cables. The pool fire source will only be applied for tests with pre-heating of the fire compartment. Data on the pool fire are given in Table 2-3.

Table 2-3 Pool fire data

	Pool data	
Pool size	1.0 x 1.0	m²
Intended filling level	10 **)	cm
	Ethanol properties (ethylene alcohol)	
Formula	CH_3CH_2OH	(C_2H_6O)
Density	0.79367	g/cm³
Heat of combustion	26.8 *)	MJ/kg
Heat of vaporization	837 *)	kJ/kg
Ignition temperature	78 *)	°C
Radiative fraction	0.20 *)	-
Burning rate	0.015 *), **)	kg/sm²

*) FDS Database 3 **) exact determination by pre-tests

2.3 Ignition Source

For igniting the cable tray a gas burner with propane gas is used. The burner power can be varied between 0 and 300 kW. The gas consists of 95 % propane/propene mixture (German DIN 51622) with a higher amount of propane as stated by the manufacturer. The other 5 % consist of ethane, ethene, and butane isomers. For the actual test series it is intended to use the gas burner with 100 kW until a temperature increase on the cable surface in level 2 (see paragraph 2.4) of more than 450°C is measured. This is defined as burning of the cables themselves.

Table 2-4 Gas burner for ignition

Parameter	**Gas burner**		
Area	300 * 300		mm * mm
Height	150		mm
Fuel	Propane		DIN 51622
Position	horizontal in front of and vertical under the cable tray		
Type of experiment	**Propane gas burner operating mode**		
	Time		
	Start [min]	End [min]*)	Power [kW]
Without pre-heating	0	cable fire 1.1 m above the lower tray level, both bundles	100
With pre-heating	20		100

*) temperature increase > 450 °C on the cable surface at the measuring point TCO 1/2-2 and TCO 3/4-2 (level 2).

2.4 Cable Routing and Installation, Temperature Measuring Points

The width of the cable trays is 50 cm. Both ladder type side racks have a width of 5 cm each. The cables are installed on the tray within two cable bundles with width of 30 cm to ensure that the gas burner with an edge length of 30 cm will heat up all the cables as symmetrical as possible. The amount of cables per bundle depends on the diameter Ø of the individual cables. It can be roughly calculated to number of cables n = (230 mm / Ø) per bundle.

The vertical ladder type cable trays are filled with cables with the corresponding measuring equipment as outlined in Figure 2-8. The cables are mounted on the trays with cable clamps. The lowest series of thermocouples are installed approx. 70 cm above the lower side of the tray. The distance between the different measuring levels is 40 cm, the distance between highest series of measuring devices and upper edge of the tray is 10 cm. The measuring devices of each row have numbers starting on the lowest level up to the highest one (last digit in the number). The exact position of the thermocouples is given in Figure 2-9.

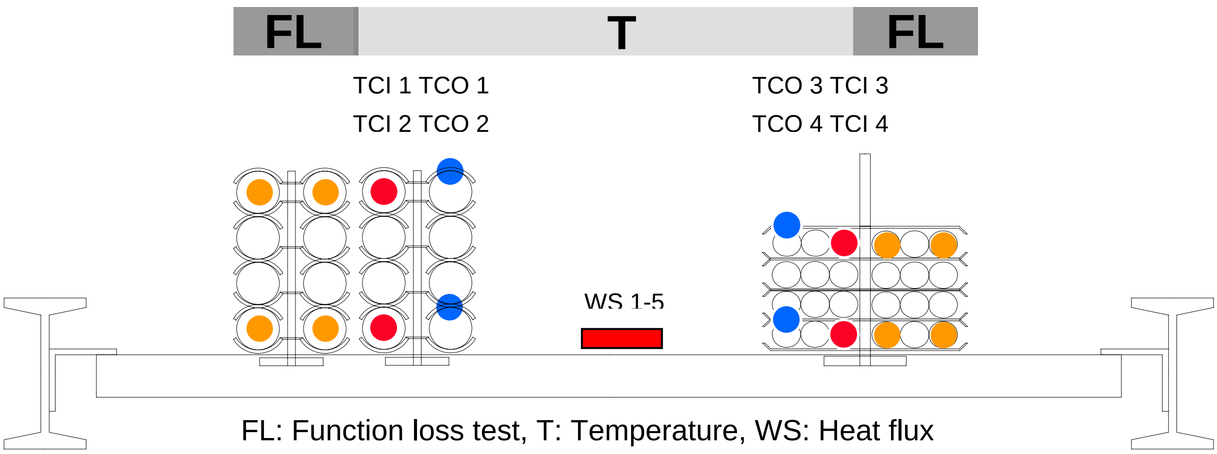


Figure 2-8 Vertical cable tray; two cable bundles; left: power cables, right: I&C cables

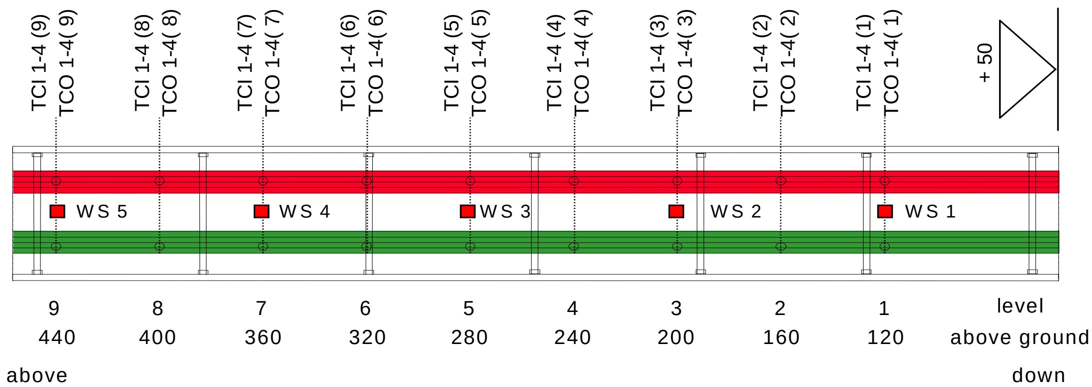


Figure 2-9 Temperature measurement positions on the cables tray, levels 1-9, and heat flux measurement positions at the cable tray

2.5 Cable Materials

PVC cables as well as FRNC (fire retardant and non corrosive) cable materials are used. Power cables as well as I&C cables will be investigated installed in two different cables bundles of the tray. Table 2-5 gives an overview of the different tapes of cables and cable materials as intended for the experiments. The layout is outlined in paragraph 2.4. Further details on the cables can be found in the appendix.

Table 2-5 Types of cable and cable insulation materials

Index	Material type / cable type	Name	Diameter Ø [mm]	n = (230 mm / Ø) per bundle
A	PVC - I&C cable	JE-Y-(St)Y 16 × 2 × 0.8	14.0	16
B	PVC - power cable	NYM-J 5 × 25	30.0	8
C	FRNC - I&C cable	JE-LIHCH (Bd) 16 × 2 × 0.5	16.0	14
D	FRNC - power cable	NHXMH-J 5 × 2.5	12.5	18

2.6 Function failure tests

For the measurement of the current conduction and short-circuit of electrical cables a measuring apparatus was developed in line with german DIN 4102-12. Hereby a parallel current conduction and short-circuit measurement of maximal 12 cable conductors are possible. The equipment works with a voltage of 9 Volt. With this testing voltage the requirements of german DIN 4102-12 are not kept. Crucial it is however that this circuit permits a parallel installation of temperatures probes on the cables, without endangering the measuring recording in the case of short-circuit. Therefore the temperature development on the cables is possible to be measured without problems.

Figure 2-10 shows the electrical schenatic of the function loss test equipment. Figure 2-11 shows a picture of the test eqipment with the front panel. For every of the twelve conductors is possible to measure the current conduction. The short circuit will be measure for six cables to the groung. Beyond that in each case 6 short-circuit measurements with in each case two cable cores can be accomplished. For this it is to be measured meaningfully in each case two cable cores next to one another.

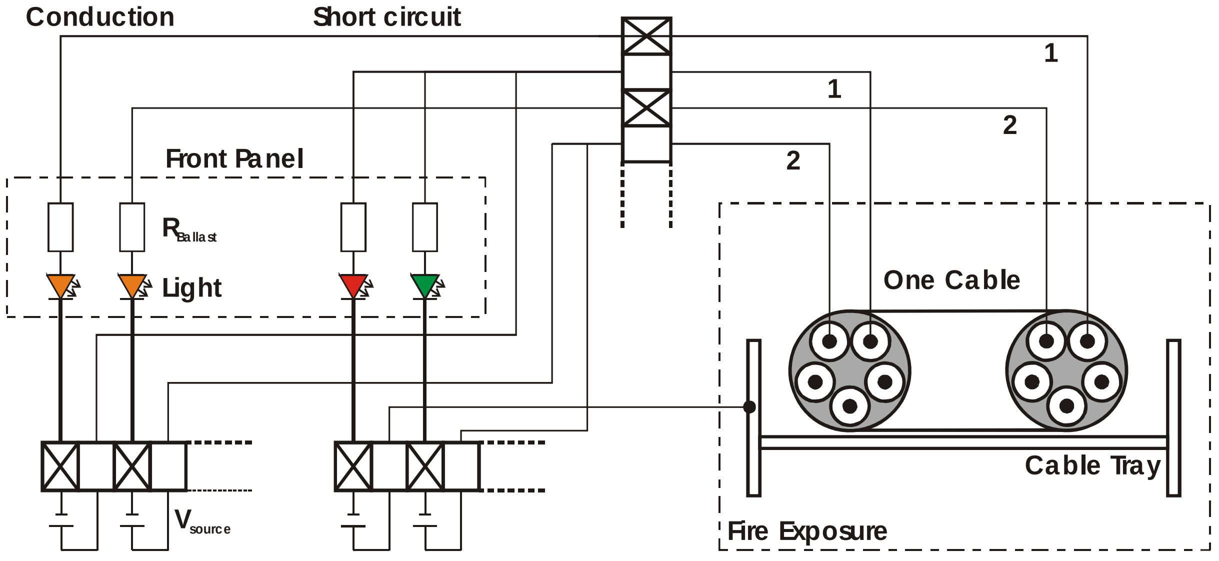


Figure 2-10 Electrical schematic of the function failure tests. The principle is shown for two conductors 1 & 2 of one cable.

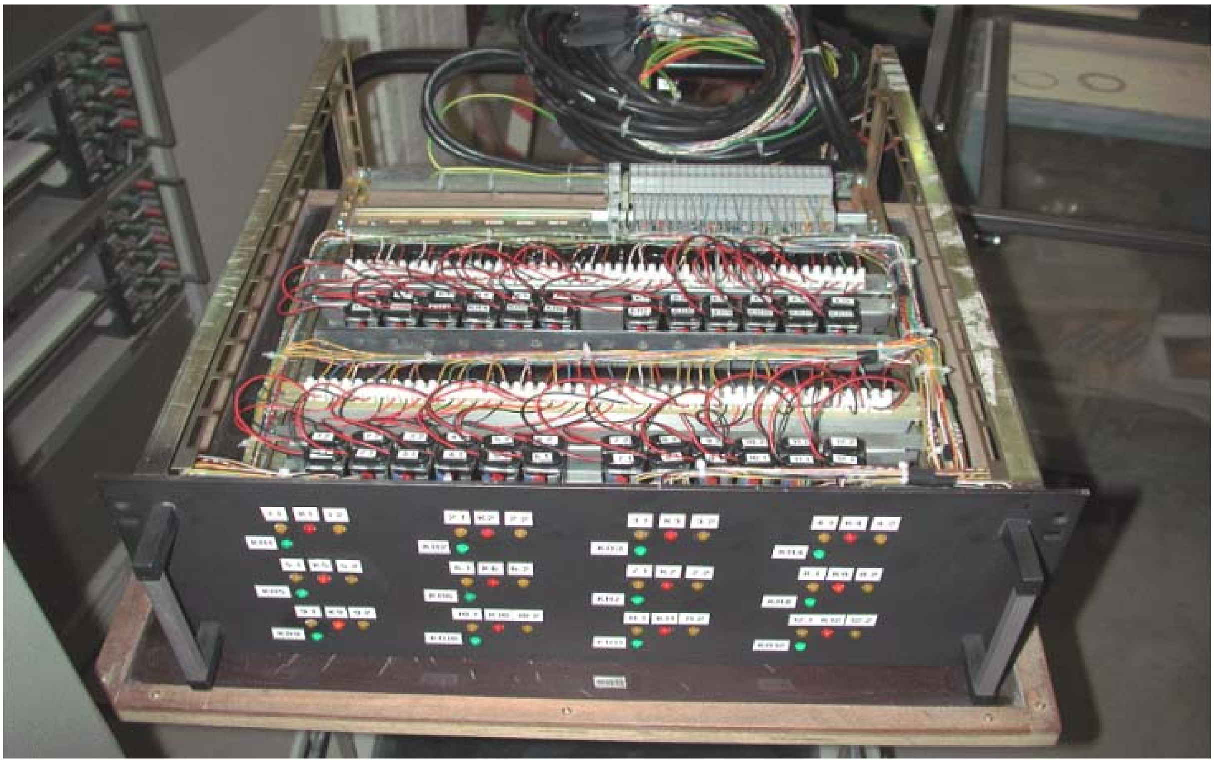


Figure 2-11 Function failure test equipment iBMB, test voltage 9 Volt

In the case of loss of electric function a light at the front panel of the test equipment will indicate the loss of current conduction or short-circuit of electrical cables.

3 Experimental Matrix

Table 3-1 gives an overview of the intended experiments. For each of the cable insulation materials, PVC and FRNC, two experiments will be carried out. One of these experiments with identical amount and type of cables will be performed without pre-heating, the other with pre-heating of the fire compartment. The operating mode of the ignition gas burner depends on the experiment and is explained in detail in paragraph 2.3.

Table 3-1 Overview on the experiments

Experimental parameters	Experiment 1	Experiment 2	Experiment 3	Experiment 4
Material	FRNC		PVC	
Positioning	Vertical			
Cable type	power cable I&C cable	power cable I&C cable	power cable I&C cable	power cable I&C cable
Pre-heating	Liquid pool (Ethanole)			
	No	Yes	No	Yes
Ignition source	gas burner 100 kW			
Function failure	Yes			

3.1 Measured Values

The following parameters will be measured at the positions outlined in detail in Table 3-3:

- Temperatures above the fire (plume) for 7 heights,
- Temperatures in the fire compartment at 4 locations for 7 heights,
- Temperatures 40 cm in front of the cable tray for 7 heights,
- Temperatures at the wall surfaces,
- Weight loss of the pool (bottom of the fire compartment with a weight scale),
- Weight loss of the cable tray (difficult because of parallel function failure tests),
- Gas velocities and temperatures in the openings and in the plume,
- Difference Pressure distribution for 3 heights of the fire compartment,
- Gas analysis (O_2, CO_2 und CO) for 2 heights in the fire compartment,
- Heat flux densities in the level of the cable bundles for 5 heights,

- Cable surface and inner cable temperatures for 9 heights,
- Gas velocity and temperature in the exhaust channel,
- Gas analysis (O_2, CO_2 und CO) in the exhaust channel,
- Smoke gas density in the exhaust channel,
- Functional failure tests for the cables,
- Flame front height (video is possible).

3.2 Measurement Overview

The different measurements are given in Figure 2-1 to Figure 2-5 with the abbreviations explained in Table 3-2. Table 3-3 gives an overview of the measuring devices and their respective locations. It further includes details on the thermocouples on the cable trays as given in paragraph 2.4. The environmental data, like temperature and pressure are taken from the standard meteorology from iBMB at each day, when the experiments will be performed.

Table 3-2 Measurement abbreviations

Parameter	Abbreviation	Location	Unit
Temperature	TP TR TW, TWO TCI TCO TE TB TH	plume compartment wall, wall outside inside cable on cable surface ethanole bi-directional probes enviromental (hall)	[°C]
Mass loss	GVP GVT	pool cable tray	[kg]
Pressure difference	DP	openings, plume, compartment	[Pa]
Gas analysis inside compartment	GA	compartment	[volume %]
Pressure	PH	enviromental (hall)	[Pa]
Heat flux density	WS	cable tray	[kW/m²]
Heat release rate *)	HRR	outside compartment	[kW]
Smoke propagation velocity	RD	outside compartment	[m²/s]
Gas burner flow rate	RG	outside compartment	[l/min]

*) by means of oxygen consumption calorimetric method due to ISO 9705

Table 3-3 List of performed measurements

Measuring Point	**Position**		
	x [cm]	y [cm]	z [cm]
TEMPERATURES			
Centerline plume			
TP 1	290	180	040
TP 2			120
TP 3			200
TP 4			280
TP 5			360
TP 6			440
TP 7			520
Compartment chain 1			
TR 1-1	60	60	040
TR 1-2			120
TR 1-3			200
TR 1-4			280
TR 1-5			360
TR 1-6			440
TR 1-7			520
Compartment chain 2			
TR 2-1	300	60	040
TR 2-2			120
TR 2-3			200
TR 2-4			280
TR 2-5			360
TR 2-6			440
TR 2-7			520
Compartment chain 3			
TR 3-1	300	300	040
TR 3-2			120
TR 3-3			200
TR 3-4			280
TR 3-5			360

Measuring Point	**Position**		
TR 3-6			440
TR 3-7			520
Compartment chain 4			
TR 4-1	60	300	040
TR 4-2			120
TR 4-3			200
TR 4-4			280
TR 4-5			360
TR 4-6			440
TR 4-7			520
Compartment chain 5 – 40 cm in front of vertical tray			
TR 5-1	85	220	040
TR 5-2			120
TR 5-3			200
TR 5-4			280
TR 5-5			360
TR 5-6			440
TR 5-7			520
Wall chain 1, thermocouple with little metal plate			
TW 1-1	260	360	040
TW 1-2			120
TW 1-3			200
TW 1-4			280
TW 1-5			360
TW 1-6			440
TW 1-7			520
Wall chain 2, thermocouple with little metal plate			
TW 2-1	0	220	040
TW 2-2			120
TW 2-3			200
TW 2-4			280
TW 2-5			360
TW 2-6			440

Measuring Point	Position		
TW 2-7			520
Ethanol, covered thermocouple			
TE	340	140	32
Door			
TB 2-1	180	-15	160
TB 2-2			205
TB 2-3			250
TB 2-4			295
TB 2-5			340
Opening side wall			
TB 3	375	215	105
Exhaust duct			
TB 4	outside fire compartment		
Wall outside			
TWO 1	260	390	120
TWO 2	-30	220	120
On surface of cable 1			
TCO 1-1	~ 45	~225	120
TCO 1-2			160
TCO 1-3			200
TCO 1-4			240
TCO 1-5			280
TCO 1-6			320
TCO 1-7			360
TCO 1-8			400
TCO 1-9			440
On surface of cable 2			
TCO 2-1	~ 40	~225	120
TCO 2-2			160
TCO 2-3			200
TCO 2-4			240
TCO 2-5			280
TCO 2-6			320

Measuring Point	Position		
TCO 2-7			360
TCO 2-8			400
TCO 2-9			440
On surface of cable 3			
TCO 3-1	~45	~215	120
TCO 3-2			160
TCO 3-3			200
TCO 3-4			240
TCO 3-5			280
TCO 3-6			320
TCO 3-7			360
TCO 3-8			400
TCO 1-9			440
On surface of cable 4			
TCO 4-1	~ 40	~215	120
TCO 4-2			160
TCO 4-3			200
TCO 4-4			240
TCO 4-5			280
TCO 4-6			320
TCO 4-7			360
TCO 4-8			400
TCO 4-9			440
In cable 1			
TCI 1-1	~ 45	~230	120
TCI 1-2			160
TCI 1-3			200
TCI 1-4			240
TCI 1-5			280
TCI 1-6			320
TCI 1-7			360
TCI 1-8			400
TCI 1-9			440

Measuring Point	**Position**		
In cable 2			
TCI 2-1	~ 40	~230	120
TCI 2-2			160
TCI 2-3			200
TCI 2-4			240
TCI 2-5			280
TCI 2-6			320
TCI 2-7			360
TCI 2-8			400
TCI 2-9			440
In cable 3			
TCI 3-1	~ 45	~210	120
TCI 3-2			160
TCI 3-3			200
TCI 3-4			240
TCI 3-5			280
TCI 3-6			320
TCI 3-7			360
TCI 3-6			400
TCI 3-9			440
In cable 4			
TCI 4-1	~ 40	~210	120
TCI 4-2			160
TCI 4-3			200
TCI 4-4			240
TCI 4-5			280
TCI 4-6			320
TCI 4-7			360
TCI 4-8			400
TCI 4-9			440
HEAT FLUX DENSITY			
WS 1	~ 40	220	120
WS 2			200

Measuring Point	Position		
WS 3			280
WS 4			360
WS 5			440
MASS LOSS			
WVP	Assembly below the pool		
WVT	Assembly below the cable rack		
DIFFERENCE PRESSURE			
Centerline plume			
DP 1-1	290	180	120
DP 1-2			280
DP 1-3			440
Door			
DP 2-1	180	-15	160
DP 2-2			205
DP 2-3			250
DP 2-4			295
DP 2-5			340
Opening side wall			
DP 3	375	215	105
Exhaust duct			
DP 4	outside fire compartment		
Fire compartment			
DP 5-1	30	65	120
DP 5-2			280
DP 5-3			440
GAS ANALYSIS			
Fire compartment			
GA 1	30	195	120
GA 2	30	195	440
Exhaust duct (oxygen consumption method and smoke production)			
GA 3	outside fire compartment		
RD	outside fire compartment		

3.3 Instrumentation

Table 3-4 gives an overview of the measuring equipment applied fort the test series.

Table 3-4 Overview on the measuring equipment

Location	Measuring equipment	Measured parameter	Measuring point
Compart-ment	bared thermocouple, type K NiCrNi	temperature	TR 1-5 (1-7)
	Oxor 610	O_2	GA 1
	Binos 610	CO, CO_2	GA 1
	Multor 610	O_2, CO, CO_2	GA 2
	gardon gage detectors	heat flux density (radiative+convective)	WS 1-5
	pressure gage	pressure difference	DP 5 (1-3)
Plume	bared thermocouple, type K NiCrNi	temperature	TP 1-7 {TB 1 (1-3)}
	bi-directional probe	pressure difference	DP 1 (1-3)
Opening Door	bared thermocouple, type K NiCrNi	temperature	TB 2 (1-5)
	bi-directional probe	pressure difference	DP 2 (1-5)
Opening Side wall	bared thermocouple, type K NiCrNi	temperature	TB 3
	bi-directional probe	pressure difference	DP 3
Wall	thermocouple with little metal plate, type K NiCrNi	surface temperature	TW
Pool	load cell	mass loss	GVP
	sheated thermocouple protected, type K NiCrNi	temperature	TE
Cable tray	bared thermocouple, type K NiCrNi	temperature	TCO, TCI
	load cell	mass loss	GVT
Off-gas flow	Ultramat 22	CO, CO_2	GA 3
	Servomex	O_2	GA 3
	bi-directional probe	Pressure difference	DP 4
	bared thermocouple, type K NiCrNi	temperature	TB 4
	Maurer Light	smoke production	RD

4 Results to Be Delivered

The results should be delivered on MS-EXCEL sheets. For an easier evaluation of the results the structure of this sheet should be fixed (according to Benchmark Exercise #4). The structure is given in the accompanied Excel file 'BM#5-Specification' in the Table 'Results Experiments". Inside the comment line the one may give a comment for a specific value (maximal one line). In the last columns the user may add some additional values. He should add all curves he uses in his technical notes. Then it may be possible to compare these results with results from other participants. Results values, which are not delivered, should left free. In the following Table 4-1 the values to be delivered and which are not measured are described in more detail.

Table 4-1 Additional variables to be delivered

Description	Name	Unit	Comment
Layer temperatures and height	Tup	°C	Upper layer temperature
	Tlow	°C	Lower layer temperature
	Layer_height	m	Layer height
Wall surface temperature	TS(up)	°C	Wall temperature of the fire compartment in the upper layer region
	TS(low)	°C	Wall temperature of the fire compartment in the lower layer region
Combustion	Combustion rate ethanol	kg/s	Combustion rate of ethanol
	Combustion rate cable	kg/s	Combustion rate of cables
	Comb. Heat release	kW	Total combustion heat release
Mass flow rates	Gin(Door)	kg/s	Mass flow rate through front door into the fire compartment
	Gout(Door)	kg/s	Mass flow rate through front door from the fire compartment
	Gin(opening side wall)	kg/s	Mass flow rate through the opening at the side wall of the fire compartment)
Heat flow rates	HeatLoss(Walls)	kW	Heat loss into the walls of the fire compartment
	HeatFlow(Door)	kW	Total heat flow through the door
	HeatFlow(opening side wall)	kW	Total heat flow through opening at the side wall

5 Time Schedule

The time schedule of the Benchmark Exercise #5 has discussed during the 7th ICFMP meeting at WPI. Take the more exact date for the experiments into account.

Table 5-1 Time schedule for Benchmark Exercise #5

Date	Action / Task
October 15, 2003	Extended specification of the Benchmark Exercise #5
October 31, 2003	Final specification of the Benchmark Exercise #5
December 08, 2003	“Blind“ pre-calculations
December 08 - 19, 2003	Experiments to be performed
February 29, 2004	Release of experimental data
April 30, 2004	Open post-calculations
June 9-11, 2004	Discussion on results

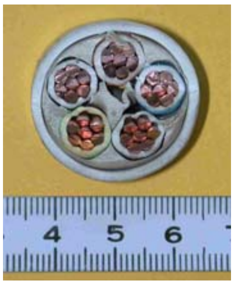
Appendix A: Cable Data

Table A-1 Detailed information regarding cable type A

<table>
<tr><th colspan="3">Labeling</th></tr>
<tr><td>Index</td><td>A</td><td rowspan="2">
</td></tr>
<tr><td>Cable type</td><td>PVC - I&C cable

∅ ≈14.0 mm</td></tr>
<tr><td colspan="2">Type label due to VDE 0815/16</td><td>JE-Y(St)Y 16 x 2 x 0,8 mm</td></tr>
<tr><td colspan="2">Labeling details</td><td>J - Installation cable
E - Electronic
Y - PVC insulation
(St) - Static foil screen
Y - PVC outer sheath
- wires => 32 wires
- diameter =>0.8 mm
- cross section => 0,5 mm²</td></tr>
</table>

Table A-2 Detailed information regarding cable type B

<table>
<tr><th colspan="3">Labeling</th></tr>
<tr><td>Index</td><td>B</td><td rowspan="2">
</td></tr>
<tr><td>Cable type</td><td>PVC - Power cable

∅ ≈ 30.0 mm</td></tr>
<tr><td colspan="2">Type label due to VDE 0250</td><td>NYM-J 5 x 25</td></tr>
<tr><td colspan="2">Labeling details</td><td>N - VDE-type
Y - PVC insulation
M - Sheathed cable
J - with protective wire
- wires => 5 wires
- cross section => 25 mm²</td></tr>
</table>

Table A-3 Detailed information regarding cable type C

Labeling		
Index	C	
Cable type	FRNC– I&C cable ∅ ≈16.0 mm	
Type label due to VDE 0250		JE-LIHCH (Bd) 16 × 2 × 0.5
Labeling details		J - Installation cable E - Electronic LI - stranded wire H - non-corrosive (non-halogenic) insulation C - shielding by copper wire mesh H - non-corrosive (non-halogenic) sheath - wires =>32 wires - cross section => 0.5 mm²

Table A-4 Detailed information regarding cable type D

Labeling		
Index	D	
Cable type	FRNC– Power cable ∅ ≈12.5 mm	
Type label due to VDE 0250		NHXMH-J 5 x 2,5
Labeling details		N - VDE-type HX - non-corrosive (non-halogenic) materials MH - connection wire of medium mechanical - load J - with protective wire - wires => 5 wires - cross section => 2.5 mm²

Table A-5 Thermo-physical data cable A

Cable A	**PVC – I&C cable**	**JE-Y(St)Y 16 x 2 x 0,8 mm**			
Thermo-physical cable data from Cone Calorimeter at iBMB (each heat flux two tests)					
		Value		**Reference**	**Unit**
Critical heat flux		12.5		theory by Janssens *)	[kW/m²]
Ignition temperature		313.6			[°C]
$\lambda\rho c_p$		0.12			[kW²s/K²m^4
		35 kW/m²	50 kW/m²		
Maximum Heat Release Rate		207.5	257.6		[kW/m²]
Average Heat Release Rate		155.8	193.6	mass loss rate 10-90% according to ISO 5660 Fire tests – Reaction to fire, part 1	[kW/m²]
Average effective heat of combustion		11.2	13.9		[MJ/kg]
Average CO_2 –Yield		1.065	0.486		[kg/kg]
Average CO –Yield		0.049	0.054		[kg/kg]
Average Soot –Yield		0.047	0.100	(average 300 s)	[kg/kg]
Average effective heat of gasification		3910		obtained from reciprocal slope of a plot of peak mass loss rate versus external heat flux	[kJ/kg]
Other methods and sources					
HCl -Yield		0.5		NUREG - 1758	[kg/kg]
Fraction of flame heat released as radiation		0.48		NUREG - 1758	-
Emissivity		0.8		NUREG - 1758	-
Specific Heat [c_p]		1040		NUREG - 1758	[J/kgK]
Thermal conductivity [λ]		0.092		NUREG - 1758	[W/mK]
Heat of combustion core insulation		21.547		iBMB, oxygen bomb calorimeter	[MJ/kg]
Heat of combustion sheath insulation		13.878			[MJ/kg]
Non-combustible volume		0.017		iBMB	[l/m]
Combustible volume		0.116			[l/m]
Density non-combustible volume		8726			[kg/m³]
Density combustible volume [ρ]		1458			[kg/m³]

Table A-6 Thermo-physical data cable B

Cable B	**PVC – power cable**	**NYM-J 5 x 25**			
Thermo-physical cable data from Cone Calorimeter at iBMB (each heat flux two tests)					
		Value		**Reference**	**Unit**
Critical heat flux		12.4		theory by Janssens *)	[kW/m²]
Ignition temperature		312.6			[°C]
$\lambda\rho c_p$		0.24			[kW²s/K²m^4
		35 kW/m²	50 kW/m²		
Maximum Heat Release Rate		157.8	216.8		[kW/m²]
Average Heat Release Rate		67.6	123.2	mass loss rate 10-90% according to ISO 5660 Fire tests – Reaction to fire, part 1	[kW/m²]
Average effective heat of combustion		18.1	20.7		[MJ/kg]
Average CO_2 –Yield		1.276	0.468		[kg/kg]
Average CO –Yield		0.022	0.027		[kg/kg]
Average Soot –Yield		0.038	0.055	(average 300 s)	[kg/kg]
Average effective heat of gasification		4930		obtained from reciprocal slope of a plot of peak mass loss rate versus external heat flux	[kJ/kg]
Other methods and source					
HCl -Yield		0.5		NUREG - 1758	[kg/kg]
Fraction of flame heat released as radiation		0.48		NUREG - 1758	-
Emissivity		0.8		NUREG - 1758	-
Specific Heat [c_p]		1040		NUREG - 1758	[J/kgK]
Thermal conductivity [λ]		0.092		NUREG - 1758	[W/mK]
Heat of combustion core insulation		15.099		iBMB, oxygen bomb calorimeter	[MJ/kg]
Heat of combustion sheath insulation		15.421			[MJ/kg]
Non-combustible volume		0.122		iBMB	[l/m]
Combustible volume		0.484			[l/m]
Density non-combustible volume		8879			[kg/m³]
Density combustible volume [ρ]		1504			[kg/m³]

Table A-7 Thermo-physical data cable C

Cable C	**FRNC – I&C cable**	**JE-LIHCH (Bd) 16 × 2 × 0.5**			
Thermo-physical cable data from Cone Calorimeter at iBMB (each heat flux two tests)					
		Value		**Reference**	**Unit**
Critical heat flux		12.1		theory by Janssens *)	[kW/m^2]
Ignition temperature		323.4			[°C]
$\lambda\rho c_p$		0.96			[kW^2s/K^2m^4
		35 kW/m^2	50 kW/m^2		
Maximum Heat Release Rate		99.4	170.5		[kW/m^2]
Average Heat Release Rate		39.5	78.2	mass loss rate 10-90% according to ISO 5660 Fire tests – Reaction to fire, part 1	[kW/m^2]
Average effective heat of combustion		18.1	22.5		[MJ/kg]
Average CO_2 –Yield		0.916	0.170		[kg/kg]
Average CO –Yield		0.076	0.017		[kg/kg]
Average Soot –Yield		0.017	0.001	(average 300 s)	[kg/kg]
Average effective heat of gasification		4281		obtained from reciprocal slope of a plot of peak mass loss rate versus external heat flux	[kJ/kg]
Other methods and source					
Fraction of flame heat released as radiation		-		-	[-]
Emissivity		0.95		no reference	[-]
Specific Heat [c_p]		-		-	[J/kgK]
Thermal conductivity [λ]		-		-	[W/mK]
Heat of combustion core insulation		23.264		iBMB, oxygen bomb calorimeter	[MJ/kg]
Heat of combustion sheath insulation		17.389			[MJ/kg]
Non-combustible volume		0.017		iBMB	[l/m]
Combustible volume		0.160			[l/m]
Density non-combustible volume		8691			[kg/m^3]
Density combustible volume [ρ]		1615			[kg/m^3]

Table A-8 Thermo-physical data cable D

Cable D	**FRNC – power cable**	**NHXMH-J 5 x 2,5**			
Thermo-physical cable data from Cone Calorimeter at iBMB (each heat flux two tests)					
		Value		Reference	Unit
Critical heat flux		13.0		theory by Janssens *)	[kW/m²]
Ignition temperature		335.7			[°C]
$\lambda\rho c_p$		1.14			[kW²s/K²m⁴
		35 kW/m²	50 kW/m²		
Maximum Heat Release Rate		113.5 *)	133.0	*) only one value	[kW/m²]
Average Heat Release Rate		41.1	59.5	mass loss rate 10-90% according to ISO 5660 Fire tests – Reaction to fire, part 1	[kW/m²]
Average effective heat of combustion		25.4	27.8		[MJ/kg]
Average CO_2 –Yield		1.105	0.012		[kg/kg]
Average CO –Yield		0.028	0.002		[kg/kg]
Average Soot –Yield		0.026	0.028	(average 300 s)	[kg/kg]
Average effective heat of gasification		18361		obtained from reciprocal slope of a plot of peak mass loss rate versus external heat flux	[kJ/kg]
Other methods and source					
Fraction of flame heat released as radiation		-		-	[-]
Emissivity		0.95		no reference	[-]
Specific Heat [c_p]		-		-	[J/kgK]
Thermal conductivity [λ]		-		-	[W/mK]
Heat of combustion core insulation		46.082		iBMB, oxygen bomb calorimeter	[MJ/kg]
Heat of combustion sheath insulation		16.802			[MJ/kg]
Non-combustible volume		0.012		iBMB	[l/m]
Combustible volume		0.095			[l/m]
Density non-combustible volume		8674			[kg/m³]
Density combustible volume [ρ]		1428			[kg/m³]

***) M., Janssens, 'Determining flame spread properties from Cone Calorimeter measurements', Heat Release in Fires, Edited by V. Babrauskas and S. Grayson**

Appendix B: Cable Tray Arrangement, Experiment 1&2 and 3&4

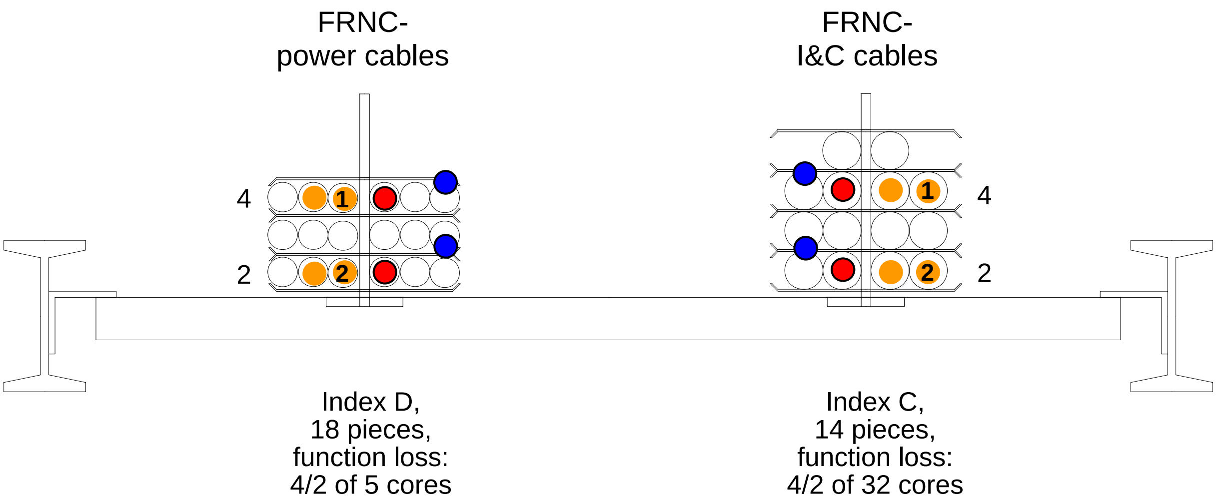


Figure B-1 Allocation of a vertical cable tray with power and I&C cables, Experiment 1&2

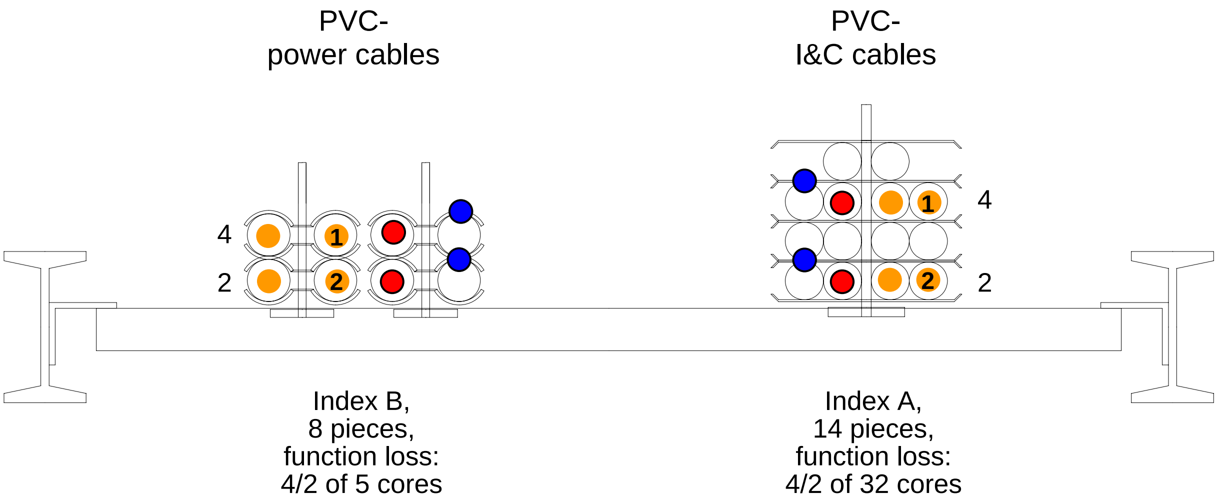


Figure B-2 Allocation of a vertical cable tray with power and I&C cables, Experiment 3&4

Legend for Figure B-1/B-2

● Functon loss test ● Temperature in cable ● Temperature on cable

INSTITUT FÜR BAUSTOFFE, MASSIVBAU UND BRANDSCHUTZ

MATERIALPRÜFANSTALT FÜR DAS BAUWESEN - MPA BRAUNSCHWEIG

TU BRAUNSCHWEIG

APPENDIX B

”Last Changes”

“BM EX # 5: Information about last changes in the specification”
MSWord-document “BM#5-LastModifications” published at the ICFMP-Platform

to the

FINAL REPORT

“Performing of Recent Real Scale Cable Fire Experiments and Presentation of the Results in the Frame of the International Collaborative Fire Modeling Project ICFMP”

Contract SR 2449
Sub-contract UA-2298

Prof. Dr.-Ing. Dietmar Hosser
Dipl.-Phys. Olaf Riese
Cand.-Ing. Mark Klingenberg

June 2004

“This report represents the expert opinion and expertise of the contractor (iBMB). It is not necessary that this is in accordance with the expert opinion of the contracting party (Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH.“

Beethovenstraße 52 · D-38106 Braunschweig · Tel. (0531) 391-5431 · Fax (0531) 391-5900 · E-Mail ibmb@tu-bs.de · Internet http://www.ibmb.tu-bs.de

BM EX #5: Information about last changes in the specification Date 03-12-04

1) Pool is resized to 0,5 m²

Pre-tests have showed that with a 1 m² pool the temperatures in front of the cable increased over 200-250 °C. The tests aim on pre-heating the cable surface on a maximum temperature level of 250 °C. Tests with a 0,5 m² pool give the desired results for the temperatures in conjunction with point 2.

2) No second small opening

The second small opening is not in use, because temperatures becomes to small with the 0,5 m² pool from point 1.

3) Filling height

The height of the ethanol liquid in the pool is fixed with 12.5 cm. The burning rate of the ethanol liquid could be assumed with 0,03 [kg/s]/m².

4) No metal rack for the cable tray

The system to measure the weight loss has changed. The mass loss will be measured now at the top of outside the room. In this way we do not need a metal racket for the cable tray.

5) Room height

The exact room height must be adjusted to 5,6 m.

6) Room difference pressure (DP5 (1-3))

The difference room pressure will be measured at the following x, y, z – location (meters)

DP 5-1 10, 65, 055

DP 5-2 10, 65, 275

DP 5-3 10, 65, 495

7) Gas–analysis in the room

The gas analysis in the room GA 1 and GA 2 will be measured at the following x, y, z –location (meters)

GA 1 30, 210, 200

GA 2 30, 210, 440

8) Cable bundles positioning

It seems that the position of the cable bundles on the cable tray is not clear. Looking from the room side, the power-cables (cable B or D) are situated on the right side of the route, the I&C-cable (cable A or C) on the left side of the cable tray.

9) Plume Temperature TP 1

The centerline plume temperature in 40 cm height (TP 1) is not measured because this is in the range of the ethanol liquid.

10) Operation mode gas burner has been modified

	Propane gas burner operation mode			
	Start [min]	End [min] *)	Power [kW]	
Material			FRNC	PVC
Without pre-heating	0	cable fire 1.5 m above the lower tray level, both bundles - level 3	**150**	**50**
With pre-heating	20		**150**	**50**
No ignition after 5 min	5 or 25		**300**	**100**

*) temperature increase > 450 °C on the cable surface at the measuring points TCO 1/2-3 and TCO 3/4-3.

INSTITUT FÜR BAUSTOFFE, MASSIVBAU UND BRANDSCHUTZ

MATERIALPRÜFANSTALT FÜR DAS BAUWESEN - MPA BRAUNSCHWEIG

TU BRAUNSCHWEIG

APPENDIX C

”Initial Conditions”

“Report of Experimental results of International Benchmarking and Validation Exercise # 5 – Flame Spread In Cable Tray Fires (Initial Conditions for test 1 – test 4)”

to the

FINAL REPORT

“Performing of Recent Real Scale Cable Fire Experiments and Presentation of the Results in the Frame of the International Collaborative Fire Modeling Project ICFMP”

Contract SR 2449
Sub-contract UA-2298

Prof. Dr.-Ing. Dietmar Hosser
Dipl.-Phys. Olaf Riese
Cand.-Ing. Mark Klingenberg

June 2004

“This report represents the expert opinion and expertise of the contractor (iBMB). It is not necessary that this is in accordance with the expert opinion of the contracting party (Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH.“

Beethovenstraße 52 · D-38106 Braunschweig · Tel. (0531) 391-5431 · Fax (0531) 391-5900 · E-Mail ibmb@tu-bs.de · Internet http://www.ibmb.tu-bs.de

INSTITUT FÜR BAUSTOFFE, MASSIVBAU UND BRANDSCHUTZ

MATERIALPRÜFANSTALT FÜR DAS BAUWESEN - MPA BRAUNSCHWEIG

TU BRAUNSCHWEIG

REPORT OF EXPERIMENTAL RESULTS OF INTERNATIONAL BENCHMARKING AND VALIDATION EXERCISE # 5

Flame Spread In Cable Tray Fires

Initial Conditions for Test 1 – Test 4

Januar, 2004

Olaf Riese

Mark Klingenberg

Beethovenstraße 52 · D-38106 Braunschweig · Tel. (0531) 391-5431 · Fax (0531) 391-5900 · E-Mail ibmb@tu-bs.de · Internet http://www.ibmb.tu-bs.de

Contents

List of Tables

1 Introduction

More information about the ambient data during test time are given in the accompanied EXCEL –file ‘BM#5-InitialCondition’. Here you can find some plots of ‘initial’ data too.

2 Experimental Matrix

The tests showed that it was difficult to control the gas burner as a function of the ignition of the cable bundles as it was intended in the specification from benchmark exercise #5. It is possible, that a bundle is already burning, although the other one did not catch fire yet clearly. For this reason in Table 2-1, the exact controlling of the burner is shown, so that this can be considered in further simulation. Table 2-1 gives also information about the overall test time until end of each record. The end of the data record gives no information about last flames at the cables. At least 20 minutes were recorded after expiring the last flames.

Table 2-1 Overview test run times and burner output

Test parameters	**Test 1**	**Test 2**	**Test 3**	**Test 4**
Date 2003	12-09	12-12	12-16	12-18
Material	FRNC		PVC	
Start data record	-0:02:00	-0:02:00	-0:02:00	-0:02:00
Pre-heating	Liquid quadratic ethanol pool: 0.7* 0.7 m², 62.5 Liter			
	no	yes	no	yes
At test time	-	0:00:00	-	0:00:00
Gasburner [kW]	At test time			
50	-	-	0:00:00	0:20:10
100	-	-	-	0:35:20
150	0:00:30	0:20:20	-	-
300	0:40:00	0:50:00	-	-
0	1:10:40	1:02:00	0:13:50	0:38:20
End data record	1:39:20	1:56:00	1:03:30	1:57:50

3 Initial Conditions

Table 3-2 and Table 3-2 gives the values for pressure and temperatures at starting test time. For the fire compartment the values are given in the upper and the lower region.

Table 3-1 Initial fire compartment temperature test 1 – test 4

	Test 1	**Test 2**	**Test 3**	**Test 4**
TEMPERATURE IN COMPARTEMENT [°C]				
Lower level: 1.2 m				
TR 1-2	14,3	15,8	18,0	17,7
TR 2-2	14,7	15,0	18,5	18,3
TR 3-2	15,3	16,0	18,7	18,7
TR 4-2	14,3	14,7	17,5	17,9
TW 1-2	15,7	17,3	19,8	19,1
TW 2-2	15,1	17,1	18,9	18,1
Upper level: 4.4 m				
TR 1-6	16,2	17,6	20,6	18,7
TR 2-6	16,3	17,7	20,6	18,8
TR 3-6	15,7	17,6	20,8	18,7
TR 4-6	16,4	17,7	20,8	18,8
TW 1-6	16,7	17,9	21,4	18,9
TW 2-6	16,8	18,2	21,6	19,0
TEMPERATURE ON CABLE SURFACE [°C]				
Lower level: 1.2 m, side of bundle				
TCO 1-1 (right)	15,0	16,9	18,5	17,9
TCO 3-1 (left)	15,2	17,1	18,5	18,3
Upper level: 4.4 m, side of bundle				
TCO 1-9 (right)	18,0	18,2	21,8	19,0
TCO 3-9 (left)	18,0	17,9	21,5	18,9

Table 3-2 Hall pressure and temperature values for test 1 – test 4

	Test 1	**Test 2**	**Test 3**	**Test 4**
PRESSURE IN HALL [mbar]				
Start test	1015,1	1015,6	1015,2	1015,0
End test	1014,5	1016,0	1015,6	1014,5
TEMPERATURE IN HALL [°C]				
Start test	16,1	18,0	18,0	18,5
End test	16,6	18,1	16,9	18,0

4 Exhaust duct

In Table 4-1 the mean values for the flow rate in the exhaust duct is given. The exact data during test is given in the accompanied EXCEL –file ‘BM#5-InitialCondition’. The flow rate $\dot{V}$ is given according to ISO 9705 with equation (1.1), the velocity is given with equation (1.2)

$$\dot{V} = A \cdot \overbrace{k_t \cdot \underbrace{\frac{1}{k_p} \cdot \frac{22,4}{T_{298}}}_{=0,07} \cdot \sqrt{T \cdot \Delta p}}^{\text{corrected velocity}} = A \cdot v_{corr} \qquad (1.1)$$

$$v_{corr} = k_t \cdot 0,07 \cdot sign(\Delta p)\sqrt{T \cdot |\Delta p|} \qquad (1.2)$$

$A =$ exhaust cross section area: 0,04 * π [m²]

$\Delta p =$ pressure difference bidirectional-probe [kPa]

$T =$ temperature [K]

$k_p =$ calibration constant for bi-directional probe: 1,08

$k_t =$ correction factor for velocity profile: 0,9 [-]

$v_{corr} =$ corrected velocity in the exhaust duct [m³/s]

Table 4-1 Mean values flow rate during test 1 – test 4

[m³/s]	**Test 1**	**Test 2**	**Test 3**	**Test 4**
Mean flow rate	2,72	2,81	2,64	2,76

INSTITUT FÜR BAUSTOFFE, MASSIVBAU UND BRANDSCHUTZ

MATERIALPRÜFANSTALT FÜR DAS BAUWESEN - MPA BRAUNSCHWEIG

TU BRAUNSCHWEIG

APPENDIX D

"Plots Test 1 - Test 4"

"Report of Experimental results of International Benchmarking and Validation Exercise # 5 – Flame Spread In Cable Tray Fires (Initial Conditions for test 1 – test 4)"

to the

FINAL REPORT

"Performing of Recent Real Scale Cable Fire Experiments and Presentation of the Results in the Frame of the International Collaborative Fire Modeling Project ICFMP"

Contract SR 2449
Sub-contract UA-2298

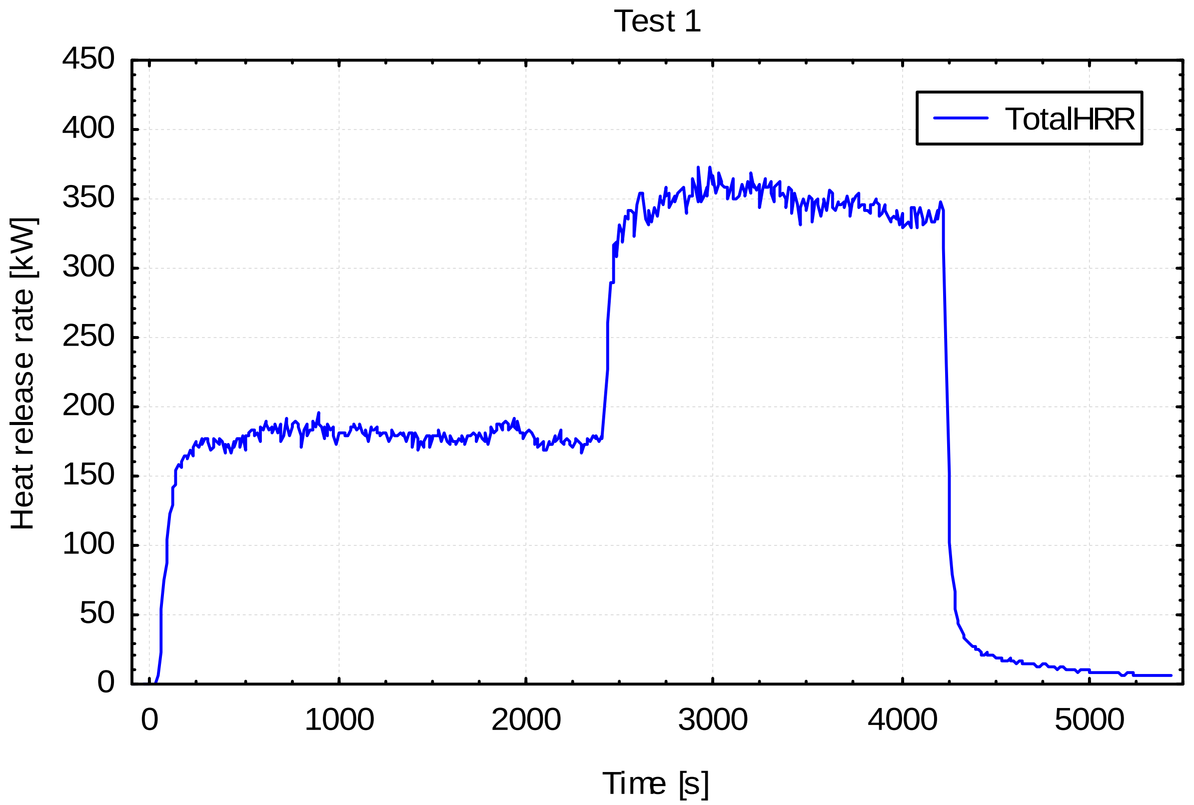
Prof. Dr.-Ing. Dietmar Hosser
Dipl.-Phys. Olaf Riese
Cand.-Ing. Mark Klingenberg

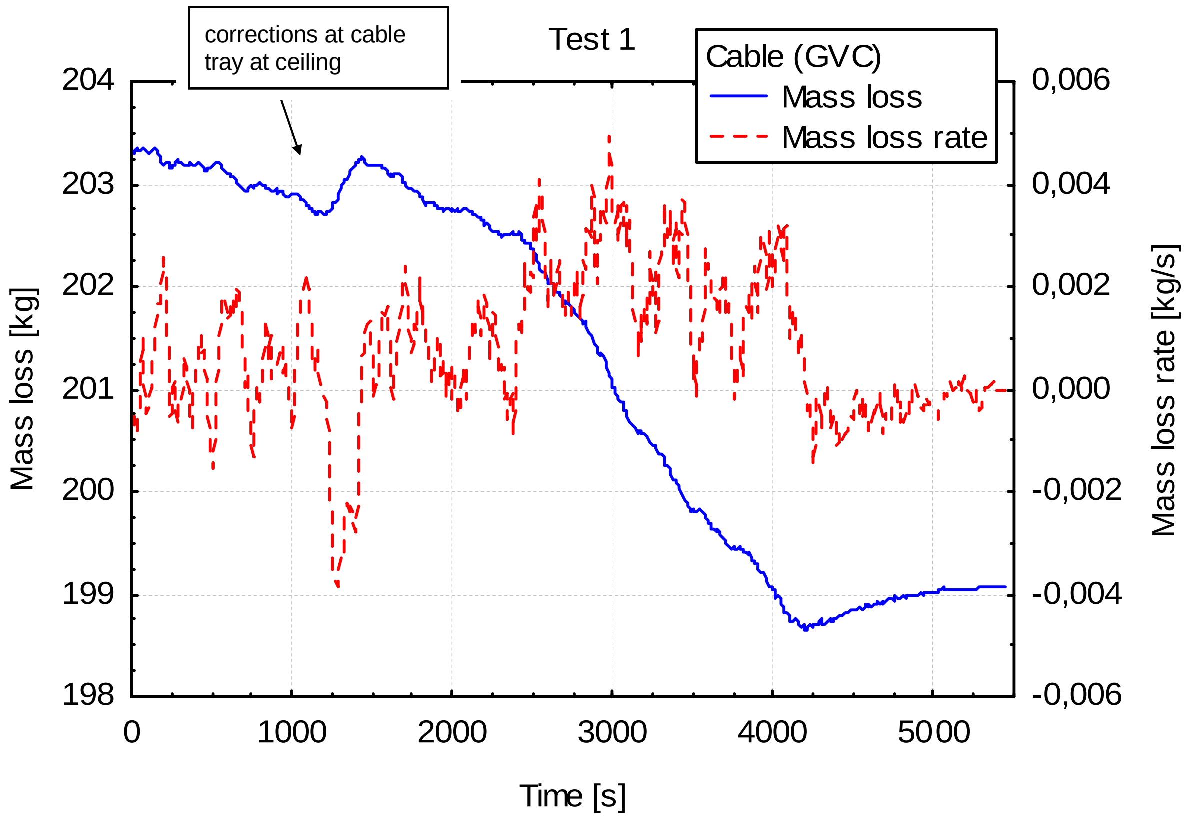
June 2004

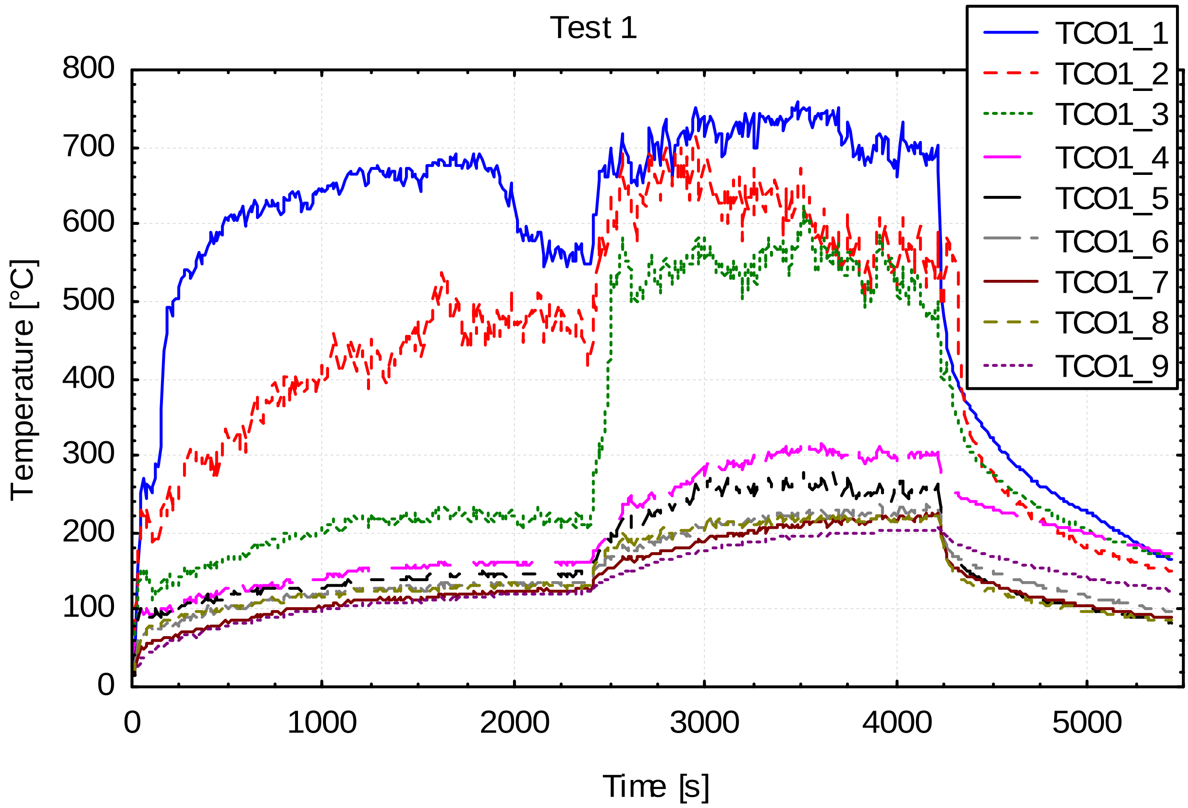
"This report represents the expert opinion and expertise of the contractor (iBMB). It is not necessary that this is in accordance with the expert opinion of the contracting party (Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH."

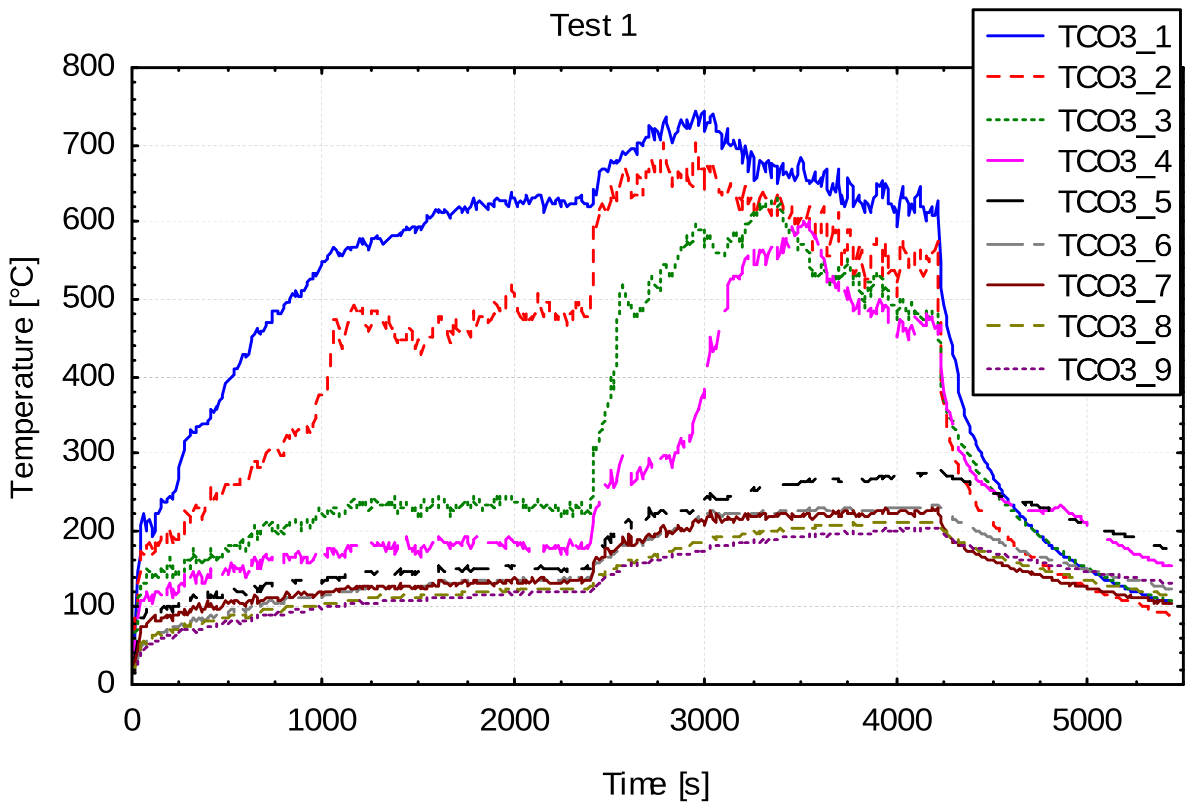
Beethovenstraße 52 · D-38106 Braunschweig · Tel. (0531) 391-5431 · Fax (0531) 391-5900 · E-Mail ibmb@tu-bs.de · Internet http://www.ibmb.tu-bs.de

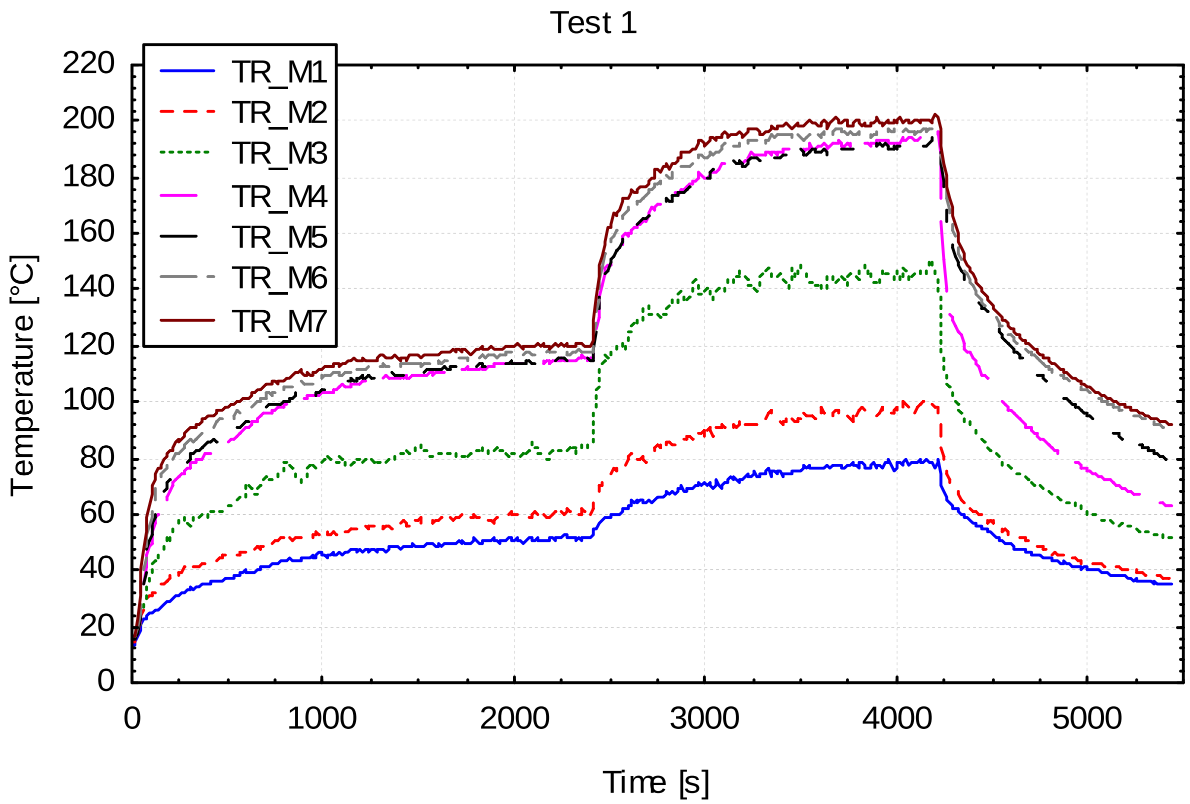
Appendix D-1 (Plots Test 1)



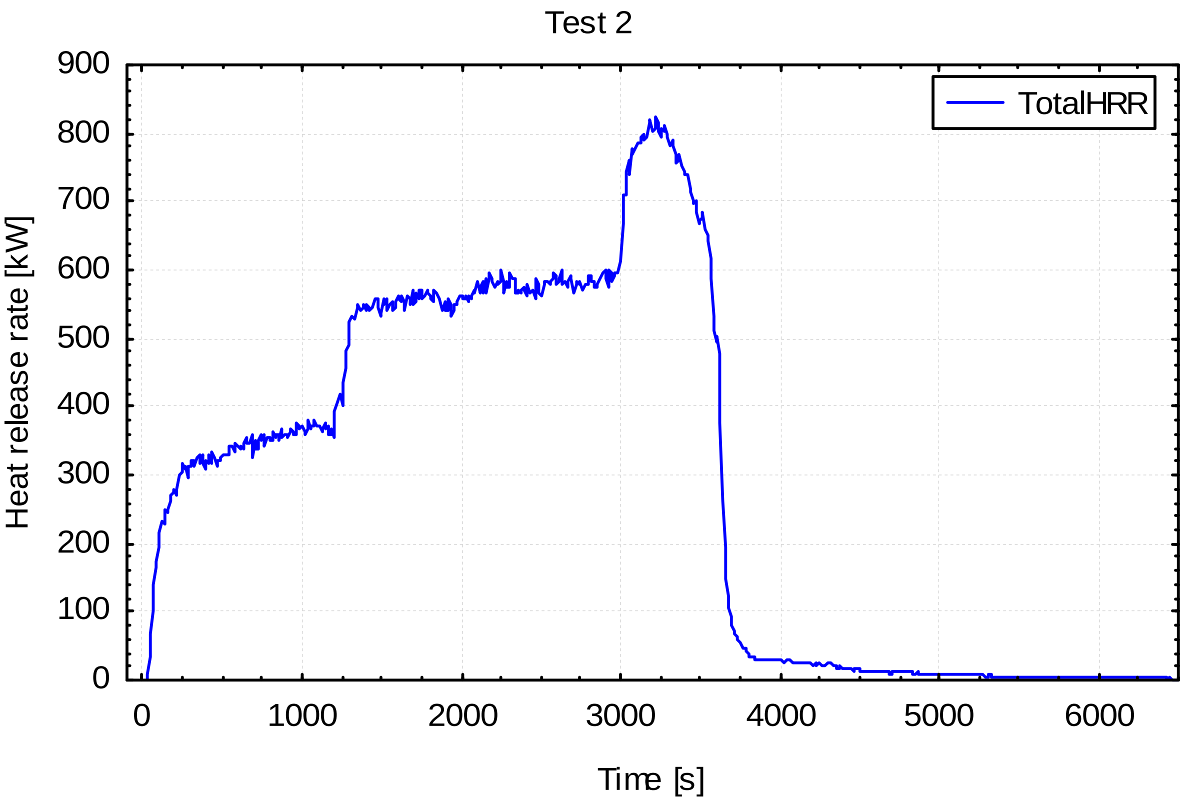


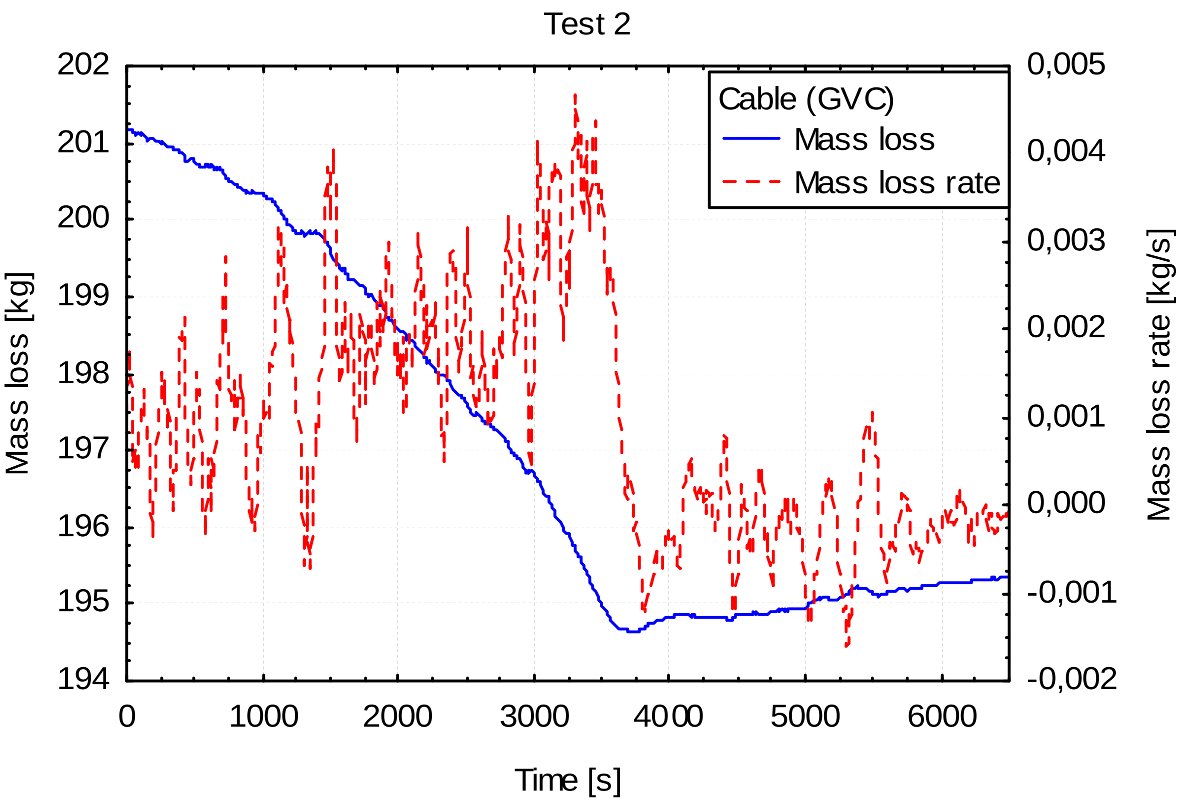

Test 1
Temperature [°C]
Time [s]
TCO1_1
TCO1_2
TCO1_3
TCO1_4
TCO1_5
TCO1_6
TCO1_7
TCO1_8
TCO1_9
0
100
200
300
400
500
600
700
800
1000
2000
3000
4000
5000

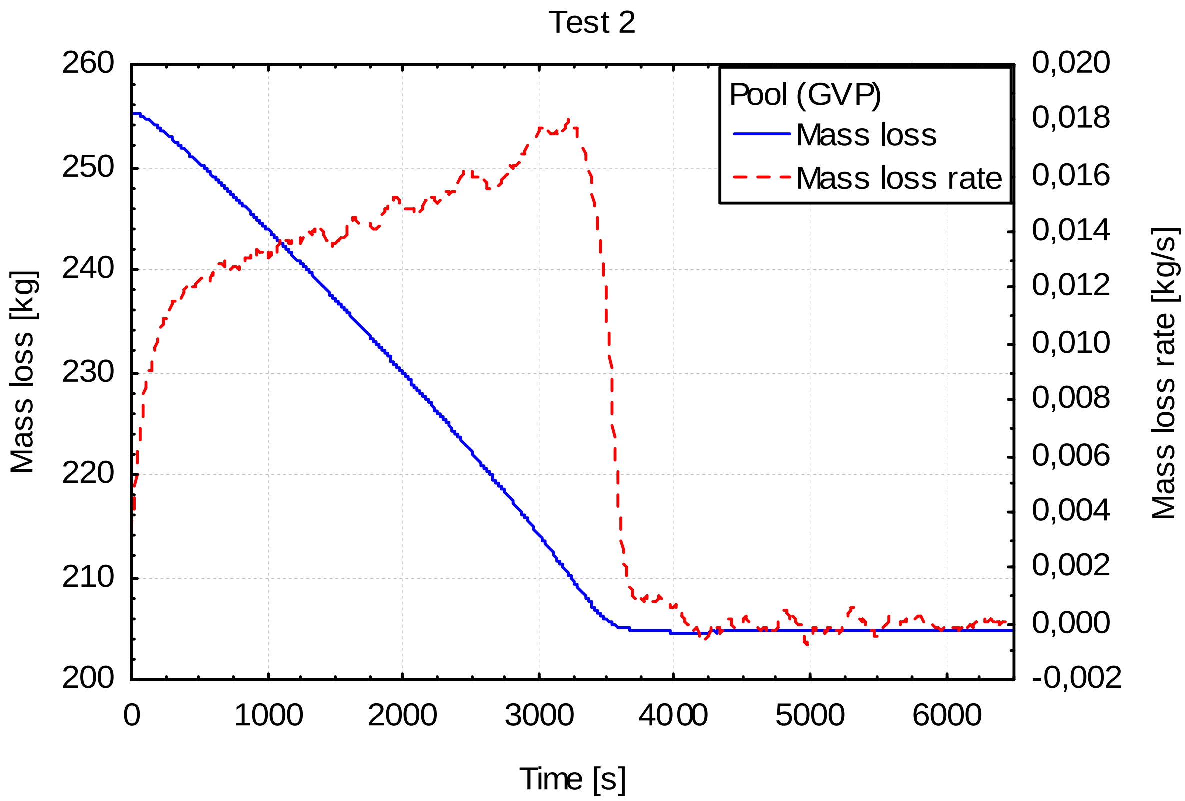

Test 1
Temperature [°C]
Time [s]
TCO3_1
TCO3_2
TCO3_3
TCO3_4
TCO3_5
TCO3_6
TCO3_7
TCO3_8
TCO3_9
0
100
200
300
400
500
600
700
800
1000
2000
3000
4000
5000

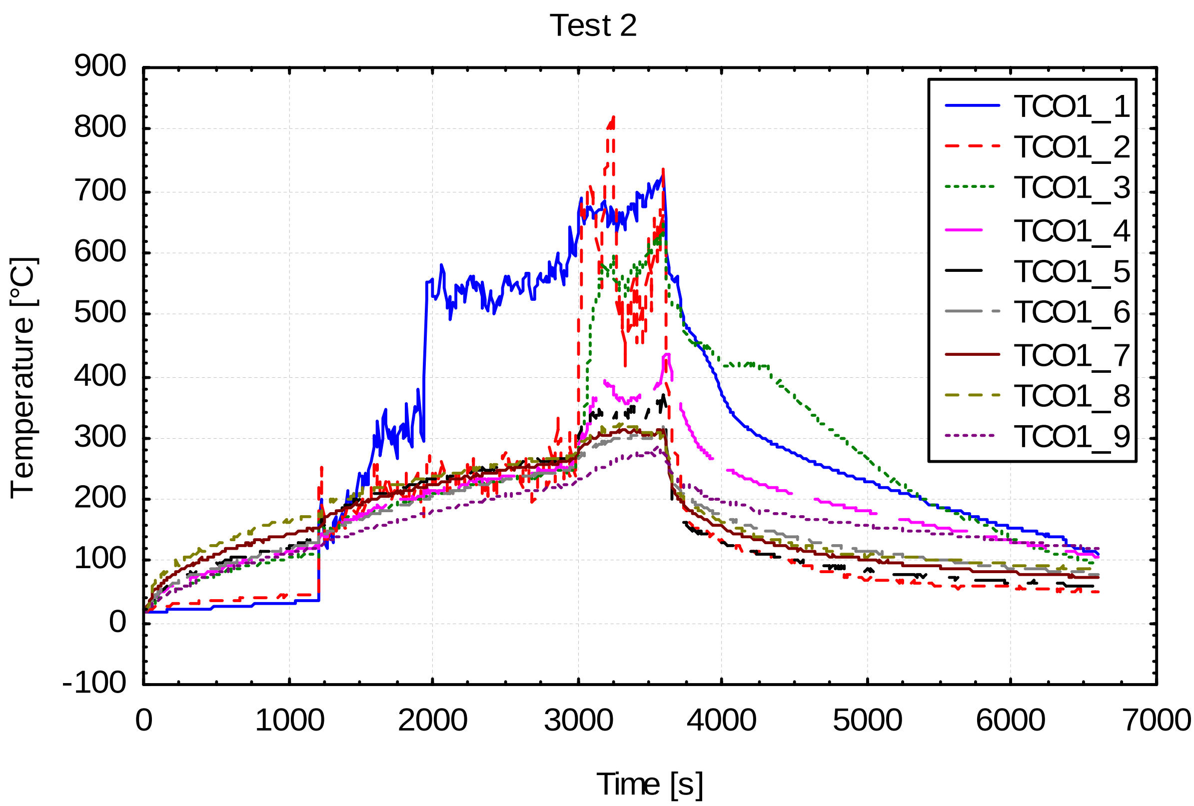

Test 1
TR_M1
TR_M2
TR_M3
TR_M4
TR_M5
TR_M6
TR_M7
Temperature [°C]
Time [s]
0
20
40
60
80
100
120
140
160
180
200
220
0
1000
2000
3000
4000
5000

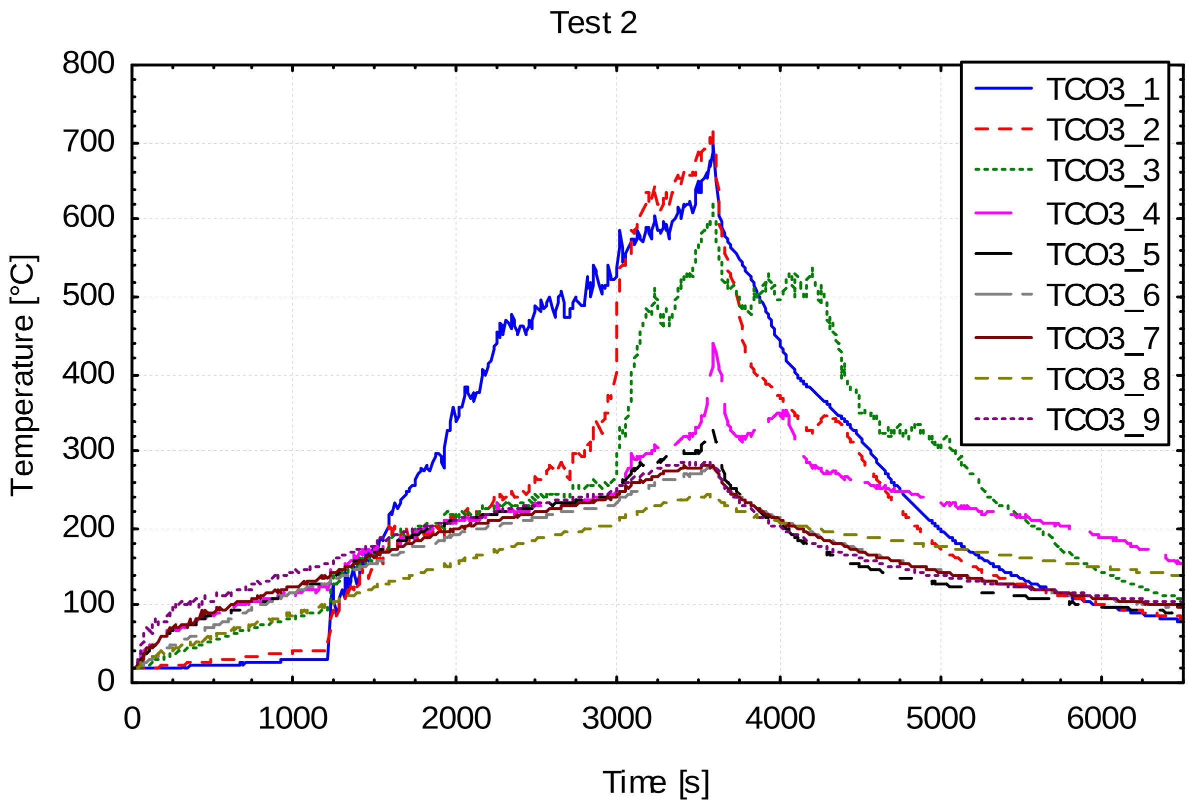
Appendix D-2 (Plots Test 2)

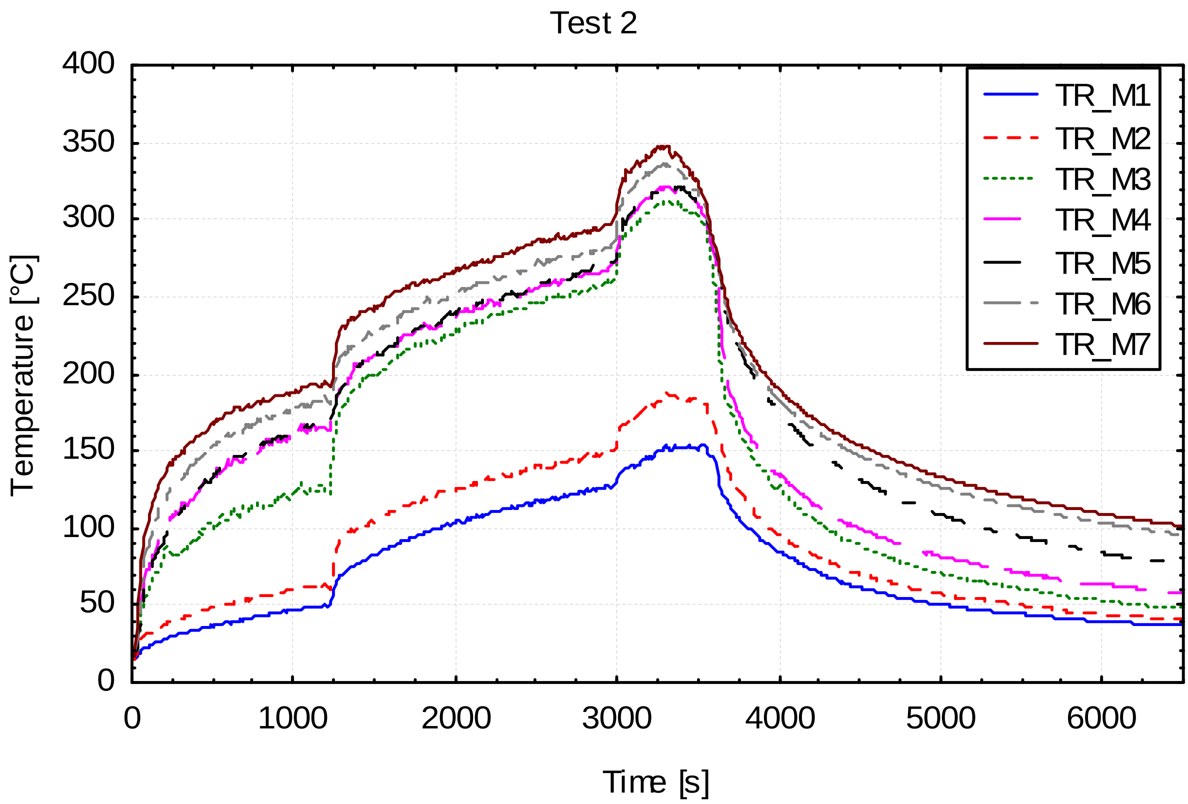




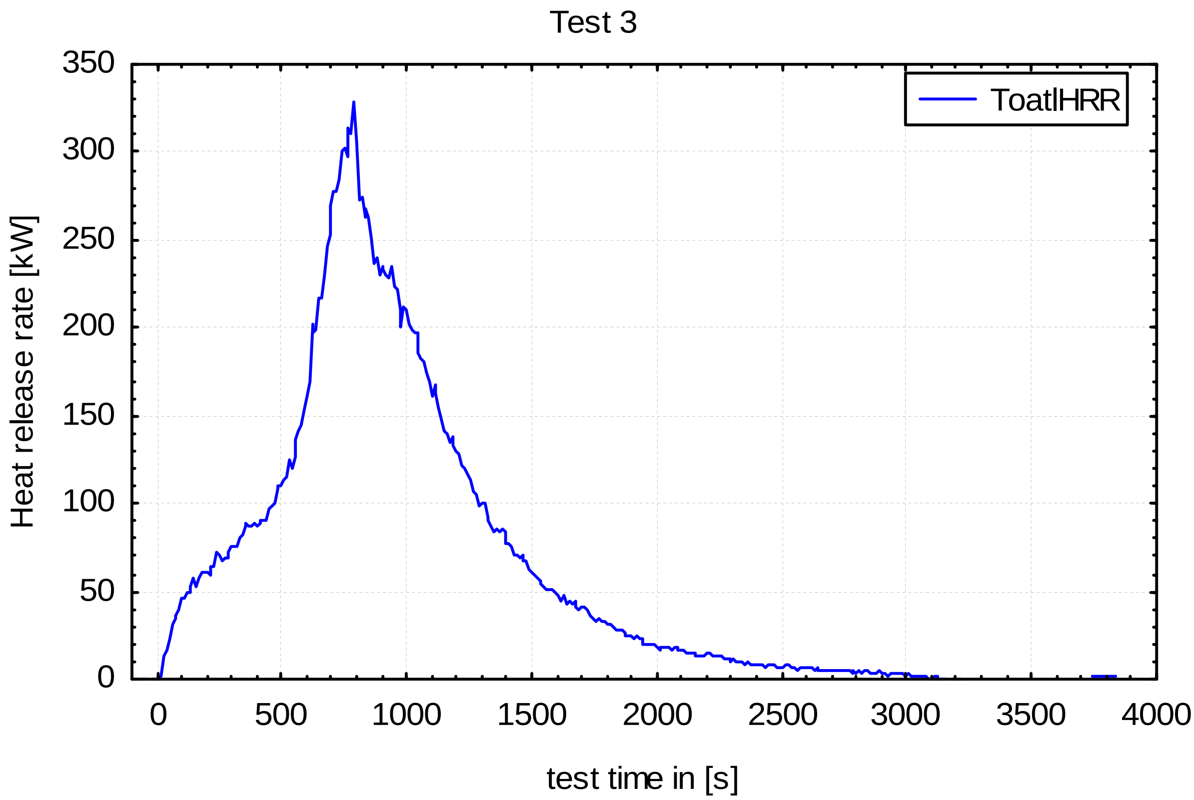

Test 2
Pool (GVP)
Mass loss
Mass loss rate
Mass loss [kg]
Mass loss rate [kg/s]
Time [s]
260
250
240
230
220
210
200
0,020
0,018
0,016
0,014
0,012
0,010
0,008
0,006
0,004
0,002
0,000
-0,002
0
1000
2000
3000
4000
5000
6000

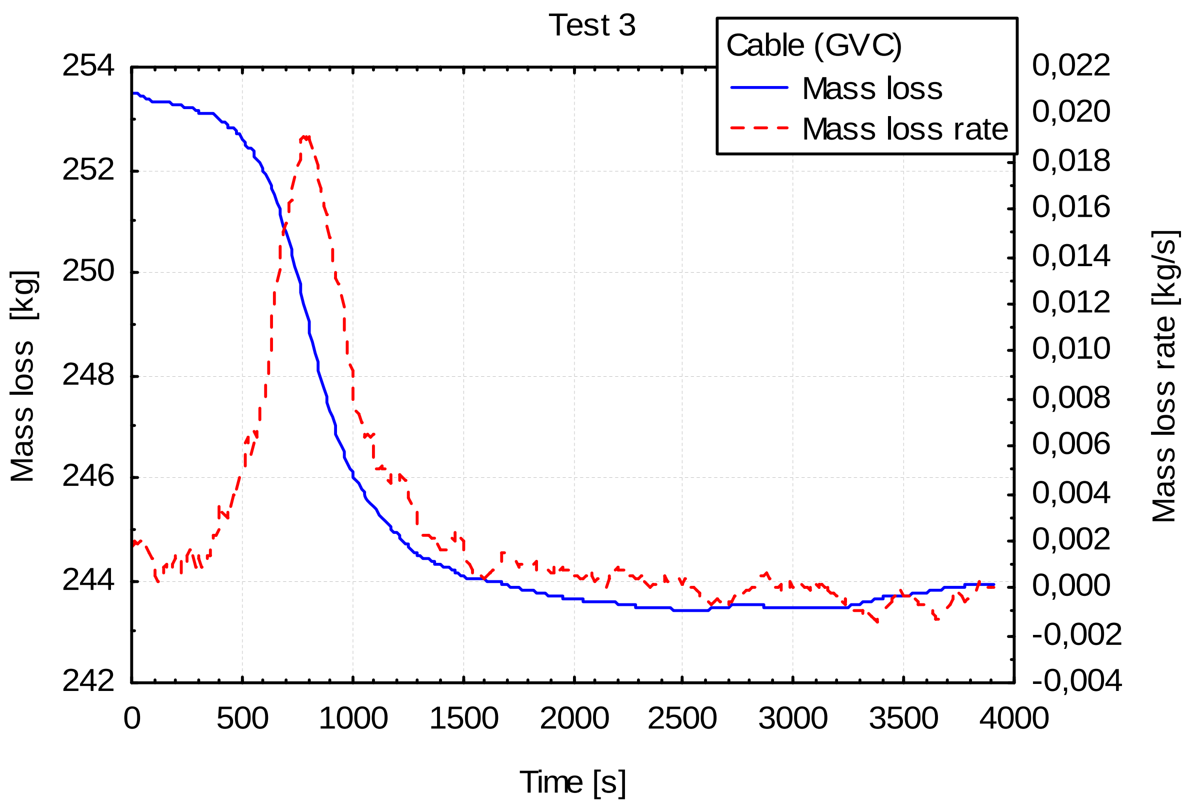

Test 2
TCO1_1
TCO1_2
TCO1_3
TCO1_4
TCO1_5
TCO1_6
TCO1_7
TCO1_8
TCO1_9
Temperature [°C]
Time [s]
900
800
700
600
500
400
300
200
100
0
-100
0
1000
2000
3000
4000
5000
6000
7000

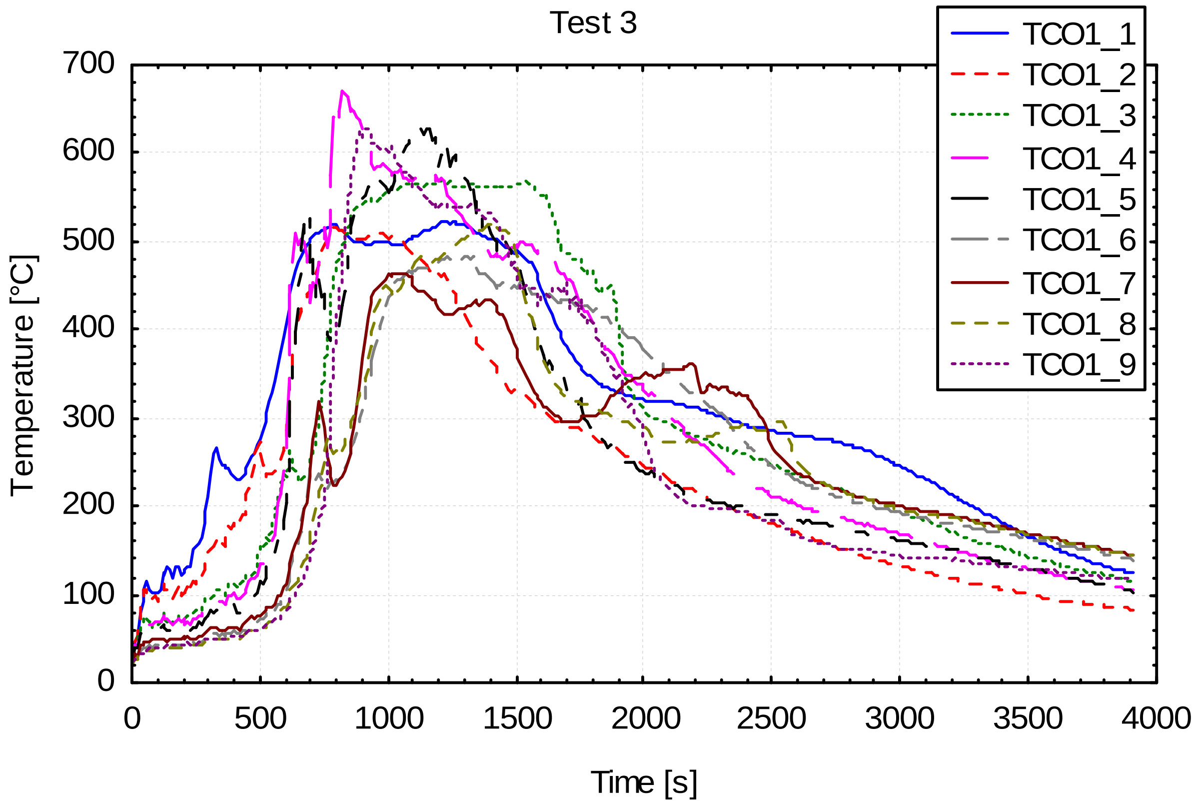

Test 2
Temperature [°C]
Time [s]
0
100
200
300
400
500
600
700
800
1000
2000
3000
4000
5000
6000
TCO3_1
TCO3_2
TCO3_3
TCO3_4
TCO3_5
TCO3_6
TCO3_7
TCO3_8
TCO3_9

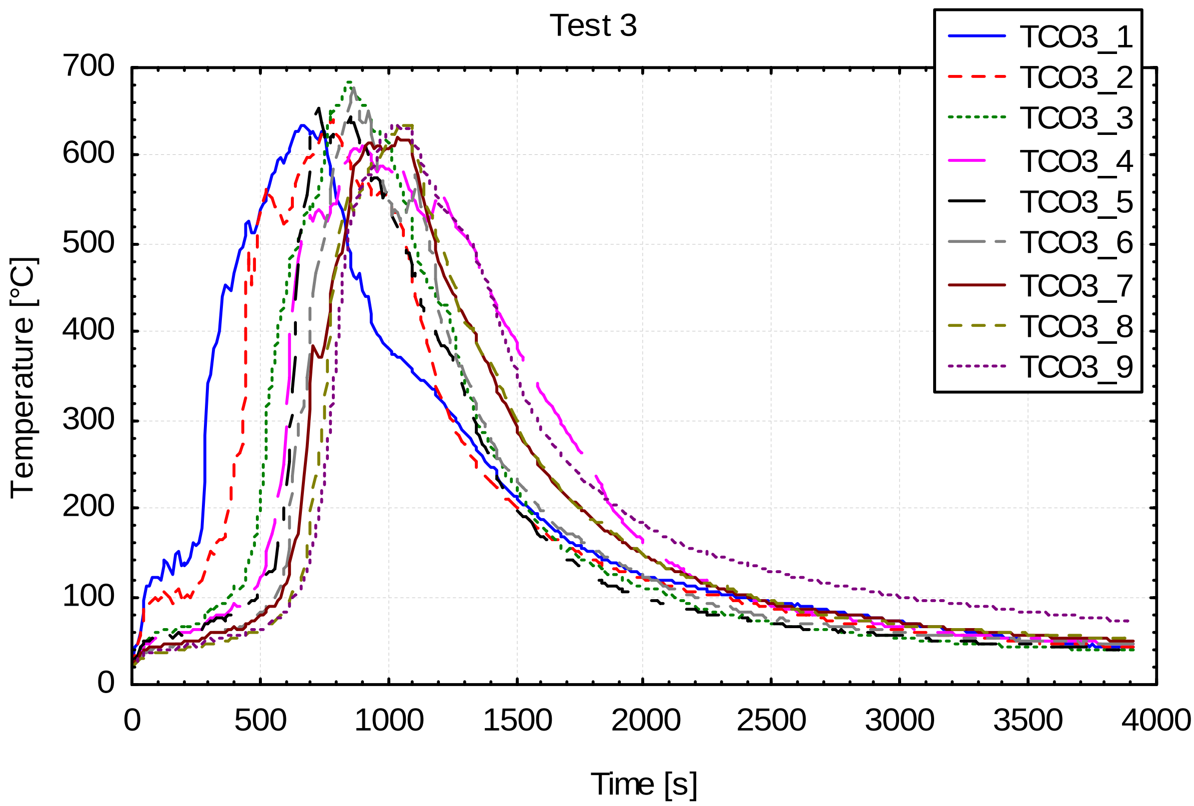

Test 2
Temperature [°C]
Time [s]
0
50
100
150
200
250
300
350
400
1000
2000
3000
4000
5000
6000
TR_M1
TR_M2
TR_M3
TR_M4
TR_M5
TR_M6
TR_M7

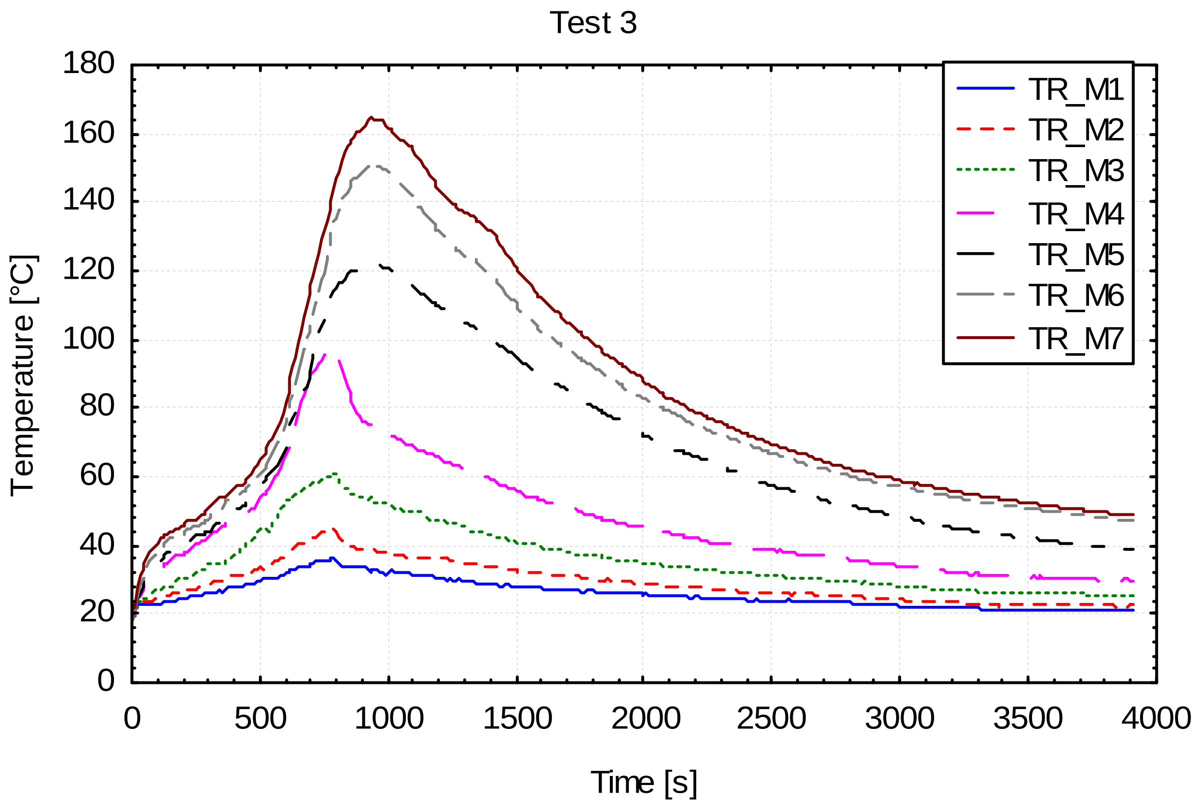
Appendix D-3 (Plots Test 3)



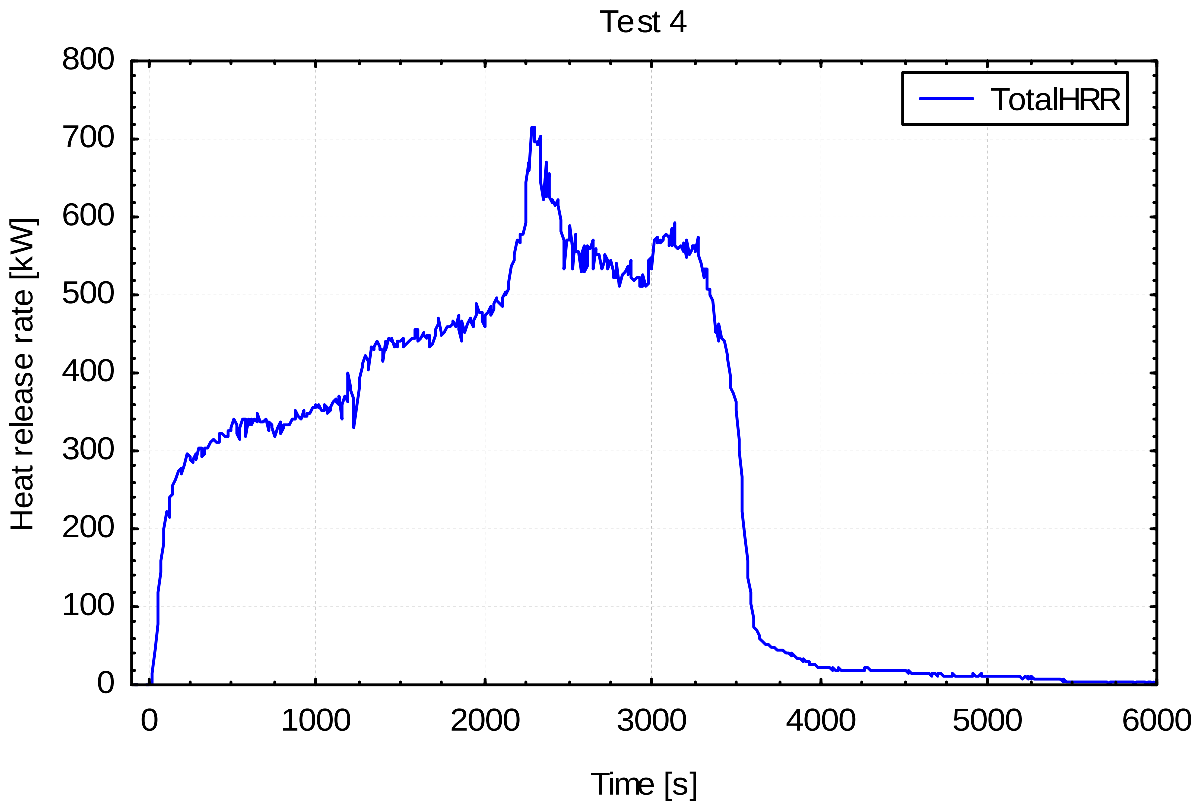


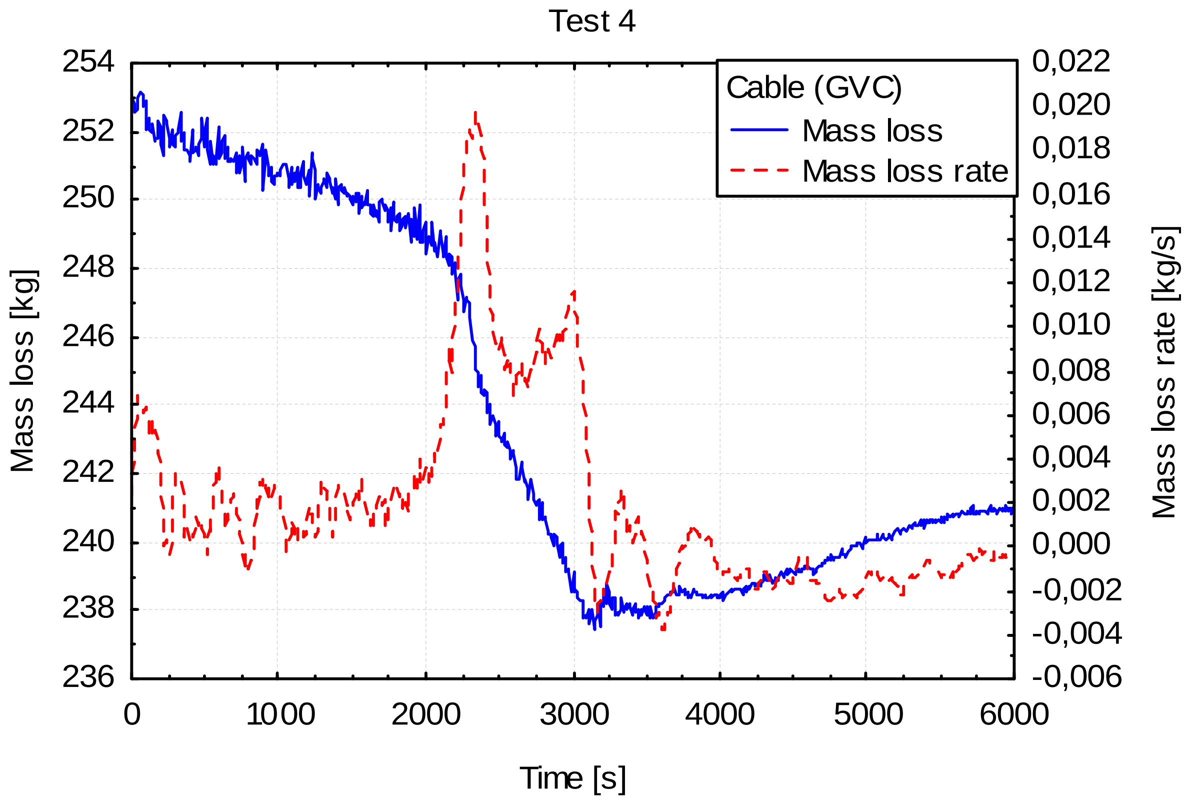

Test 3
Temperature [°C]
Time [s]
0
100
200
300
400
500
600
700
0
500
1000
1500
2000
2500
3000
3500
4000
TCO1_1
TCO1_2
TCO1_3
TCO1_4
TCO1_5
TCO1_6
TCO1_7
TCO1_8
TCO1_9

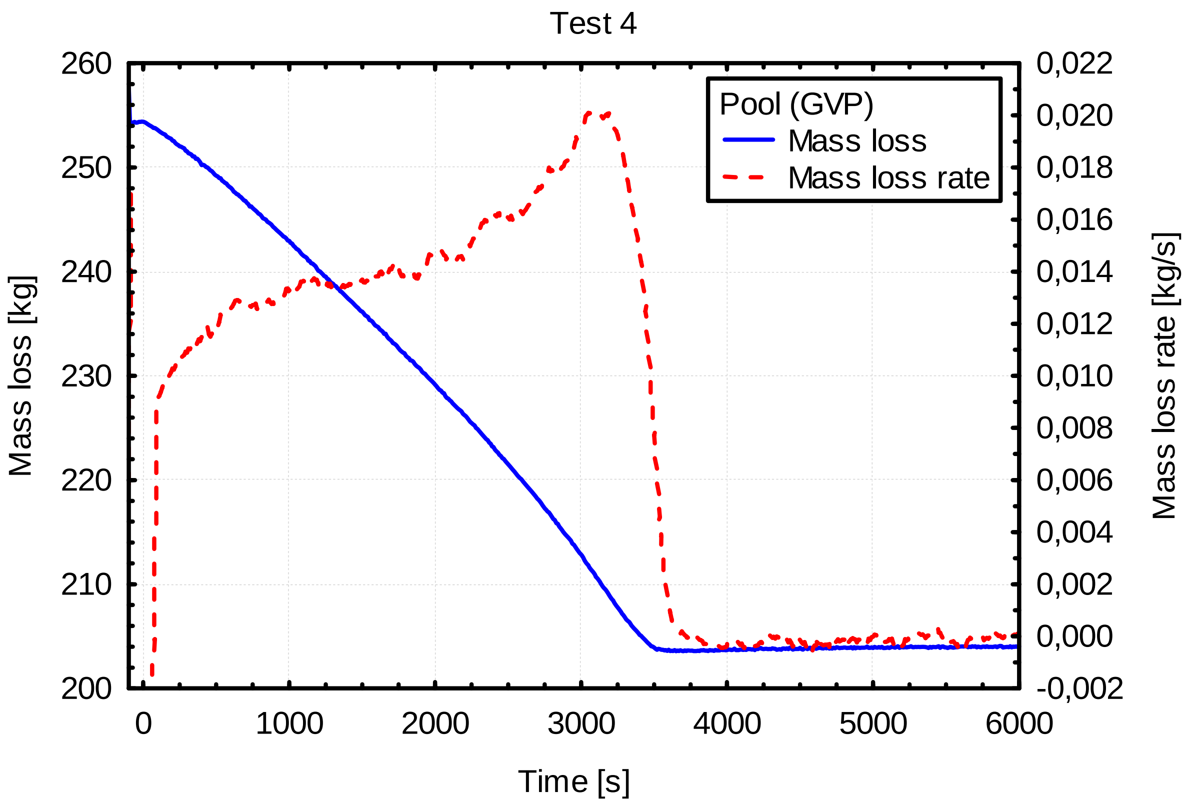

Test 3
Temperature [°C]
Time [s]
0
100
200
300
400
500
600
700
0
500
1000
1500
2000
2500
3000
3500
4000
TCO3_1
TCO3_2
TCO3_3
TCO3_4
TCO3_5
TCO3_6
TCO3_7
TCO3_8
TCO3_9

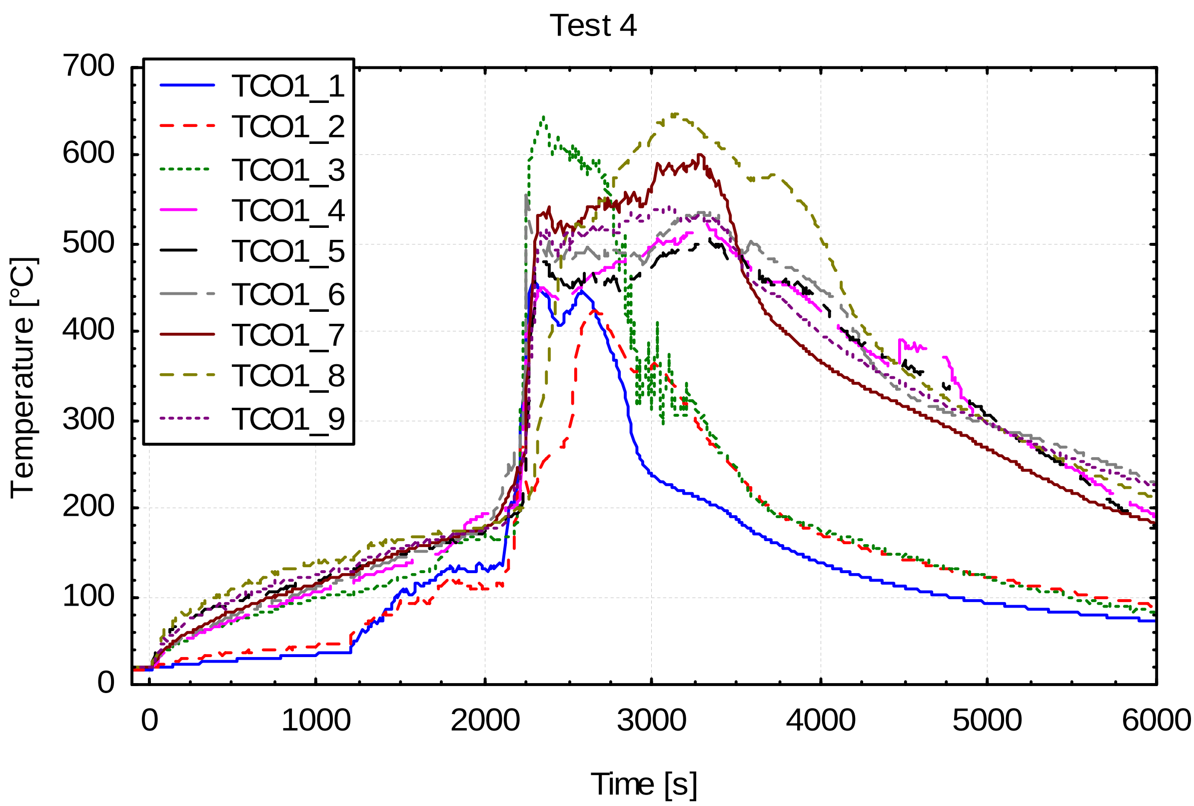

Test 3
Temperature [°C]
Time [s]
0
20
40
60
80
100
120
140
160
180
0
500
1000
1500
2000
2500
3000
3500
4000
TR_M1
TR_M2
TR_M3
TR_M4
TR_M5
TR_M6
TR_M7

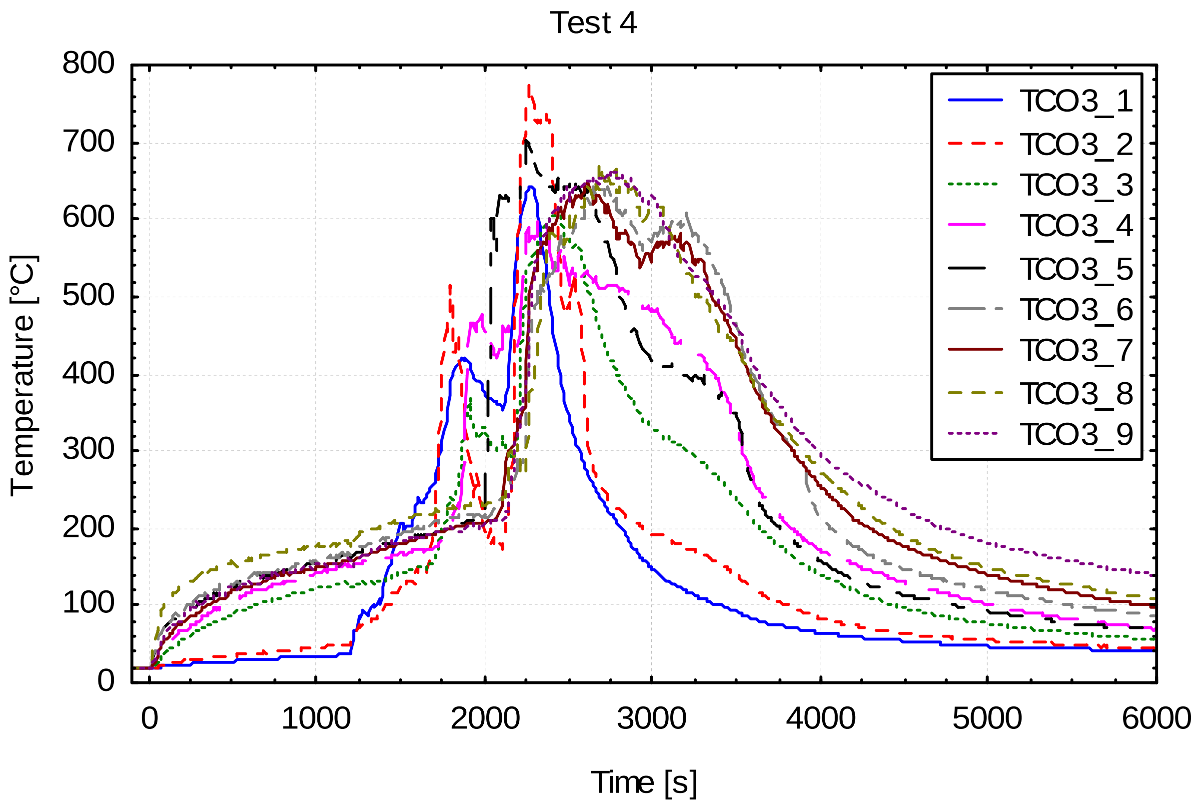
Appendix D-4 (Plots Test 4)

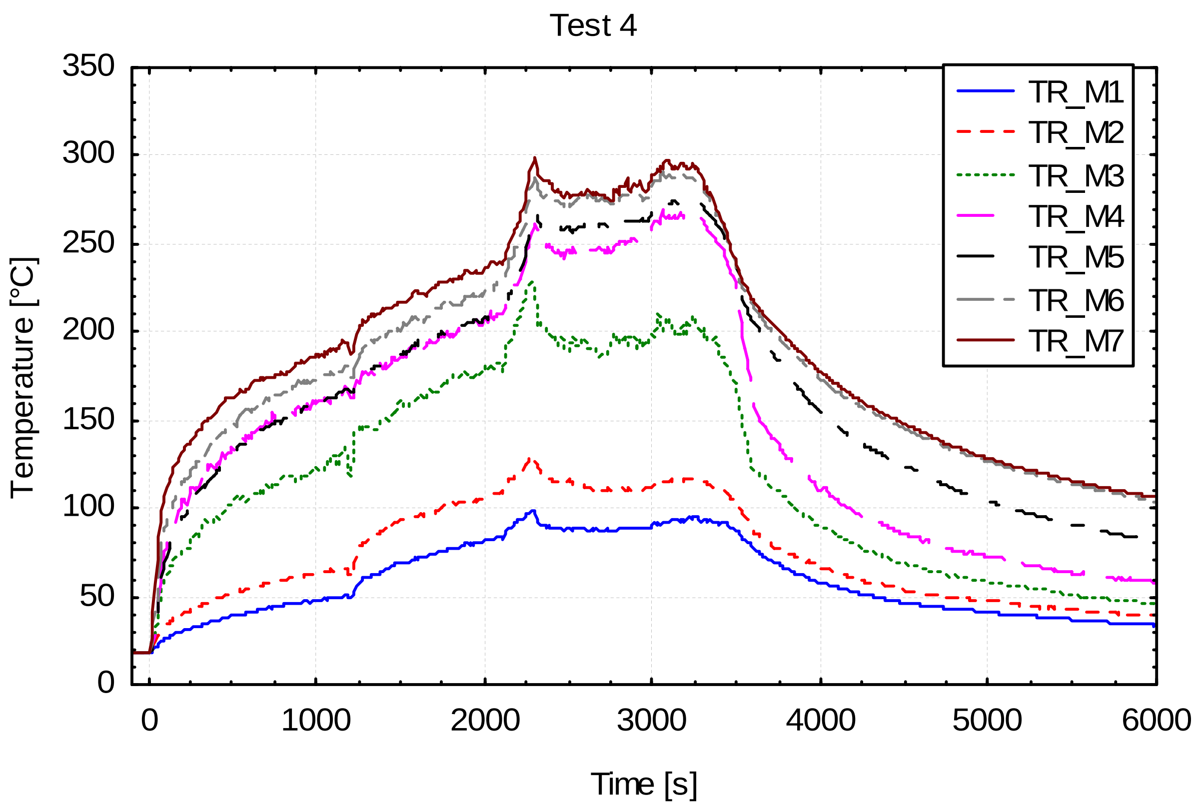





Test 4
Pool (GVP)
Mass loss
Mass loss rate
260
250
240
230
220
210
200
0,022
0,020
0,018
0,016
0,014
0,012
0,010
0,008
0,006
0,004
0,002
0,000
-0,002
0
1000
2000
3000
4000
5000
6000
Mass loss [kg]
Mass loss rate [kg/s]
Time [s]


Test 4
TCO1_1
TCO1_2
TCO1_3
TCO1_4
TCO1_5
TCO1_6
TCO1_7
TCO1_8
TCO1_9
700
600
500
400
300
200
100
0
0
1000
2000
3000
4000
5000
6000
Temperature [°C]
Time [s]


Test 4
Temperature [°C]
Time [s]
0
100
200
300
400
500
600
700
800
0
1000
2000
3000
4000
5000
6000
TCO3_1
TCO3_2
TCO3_3
TCO3_4
TCO3_5
TCO3_6
TCO3_7
TCO3_8
TCO3_9


Test 4
Temperature [°C]
Time [s]
0
50
100
150
200
250
300
350
0
1000
2000
3000
4000
5000
6000
TR_M1
TR_M2
TR_M3
TR_M4
TR_M5
TR_M6
TR_M7

INSTITUT FÜR BAUSTOFFE, MASSIVBAU UND BRANDSCHUTZ

MATERIALPRÜFANSTALT FÜR DAS BAUWESEN - MPA BRAUNSCHWEIG

TU BRAUNSCHWEIG

APPENDIX E

”Functional Failure Test 1 - Test 4”

“Report of Experimental results of International Benchmarking and Validation Exercise # 5 – Flame Spread In Cable Tray Fires (Initial Conditions for test 1 – test 4)”

to the

FINAL REPORT

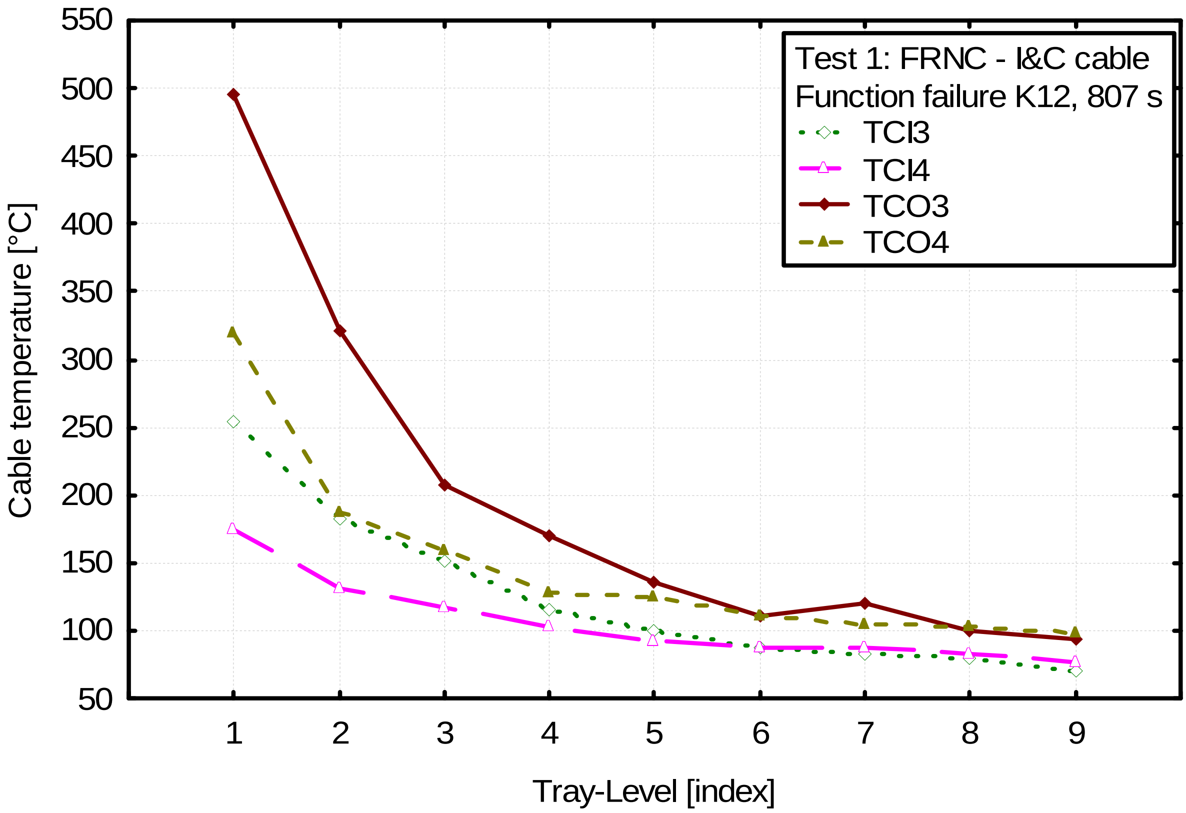
“Performing of Recent Real Scale Cable Fire Experiments and Presentation of the Results in the Frame of the International Collaborative Fire Modeling Project ICFMP”

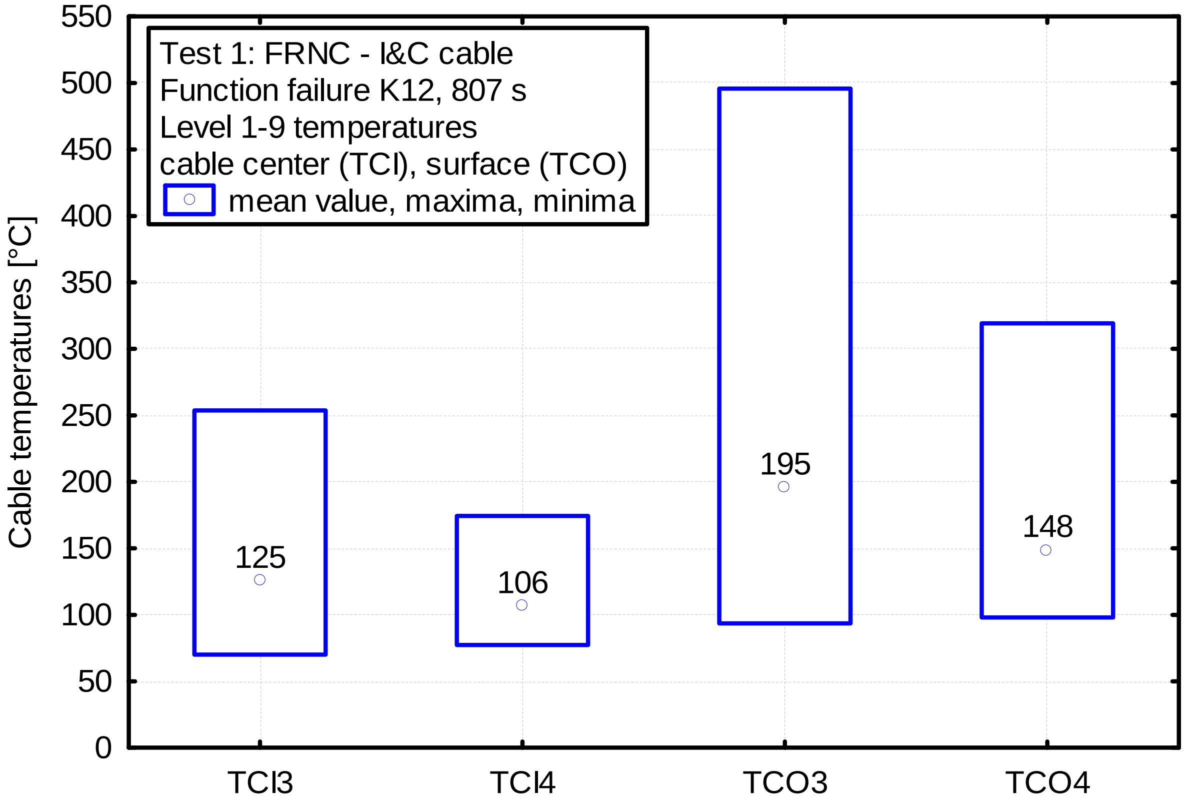
Contract SR 2449
Sub-contract UA-2298

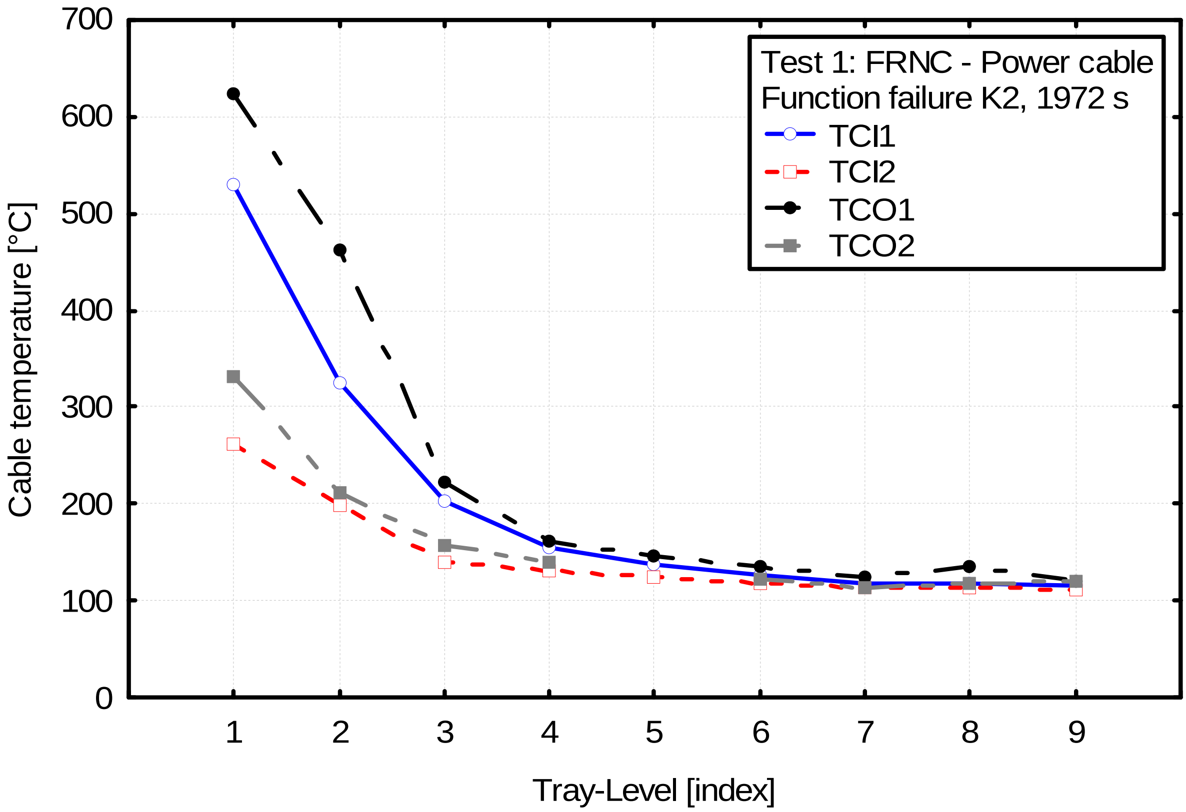
Prof. Dr.-Ing. Dietmar Hosser
Dipl.-Phys. Olaf Riese
Cand.-Ing. Mark Klingenberg

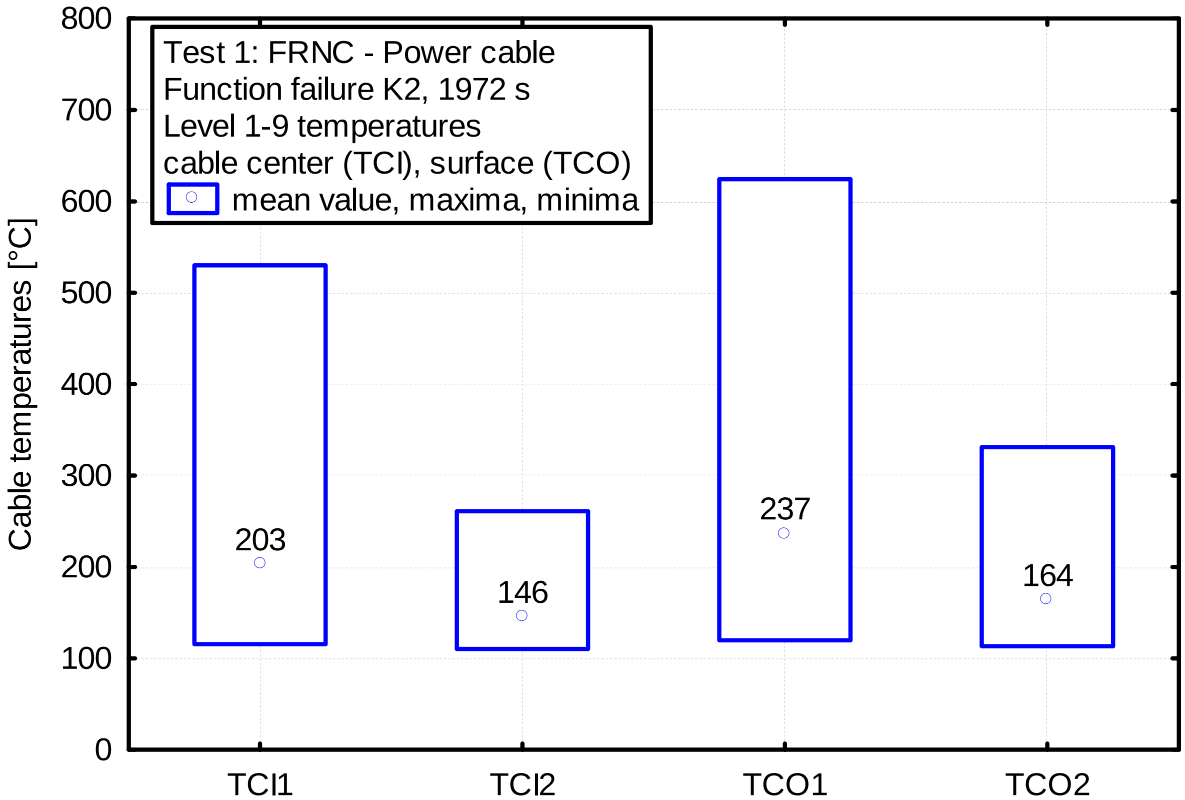
June 2004

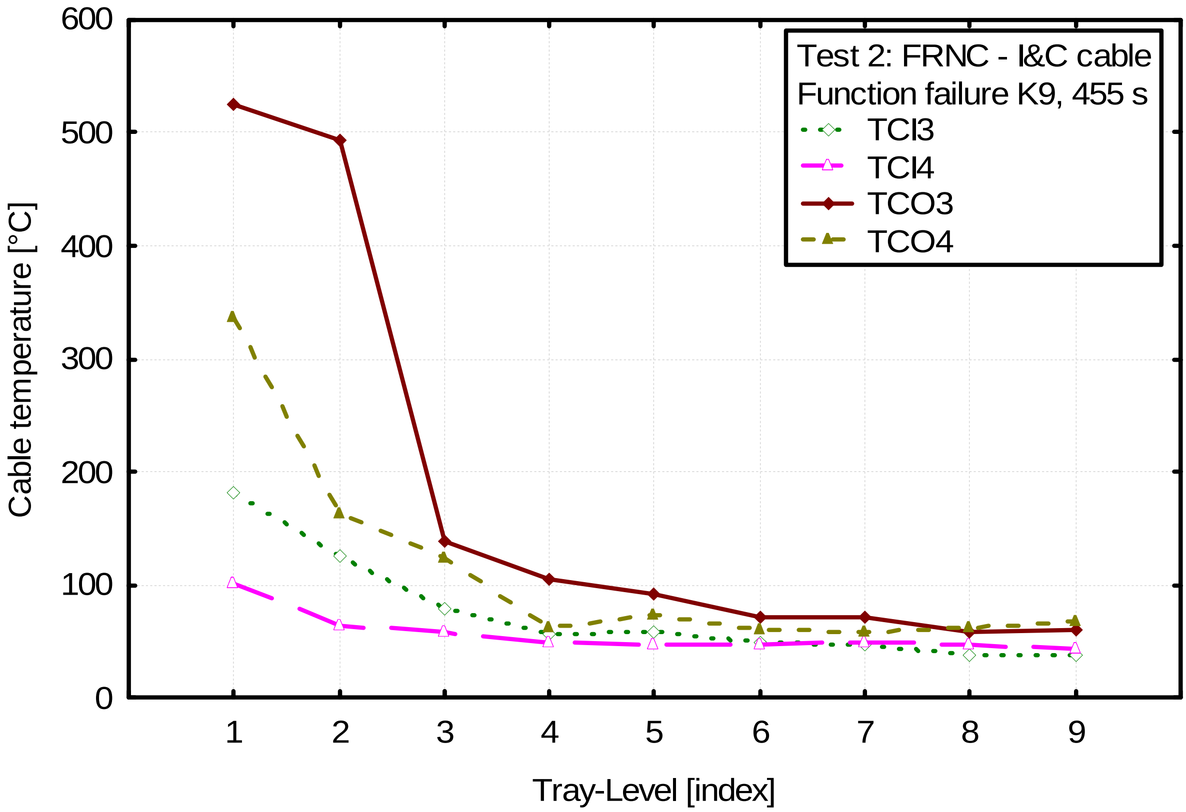
Beethovenstraße 52 · D-38106 Braunschweig · Tel. (0531) 391-5431 · Fax (0531) 391-4573 · E-Mail ibmb@tu-bs.de · Internet http://www.ibmb.tu-bs.de

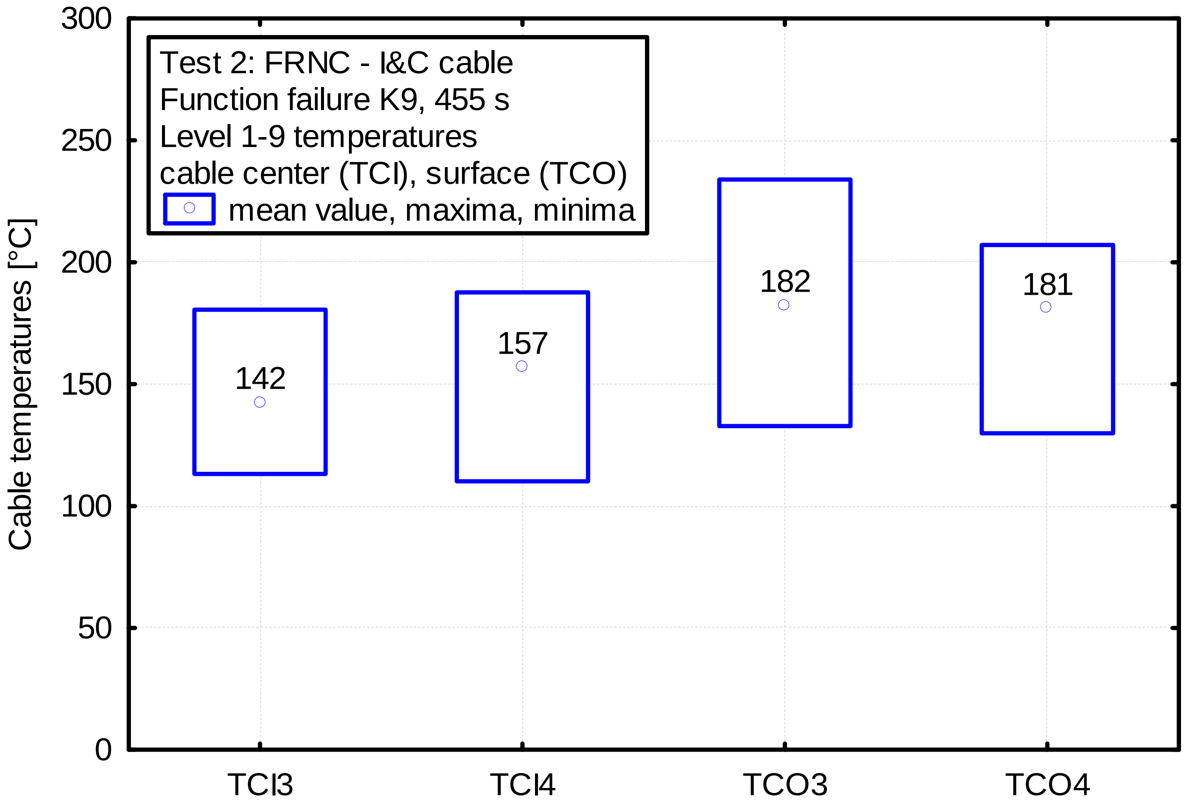

Test 1: FRNC - I&C cable
Function failure K12, 807 s
TCI3
TCI4
TCO3
TCO4
Cable temperature [°C]
Tray-Level [index]
550
500
450
400
350
300
250
200
150
100
50
1
2
3
4
5
6
7
8
9

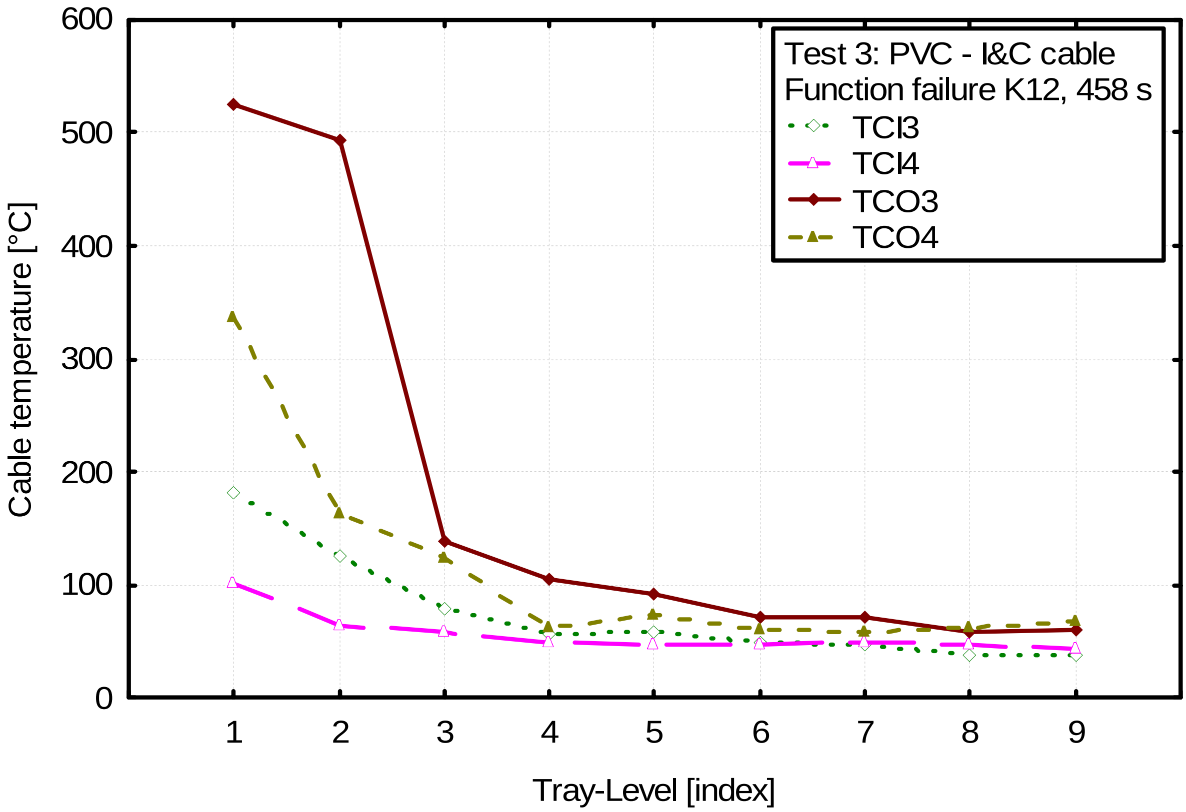

Test 1: FRNC - I&C cable
Function failure K12, 807 s
Level 1-9 temperatures
cable center (TCI), surface (TCO)
mean value, maxima, minima
Cable temperatures [°C]
125
106
195
148
TCI3
TCI4
TCO3
TCO4

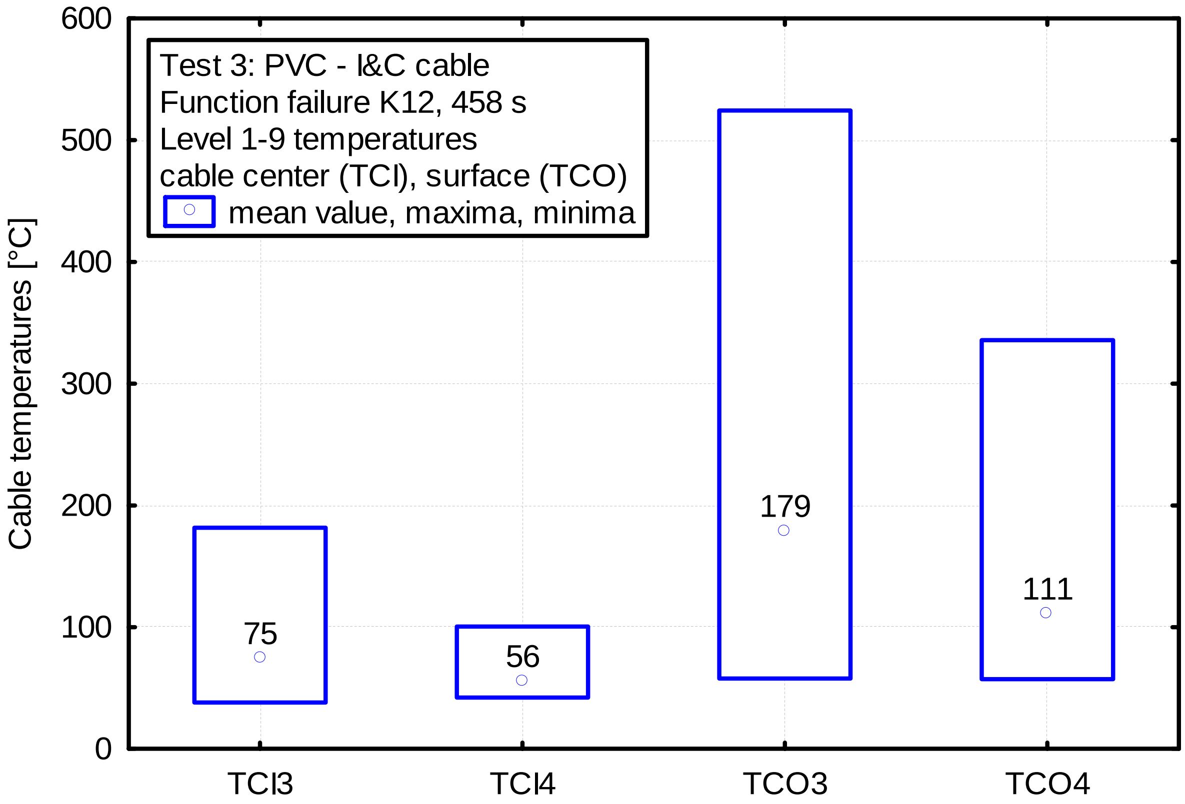

Test 1: FRNC - Power cable
Function failure K2, 1972 s
TCI1
TCI2
TCO1
TCO2
Cable temperature [°C]
Tray-Level [index]
0
100
200
300
400
500
600
700
1
2
3
4
5
6
7
8
9

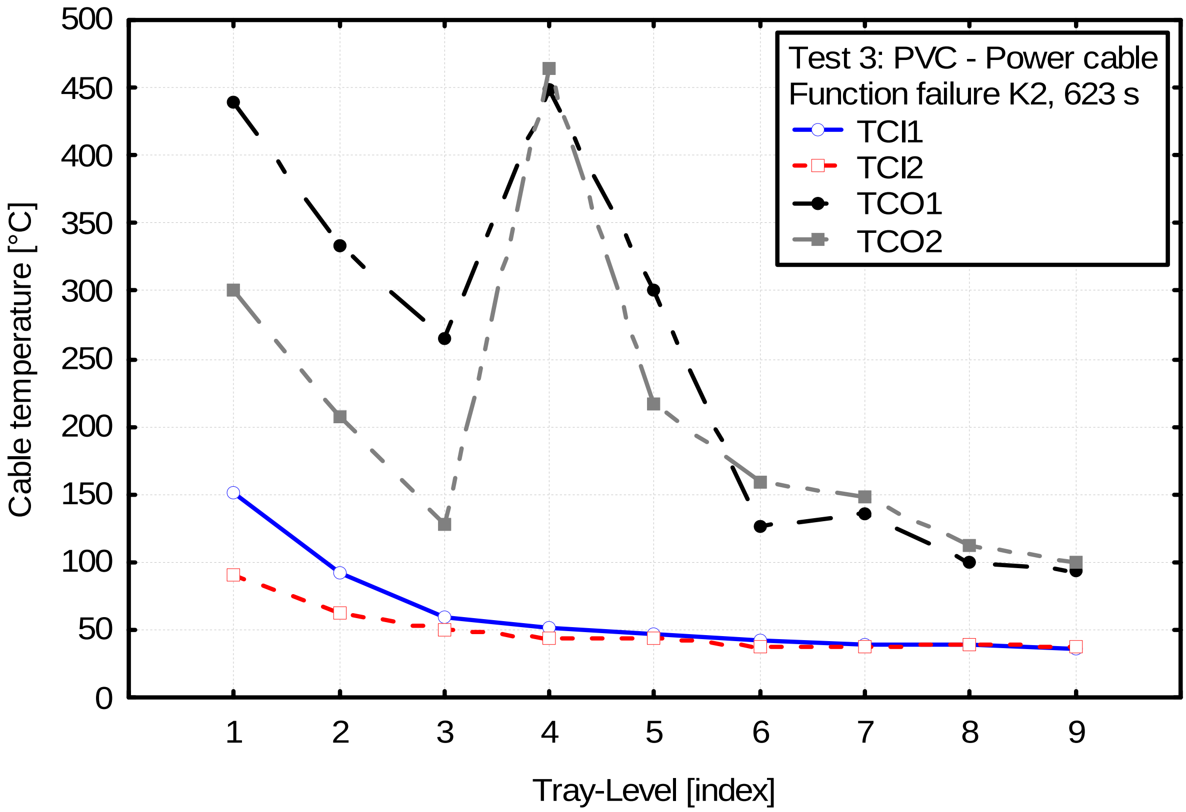

Test 1: FRNC - Power cable
Function failure K2, 1972 s
Level 1-9 temperatures
cable center (TCI), surface (TCO)
mean value, maxima, minima
Cable temperatures [°C]
0
100
200
300
400
500
600
700
800
203
146
237
164
TCI1
TCI2
TCO1
TCO2

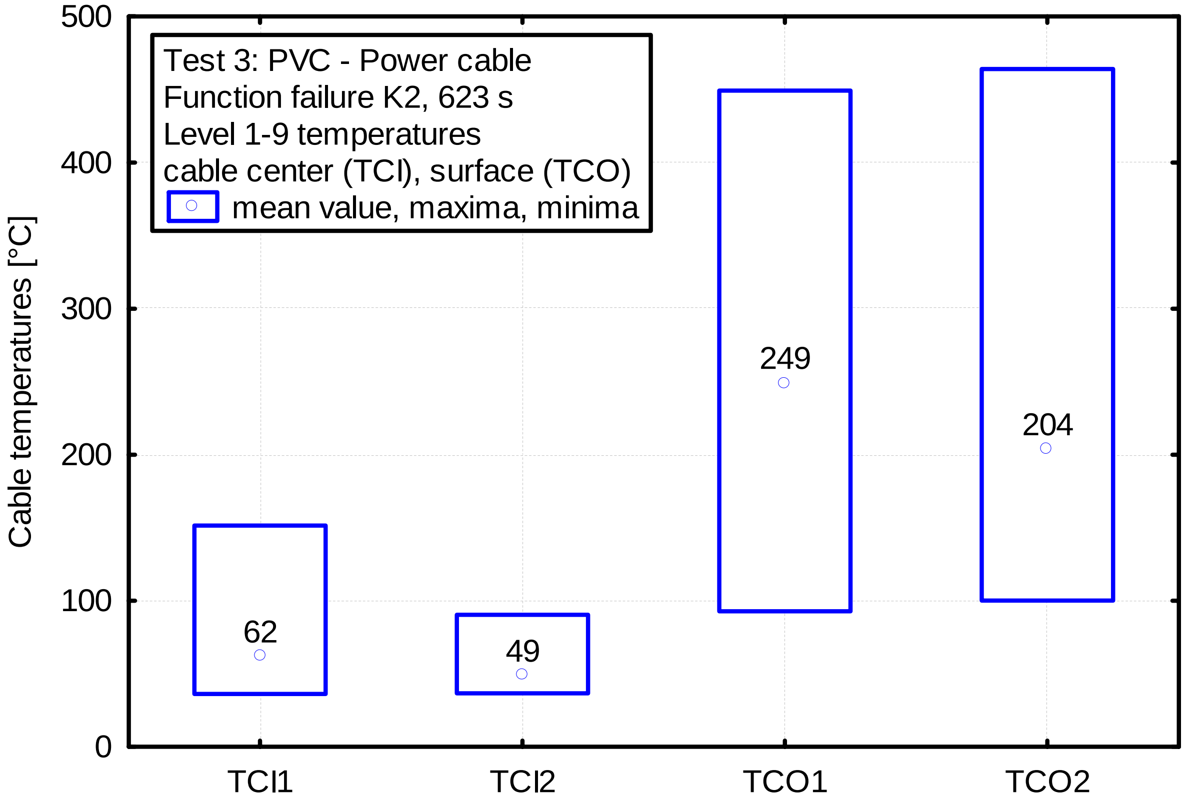

Test 2: FRNC - I&C cable
Function failure K9, 455 s
TCI3
TCI4
TCO3
TCO4
Cable temperature [°C]
Tray-Level [index]
0
100
200
300
400
500
600
1
2
3
4
5
6
7
8
9

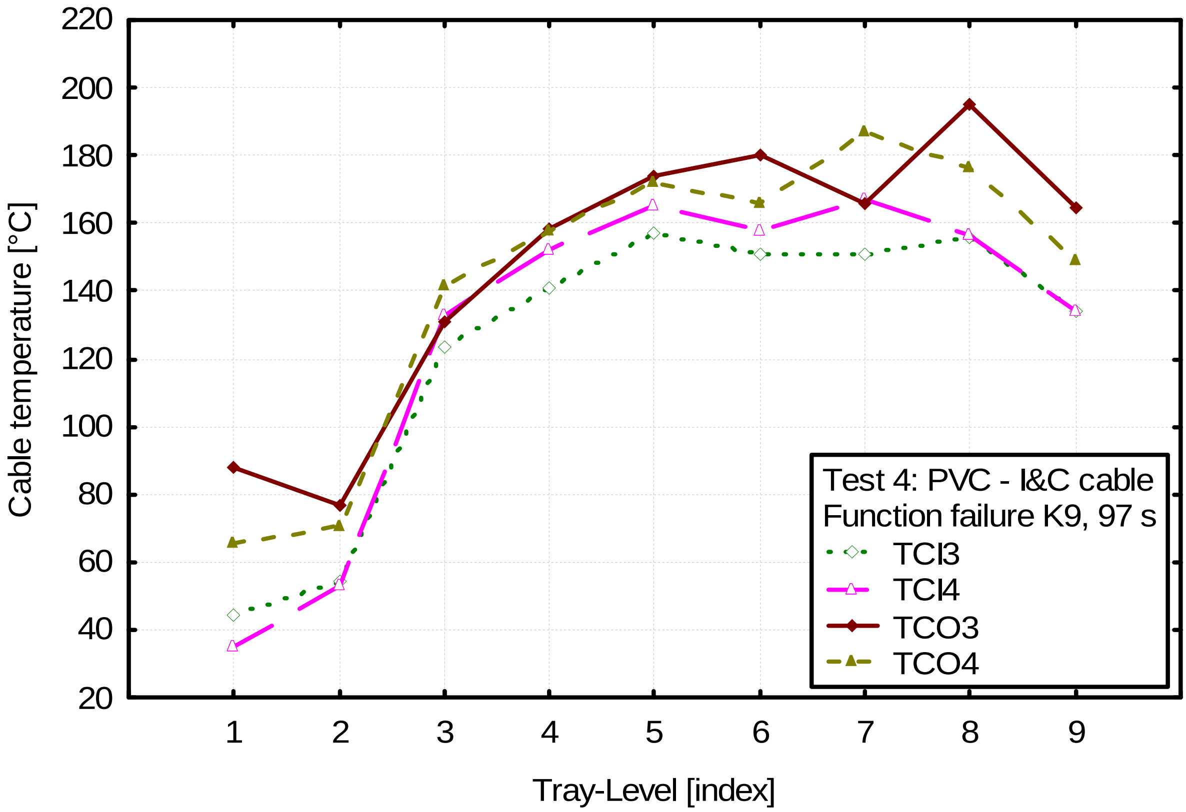

Test 2: FRNC - I&C cable
Function failure K9, 455 s
Level 1-9 temperatures
cable center (TCI), surface (TCO)
mean value, maxima, minima
Cable temperatures [°C]
0
50
100
150
200
250
300
142
157
182
181
TCI3
TCI4
TCO3
TCO4

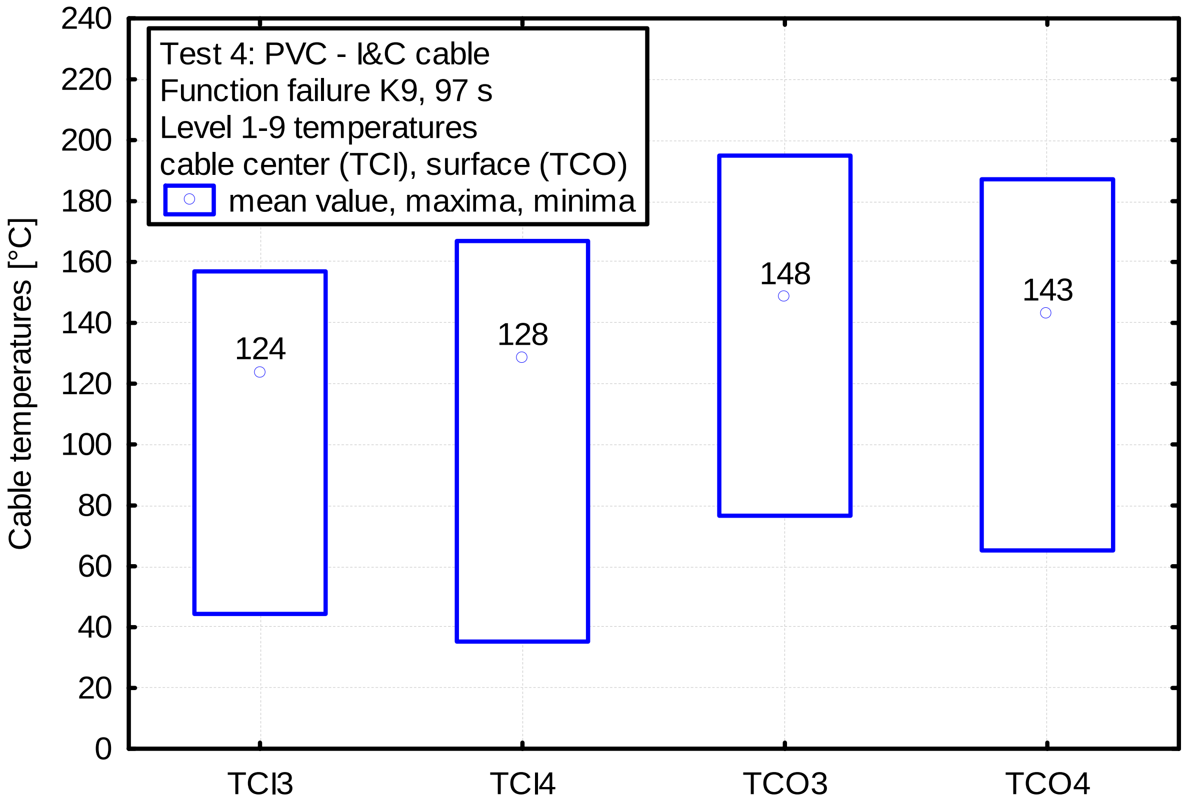

Test 3: PVC - I&C cable
Function failure K12, 458 s
TCI3
TCI4
TCO3
TCO4
Cable temperature [°C]
Tray-Level [index]
0
100
200
300
400
500
600
1
2
3
4
5
6
7
8
9

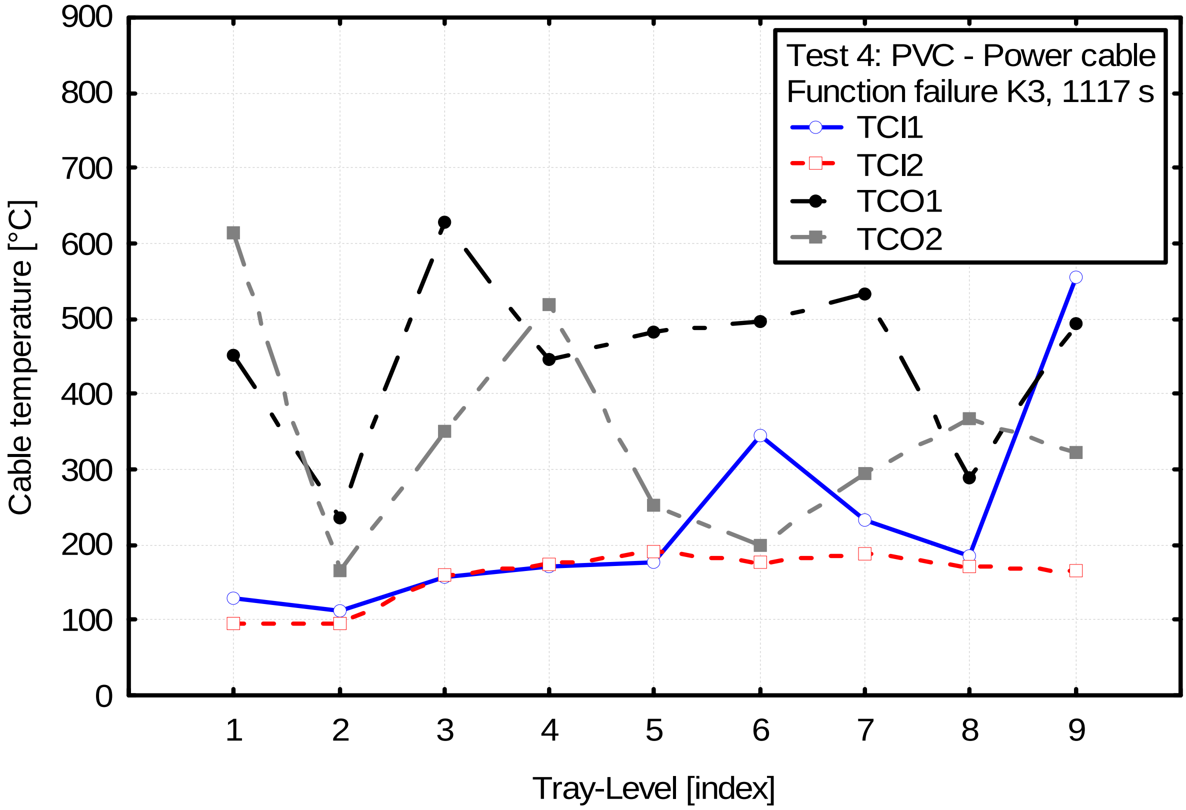

Test 3: PVC - I&C cable
Function failure K12, 458 s
Level 1-9 temperatures
cable center (TCI), surface (TCO)
mean value, maxima, minima
Cable temperatures [°C]
0
100
200
300
400
500
600
75
56
179
111
TCI3
TCI4
TCO3
TCO4


Test 3: PVC - Power cable
Function failure K2, 623 s
TCI1
TCI2
TCO1
TCO2
Cable temperature [°C]
Tray-Level [index]
0
50
100
150
200
250
300
350
400
450
500
1
2
3
4
5
6
7
8
9


Test 3: PVC - Power cable
Function failure K2, 623 s
Level 1-9 temperatures
cable center (TCI), surface (TCO)
mean value, maxima, minima
Cable temperatures [°C]
0
100
200
300
400
500
62
49
249
204
TCI1
TCI2
TCO1
TCO2


Cable temperature [°C]
220
200
180
160
140
120
100
80
60
40
20
1
2
3
4
5
6
7
8
9
Tray-Level [index]
Test 4: PVC - I&C cable
Function failure K9, 97 s
TCI3
TCI4
TCO3
TCO4


Cable temperatures [°C]
240
220
200
180
160
140
120
100
80
60
40
20
0
Test 4: PVC - I&C cable
Function failure K9, 97 s
Level 1-9 temperatures
cable center (TCI), surface (TCO)
mean value, maxima, minima
124
128
148
143
TCI3
TCI4
TCO3
TCO4


Test 4: PVC - Power cable
Function failure K3, 1117 s
TCI1
TCI2
TCO1
TCO2
Cable temperature [°C]
Tray-Level [index]
0
100
200
300
400
500
600
700
800
900
1
2
3
4
5
6
7
8
9