FIRE AND TOXICITY TEST FOR SEATS

J.G. Quintiere

Phase II: US ARMY CCDC project on Seat Flammability and Toxicity

Supported by

Sean Crowley and Carleen Houston

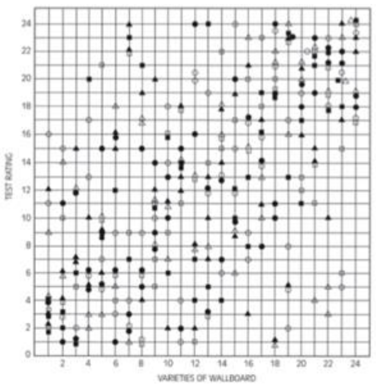
Objective

The U.S Army: Mitigate fire threat from seat material in a combat vehicle interior space for occupants

Thermal and Toxicity hazard

Pick a test because:

- Adopted by regulators
- International
- Supported by Industry
- Has a clear numerical scale
- Invented especially for an application
- Has the support of national labs
- Gives real engineering data
- Has been around a long time



Emmons on agreement among 6 country tests of 12 materials

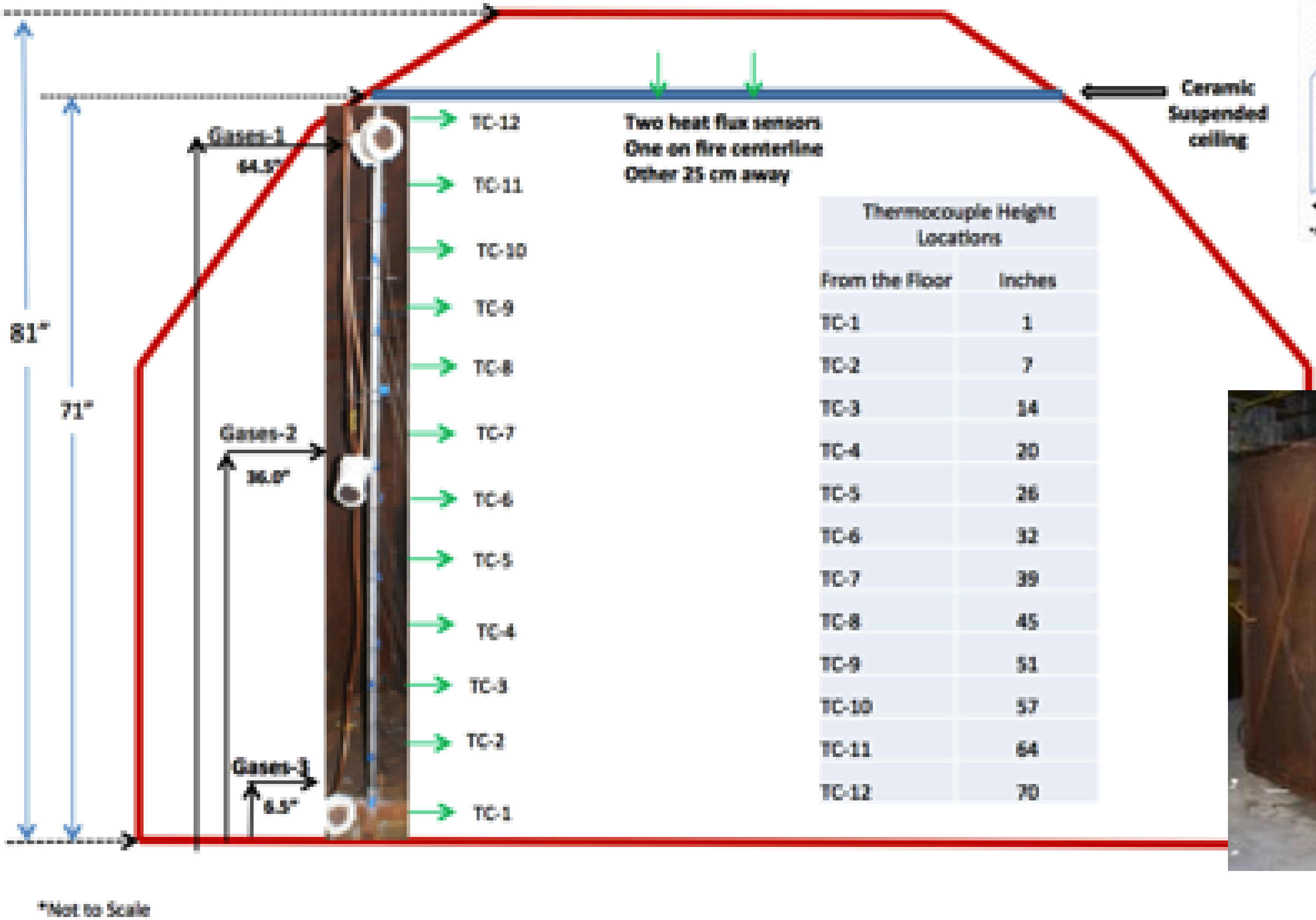
Troitzch, J., *International Plastics Flammability Handbook*, *2nd ed.*, Hanser Publishers, 1990, p. 95.

Tests give conceptual rankings as “minimal, slight, normal, and large”.

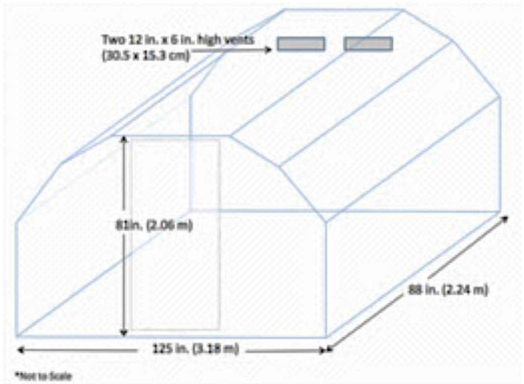
Test Method Design Process

- Fire threat scenarios for the interior of combat vehicles.
- Fire hazards for the occupants are established.
- Seat fire testing alone and within a mock-up military vehicle.
- Specific properties are identified for measurement
- Based on the safety criteria and engineering design an acceptable set of material properties level is established.

Mock-up Vehicle

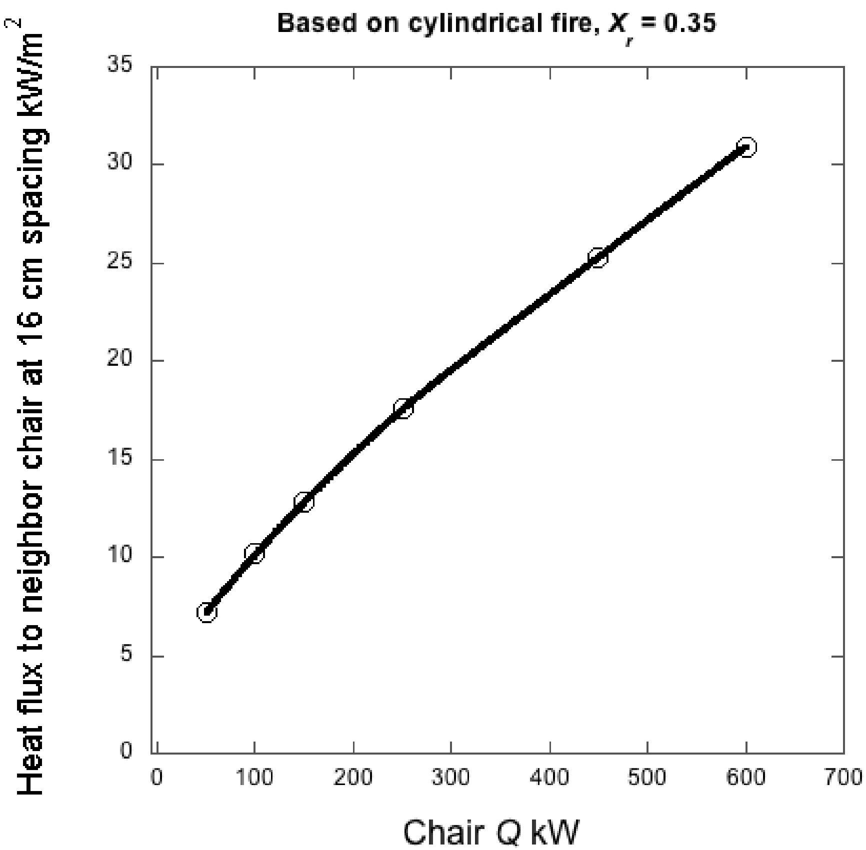


Thermocouple Height Locations	
From the Floor	Inches
TC-1	1
TC-2	7
TC-3	14
TC-4	20
TC-5	26
TC-6	32
TC-7	39
TC-8	45
TC-9	51
TC-10	57
TC-11	64
TC-12	70



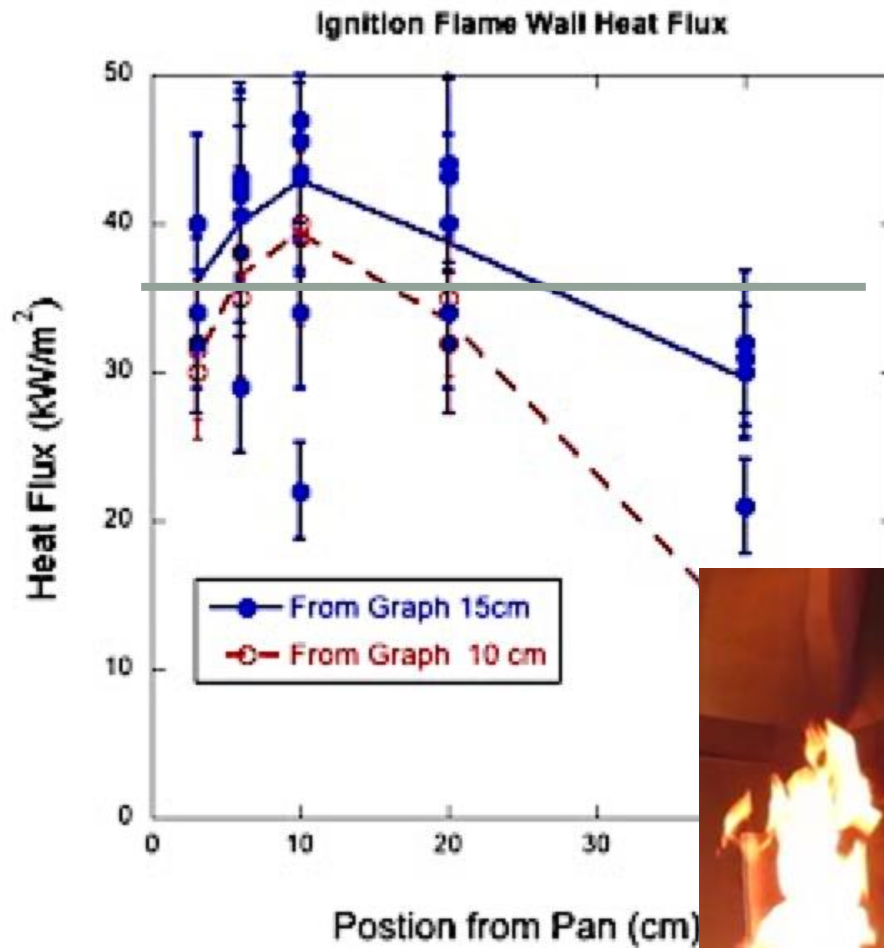
Criterion for thermal hazard

- Not acceptable: seat flame would impinge over the entire ceiling.
- Should not ignite the adjacent seat. 300 kW
- **Criterion:**
  - **Should not touch the ceiling. 100 kW**



Ignition source

- The ignition source shall not be a threat to the occupants.
-
- Ignition flame heat flux: 40 kW/m^2 was chosen.
- *Ignition source will be a 15 cm square pan with 90 ml of heptane.*



Effect of ignition location on seat fire growth behavior

- **bottom seat back**

front seat base

side seat base

side seat back

Seats to consider

Table 1. Description of seat assemblies

Chair no.	Color	Source	Seat bottom width x length cm	Seat back width x height cm	Total face area m^2
2	Red	Generic office	51 x 51	48 x 41	0.46
4	Beige	US ARMY CCDC	43 x 38	41 x 56	0.39
5	Blue	FAA block	46 x 51	46 x 61	0.52
6	Blue	FAA retarded	46 x 51	46 x 61	0.52
7	Green	US ARMY CCDC	46 x 38	30 x 48	0.32
8	Black	US ARMY CCDC	46 x 41	41 x 76	0.50
9	Blue	FAA no. 5 with block removed	46 x 51	46 x 61	0.52

Heat release rate results

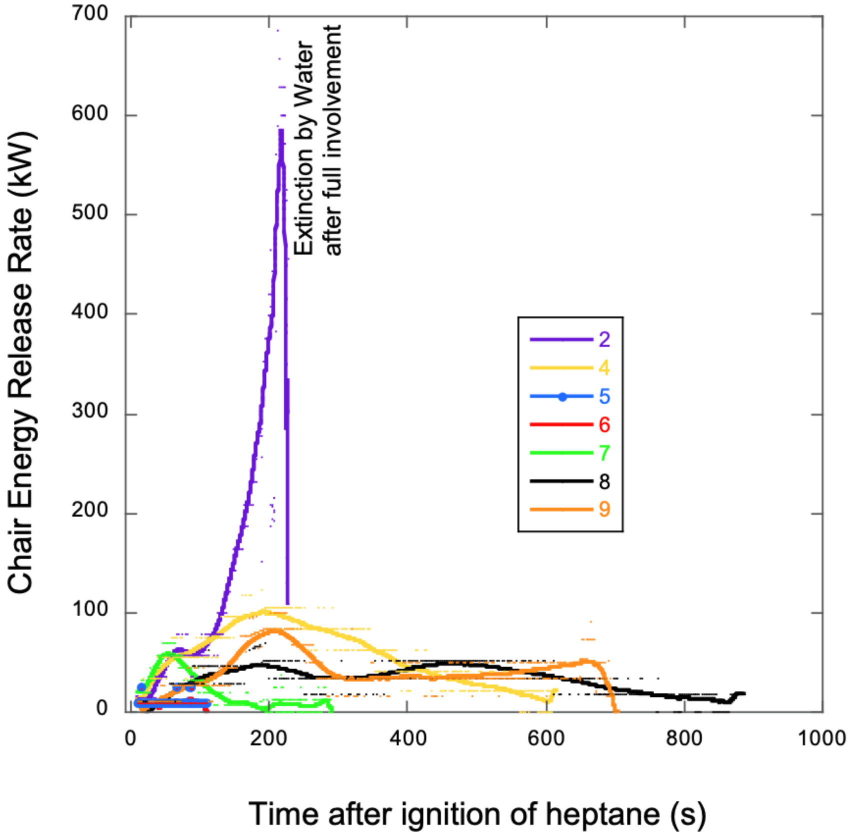


Figure 29a. Chair energy release rates

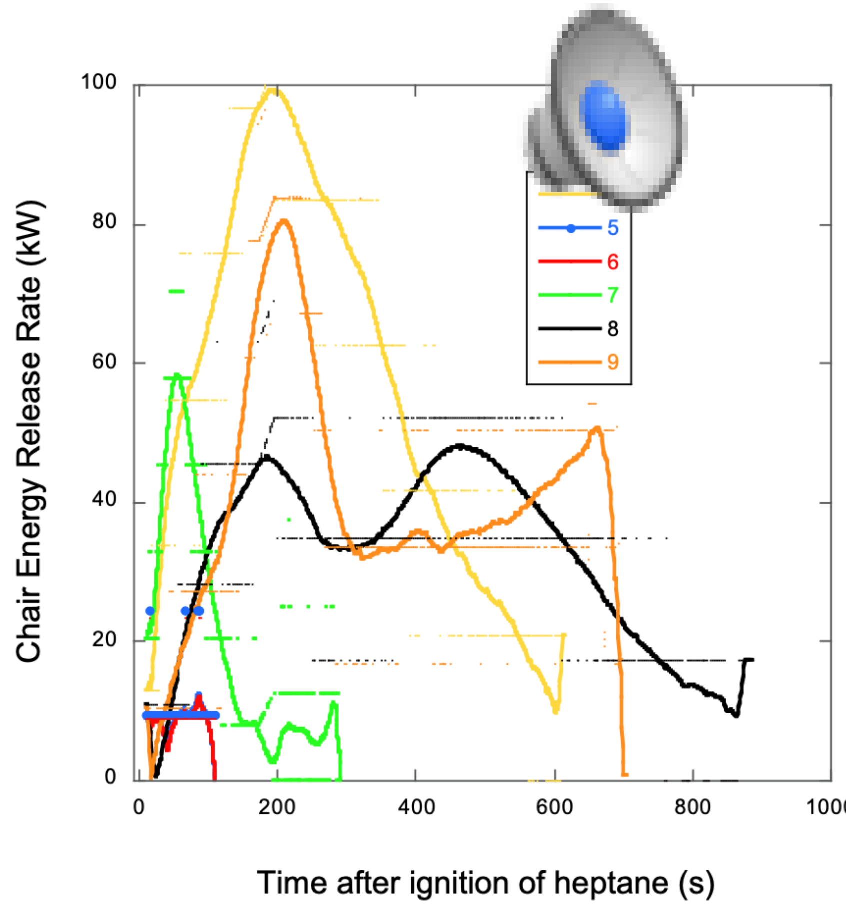


Figure 29b. Without Chair 2

Sufficient set of flammability properties

Table 2. Principle set of flammability parameters.

Parameter	Physical Meaning	Measurement Means
HRP Heat Release Parameter	$\Delta h_c / L$ Heat of combustion/Heat of gasification	Slope of Peak HRR and Flux
TRP Thermal Response Parameter	$\sqrt{\frac{\pi}{4} k\rho c} \left(T_{ig} - T_o\right)$ For a given heat flux, TRP^2 is directly proportional to the time to ignite	Inverse slope of (Time to ignition)$^{-1/2}$ and applied Heat Flux
CHF Critical Heat Flux	Proportional to ignition temperature, and is the minimum heat flux needed for ignition	Lowest Heat Flux for Piloted Ignition
AEP Available Energy Parameter	Total energy released in burning per area	Integral of energy release rate per area

Source of measuring properties

Table 3. Standard tests for fire properties.

Adoption Year	ASTM* Test Standard	Measurable Properties
1978	E 648	CHF (for lateral flame spread)
1990	E 1321	CHF (for piloted ignition) Flame spread velocity parameter, TRP
1990	E 1354	Δh_c, AEP
2000	E 2058	CHF, TRP, Δh_c, L, HRP, AEP

* ASTM International, West Conshohocken, PA 19428-2959. United States

By Cone Calorimeter

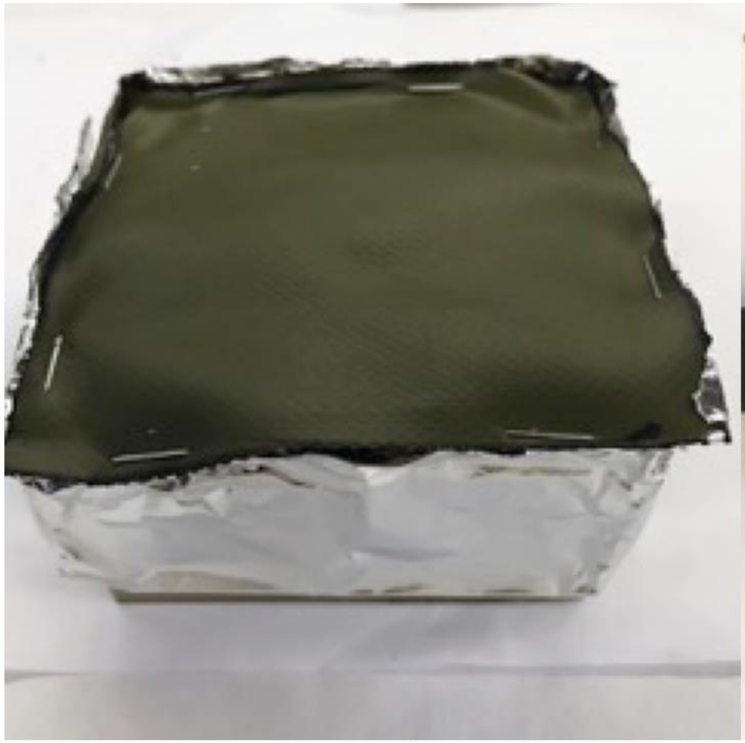


Figure 30a. General specimen holder

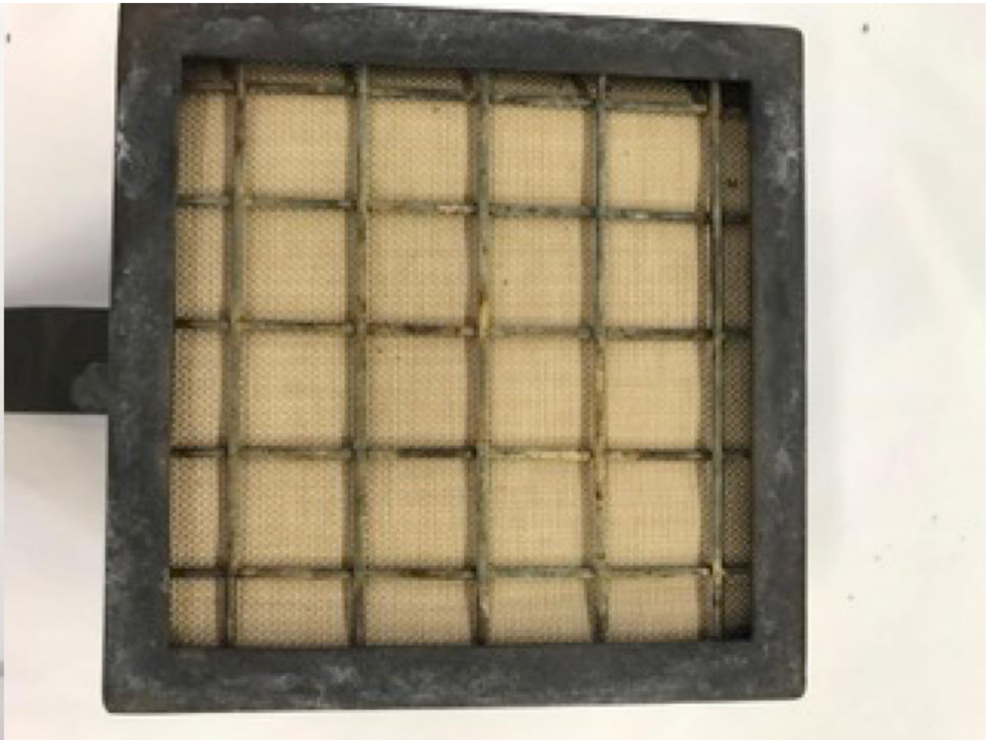
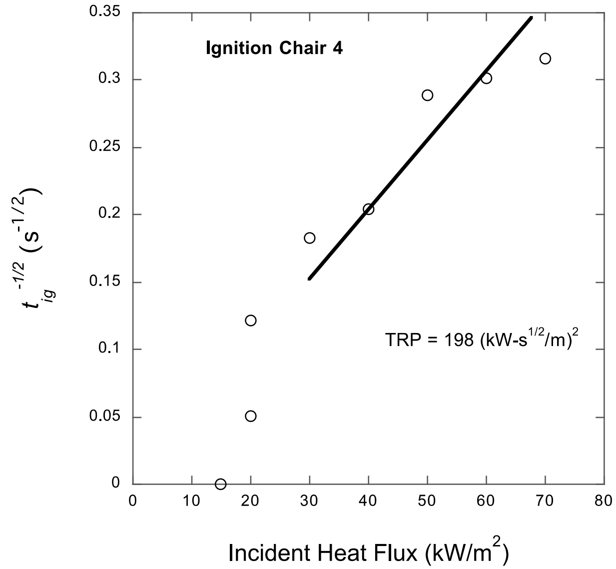
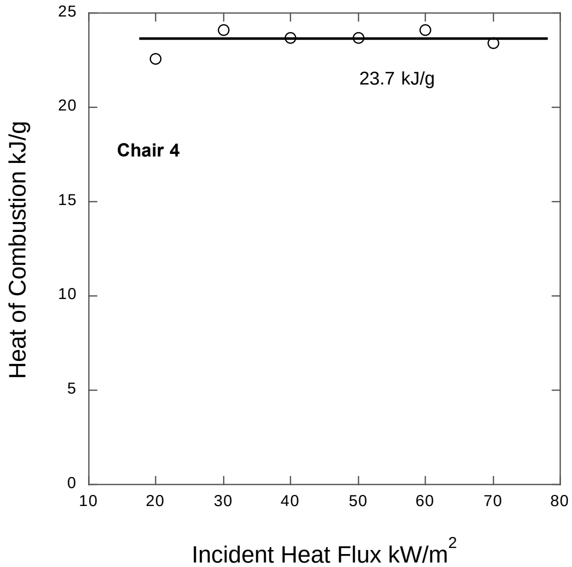
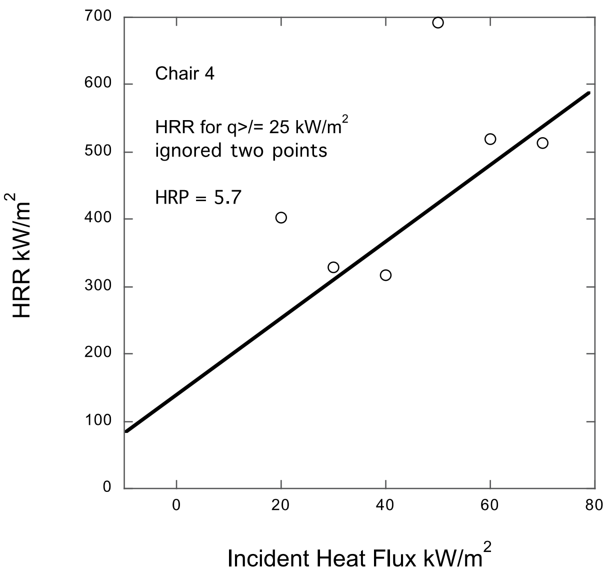


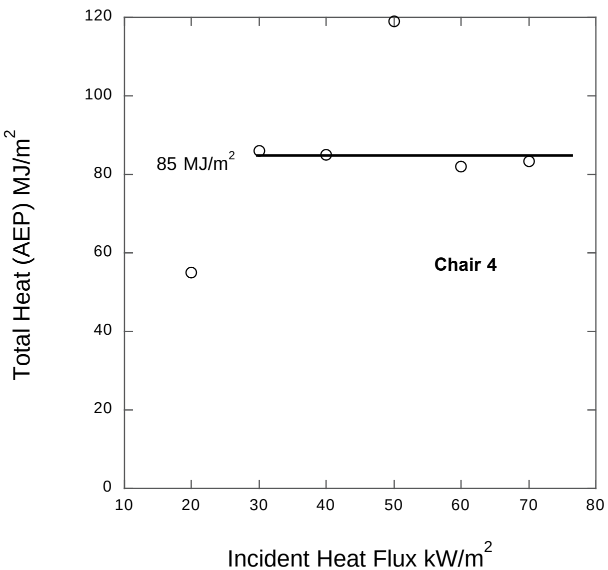
Figure 30b. Holder for CHF

Property example, Chair 4









Summary of properties

Table 11. Summary of Chair Properties

Chair	Material	TRP kW-$s^{1/2}/m^2$	CHF kW/m^2	Heat of Combustion kJ/g	HRP ----	AEP MJ/m^2
2	Office	210	20	25	18.8	92
4	T- beige	198	15	23.4	5.7	85
5	F-block	180	15	20/13*	2.4	55/5*
6	F -FR	192	15	16.4	3.0	21/10*
7	T-green	133	15	14.3	2.4	63/35*
8	T-black	169	15	20	4.5	71
9	F-no block	193	15	21	4.4	55

* values at lower heat flux < 40 kW/m^2, T=US ARMY CCDC, F=FAA

Pass/Fail Criteria

Does seat ignite?

Ignition heat flux of $\dot{q}''_{ig}$ = 40 kW/m^2

Passes If CHF > $\dot{q}''_{ig}$ = 40 kW/m^2

Does seat ignite after 2 minutes?

$$t_{ig} = \left(\frac{TRP}{\dot{q}''_{ig}}\right)^2$$ Passes if t_{ig} > 2 minutes

Does seat fire allow ignition of neighboring seat?

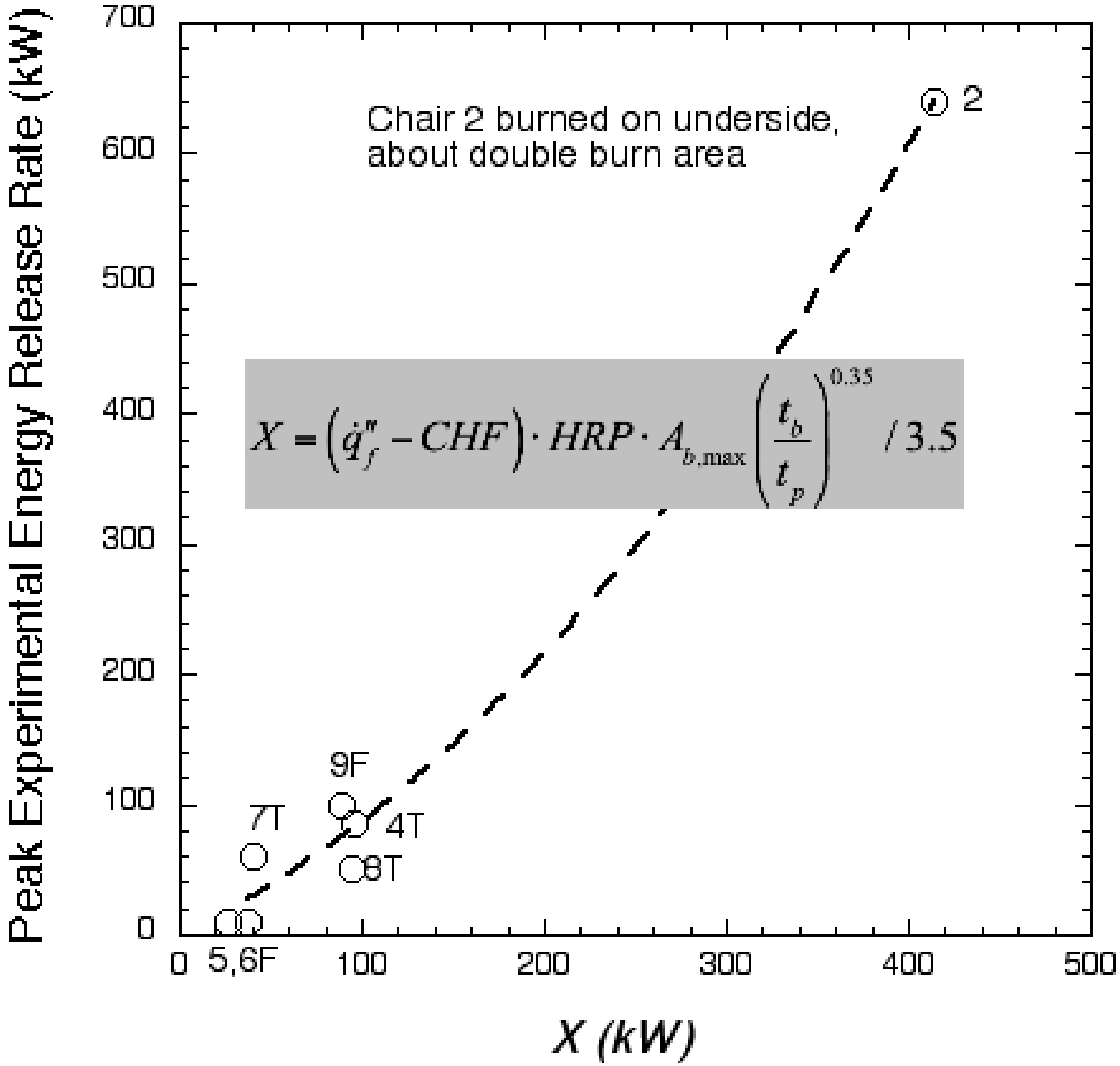
Passes if energy release rate < 100 kW.

Correlation for Heat Release Rate

$$\dot{Q} = \left(\dot{q}''_f - CHF\right) \cdot HRP \cdot A_{b,\max} \left(\frac{t_b}{t_p}\right)^{0.35} / 3.5$$

Chair	Peak Power kW	CHF kW/m^2	HRP ----	TRP kW-s$^{1/2}$/m^2	AEP MJ/m^2	t_{ig} s	t_b s	$A_{b,max}$ m^2
2 generic office	640	20	18.8	210	92	8.8	167	0.46**
4 US ARMY CCDC Beige	100	15	5.7	198	85	8.2	436	0.39
5 FAA seat block	10	15	2.4	180	5*, 55	6.7	60	0.52
6 FAA grey, FR	10	15	3.0	192	10, 21	7.9	95	0.52
7 US ARMY CCDC Green	60	15	2.4	133	35, 63	3.7	417	0.32
8 US ARMY CCDC Black	50	15	4.5	169	71	7.6	451	0.50
9 FAA, 5 no block	85	15	4.4	193	55	6.0	357	0.52

Correlation over Matlab model



$$X = \left(\dot{q}''_f - CHF\right) \cdot HRP \cdot A_{b,\max} \left(\frac{t_b}{t_p}\right)^{0.35} / 3.5$$

Summary of Pass/Fail

Table 13. Summary of Properties and Protocol Test Results

Chair	Exper. Peak Power kW	Calc. Peak Power Eq. (12) kW	CHF kW/ m^2	HRP ----	TRP kW-$s^{1/2}/m^2$	AEP MJ/m^2	FED CO & *T*
2 generic office	640**	415**	20	18.8	210	92	773
4 CCDC Beige	100	89	15	5.7	198	85	9.2
5 FAA seat block	10	27	15	2.4	180	5*, 55	0.058
6 FAA grey, FR	10	37	15	3.0	192	10, 21	0.29
7 CCDC Green	60	40	15	2.4	133	35, 63	16.4
8 CCDC Black	50	94	15	4.5	169	71	21
9 FAA, 5 no block	85	96	15	4.4	193	55	9.2

* burn time based on lower AEP

** area is double as at peak, burning under/behind (0.92 m^2)

Fail

Pass < 100 kW

Review of Process

- Identify the scenario
- Establish pass/fail criteria
- Determine the scenario heat flux
- Measure material fire properties
- Develop a formula to predict pass/fail from properties and heat flux
- Needs to be a transparent process