NRC INSPECTION MANUAL

INSPECTION MANUAL CHAPTER 0609 APPENDIX F ATTACHMENT 5

CHARACTERIZING FIRE IGNITION SOURCES

FIXED AND TRANSIENT IGNITION SOURCE FIRES

Heat Release Rate Profile of Fixed Ignition Sources

The Heat Release Rate (HRR) profile of fixed ignition sources consists of three stages as shown in Figure A5.1:

- First Stage: t-squared growth stage during which the HRR increases from 0 kW at ignition (t = 0 seconds) to the peak HRR (HRR_{peak}) at t = t_{peak} seconds. The HRR as a function of time during this stage is given by

$$\mathrm{HRR(t)} = \mathrm{HRR_{peak}}\left(\frac{\mathrm{t}}{\mathrm{t_{max}}}\right)^2 \quad \text{for} \quad 0 \leq \mathrm{t} \leq \mathrm{t_{peak}} \qquad [5\text{-}1]$$

- Second Stage: HRR remains equal to HRR_{peak} for a period of Δt_{steady} seconds.
- Third Stage: Linear decay from HRR = HRR_{peak} to HRR = 0 kW in Δt_{decay} seconds.

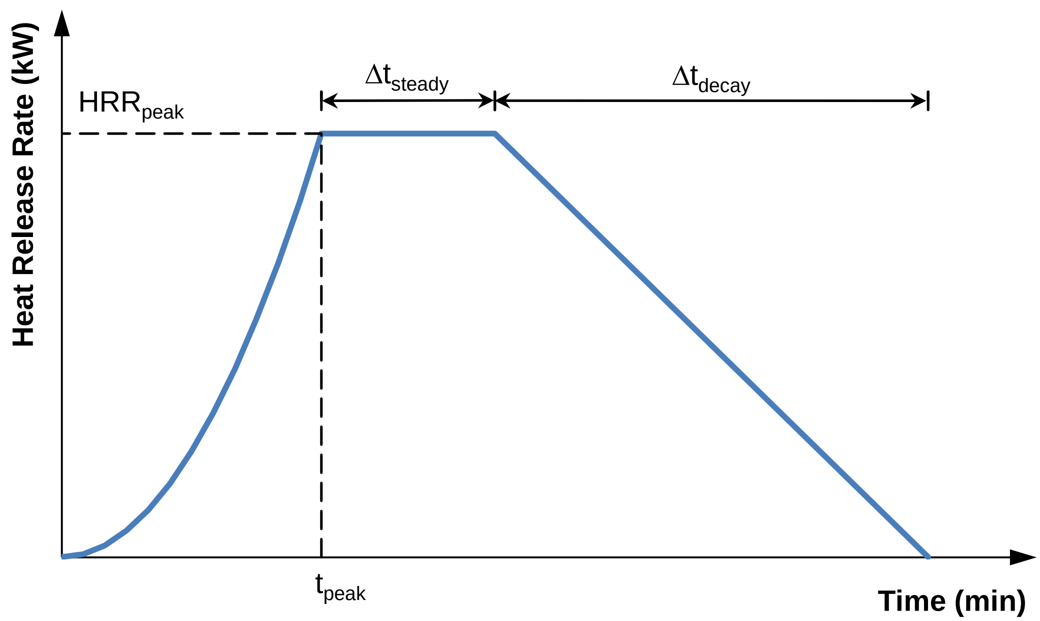

Figure A5.1 - HRR Profile for Fixed and Transient Ignition Sources

Table A5.1 gives the HRR profile parameters for fixed ignition sources assumed in the Phase 2 based on NUREG-2178, Vol. 1. The HRR_{peak} values for electrical enclosures are the 98th percentile HRRs taken from Table 7-1. The 98th percentile HRR is recommended for screening. According to Table A5.1, the 98th percentile HRR of an electrical enclosure with a specified configuration and default fuel loading is independent of the type of cables (i.e., thermoset or thermoplastic) it contains.

Table A5.1 - HRR Profiles for Fixed and Transient Ignition Sources						
Ignition Source		Configuration*	HRR Profile Parameters			
			HRR_{peak} (kW)	t_{peak} (s)	Δt_{steady} (s)	Δt_{decay} (s)
Motors		NA	69	720	480	1200
Pumps		NA	211	720	480	1200
Loose Transients		NA	317	120	120	480
Contained Transients		NA	317	480	180	480
Enclosure Set 1	Small Electrical Enclosures ($V \le 12$ ft^3)	Open or Closed	45	720	480	1200
	MCCs & Battery Chargers	Closed	130	720	480	1200
	Switchgear & Load Centers	Closed	170	720	480	1200
	Power Inverters	Closed	200	720	480	1200
Enclosure Set 2	Medium Enclosures (12 ft^3 < V ≤ 50 ft^3)	Closed	200	720	480	1200
	Medium Enclosures (12 ft^3 < V ≤ 50 ft^3)	Open	325	720	480	1200
	Large Enclosures (V > 50 ft^3)	Closed	400	720	480	1200
	Large TP Enclosures (V > 50 ft^3)	Open	1000	720	480	1200

* See Attachment 3 for definition of "open" and "closed" cabinets

HRR Profile of Electrical Cabinet Fires (HEAF)

Switchgear and load centers (440V and above) are subject to high energy arcing faults (HEAFs) in addition to the possibility of a general or thermal fire. As a result, two ignition scenarios need to be considered for electrical cabinets ≥ 440 V; HEAF and non-HEAF. For the HEAF scenario, the vertical ZOI is within 5 ft. above the top of the cabinet, and the horizontal ZOI is within 3ft. of all sides of the cabinet. All unprotected targets within this region are assumed to be damaged instantaneously when the HEAF occurs and all unprotected secondary combustibles within the region are assumed to ignite instantaneously. The HRR profile for a HEAF fire has no t-squared growth stage. The HEAF fire reaches HRR_{peak} instantaneously at ignition (t = 0 seconds), remains at HRR_{peak} for 1200 seconds, and subsequently decays linearly to 0 kW in 1200 seconds. The ZOI and HRR profile for non-HEAF scenarios is determined in the same manner as for electrical cabinets < 440 V.

HRR Profile of Main Control Board Panel Fires

The HRR of Main Control Board (MCB) panel fires used in an analysis to determine the probability for control room abandonment is identical to that for the electrical enclosures with the same volume.

HRR Profile for Propagating Electrical Cabinet Fires

Electrical cabinet fires can be assumed not to propagate to adjacent cabinets if at least one of the following conditions are met:

- The cabinets are separated by a double wall with an air gap, or
- Either the exposed or exposing cabinet has an open top, and there is an internal wall, possibly with some openings, and there is no diagonal cable run between the exposing and exposed cabinet.

If neither of these conditions are met, electrical cabinet fires are assumed to propagate from the exposing cabinet to adjacent exposed cabinets. There can be one or two exposed cabinets, depending on whether the fire originates in a cabinet located at one end of a bank or in a cabinet that has adjacent cabinets on both sides, respectively. The HRR profile of a propagating cabinet fire is obtained by combining the HRR profiles of the exposing and exposed cabinets, assuming the exposed cabinets ignite 10 or 15 minutes after the exposing cabinet:

- Assume an ignition delay of 10 minutes if the cabinets are not separated by a metal wall, or if the cabinets are separated by a single metal wall and cables in the adjacent cabinet are in direct contact with the wall.
- Assume 15 minutes if the cabinets are separated by a single metal wall, and cables in the adjacent cabinet are not in contact with the wall.

<u>HRR Profile of Transient Combustible</u>

The HRR profile for transient combustible fires is of the same form as shown in Figure A5.1. The corresponding HRR profile parameters are provided in Table A5.1. These fire characteristics bound transient fire sources with the following characteristics:

- A single plastic or metal trash can of up to 55 gallons size loaded with general waste materials such as paper, packing materials, etc.
- Up to three small office-size trash cans with general waste (e.g., on the order of 2-4 gallons each, typically either plastic or fiberglass construction).
- A single wooden pallet.
- A single small packing crate (no more than 24" cube).
- A plastic bucket of up to 7 gallons in size (e.g., a used paint bucket) with cleaning materials (e.g., rags, brushes, no more than a pint of cleaning solvents).
- One or two plastic trash bags containing general waste materials.
- An open grease bucket up to one gallon.
- A single collection bin for protective clothing (e.g., at a step-off / dress-out area).

If, in the judgement of the analyst, the as-found conditions exceed the above examples, the fire intensity may have to be increased to reflect the as-found conditions. In that case it is recommended that additional guidance be sought from either the Regional or Headquarters fire protection staff.

OIL FIRES

Liquid fuel spills can be confined or unconfined. For confined liquid fuel pool fires the area is known and the HRR is a function of the size of the containment area (pool) and combustion properties of the fuel. The area of an unconfined liquid fuel spill is a function of the spill volume, and the HRR is therefore a function of the volume and combustion properties of the spilled fuel.

Two distinct oil spill fires may need to be considered. The first scenario assumes a spill of 100% of the amount of oil that can be spilled. The second scenario considers a 10% spill. A severity factor of 0.02 is assigned to the first scenario, and 0.98 is used for the second scenario. For confined liquid pool fires it is not necessary to evaluate the two scenarios separately if the containment area is large enough to hold 100% of the amount of oil that can be spilled.

Confined Liquid Pool Fires

Table A5.2 gives the steady HRR and burning rate of confined liquid pool fires as a function of the pool diameter for the following liquid fuels: (1) diesel fuel and fuel oil, (2) lube oil and mineral oil, and (3) silicone fluid.

Table A5.2 - HRRs and Burning Times for Confined Liquid Pool Fires						
D_{eff} (ft.)	Diesel Fuel & Fuel Oil		Lube Oil & Mineral Oil		Silicone Fluid	
	HRR (kW)	Burning Rate (gal/min)	HRR (kW)	Burning Rate (gal/min)	HRR (kW)	Burning Rate (gal/min)
1.0	41	0.017	25	0.011	2.7	0.002
1.5	123	0.051	81	0.037	8.5	0.005
2.0	262	0.108	183	0.083	19	0.011
2.5	460	0.190	341	0.154	34	0.020
3.0	720	0.297	562	0.253	55	0.032
3.5	1039	0.428	851	0.383	82	0.047
4.0	1418	0.584	1213	0.546	116	0.067
4.5	1854	0.764	1650	0.743	155	0.089
5.0	2345	0.966	2165	0.975	200	0.116
5.5	2890	1.191	2759	1.242	252	0.145
6.0	3487	1.437	3432	1.545	310	0.179
6.5	4136	1.705	4185	1.884	373	0.215
7.0	4836	1.993	5017	2.258	443	0.255
7.5	5586	2.302	5928	2.668	518	0.299
8.0	6386	2.632	6917	3.114	599	0.345
8.5	7236	2.982	7984	3.594	685	0.395
9.0	8135	3.353	9128	4.108	777	0.448
9.5	9083	3.744	10347	4.657	874	0.504
10	10082	4.156	11640	5.240	977	0.563
11	12227	5.040	14448	6.504	1197	0.690
12	14570	6.006	17544	7.897	1438	0.829
13	17114	7.054	20921	9.417	1700	0.980
14	19858	8.185	24574	11.06	1981	1.142
15	22802	9.399	28498	12.83	2283	1.316
16	25948	10.70	32689	14.71	2604	1.501
17	29296	12.08	37145	16.72	2946	1.698
18	32846	13.54	41862	18.84	3308	1.907
19	36598	15.09	46839	21.08	3690	2.127
20	40553	16.72	52075	23.44	4091	2.358
21	44710	18.43	57570	25.91	4513	2.602
22	49070	20.23	63322	28.50	4956	2.857
23	53633	22.11	69332	31.21	5418	3.123
24	58398	24.07	75600	34.03	5901	3.401
25	63366	26.12	82126	36.97	6404	3.691

For non-circular fires with an area A_f, an equivalent effective diameter is used, which is calculated as follows:

$$D_{eff} = \sqrt{\frac{4A_f}{\pi}} \quad [5\text{-}2]$$

Liquid pool fires are conservatively assumed to reach the steady HRR instantaneously at ignition (t=0 seconds). The burning time can be calculated by dividing the spill volume by the burning rate.

Unconfined Liquid Spill Fires

Table A5.3 gives the steady HRR and burning time of unconfined liquid spill fires as a function of spill volume for the same three liquid fuels.

Table A5.3 - HRRs and Burning Times for Unconfined Liquid Spill Fires

V (gal)	Diesel Fuel & Fuel Oil		Lube Oil & Mineral Oil		Silicone Fluid	
	HRR (kW)	Burning Time (s)	HRR (kW)	Burning Time (s)	HRR (kW)	Burning Time (s)
1	2438	226	2265	222	209	1880
2	5126	215	5368	188	472	1668
3	7797	212	8696	174	742	1590
4	10451	211	12121	166	1014	1551
5	13095	210	15592	162	1286	1529
6	15732	210	19085	158	1558	1516
7	18366	210	22588	156	1828	1507
8	20997	210	26093	154	2098	1500
9	23627	210	29597	153	2367	1496
10	26255	210	33098	152	2636	1493
11	28883	210	36595	151	2904	1490
12	31143	212	39599	153	3134	1506
13	33059	216	42144	155	3329	1536
14	34950	220	44654	158	3522	1564
15	36820	224	47132	160	3712	1590
16	38668	228	49580	163	3900	1614
17	40498	231	52002	165	4086	1637
18	42310	234	54398	167	4270	1659
19	44106	237	56771	169	4452	1679
20	45886	240	59122	170	4633	1699
21	47653	242	61453	172	4812	1717
22	49406	245	63764	174	4990	1735
23	51146	247	66057	175	5166	1752
24	52874	250	68334	177	5341	1768
25	54591	252	70594	178	5515	1784
26	56298	254	72838	180	5688	1798
27	57994	256	75069	181	5860	1813
28	59680	258	77285	183	6031	1827
29	61357	260	79488	184	6201	1840
30	63026	262	81679	185	6370	1853

CABLE TRAY FIRES

Fires in Vertical Stacks of Horizontal Cable Trays

Vertical stacks of horizontal cable trays located within the zone of influence (ZOI) of an ignition source may act as secondary combustibles and contribute to the HRR in the area under evaluation. Tables and plots of the combined HRR as a function of time for various cable types (TS and TP), tray widths (1.5 or 3.0 ft.), and ignition source/cable tray configurations can be found in table/plot set C in Attachment 8. These tables and plots are applicable for non-HEAF scenarios. For HEAF scenarios, add HRR_{peak} of the ignition source to the cable tray HRR from Figures C.01 (for 1.5 ft. wide trays) or C.02 (for 3.0 ft. wide trays) in Attachment 8.

Flame spread and fire propagation characteristics for fires involving stacks of cable trays are discussed in the section for FDS 2 scenarios in Attachment 3 and in Section 06.03.03 of the basis document (IMC 0308 Attachment 3 Appendix F). It can be assumed that flame spread and fire propagation will not occur under the following conditions:

- All trays within the ZOI are fully enclosed, i.e., they have solid bottom and top covers.
- All trays within the ZOI have solid bottoms and are tightly covered with at least one in. of ceramic fiber blanket (e.g., Kaowool)
- All trays are within the ZOI are protected with a rated fire barrier or wrap, except for HEAF scenarios, in which case wraps within the ZOI are assumed to be destroyed and ineffective.

Vertical Cable Tray Fires

The HRR of a vertical cable tray is conservatively estimated as the product of the width of the tray covered with cables, the height of the tray, and the HRR per unit area (HRRPUA) of the cables. The latter is equal to 150 kW/m^2 for TS cables, and 250 kW/m^2 for TP and Kerite cables (from NUREG/CR-7010). Flames are assumed to spread very rapidly in the vertical direction, and the HRR is therefore assumed to be instantaneous at ignition.

Self-Ignited Cable Fires

The HRR profile of vertical stacks of horizontal cable trays involved in a self-ignited cable fire scenario can be obtained from Figures C.01 (for 1.5 ft. wide trays) or C.02 (for 3.0 ft. wide trays) in Attachment 8. A conservative estimate of the HRR of a vertical self-ignited cable tray can be obtained as discussed in the previous section.

HOT WORK FIRES

For hot work fires, it will be assumed that the hot work leads to ignition of either transient combustibles, exposed cables, or insulation materials depending on the specific situation. Transient combustibles could include flammable materials used in conjunction with the hot work itself (e.g., plastic sheeting or non-fire retardant scaffold materials).

- If the hot work is assumed to ignite transients, treat the subsequent fire like any other transient fuel fire. As-found conditions may be reflected in fire characterization.

- If the hot work is assumed to ignite exposed cables, treat the subsequent fire like a self-ignited cable fire.
- If the hot work fire is assumed to ignite insulation materials, seek additional guidance from Regional or Headquarters fire protection staff.

SEVERE FIRES INVOLVING THE MAIN TURBINE GENERATOR SET

For inspections involving the turbine building, a need to address severe fires involving the main turbine generator set may arise. In this case, additional guidance will be needed to complete the Phase 2 analysis. Guidance from either Regional or Headquarters fire protection staff should be sought in the treatment of these fires.

HYDROGEN FIRES

If for a given fire area, hydrogen fires might be a significant factor in the risk quantification, additional guidance will be needed to complete the Phase 2 analysis. Guidance from either Regional or Headquarters fire protection staff should be sought in the treatment of these fires.

ATTACHMENT 1
Revision History for IMC 0609, Appendix F Attachment 5

Commitment Tracking Number	Accession Number Issue Date Change Notice	Description of Change	Description of Training Required and Completion Date	Comment Resolution and Feedback Form Accession Number (Pre-Decisional, Non-Public)
	05/28/2004 CN 04-016	IMC 0609, App F, Att 5 “Characterizing Non-Simple Fire Ignition Sources,” is added to provide guidance on the need to consider whether non-simple ignition sources such as self-ignited cable fires, energetic electrical arcing faults, transient combustibles, hot work, liquid fuel spills, and hydrogen are plausible fire ignition sources.	None	N/A
	02/28/2005 CN 05-007	IMC 0609, App F, Att 5 “Characterizing Non-Simple Fire Ignition Sources,” is revised to change all references from 50th and 95th percentile to 75th and 98th percentile, respectively, for expected and high confidence fire intensity values.		
	ML17089A422 DRAFT CN 17-XXX	Revised to reflect changes to the Phase 2 process and for consistency with the guidance in NUREG/CR-6850 and superseding guidance in NFPA 805 FAQs and NUREG-2178. CA Note sent 7/18/17 for information only, ML17191A681. Issued 10/11/17 as a draft publically available document to allow for public comments.	November 2017	ML17093A184
	ML18087A409 05/02/18 CN 18-010	Draft document revised to incorporate minor public comments and re-issued with new accession number in order to issue as an official revision after receipt of public comments.	Gap training covering changes to the procedure completed November 2017	ML17093A184