FLAMMABILITY OF ALTERNATIVE DAILY COVER MATERIALS - A SUMMARY OF ASTM E1354 CONE CALORIMETER RESULTS

A SUMMARY OF RECENTLY DEVELOPED TECHNICAL INFORMATION

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(1) The combustion process yields heat;

(2) The combustion process is the result of a material reacting with oxygen;

(3) The combustion process, yielding heat, decreases enthalpy, and therefore is exothermic;

(4) The Heat of Reaction for a combustion process is exothermic;

(5) The Heat of Reaction is equal to the Heat of Combustion of a material (fuel) involved in the combustion (oxidation, burning) process;

(6) The Heat of Combustion is the measure of the heat released during the combustion process;

(7) Materials with Heats of Combustion equal to zero are the least combustible and would be considered <u>noncombustible</u>.

Therefore, the measure of combustibility or noncombustibility must be the

HEAT OF COMBUSTION

of the material - if the value is exothermic, the material is combustible.

The only materials that could be considered <u>noncombustible</u> are those with zero value

HEATS OF COMBUSTION .

DETERMINATION OF NONCOMBUSTIBILITY CONCLUSIONS

(1) The Heat of Combustion can be measured by the ASTM E1354 Cone Calorimeter procedure;

(2) The ASTM E1354 procedure tests samples in the horizontal position;

(3) The ASTM E1354 procedure determines the heat evolved from or contributed to a fire;

(4) The ASTM E1354 procedure is not limited to representing a single fire scenario.

By contrast -
(5) The ASTM E84 Steiner Tunnel Test does not measure the Heat of Combustion;

(6) The ASTM E84 procedure evaluates the comparative surface burning behavior of materials;

(7) The ASTM E84 procedure will yield a lower flame spread index when materials that melt, drip or delaminate are evaluated;

(8) The ASTM E84 test method is intended to provide only comparative measurements of surface flame spread;

(9) The ASTM E84 test method does not provide for defining a material <u>noncombustible.</u>

FLAMMABILITY TESTING CONCLUSIONS

(1) The ignition times of all the tarpaulins/geotextiles, standards, references, and alternative daily cover foams are listed, in increasing order, in Table I.

(2) Cardboard, and all the tarpaulins/geotextiles, ignite in less than one minute with the exception of Air Space Saver, which takes 77 seconds.

(3) Plywood, Plexiglas, and red oak ignite between 150 seconds and 300 seconds.

(4) Shaving cream ignites between 1100 seconds and 2000 seconds depending upon the thickness.

(5) Rusmar Incorporated, Long Duration Foam, at 3" or 6" thickness, does not ignite.

(6) Dry wall does not ignite.

(7) The Heats of Combustion of Common Plastics, Common Tarpaulins/Geotextiles, Shaving Cream, Rusmar Incorporated Long Duration Foam, and Other Common Materials are listed in Table II.

(8) The Heats of Combustion for the nine tarpaulins/geotextiles evaluated, including most of the commercially available materials, ranges between 14.6 and 33.7 MJ/Kg, with the average being 29.0 MJ/Kg.

(9) The only material with a demonstrated Heat of Combustion equal to zero is Rusmar Incorporated Long Duration Foam.

TABLE I

ASTM E1354 CONE CALORIMETER TEST RESULTS

MATERIAL	IGN TIME (SECS)
CORMIER RPVC	24
CORMIER WP-1440	31
CARDBOARD	34
CORMIER WP-1440-FR (#1)	39
CORMIER WP-1440-FR (#2)	39
SANICOVER	42
GRIFFOLYN	43
FABRISOIL	44
TYPAR	52
AIR SPACE SAVER	77
PLYWOOD	151
PLEXIGLAS	156
RED OAK	266
3" SHAVING CREAM	1111
6" SHAVING CREAM	1947
3" LONG DURATION FOAM	INFINITE
6" LONG DURATION FOAM	INFINITE
DRY WALL	INFINITE

TABLE II
HEATS OF COMBUSTION OF COMPARATIVE MATERIALS

COMMON PLASTICS

Polyethylene	46.3 MJ/Kg
Polypropylene	46.4 MJ/Kg
Polystyrene	41.4 MJ/Kg
Polyvinyl Chloride	18.0 MJ/Kg
Urea Formaldehyde Foam	15.0 MJ/Kg
Unsaturated Polyester	26.0 MJ/Kg

COMMON TARPAULINS/GEOTEXTILES

Cormier RPVC	14.6 MJ/Kg
Cormier WP-1440-FR (#2)	27.2 MJ/Kg
Griffolyn	28.7 MJ/Kg
Cormier WP-1440-FR (#1)	29.6 MJ/Kg
Sanicover	31.3 MJ/Kg
Air Space Saver	32.0 MJ/Kg
Cormier WP-1440	32.1 MJ/Kg
Fabrisoil	32.5 MJ/Kg
Typar	33.7 MJ/Kg

SHAVING CREAM

3" Thick	1.6KJ/Kg
6" Thick	3.0MJ/Kg

RUSMAR INCORPORATED
LONG DURATION FOAM

Three Inch Thick	0.0 MJ/Kg
Six Inch Thick	0.0 MJ/Kg

OTHER COMMON MATERIALS

Charcoal	34.2 MJ/Kg
Coal, Bituminous	30.5 MJ/Kg
Fuel Oil, #1	46.1 MJ/Kg
Gasoline	46.8 MJ/Kg
Paper, Newsprint	19.7 MJ/Kg
Straw	15.6 MJ/Kg
Wood, Dry, Average	20.0 MJ/Kg

I. FEDERAL AND STATE REGULATIONS -

The RCRA Subtitle D regulations - Criteria For Municipal Solid Waste Landfills (1) became effective on October 9, 1993. Of specific interest is paragraph 258.21, Cover Material Requirements, which state:

(a) Except as provided in paragraph (b) of this section, the owners or operators of all MSWLF units must cover disposed solid waste with six inches of earthen material at the end of each operating day, or at more frequent intervals, if necessary, to control disease vectors, fires, odors, blowing litter, and scavenging.

(b) Alternative materials of an alternative thickness (other than at least six inches of earthen material) may be approved by the Director of an approved State if the owner or operator demonstrates that the alternative material and thickness control disease vectors, fires, odors, blowing litter, and scavenging without presenting a threat to human health and the environment.

(c) The Director of an approved State may grant a temporary waiver from the requirement of paragraph (a) and (b) of this section if the owner or operator demonstrates that there are extreme seasonal climatic conditions that make meeting such requirements impractical.

The Commonwealth of Pennsylvania, Department of Environmental Resources, Municipal Waste Regulations (2) require all of the performance standards for daily cover included in the RCRA Subtitle D regulations, however, with respect to the "control of fire" requirement, Section 273.232 (b)(4) of the municipal waste regulations and Section 288.232(c)(4) of the residual waste regulations both indicate that daily cover must meet the performance standard of being noncombustible (2,3).

II. DEFINITION OF COMBUSTIBLE & NONCOMBUSTIBLE -

The dictionary (4) defines "combustible" as "capable of combustion" and subsequently defines "combustion" as (1) an act or instance of burning, and (2) a chemical process (as an oxidation) accompanied by the evolution of light and heat (3,4). It naturally follows then that "noncombustible" means incapable of combustion, incapable of burning, or incapable of participating in a chemical process yielding light and heat. The dictionary further defines the correctness of this conclusion (5), indicating that "non-" as a prefix means: (1) not, other than, reverse of, or absence of, or (2) lacking the usual, especially positive, characteristics of the thing specified.

III. HEAT OF COMBUSTION -

In the common, conventional world, the combustion or burning, defined above, usually involves oxygen (from the air) combining in a chemical process with another material, often called "the fuel", yielding the heat and light as an energy output or yield. The amount of heat produced by this combustion process can be measured and is defined as the Heat of Combustion or the Fuel Value.

When pure substances, like methane, are burned the Heat of Combustion is defined with respect to the gram-molecular weight (mole) of the material consumed in the oxidation process. Under these conditions, the Heat of Combustion of a substance is the amount of heat evolved by the combustion of one gram-molecular weight of the substance (6).

Most combustion or burning processes do not involve pure substances, but mixtures of substances each of which have their respective Heat of Combustion. When these mixtures are very complex, like coal or wood, it is more convenient to express the Heat of Combustion on the basis of weight, not moles. The National Fire Protection Association Handbook, for instance, uses the following definition for the Heat of Combustion: The heat released by the complete combustion of a unit mass of combustible material. This is a measure of the maximum amount of heat that can be released by a certain mass of combustible material (7).

The National Fire Protection Association Handbook extends and broadens the definition of Heat of Combustion as follows: The Heat of Combustion is the amount of heat released during a substance's complete oxidation (combustion, i.e., conversion to carbon dioxide and water). Heat of Combustion, commonly referred to as calorific, or fuel value, depends upon the kinds and numbers of atoms in the molecule as well as upon their arrangement. The values are commonly expressed in Joules per gram, but are sometimes reported in BTUs per pound or calories per gram (1.0 BTU/pound = 2.32 Joules/gram, and 1.0 calorie/gram = 4.18 Joules/gram) (8).

Somewhat more in line with the dictionary definition having to do with "...accompanied by the evolution of light and heat...", conventional chemical engineering textbooks define the Heat of Combustion as follows (9,10):

The Heat of Combustion of a substance is the Heat of Reaction resulting from the oxidation of the substance with molecular oxygen.

IV. HEATS OF REACTION, FORMATION, AND COMBUSTION -

A. THERMODYNAMIC RELATIONSHIPS -

All chemical reactions are accompanied by either an absorption or an evolution of energy, which usually manifests itself as heat. The science of thermochemistry deals with the changes of energy in chemical reactions (9).

The Heat of (a chemical) Reaction is the heat absorbed, or released, in the course of the reaction, or, in a more general sense, it is equal to the change in enthalpy of the system for the reaction proceeding at constant pressure. This Heat of Reaction is dependent not only on the chemical nature of each reacting material and product, but also on their physical states. For purposes of organizing thermochemical data, it is necessary to define a Standard Heat of Reaction which may be recorded as a characteristic property of the reaction, and from which Heats of Reaction under other conditions may be calculated. The Standard Heat of Reaction is defined as the change in the enthalpy resulting from the procedure of the reaction under a pressure of 1.0 atmosphere, starting and ending with all materials at a constant temperature of 25C (9).

The Heat of Formation of a chemical compound is a special case of the Standard Heat of Reaction, wherein the reactants are the necessary elements, and the compound in question is the only product formed. Heats of Formation are always expressed with reference to a standard state. The molal Heat of Formation of a compound represents, unless otherwise stated, the Heat of Reaction, when 1.0 gram-molecular weight (mole) of the compound is formed from the elements in a reaction beginning and ending at 25C, and at a pressure of 1.0 atmosphere, with the reacting elements originally in the states of aggregation which are stable at these conditions of temperature and pressure. The Heat of Formation of a compound is positive when its formation from the elements is accompanied by an increase in enthalpy (6,9).

A compound whose Heat of Formation is negative is termed an exothermic compound. If the Heat of Reaction is positive, it is called an endothermic compound (9).

For reference, thermodynamic conventions define that: (1) when heat is evolved in a reaction, corresponding to a decrease in enthalpy, the reaction is termed to be exothermic; (2) when heat is absorbed in a reaction, corresponding to an increase in enthalpy, the reaction is termed to be endothermic (9).

V. COMBUSTIBILITY & NONCOMBUSTIBILITY CONCLUSIONS -
These referenced definitions are comprehensive and allow the following conclusions:

(1) The combustion process yields heat;

(2) The combustion process is the result of a material reacting with oxygen;

(3) The combustion process, yielding heat, decreases enthalpy, and therefore is exothermic;

(4) The Heat of Reaction for a combustion process is exothermic;

(5) This Heat of Reaction is equal to the Heat of Combustion of a material (fuel) involved in the combustion (oxidation, burning) process;

(6) The Heat of Combustion is the measure of the heat released during the combustion process;

(7) Materials with larger Heats of Combustion are more combustible and those with smaller Heats of Combustion are less combustible;

(8) Materials with Heats of Combustion equal to zero are the least combustible and would be considered noncombustible.

Therefore, the measure of combustibility or noncombustibility must be the
HEAT OF COMBUSTION
of the material - if the value is exothermic, the material is combustible.

The only materials that could be considered noncombustible are those with zero value
HEATS OF COMBUSTION .

VI. DETERMINATION OF NONCOMBUSTIBILITY-

A. MEASUREMENT OF HEAT OF COMBUSTION -

During the ongoing discussion concerning the flammability of Alternative Daily Cover Materials (ADCMs), there have been many comments concerning a testing procedure suitable for evaluating the flammability of ADCMs. Although the flammability of the ADCMs was the original issue - the Subtitle D rules specified "...control of fires..." - in actual fact, within the Commonwealth of Pennsylvania, the issue was noncombustibility, not flammability.

This original mis-direction added some additional confusion to the discussion, but if the facts are reviewed (2,3), it is clear that the issue is noncombustibility, and the preceding information defines that evaluating noncombustibility equates to evaluating the Heat of Combustion.

Through consultation with Underwriters Laboratories (11) and the American Society for Testing and Materials, it has been concluded that only one "fire test" is suitable for the evaluation of noncombustibility via the Heat of Combustion measurement (12), and that procedure is the ASTM E1354, "Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter". This test procedure is commonly referred to as the Cone Calorimeter Test (12).

It is important to understand the scope and the significance of this test procedure - note bold highlights.

B. ASTM E1354 SCOPE (12) -

(1) This fire test response standard provides for measuring the response of materials exposed to controlled levels of radiant heating with or without an external ignitor.

(2) This test method is used to determine the ignitability, heat release rates, mass loss rates, effective heat of combustion, and visible smoke development of materials and products.

(3) The rate of heat release is determined by measurement of the oxygen consumption as determined by the oxygen concentration and the flow rate in the exhaust product stream. The effective heat of combustion is determined from a concomitant measurement of specimen mass loss rate, in combination with heat release rate.

(4) Specimens may be exposed to heating fluxes ranging from 0 to 100 kW/sq. meter. External ignition, when used, is by electric spark. The normal specimen testing orientation is horizontal.

(5) Ignitability is determined as a measurement of time from initial exposure to time of sustained flaming.

(6) This test method has been developed for use for material and product evaluations, mathematical modeling, design purposes, or development and research.

C. ASTM E1354 SIGNIFICANCE AND USE (12) -

(1) This test method is used primarily to determine the heat evolved in, or contributed to, a fire involving products of the test material. Also included is a determination of the effective heat of combustion, mass loss rate, the time to sustained flaming, and smoke production.

(2) This test method is applicable to various categories of products and is not limited to representing a single fire scenario.

The other "fire test" procedure that has been supported specifically by the tarpaulin/geotextile manufacturers is ASTM E84, "Standard test Method for Surface Burning Characteristics for Building Materials". This test is commonly called the Steiner Tunnel Test (13).

It is important to understand the scope and the significance of this test procedure - note bold highlights.

D. ASTM E84 SCOPE (13) -

(1) This test method for the comparative surface burning behavior of building materials is applicable to exposed surfaces, such as ceilings or walls, provided that the material or assembly of materials, by its own structural quality or the manner in which it is tested and intended for use, is capable of supporting itself in position or being supported during the test period. These tests are conducted with the material in the ceiling position.

(2) The purpose of this test method is to determine the relative burning behavior of the material by observing the flame spread along the specimen.

(3) The use of supporting materials on the underside of the test specimen may lower the flame spread index from that which might be obtained if the specimen could be tested without such a support, and the test results do not necessarily relate to indices obtained by testing materials without such support.

(4) Testing of materials that melt, drip, or delaminate to such a degree that the continuity of the flame front is destroyed, results in low flame spread indices that do not relate directly to indices obtained by testing materials that remain in place.

E. ASTM E84 SIGNIFICANCE AND USE (13) -

(1) This test method is intended to provide only comparative measurements of surface flame spread and smoke density measurements with that of select grade red oak and inorganic reinforced cement board surfaces under specific fire exposure conditions described by the test procedure.

(2) This test method exposes a nominal 24 foot long by 20 inch wide specimen to a controlled airflow and flaming fire exposure adjusted to spread the flame along the entire length of the select grade of red oak specimen in 5.5 minutes.

(3) This test method does not provide for the following:

(a) Measurement of heat transmission through the tested surface.
(b) The effect of aggravated flame spread behavior of an assembly resulting from the proximity of combustible walls and ceilings.
(c) Classifying or defining a material as noncombustible, by means of a flame spread index by itself.

VII. DETERMINATION OF NONCOMBUSTIBILITY CONCLUSIONS -

(1) The Heat of Combustion can be measured by the ASTM E1354 Cone Calorimeter procedure;

(2) The ASTM E1354 procedure tests samples in the horizontal position;

(3) The ASTM E1354 procedure determines the heat evolved or contributed to a fire;

(4) The ASTM E1354 procedure is not limited to representing a single fire scenario.

(5) The ASTM E84 Steiner Tunnel Test does not measure the Heat of Combustion;

(6) The ASTM E84 procedure evaluates the comparative surface burning behavior of materials;

(7) The ASTM E84 procedure will yield a lower flame spread index when materials that melt, drip or delaminate are evaluated;

(8) The ASTM E84 test method is intended to provide only comparative measurements of surface flame spread;

(9) The ASTM E84 test method does not provide for defining a material noncombustible.

VIII. THE RESULTS OF FLAMMABILITY TESTING -

Rusmar Incorporated has completed an extensive experimental program evaluating the flammability of standard building materials (as references) and alternative daily cover materials, including tarpaulins, geotextiles, conventional shaving cream (as a reference), and Rusmar Incorporated Long Duration Foam.

Additionally, an analysis, based on the existing Commonwealth of Pennsylvania, Municipal Solid Waste rules, Section 273.232(c)(3), relating to the bituminous coal content of cover material, has been submitted, in order to support that the flammability of daily cover materials has already been considered and, minimally, quantified (14).

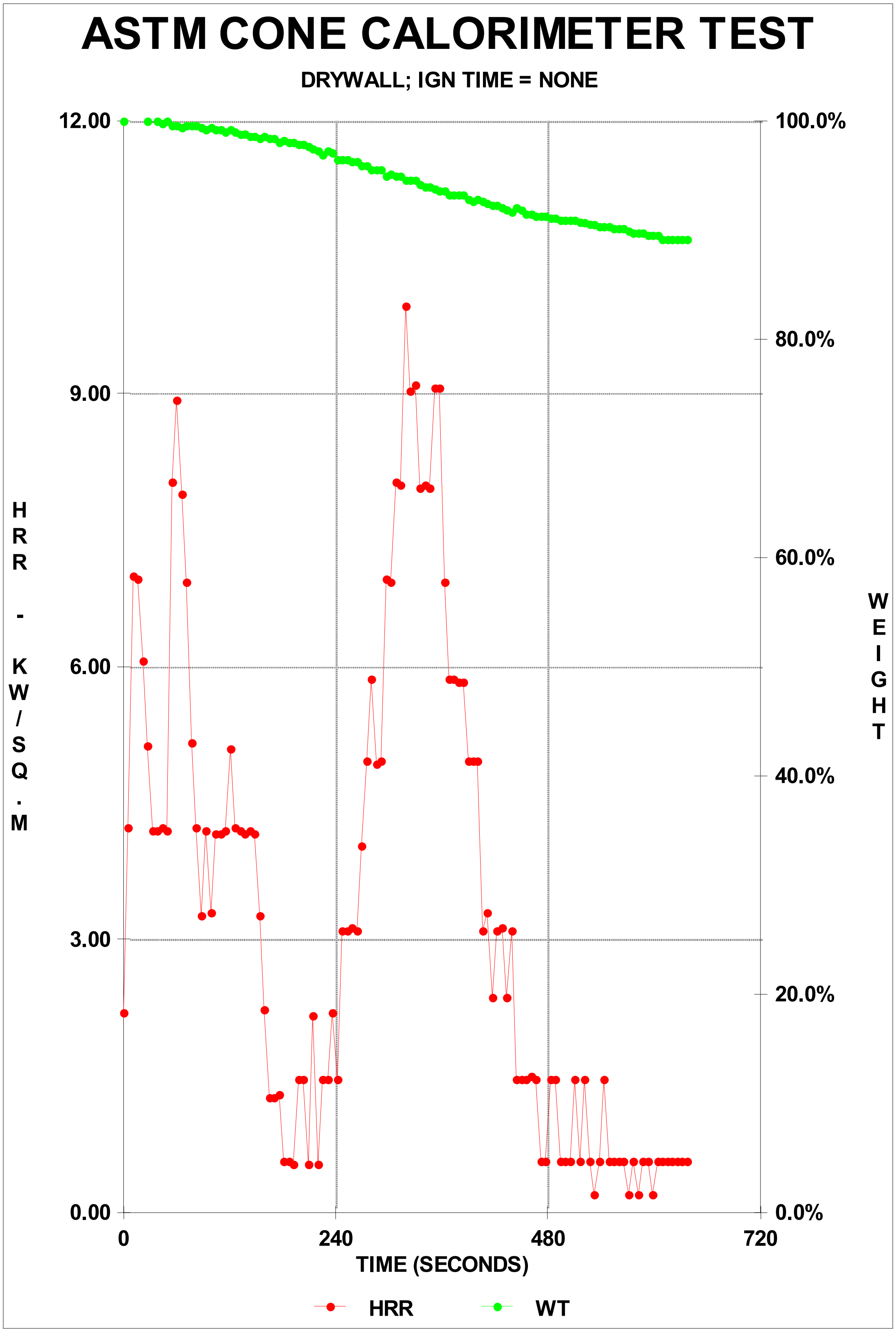
The other documents and publications have been presented at Waste Tech '93 and Waste Expo '94, and, they have all been distributed throughout the regulatory community (15-18).

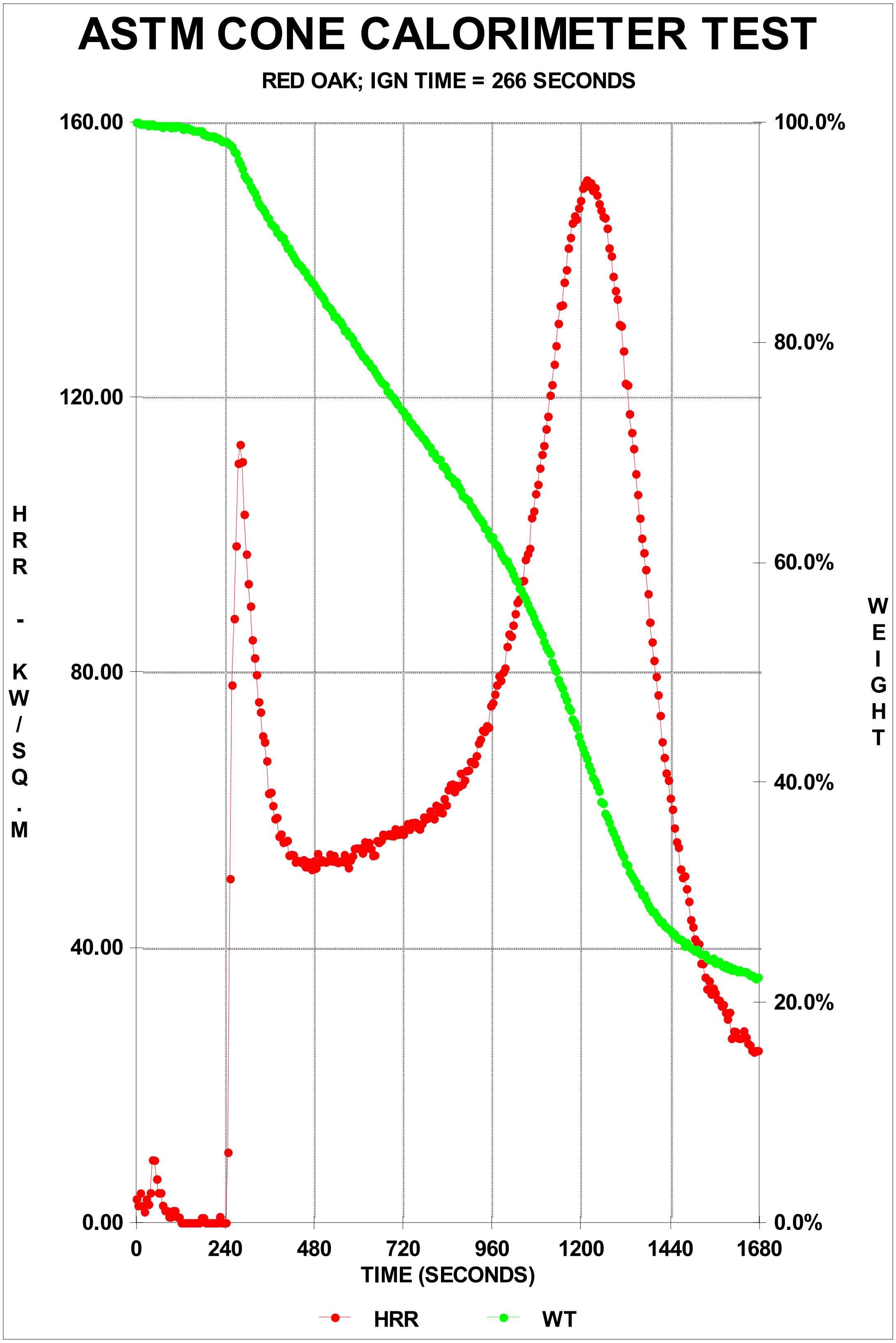
A. THE STANDARDS -

In order to make the comparisons between different samples submitted for flammability testing, Underwriters Laboratories (11) suggested evaluating an array of "conventional" materials that were commonly "understood" so that comparisons could be made to these references instead of using the "true" thermodynamic data developed by the test procedure (12).

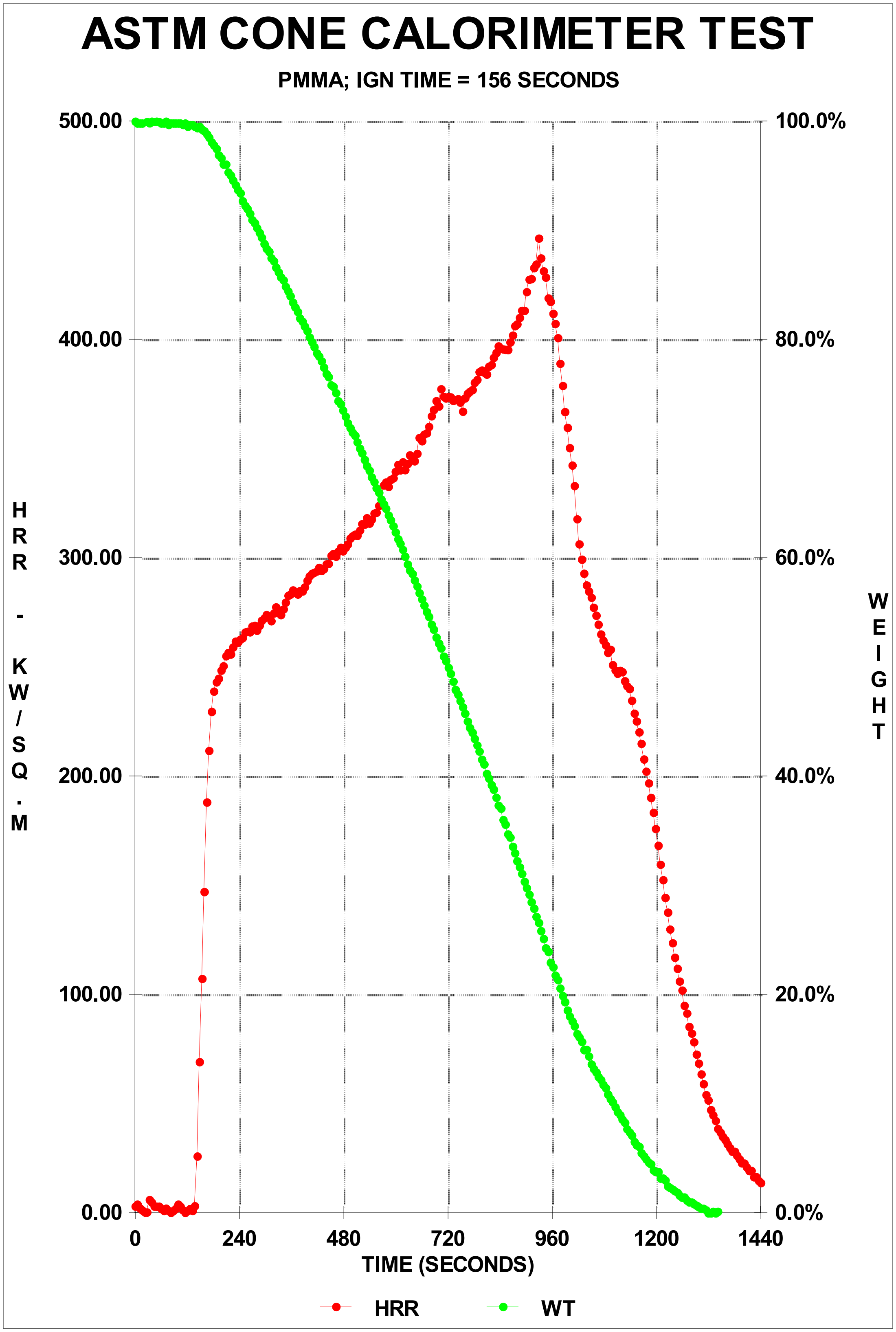
The standards selected were those common to the building industry: dry wall, red oak, Plexiglas (PMMA), plywood, and cardboard, and these data are shown on pages 10 through 14, in order of decreasing ignition times, as listed above. Each graph displays the Heat Release Rate along the left hand ordinate and the weight loss, in percentage, along the right hand ordinate.

The incident radiation was 25 kW/sq. meter, equivalent to a common wastebasket fire (11).

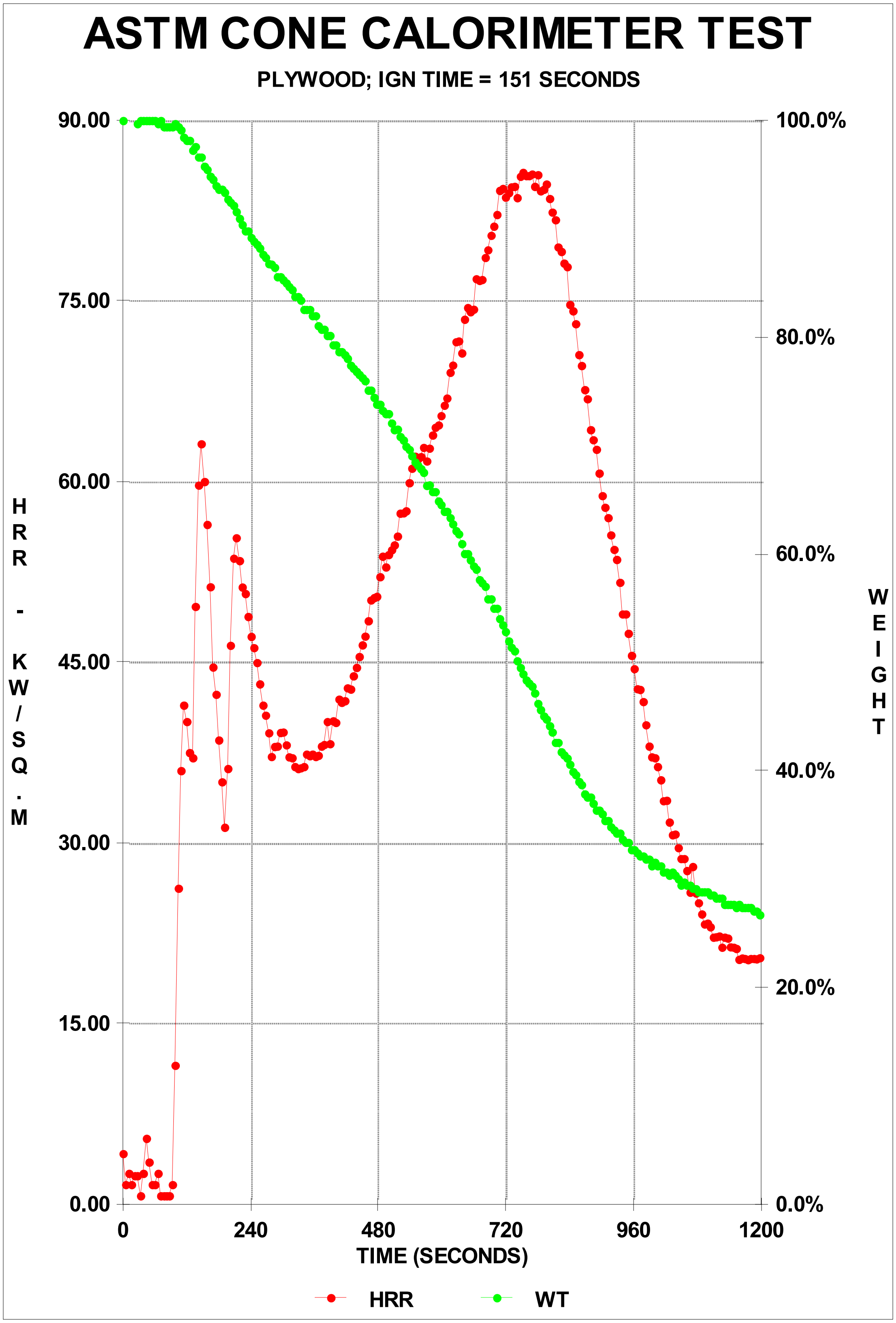

ASTM CONE CALORIMETER TEST
DRYWALL; IGN TIME = NONE
12.00
9.00
6.00
3.00
0.00
HRR - KW/SQ.M
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
WEIGHT
0
240
480
720
TIME (SECONDS)
HRR
WT

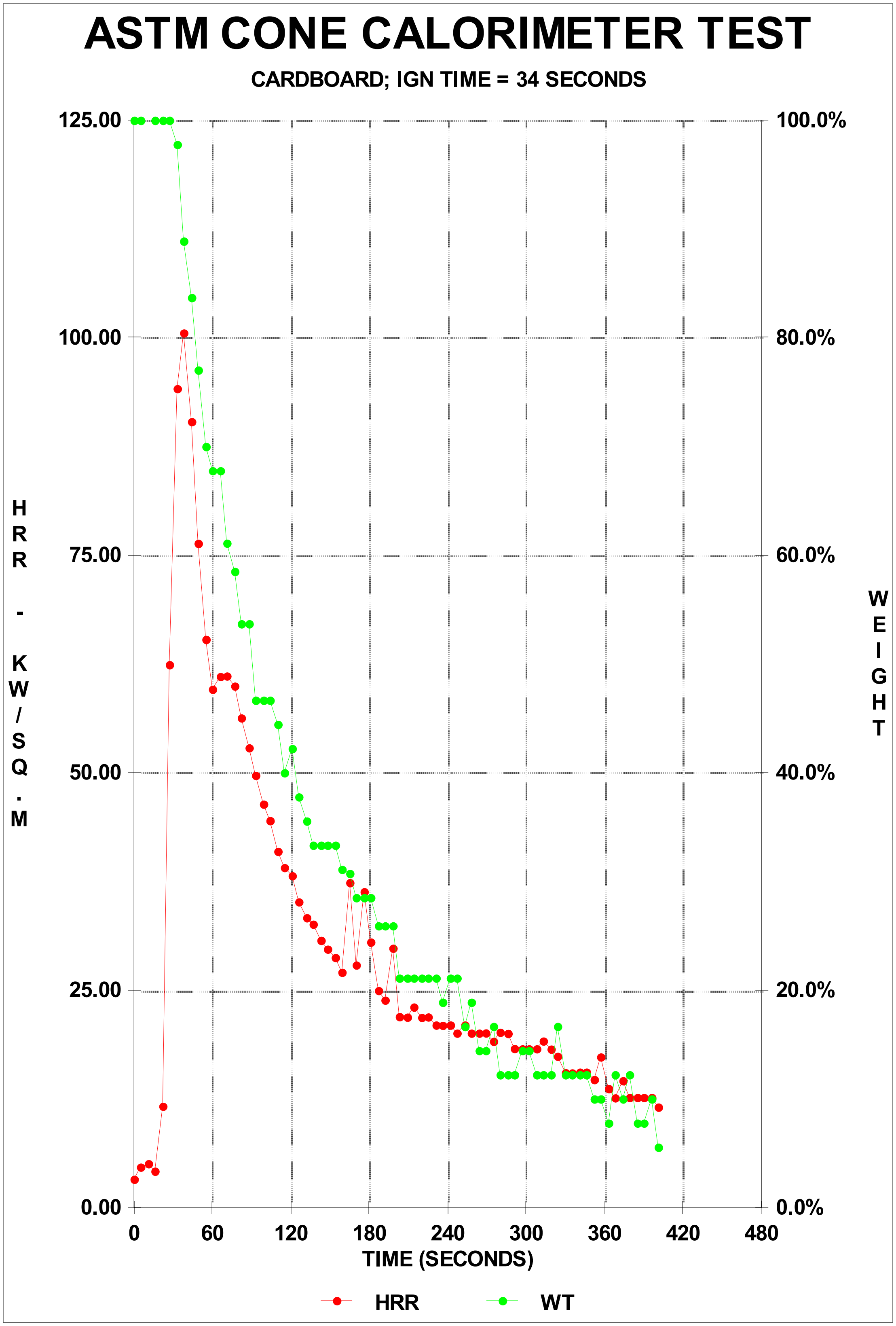


ASTM CONE CALORIMETER TEST
RED OAK; IGN TIME = 266 SECONDS
160.00
120.00
80.00
40.00
0.00
HRR - KW/SQ.M
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
WEIGHT
0
240
480
720
960
1200
1440
1680
TIME (SECONDS)
HRR
WT



ASTM CONE CALORIMETER TEST
PMMA; IGN TIME = 156 SECONDS
HRR - KW/SQ.M
500.00
400.00
300.00
200.00
100.00
0.00
WEIGHT
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
0
240
480
720
960
1200
1440
TIME (SECONDS)
HRR
WT


ASTM CONE CALORIMETER TEST
PLYWOOD; IGN TIME = 151 SECONDS
HRR - KW/SQ.M
WEIGHT
90.00
75.00
60.00
45.00
30.00
15.00
0.00
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
0
240
480
720
960
1200
TIME (SECONDS)
HRR
WT


ASTM CONE CALORIMETER TEST
CARDBOARD; IGN TIME = 34 SECONDS
H R R - K W / S Q . M
125.00
100.00
75.00
50.00
25.00
0.00
W E I G H T
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
0
60
120
180
240
300
360
420
480
TIME (SECONDS)
HRR
WT

B. TARPAULINS & GEOTEXTILES -

The tarpaulins/geotextiles subjected to this testing procedure include the following:

Air Space Saver, Fabrene Incorporated, PO Box 77757, Baton Rouge, LA, 70879-7757 (800-673-1570);

Typar, Reemay - Exxon Chemical, PO Box 511, Old Hickory, TN 37138 (800-321-6271);

Fabrisoil, Phillips Fibers, PO Box 66, Greenville, SC 29602 (803-242-6600);

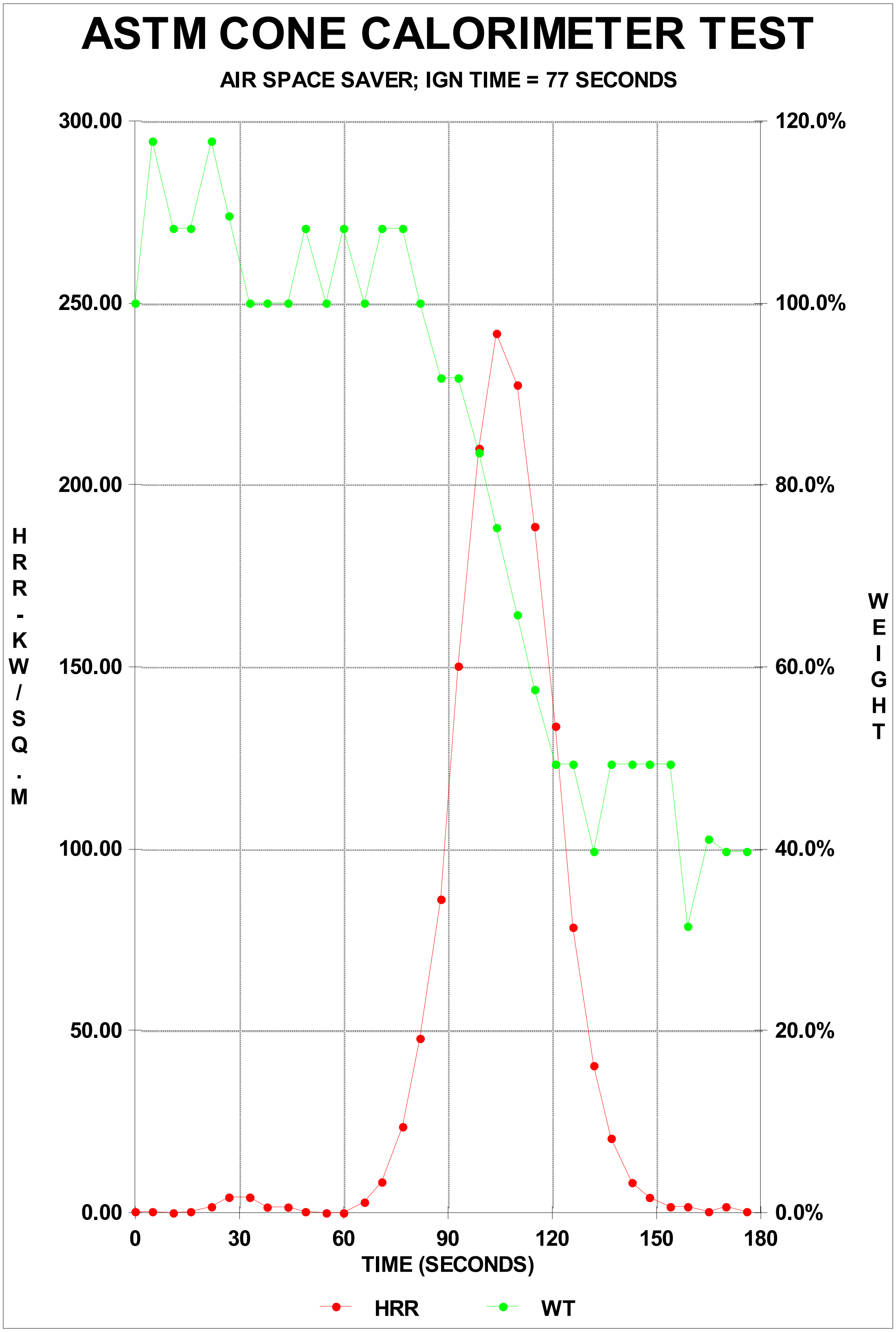
Griffolyn, Reef Industries, PO Box 750250, Houston, TX 77275-0250 (800-231-6074);

Sanicover, Amoco Products, Fluid Systems Incorporated, 32 Triangle Park Drive, Suite 3201, Cincinnati, OH 45246 (800-346-9107); and,

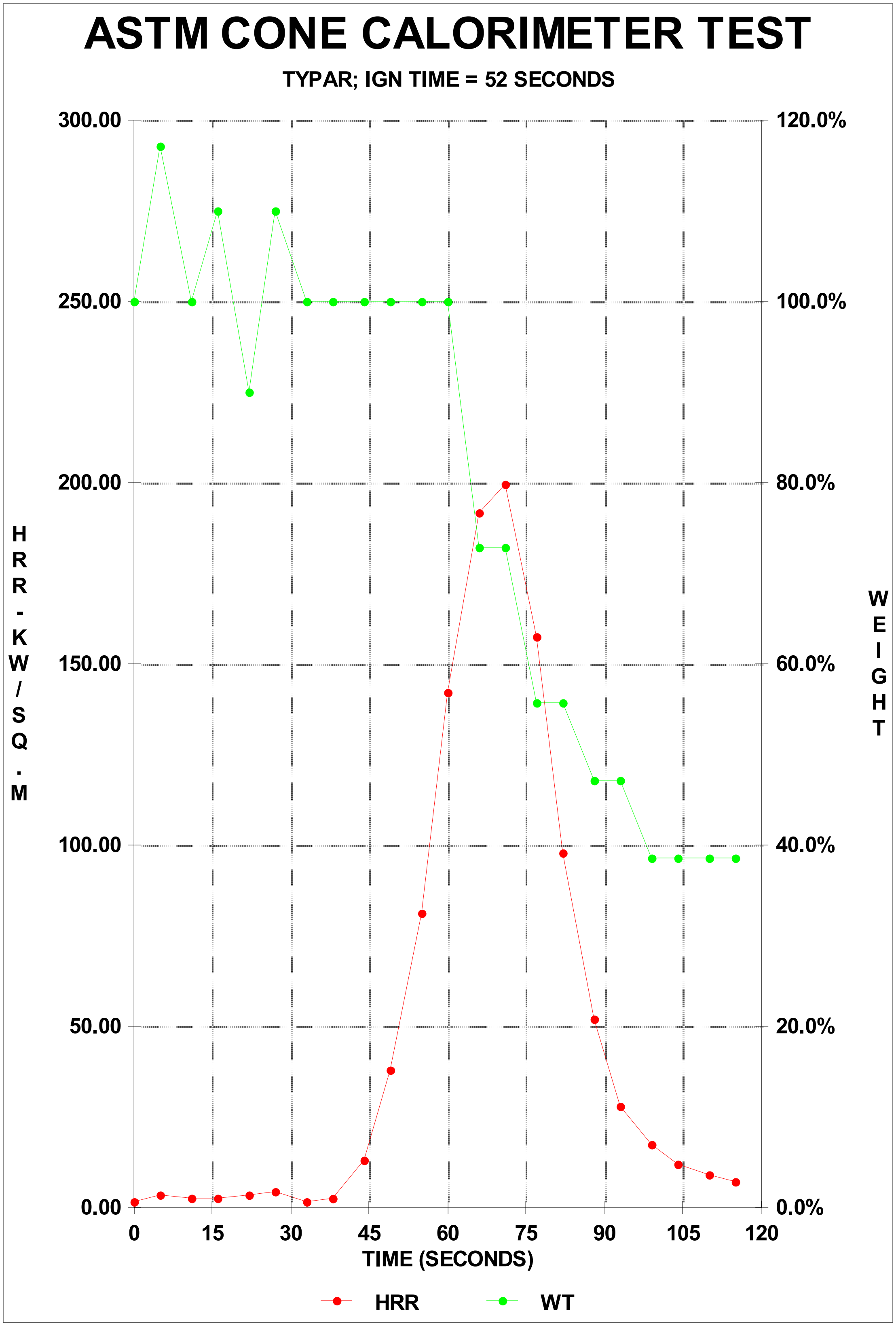
Cormier RPVC-22, Cormier Textile Products, Inc., PO Box 1718, 61 Emery Street, Sanford, ME 04073 (207-490-2400).

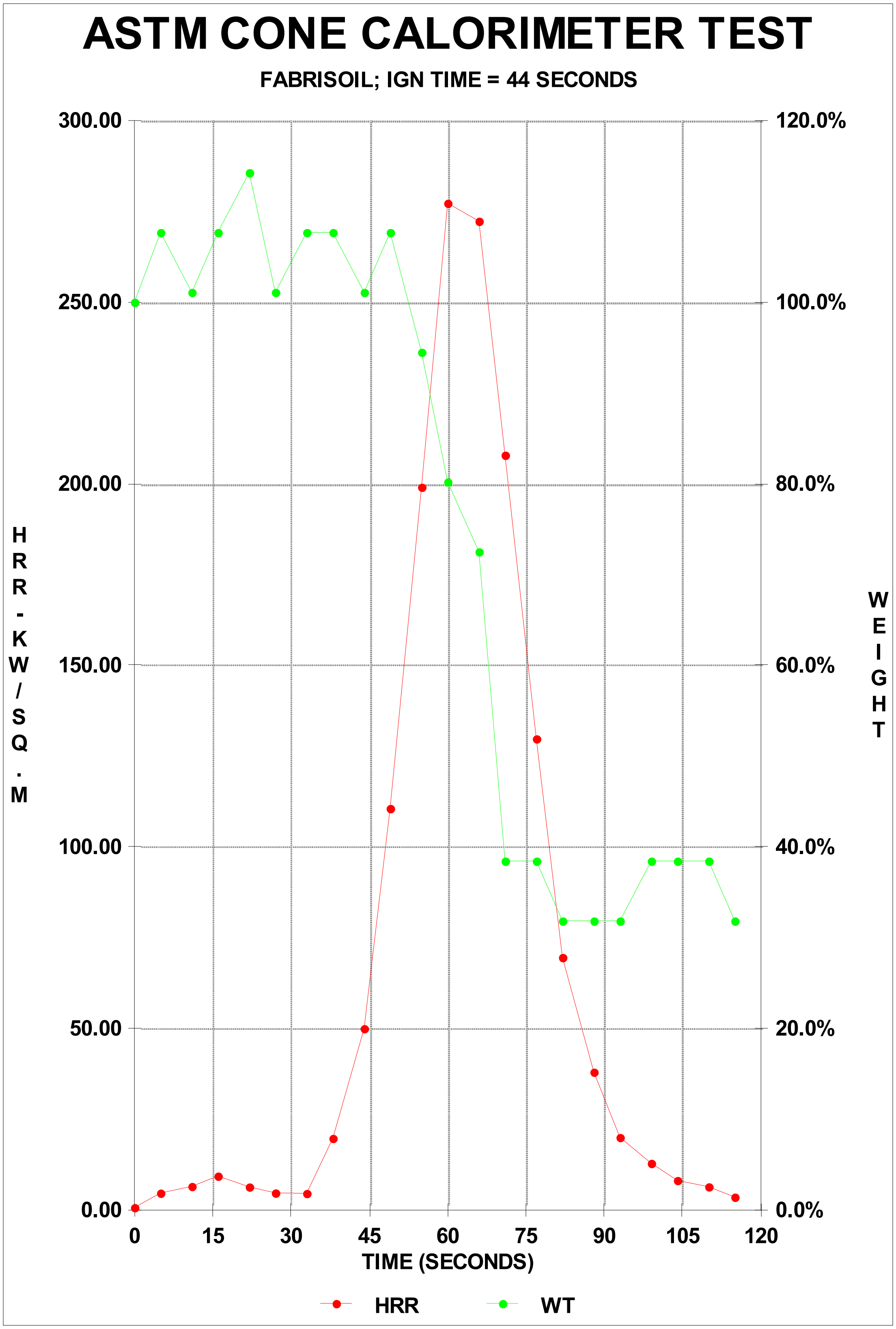
These data are shown on pages 16 through 21, in order of decreasing ignition times, as listed above. Each graph displays the Heat Release Rate along the left hand ordinate and the weight loss, in percentage, along the right hand ordinate.

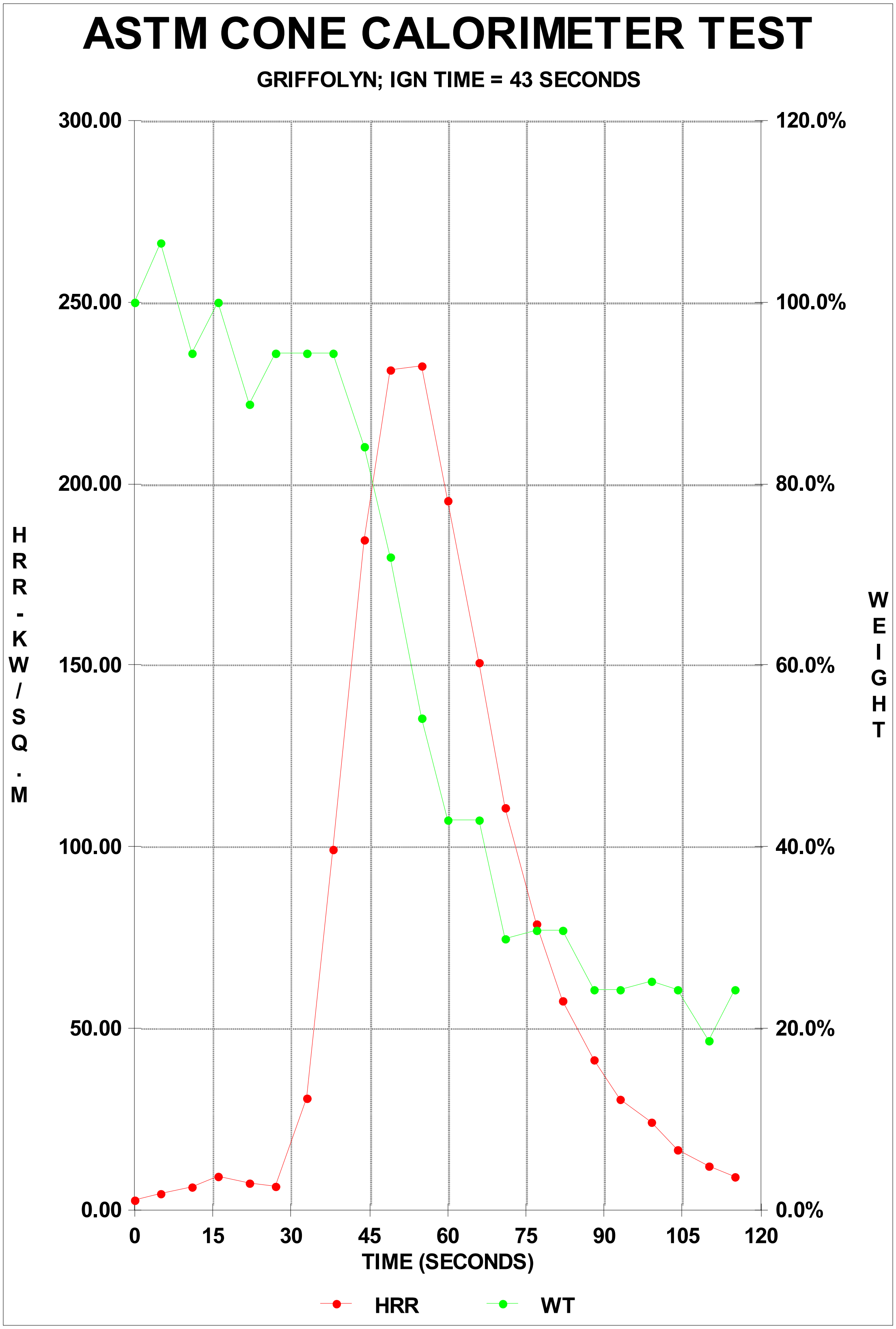
The incident radiation was 25 kW/sq. meter, equivalent to a common wastebasket fire (11), which was the same as the standards' test, above.

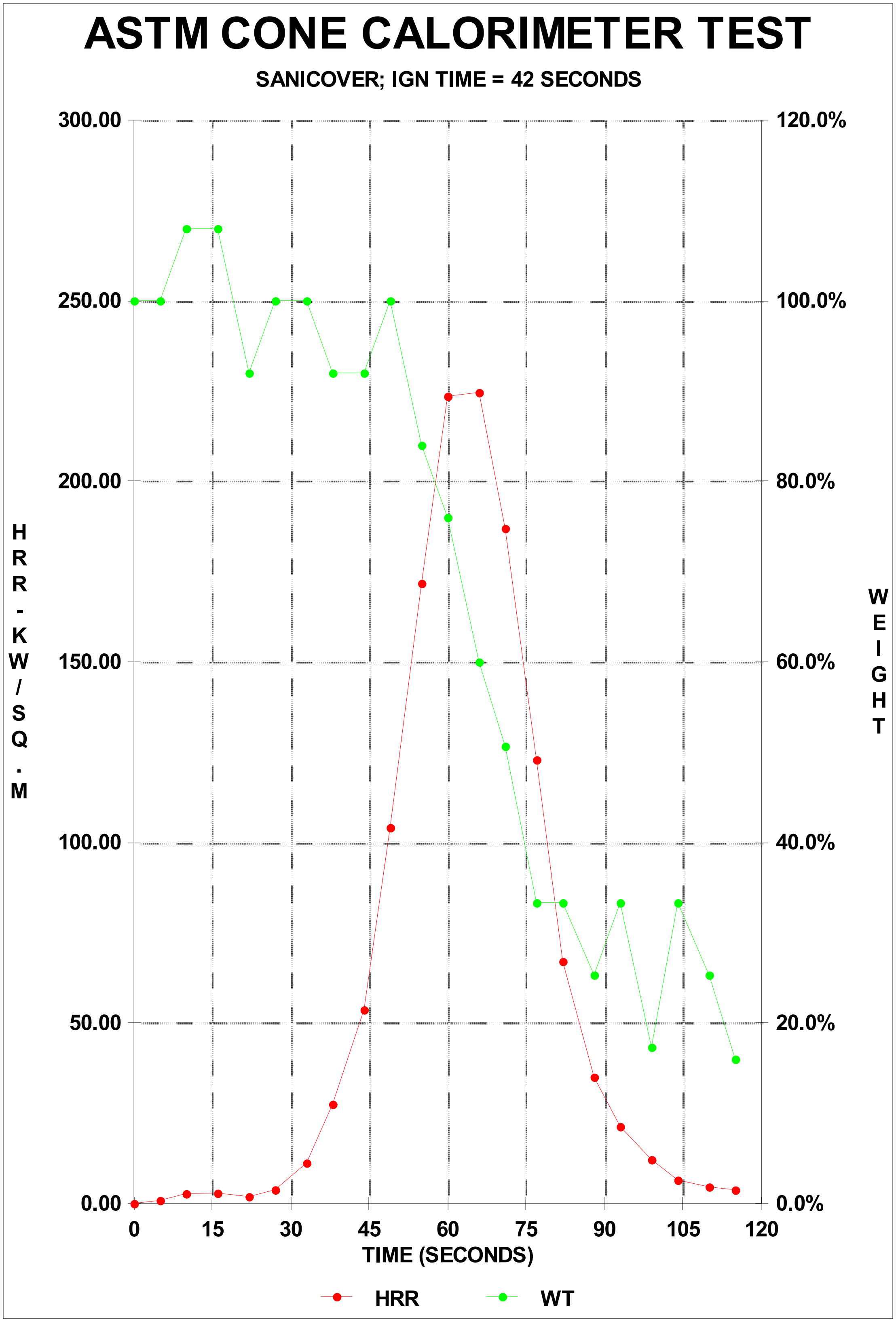


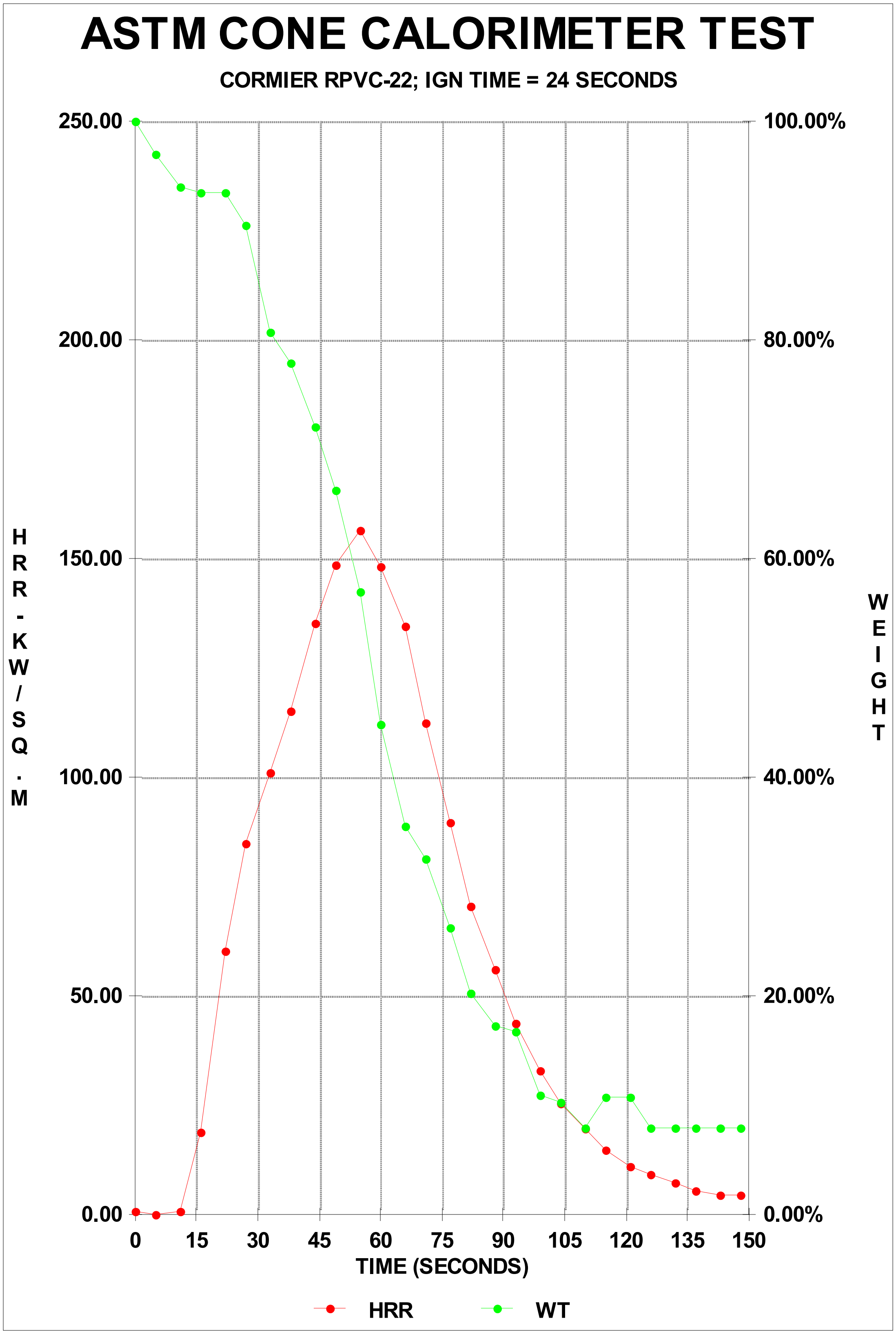
ASTM CONE CALORIMETER TEST
AIR SPACE SAVER; IGN TIME = 77 SECONDS
HRR - KW / SQ . M
WEIGHT
TIME (SECONDS)
300.00
250.00
200.00
150.00
100.00
50.00
0.00
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
0
30
60
90
120
150
180
HRR
WT


ASTM CONE CALORIMETER TEST
TYPAR; IGN TIME = 52 SECONDS
HRR - KW/SQ.M
WEIGHT
300.00
250.00
200.00
150.00
100.00
50.00
0.00
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
0
15
30
45
60
75
90
105
120
TIME (SECONDS)
HRR
WT


ASTM CONE CALORIMETER TEST
FABRISOIL; IGN TIME = 44 SECONDS
HRR - KW / SQ . M
WEIGHT
300.00
250.00
200.00
150.00
100.00
50.00
0.00
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
0
15
30
45
60
75
90
105
120
TIME (SECONDS)
HRR
WT


ASTM CONE CALORIMETER TEST
GRIFFOLYN; IGN TIME = 43 SECONDS
HRR - KW / SQ . M
WEIGHT
TIME (SECONDS)
0.00
50.00
100.00
150.00
200.00
250.00
300.00
0.0%
20.0%
40.0%
60.0%
80.0%
100.0%
120.0%
0
15
30
45
60
75
90
105
120
HRR
WT


ASTM CONE CALORIMETER TEST
SANICOVER; IGN TIME = 42 SECONDS
HRR - KW / SQ . M
WEIGHT
300.00
250.00
200.00
150.00
100.00
50.00
0.00
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
0
15
30
45
60
75
90
105
120
TIME (SECONDS)
HRR
WT


ASTM CONE CALORIMETER TEST
CORMIER RPVC-22; IGN TIME = 24 SECONDS
HRR - KW / SQ . M
WEIGHT
250.00
200.00
150.00
100.00
50.00
0.00
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
0
15
30
45
60
75
90
105
120
135
150
TIME (SECONDS)
HRR
WT

C. FLAME RETARDANT TARPAULINS

Since all of the commonly available tarpaulins/geotextiles used for Alternative Daily Cover Materials are flammable, some of the tarpaulin/geotextile suppliers have been promoting "flame retardant" materials as suitable, since they have ASTM E84 flame spread data indicating a lower flame spread rate than the "conventional" or "non-flame retardant" materials.

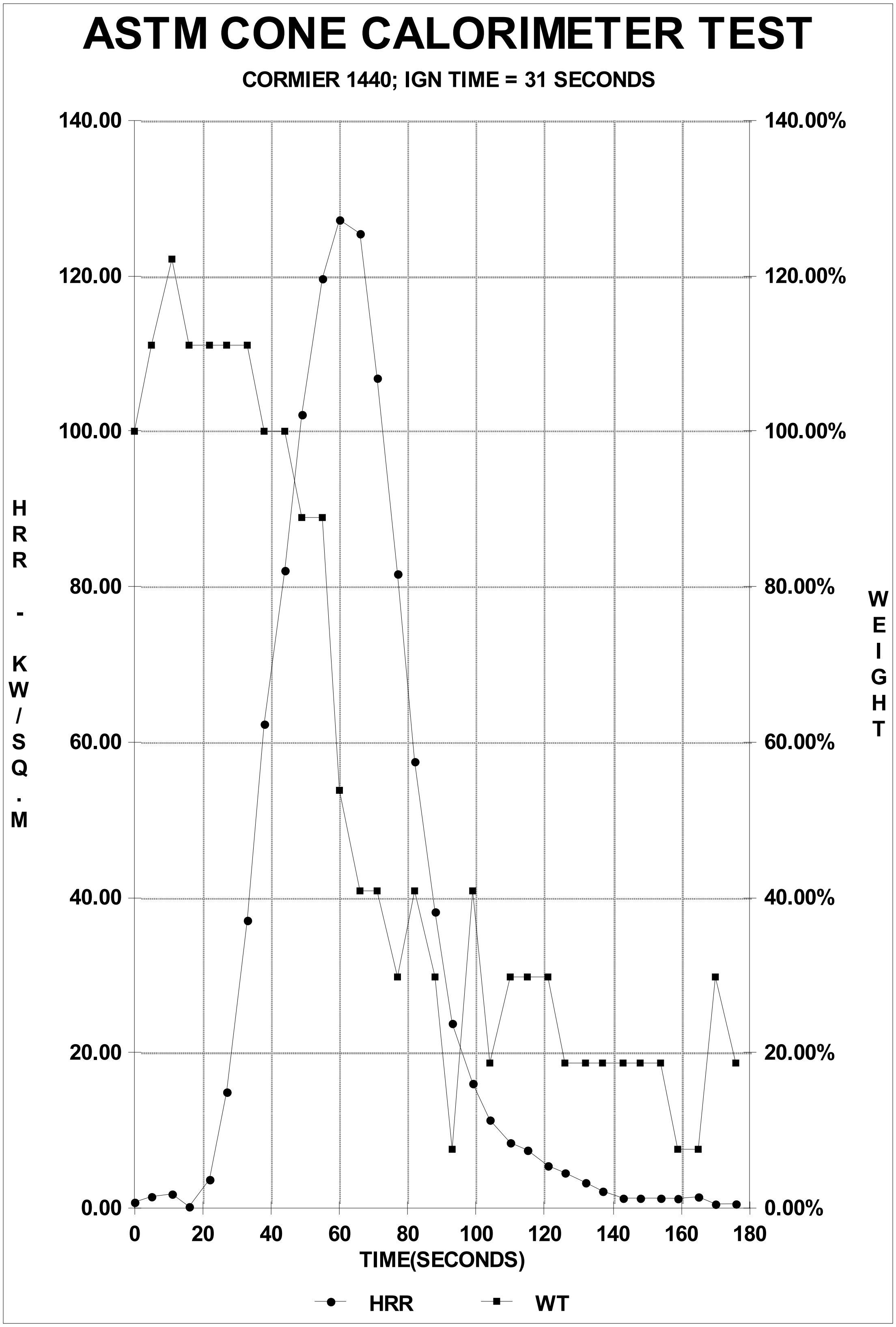
Although Rusmar Incorporated did not doubt the slower flame spread data produced by these "flame retardant" tarpaulins/geotextiles, it was clearly recognized that in order to have a comparative lower flame spread rating the "flame retardant" material must have been burning, and therefore, it must have been combustible.

Through the cooperation of Cormier Textiles Products, Inc., and the Commonwealth of Pennsylvania, Department of Environmental Resources, we obtained samples of Cormier Textiles Products' WP-1440 (conventional, "non-flame retardant") and two different samples of WP-1440-FR (obviously, "flame retardant"). We obtained the second sample of the WP-1440-FR because the first pair of materials, WP-1440 and WP-1440-FR, were so similar with respect to their ASTM E1354 Cone Calorimeter results, it was thought a mistake might have been made.

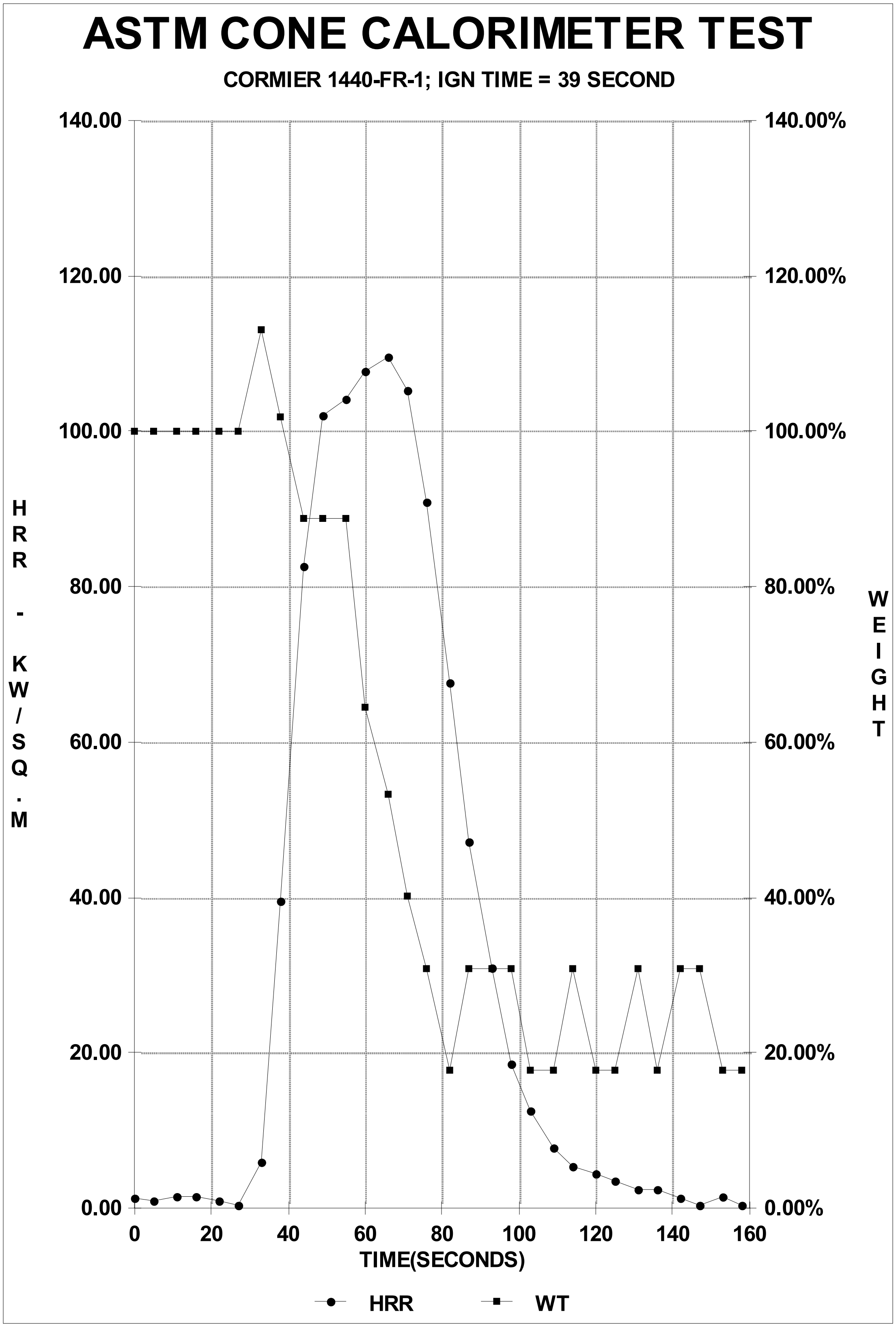
The ASTM E1354 Cone Calorimeter data are shown on page 23-25, and, although there is a slight difference between the WP-1440 and the WP-1440-FR, and between the two WP-1440-FR samples, all three are obviously about equivalent with respect to the ignition times, and the timing and magnitude of the exotherms. It is important to note that the first pair was evaluated at one time, while the second WP-1440-FR sample was evaluated at a later time. If any significance were to be drawn from the slight exothermic differentials, all three samples really need to be rerun at one time. This will simply improve the data set.

For comparison purposes, the heat release data for all three samples have been plotted on a single coordinate system (page 26) in order to more easily observe the similarities or differences. There is no question that all three samples are combustible.

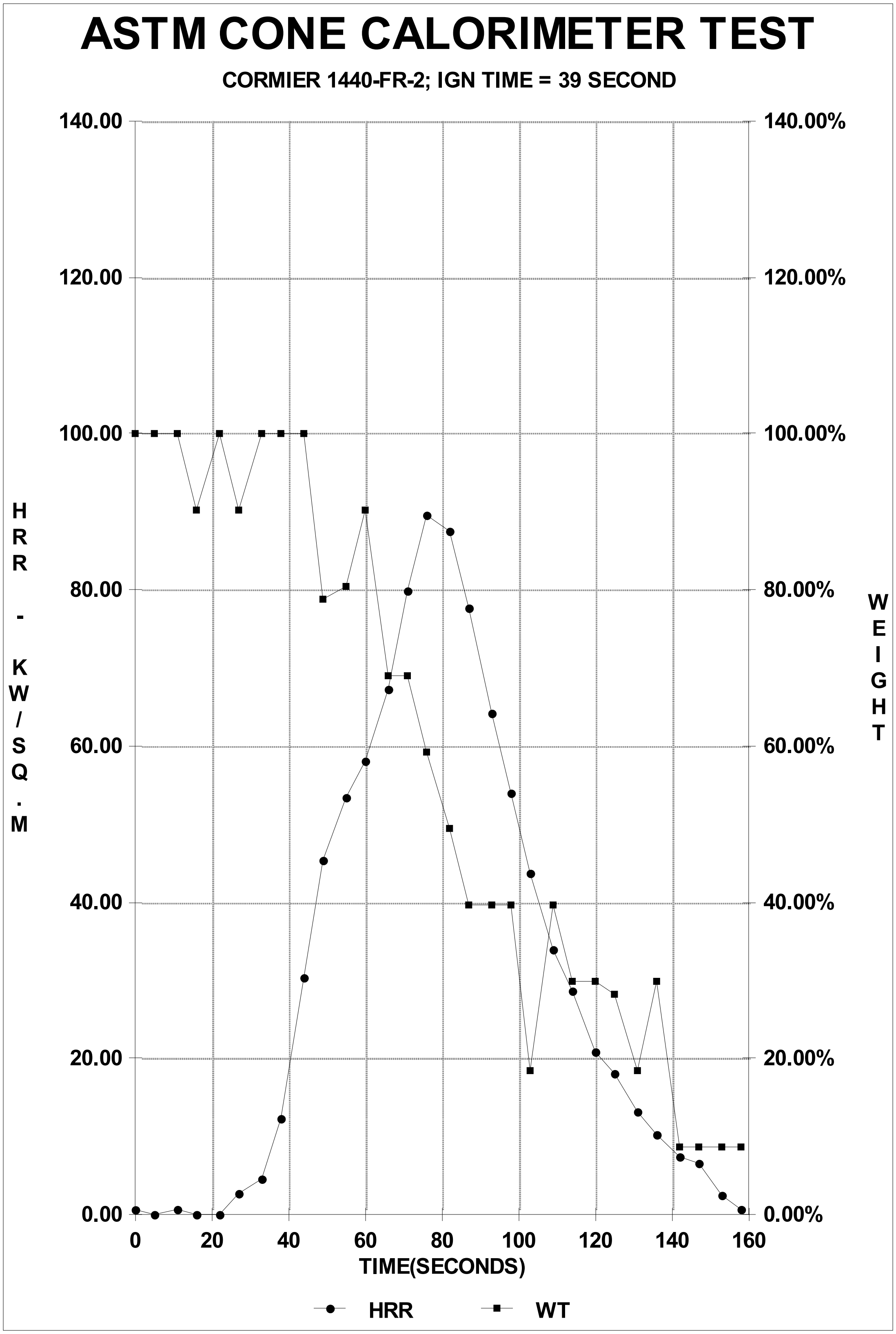
The incident radiation was 25 kW/sq. meter, equivalent to a common wastebasket fire (11), which was the same as the previous tests, above.

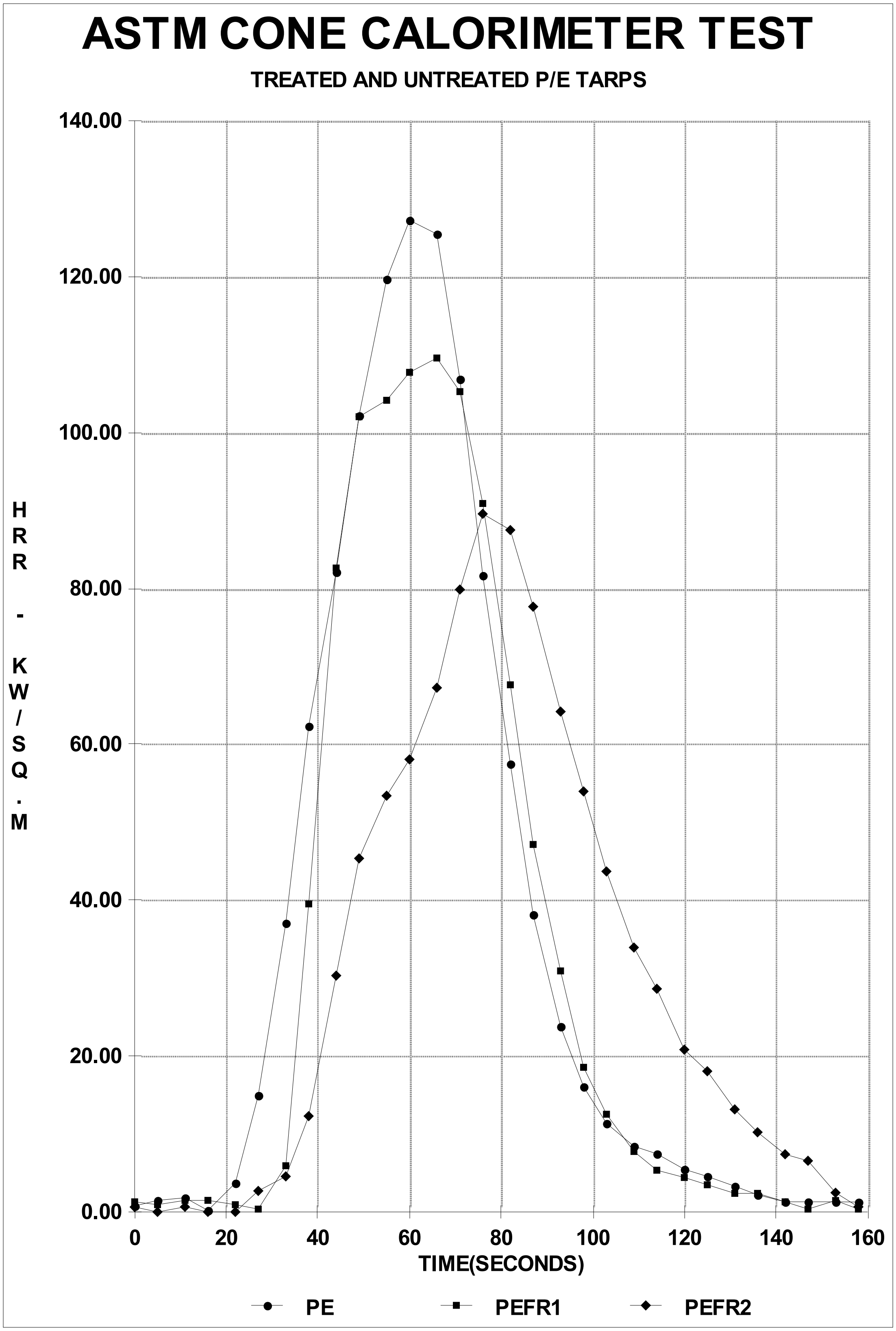


ASTM CONE CALORIMETER TEST
CORMIER 1440; IGN TIME = 31 SECONDS
HRR - KW/SQ.M
WEIGHT
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
140.00%
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
0
20
40
60
80
100
120
140
160
180
TIME(SECONDS)
HRR
WT



ASTM CONE CALORIMETER TEST
CORMIER 1440-FR-1; IGN TIME = 39 SECOND
HRR - KW/SQ.M
WEIGHT
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
140.00%
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
0
20
40
60
80
100
120
140
160
TIME(SECONDS)
HRR
WT


ASTM CONE CALORIMETER TEST
CORMIER 1440-FR-2; IGN TIME = 39 SECOND
HRR - KW/SQ.M
WEIGHT
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
140.00%
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
0
20
40
60
80
100
120
140
160
TIME(SECONDS)
HRR
WT


ASTM CONE CALORIMETER TEST
TREATED AND UNTREATED P/E TARPS
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
HRR - KW/SQ.M
0
20
40
60
80
100
120
140
160
TIME(SECONDS)
PE
PEFR1
PEFR2

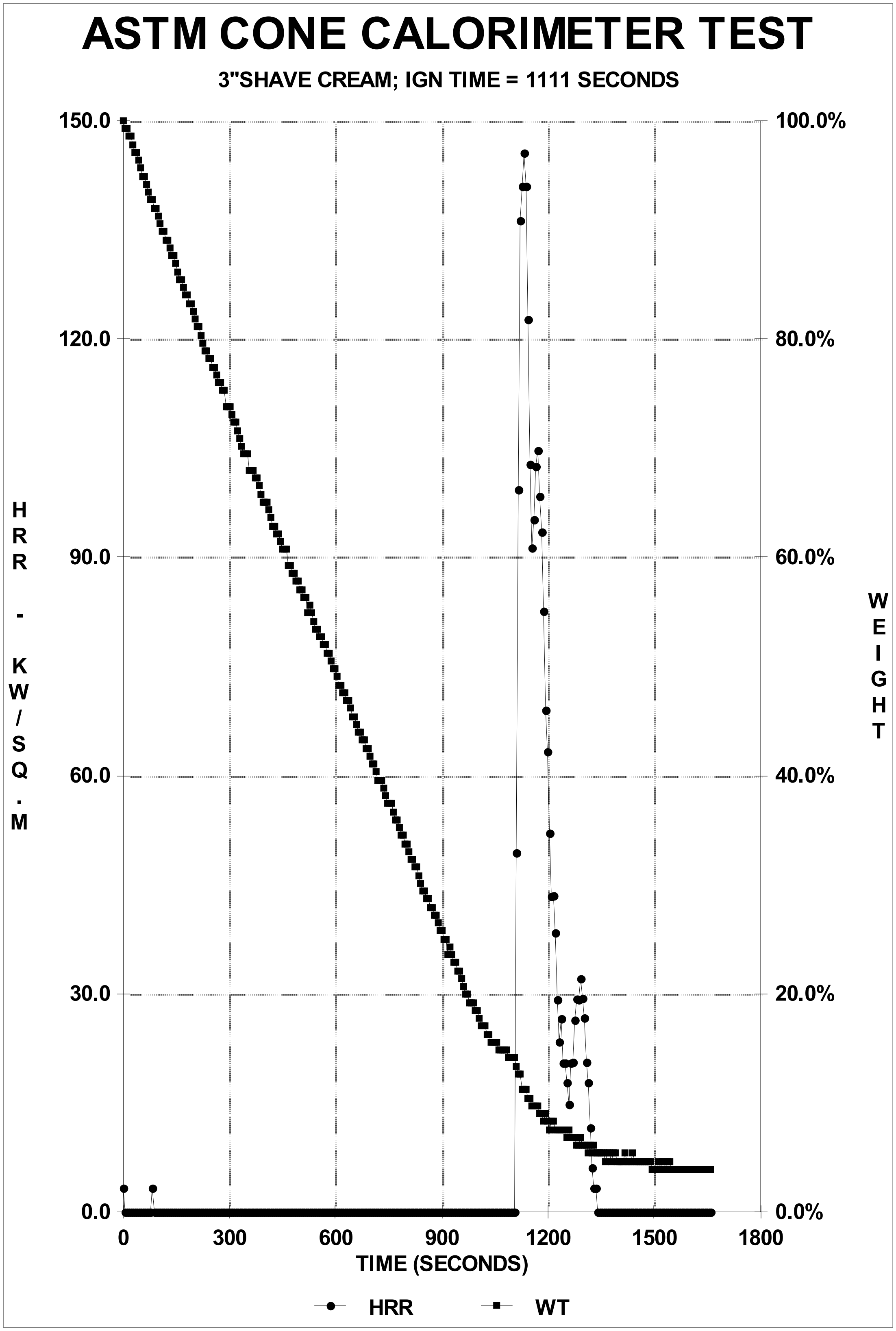
D. COMMERCIAL SHAVING CREAM

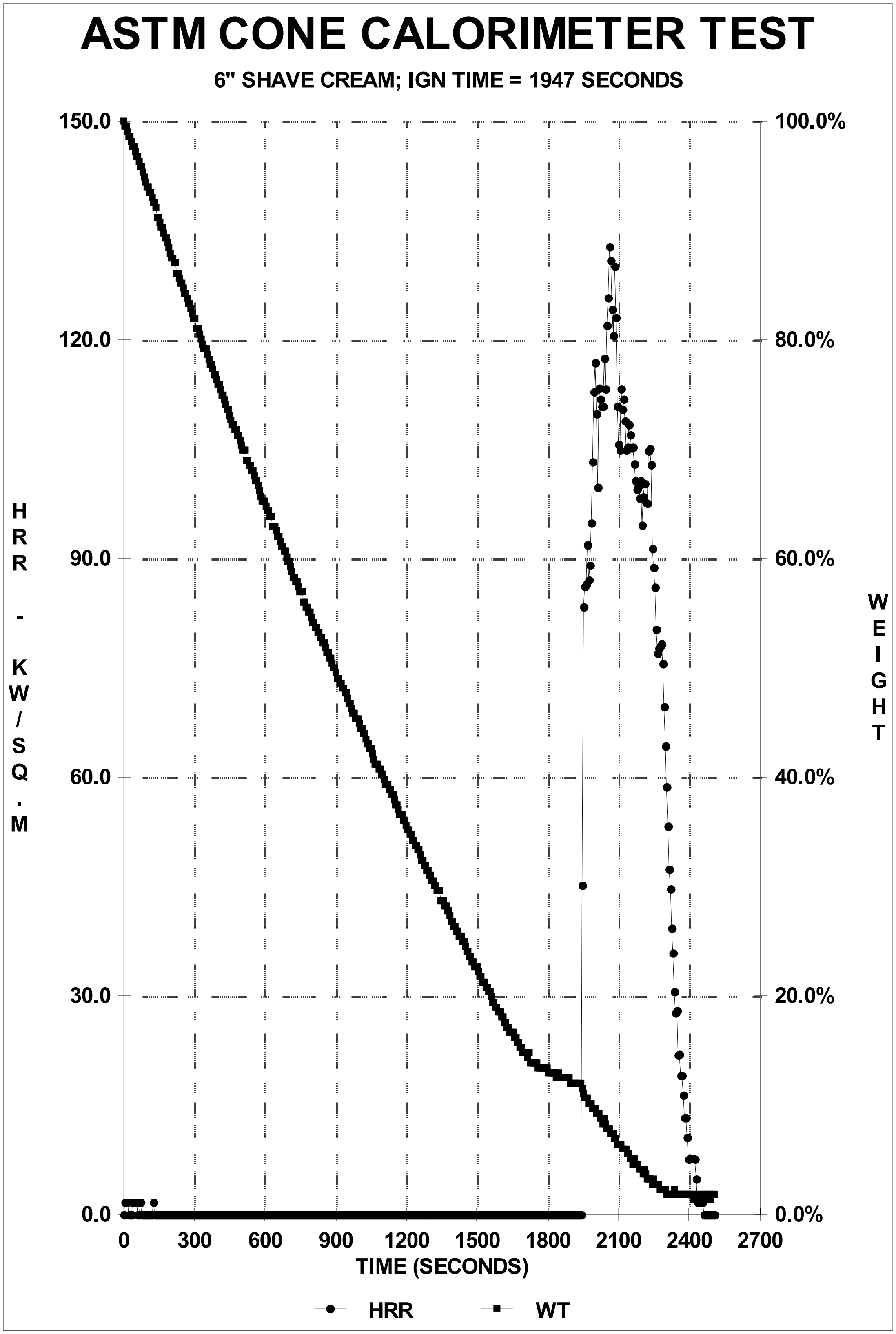
As this development effort continued, it became obvious that one or more alternative daily cover foams would have to be evaluated just to complete the picture. It was also obvious that the conventional ASTM E1354 test procedure (12) was not equipped to handle foam without some adjustments and modifications. Therefore, Underwriters Laboratories and Rusmar Incorporated developed the procedures for using foam in the Cone Calorimeter, but used conventional, commercially available, shaving cream as the source of the foam. This was simply an experimental expedient.

Since alternative daily cover foams are used in the three to six inch thickness range, it was decided to perform the evaluation at both thicknesses. It was recognized, in advance, that the commercial shaving cream would likely show some heat release exotherm since it contains propellant, nonionic surfactant, and fragrance, and, additionally, the solids level would be quite high - probably about 12 to 15% by weight.

The data, shown on pages 28 and 29, support all of these conclusions. The weight loss, in both cases, corresponds to solvent, water. The ignition times, 1111 seconds and 1947 seconds, respectively, correspond to the approximate total evaporation times. The intersection of the weight loss curve with the heat release exotherm corresponds to about 85% weight loss, 15% solids, in both cases, even though the ignition times are about in the ratio of the foam thicknesses, 2:1.

The incident radiation was 25 kW/sq. meter, equivalent to a common wastebasket fire (11), which was the same as the previous tests, above.


ASTM CONE CALORIMETER TEST
3"SHAVE CREAM; IGN TIME = 1111 SECONDS
HRR - KW/SQ.M
WEIGHT
150.0
120.0
90.0
60.0
30.0
0.0
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
0
300
600
900
1200
1500
1800
TIME (SECONDS)
HRR
WT

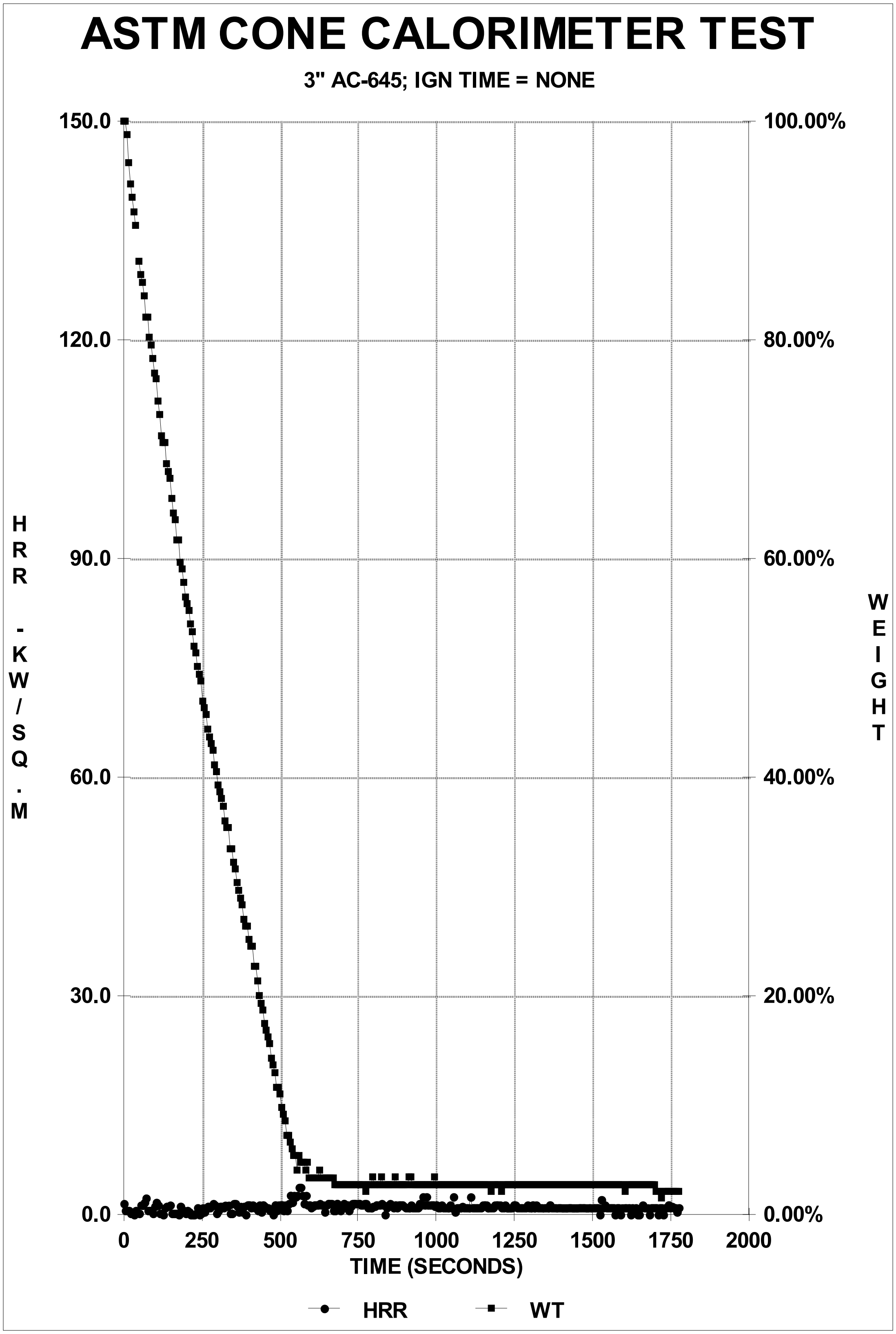


E. RUSMAR INCORPORATED LONG DURATION FOAM

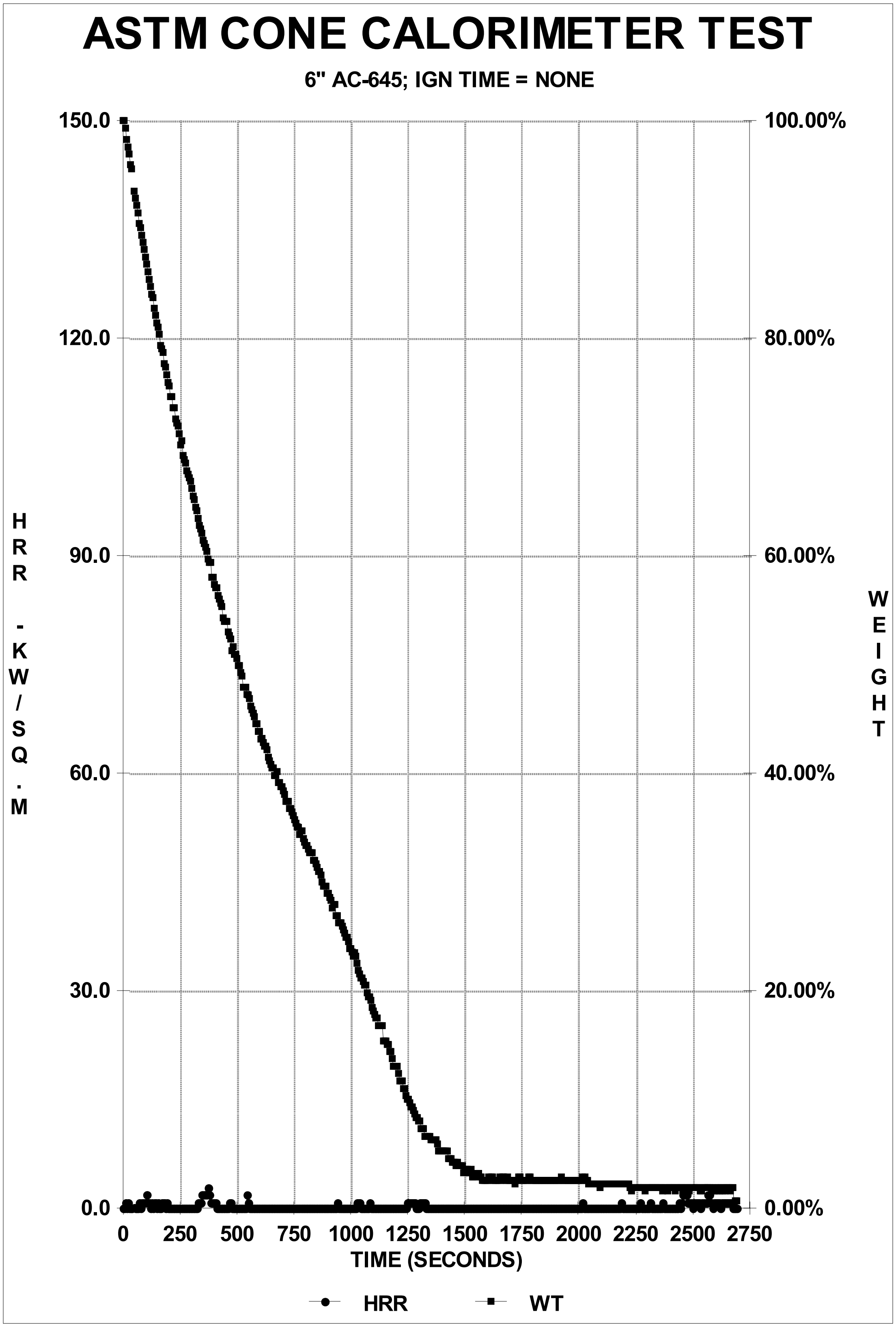
After developing the ASTM E1354 evaluation procedure for alternative daily cover foam materials, collecting the data for the Rusmar Incorporated AC-645 Long Duration Foam was quite simple. A container of AC-645 concentrate and a laboratory pneumatic foam unit were taken to Underwriters Laboratories and the foam for each of the triplicate, three inch and six inch samples was freshly prepared (diluted and foamed). This procedure eliminated any dilution or aging characteristics, which might have altered the consistency of the ASTM E1354 Cone Calorimeter procedure.

The data, shown on pages 31 and 32, clearly define that no ignition occurred, even 1000 seconds (17 minutes) after maximum equilibrium evaporation had been achieved. These data are plotted on the same coordinate system (HRR from 0 to 150 kW/sq. meter) as the shaving cream, and the data show, without question, no exothermicity. The three inch sample was exposed for 1800 seconds (30 minutes), while the six inch sample was exposed for 2700 seconds (45 minutes).

The incident radiation was 25 kW/sq. meter, equivalent to a common wastebasket fire (11), which was the same as the previous tests, above.



ASTM CONE CALORIMETER TEST
3" AC-645; IGN TIME = NONE
HRR - KW/SQ.M
WEIGHT
150.0
120.0
90.0
60.0
30.0
0.0
100.00%
80.00%
60.00%
40.00%
20.00%
0.00%
0
250
500
750
1000
1250
1500
1750
2000
TIME (SECONDS)
HRR
WT



IX. FLAMMABILITY TESTING CONCLUSIONS

(1) The ignition times of all the tarpaulins/geotextiles, standards, references, and alternative daily cover foams are listed, in increasing order, in Table I.

TABLE I

ASTM E1354 CONE CALORIMETER TEST RESULTS

MATERIAL	IGN TIME (SECS)
CORMIER RPVC	24
CORMIER WP-1440	31
CARDBOARD	34
CORMIER WP-1440-FR (#1)	39
CORMIER WP-1440--FR (#2)	39
SANICOVER	42
GRIFFOLYN	43
FABRISOIL	44
TYPAR	52
AIR SPACE SAVER	77
PLYWOOD	151
PLEXIGLAS	156
RED OAK	266
3" SHAVING CREAM	1111
6" SHAVING CREAM	1947
3" LONG DURATION FOAM	INFINITE
6" LONG DURATION FOAM	INFINITE
DRY WALL	INFINITE

(2) Cardboard, and all the tarpaulins/geotextiles, ignite in less than one minute with the exception of Air Space Saver, which takes 77 seconds.

(3) Plywood, Plexiglas, and red oak ignite between 150 seconds and 300 seconds.

(4) Shaving cream ignites between 1000 seconds and 2000 seconds depending upon the thickness.

(5) Rusmar Incorporated, Long Duration Foam, at 3" or 6" thickness, does not ignite.

(6) Dry wall does not ignite.

(7) The Heats of Combustion of Common Plastics, Common Tarpaulins/Geotextiles, Shaving Cream, Rusmar Incorporated Long Duration Foam, and Other Common Materials are listed in Table II.

(8) The Heats of Combustion for the nine tarpaulins/geotextiles evaluated, including most of the commercially available materials, ranges between 14.6 and 33.7 MJ/Kg, with the average being 29.0 MJ/Kg.

(9) The only material with a demonstrated Heat of Combustion equal to zero is Rusmar Incorporated Long Duration Foam.

TABLE II
HEATS OF COMBUSTION OF COMPARATIVE MATERIALS

COMMON PLASTICS (19-22)	
Polyethylene	46.3 MJ/Kg
Polypropylene	46.4 MJ/Kg
Polystyrene	41.4 MJ/Kg
Polyvinyl Chloride	18.0 MJ/Kg
Urea Formaldehyde Foam	15.0 MJ/Kg
Unsaturated Polyester	26.0 MJ/Kg

COMMON TARPAULINS/GEOTEXTILES (15)	
Cormier RPVC	14.6 MJ/Kg
Cormier WP-1440-FR (#2)	27.2 MJ/Kg
Griffolyn	28.7 MJ/Kg
Cormier WP-1440-FR (#1)	29.6 MJ/Kg
Sanicover	31.3 MJ/Kg
Air Space Saver	32.0 MJ/Kg
Cormier WP-1440	32.1 MJ/Kg
Fabrisoil	32.5 MJ/Kg
Typar	33.7 MJ/Kg

SHAVING CREAM	
3" Thick	1.6KJ/Kg
6" Thick	3.0MJ/Kg

RUSMAR INCORPORATED LONG DURATION FOAM	
Three Inch Thick	0.0 MJ/Kg
Six Inch Thick	0.0 MJ/Kg

OTHER COMMON MATERIALS (19-22)	
Charcoal	34.2 MJ/Kg
Coal, Bituminous	30.5 MJ/Kg
Fuel Oil, #1	46.1 MJ/Kg
Gasoline	46.8 MJ/Kg
Paper, Newsprint	19.7 MJ/Kg
Straw	15.6 MJ/Kg
Wood, Dry, Average	20.0 MJ/Kg

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(1) Code of Federal Regulations, Protection of Environment, 40, Part 258, Criteria For Municipal Solid Waste Landfills, Revised as of July 1, 1992.

(2) Commonwealth of Pennsylvania, Pennsylvania Code, Title 25, Department of Environmental Resources, Chapters 271-285, Municipal Solid Waste Regulations, Department of Environmental Resources, Bureau of Waste Management, 14th Floor, Market Street State Office Building, 400 Market Street, Harrisburg, PA 17101-2301, Amended through October 10, 1992.

(3) William F. Pounds, Chief, Division of Municipal and Residual Waste, Bureau of Waste Management, Department of Environmental Resources, Commonwealth of Pennsylvania, "Geotextiles as Alternate Daily Cover", memorandum to Regional Solid Waste Managers, Regional Facilities Managers, Regional Operations Managers, Regional Sanitary Engineers, and Regional Soil Scientists, July 14, 1993.

(4) "Webster's ninth New Collegiate Dictionary", Merriam-Webster Inc., Publishers, Springfield, Massachusetts, USA, 1988, page 262.

(5) "Webster's ninth New Collegiate Dictionary", Merriam-Webster Inc., Publishers, Springfield, Massachusetts, USA, 1988, page 802.

(6) Weast, Robert C., Editor, "Handbook of Chemistry and Physics" 55th Edition, CRC Press, 18901 Cranwood Parkway, Cleveland, Ohio 44128, 1974, page F96.

(7) de Ris, John, "Chemistry and Physics of Fire", in Fire Protection Handbook, Fifteenth Edition, National Fire Protection Association, Quincy, MA, 1981, page 3-7.

(8) de Ris, John, "Chemistry and Physics of Fire", in Fire Protection Handbook, Fifteenth Edition, National Fire Protection Association, Quincy, MA, 1981, page 3-11.

(9) Hougen, Olaf A., Watson, Kenneth M., and Ragatz, Roland A., "Chemical Process Principles. Part One. Material and Energy Balances", John Wiley & Sons, Inc., New York, NY, 1956, pages 293-367.

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(11) Advice and consultation received from the Fire Protection Group, Engineering Services Division, Underwriters Laboratories, Inc., Northbrook, IL.

(12) ASTM E1354-92, "Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter", American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

(13) ASTM E84-91a, "Standard Test Method for Surface Burning Characteristics of Building Materials", American Society for Testing and Materials, 1916 Race

Street, Philadelphia, PA 19103.

(14) Kittle, Paul A., "Daily Cover Flammability", letter to William E. Pounds, May 11, 1993.

(15) Kittle, Paul A. and Schmidt, C.E., "Comparison of Long Duration Foam, Synthetic Tarpaulins, Geotextiles, and Soil as Subtitle D Compliant Daily Cover Materials for Sanitary Landfills", presented at Waste Tech '93, Marina Del Rey, CA, January, 1993.

(16) "Flammability of Plastics & Polymers Used as Alternative Daily Covers - A Summary of Technical Information from the Public Domain", compiled and edited by Paul A. Kittle, April, 1993.

(17) Kittle, Paul A., "Alternative Daily Cover Materials and Subtitle D - The Selection Technique", presented at waste Expo '93, Chicago, IL, June, 1993.

(18) "Alternative Daily Cover Materials and Subtitle D - Control of Fires - A Summary of Technical Information from the Public Domain", compiled and edited by Paul A. Kittle, October, 1993.

(19) Clarke, Frederick B., "Fire Hazards of Materials: An Overview", in Fire Protection Handbook, Fifteenth Edition, National Fire Protection Association, Quincy, MA, 1981, pages 4-2 to 4-8.

(20) Clarke, Frederick B., "Fire Hazards of Materials: An Overview", in Fire Protection Handbook, Seventeenth Edition, National Fire Protection Association, Quincy, MA, 1991, pages 3-15 to 3-20.

(21) Cohn, Bert M. "Plastics", in Fire Protection Handbook, Fifteenth Edition, National Fire Protection Association, Quincy, MA, 1981, pages 4-68 to 4-83.

(22) Cohn, Bert M. "Plastics", in Fire Protection Handbook, Seventeenth Edition, National Fire Protection Association, Quincy, MA, 1991, pages 3-101 to 3-120.