Whitepaper: Clothing for Primary & Secondary FR Protection

How is Primary and Secondary FR Workwear Certified and tested in North America and Europe? What are the Differences between North American NFPA and European EN FR standards?

Both North American and European standards address minimum performance requirements for Primary & Secondary FR workwear. However, whilst the standards for primary FR workwear (NFPA 2112 and EN 11612) are similar and address comparable performance requirements, there are some notable differences. Meanwhile, for Secondary FR Workwear (garments worn over primary FR workwear for protection against other hazards), whilst in Europe a standard defines minimum performance requirements through a specific test, in North America, at least until recently, there has been no such standard or test, only a general requirement that they should be "flame resistant".

This whitepaper looks at the standards in North America and Europe, considers how they are similar, how they differ, and how they can be best used for assessment of combinations of primary FR garments and chemical protective clothing, where both are required *at the same time.*

The similarity of standards for primary FR workwear in both regions is reassuring. However, the lack of a clear standard until recently in North America for secondary FR workwear has led to some confusion, with manufacturers basing claims of "flame resistance" on tests with limited or no relevance.

Furthermore, until the publication of ANSI 203 in 2018, neither US nor EU standards provided for testing of secondary FR (SFR) workwear *in the way they are intended to be used in the real world;* specifically, *when worn over primary FR garments.* Thus, to be confident that chosen SFR clothing is effective, users must go further than the previous standards and make use of the available, relevant tests, especially those defined in ANSI 203.

What is Primary and Secondary FR Workwear?

First, it is important to understand the difference between Primary and Secondary FR Workwear: -

Primary FR Workwear is used to provide users with some level of protection against the risk of contact with flames and heat, and especially against flash fire hazards.

Secondary FR Workwear is not designed to protect against thermal hazards at all. Its purpose it to protect against other hazards – in most cases chemicals in liquid or dust form, and to be worn OVER the Primary FR Workwear, *but without undermining its thermal protective properties.*

This addresses a problem common throughout refining, petrochemical and other industries. Where both types of protection are needed, users commonly wear standard disposable or chemical suits over their primary FR workwear. In fact, in many cases, given that primary FR workwear can be expensive and is often used in very dirty environments, users sometimes wear disposable coveralls over them simply to keep them clean and prolong usable life (frequent washing often degrades FR properties).

However, standard disposable coveralls and chemical protective clothing is generally based on polymers which will ignite and burn.

Is this just theoretical? No. Thermal mannequin testing of layered primary and secondary Fr workwear ensembles (described later in this document) has proved that wearing a simple standard disposable over a primary FR garment can dramatically reduce its effectiveness and result in a substantial increase in body burn compared to the performance of the primary FR garment worn alone. This increase could easily take likely body burn above 50%, the generally accepted threshold that could be the difference between life and death.

Thus, any garments worn over primary FR workwear must not be flammable and must be constructed of fabric that will not ignite, burn, melt, and consequently degrade thermal protection.

Basic Properties of Primary & Secondary FR Workwear			Relevant Standards	
FR Workwear Type	• Must resist ignition • Must not continue to burn or drip molten debris	Must provide resistance to transfer of heat energy from the source to the wearer's skin	Relevant US NFPA Standards	Relevant EU EN Standards
Primary FR Workwear	✓	✓	NFPA 2112	EN 11612
Secondary FR Workwear	✓	✗	NFPA 2113 ANSI 203	EN 14116

Table 1

Thus, if worn over primary FR workwear, in the event of contact with flame, they may do so, transferring heat energy through to the wearer and degrading thermal protection. In the worst cases wearing standard disposable garments over primary FR workwear can completely degrade the thermal protection provided. The effect could be fatal.

> *"…wearing standard disposable garments over primary FR workwear can completely degrade thermal protection provided. The effect could be fatal"*

The principal difference, therefor, in required general properties of primary and secondary FR workwear lies in the need for the former to feature some level of resistance to heat energy transfer, as indicated in **Table 1**.

Standards for Primary FR Workwear

Fire protective clothing, providing the primary protection against flames, heat or

flash fire is certified to either NFPA 2112 in North America or EN 11612 in Europe.

A key property of these garments is an ability not only to resist ignition (a fabric that will ignite and burn will obviously do more damage) but to feature some level of resistance to transfer of heat energy through the fabric to the wearers skin, too rapid heat energy transfer being cause of burn injury. The more effectively heat transfer is resisted, the better the protection and the less likelihood of harmful burns.

Both standards feature similar essential garment design requirements, and whilst having some differences, both reference similar tests of performance. These are indicated, with general descriptions and requirements, in table 2.

Both EN 11612 and NFPA 2112 provide for tests to assess: -

- **resistance to heat transfer** (the key requirement for primary FR workwear)
- **resistance to ignition** (important to prevent a garment igniting and causing more damage)
- **resistance to shrinkage in response to heat** (important as a garment that shrinks will tighten on the body, resulting in more heat energy transfer)
- **Whole Garment Mannequin Test.** An assessment of the protection offered by the whole garment in a simulated flash fire event (important in assessing the effectiveness of the whole garment and in comparing garment performance)

Whilst mandatory in the US standard and optional in the EN test, it is this last that provides users with the best opportunity for both assessment of the effectiveness of the protection provided and for comparison of different primary FR garments or combinations of primary and secondary FR garments.

Table 2: Essential Tests in EU and US Primary FR Workwear

EU Standard EN 11612	Test Type & Requirements	US Standard NFPA 2112
ISO 9151 ✓	**Heat Transfer Resistance Performance** • **Measures resistance to transfer of heat energy through the fabric** • ASTM 2700 features a single test applying a small flame to the underneath of a horizontally suspended fabric sample. A heat sensor above records heat energy transfer (both spaced and contact variants). • EN 11612 contains 5 (optional) heat transfer resistance tests against different forms of heat energy (contact, convective, radiant and molten iron and aluminium splash). • The ASTM F2700 test is roughly equivalent to the ISO 9151 test for convective heat transfer • Whilst the tests ASTM 2700 and ISO 9151 are similar, measurement of heat resistance is done differently: - • The US test assesses Heat Transfer Performance (HTP), the percentage of energy resisted by the fabric. • The European test measures heat flux (the rate of heat transfer), by measuring the time until a specific rise in temperature is detected behind the fabric. • Both feature minimum performance requirements.	ASTM F2700 ✓

ISO 15025 ✓	**Flame Resistance (Vertical Flammability) Test**
	• Applies a small flame to the bottom edge (or in the European test, an option of the centre) of a vertically suspended fabric sample.
	• Assesses the resistance of fabric to ignition and burning when in contact with a small flame
	• Tests are similar with minor differences: -
	  • ISO 15025: Sample Size 200mm x 160mm with 10 second burn
	  • ASTM D6143: Sample size 12" x 3" with a 12 second burn
	• Both tests require no burning and no dripping of molten debris
	• Because the ASTM test requires bottom edge flame contact whereas the EN test allows centre contact, the ASTM tests is marginally more stringent (because the heat remains underneath the sample)
		ASTM D6143 ✓

ISO 17493 ✓ Standard 180 °C (Optional 260 °C)	**Thermal Shrinkage Test** • Assesses shrinkage in response to high temperatures when placed in an oven. Key differences are: - • The standard temperature for NFPA 2112 is 260 °C for 5 minutes • The standard temperature for EN 11612 is 180 °C for 5 minutes (with an option for 260 °C) • Both require the fabric must not shrink more than 10% at 260 °C (in the EN test, 5% at 180 °C	ASTM F2894 ✓ Standard 260 °C
ISO 13506 ✗ Optional – no minimum performance	**Thermal Mannequin Test** • Assesses garment effectiveness of protection against simulated flash fire producing a body map predicted burn injury • Mandatory with specific parameters (burn energy & length, etc) & minimum performance in NFPA standard but optional in EN with no minimum performance required.	ASTM F1930 ✓ Mandatory with min performance

The key difference between NFPA 2112 and EN 11612 is that in the NFPA standard the thermal mannequin test is mandatory, with specified test parameters and minimum performance requirements

Differences in Primary FR Workwear Standards

The parameters of individual tests in these standards do vary but the two major differences are in the heat transfer resistance and thermal mannequin tests.

a. Differences in Heat Transfer Resistance Tests

EN 11612 contains five different tests for heat energy transfer resistance, each dealing with a different type of heat energy flow: -

- **Convective Heat** (energy transferred through a medium such as the plasma of a flame)
- **Radiant Heat** (energy transferred via infra-red waves)
- **Contact Heat** (energy transferred because of direct physical contact)

In the European EN 11612 standard there are also two heat resistance tests for molten metal splash: aluminium, and iron. However, this primarily measures the ability of the fabric to allow molten metal drops to quickly roll off rather than stick.

Nevertheless, these can be useful tests for applications where molten metal splash is a hazard.

In each case the tests measure a time until a heat sensor behind the test fabric records a specific rise in temperature. The longer the time to achieve the specified increase, the better the heat resistance of the fabric. Results are rated as Class 1 to 3 with 3 the highest (or 1 to 4 for radiant heat, the 4th class being specifically used for clothing for high radiant heat resistance such as reflective aluminised garments).

Further, each test is designated a code letter (B to F), and this, along with the classification achieved, is required to be indicated on the garment label making the information easily accessible.

For certification a garment must be tested to at least one of these tests and achieve a minimum class 1. The choice of test selected (it could be one or all five) depends on the intended use of the garment.

However, NFPA 2112 includes only a single, mandatory heat resistance test, featuring contact with a flame in both spaced and contact format and producing a "Heat Transfer Performance" (HTP). This is defined as the level of energy exposed to the fabric minus the level of energy transferring through the fabric. A minimum performance level is required for both spaced and contact settings.

This NFPA test equates roughly to the convective heat test in EN 11612 (ISO 9151), though the way heat transfer resistance is measured is different.

Heat Energy Transfer Tests: Conclusion

Thus, for users of Primary FR Workwear, both standards feature assessment of resistance to heat energy transfer, the key role of primary FR workwear.

However, the more varied tests in EN 11612, considering performance against different types of heat energy, offer greater choice for assessing suitability for specific applications, depending on the type of heat energy transfer likely to be encountered.

In addition, the classification of performance in each test in EN 11612 offers greater ability to compare the performance of different garments.

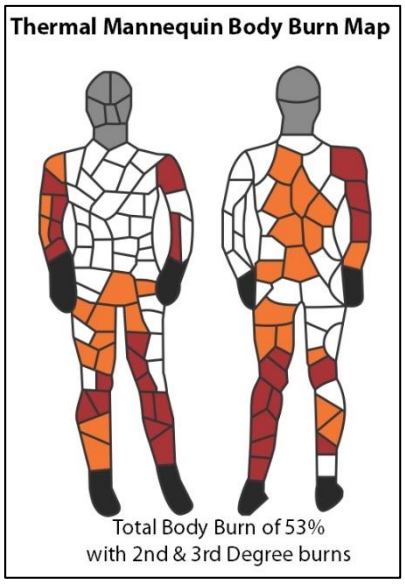
Thus, whilst NFPA sets a minimum performance requirement, EN 11612 provides more useful information for safety managers interested in ensuring more targeted and more effective protection against heat hazards.

b. Differences in the Thermal Mannequin Tests

Both standards reference a thermal mannequin test, in which a test garment worn on a thermal mannequin is subjected to a simulated flash fire. Heat sensors measure the heat energy penetrating the garment and, using Stoll analysis, produce a prediction of likely body burn. This provides an excellent comparison of performance of different FR garments or combinations of garments, such as when wearing secondary FR over primary FR.

The thermal mannequin test produces a prediction of likely body burn and can show areas of pain, 1st, 2nd, and 3rd degree burns.

In the example body map shown, each section relates to a single heat sensor. Orange represents 2nd degree burns and red, 3rd degree.



The test parameters can be varied according to burn energy level, burn duration, and duration of data collection.

However, a major difference between the US and EN standards is that in the NFPA version the thermal mannequin test is mandatory, is performed with specific test parameters, and defines a minimum performance; a maximum 50% body burn prediction.

In the EN standard however, the thermal mannequin test:

- is purely optional
- does not define specific test parameters (though the annex does make recommendations)
- details no minimum performance requirement

This is a relatively expensive test, so, many (perhaps the majority of) EN certified garments have not been subjected to a thermal mannequin test at all!

"Stoll Analysis" is a method of calculating predicted body burn from given rates of heat energy transfer. It was developed in the 1960's by Alice Mary Stoll whilst working on the development of FR fabrics for the US Navy, often using experimental burns on the skin of both pigs and volunteer sailors, who received a free shore pass in return for their trouble!

It predicts body burn based on the relationship between the rate of heat energy transfer and time, using calculation of a 50% probability of a 2nd degree burn.

This remains the essential method for burn injury prediction and is the central part of thermal mannequin testing

Furthermore, because the EN standard fails to specify test parameters, even garments that have been tested may not be comparable with others if the same parameters have not been used. *For comparison of performance, it is vital to ensure test parameters are the same*, yet it is not uncommon for manufacturers to quote body burn results without making test parameters clear.

Thermal Mannequin Test Parameters

The test parameters can be varied according to:

- The calorific energy level of the burn (The ASTM test requires 84Kw /M^2 (2 cals / cm^2)
- The duration of the burn (The ASTM test defines a 3 second burn)
- The duration of recording data. This could be 30 seconds or more and can be important when assessing Primary FR workwear with other workwear worn over it if the outer wear is flammable and continues to burn
- The NFPA standard requires a maximum predicted body burn of 50%

Thermal Mannequin Test: Conclusions

The thermal mannequin test is useful (and the only option) for both assessing performance of the whole garment and in comparing performance of different garments, so the lack of a mandatory test in Europe is a weakness.

For users, it is useful to require this test on garments and according to specific test parameters. Matching those defined in the US test makes sense.

Standards for Secondary FR Workwear

Since the purpose of Secondary FR workwear is not to protect against flames and heat but against other hazards such as chemicals, then its principal certification is to standards relating those other hazards.

However, as far as secondary FR performance is concerned, whereas in Europe there is a specific standard (EN 14116) defining test requirements, until recently there was no testing defined in US standards.

That is not to say SFR workwear is not mentioned in previous NFPA standards. NFPA 2113 could be described as a partner standard to NFPA 2112 as it contains recommendations for selection, care, maintenance, and use of primary FR Workwear. Whilst it contains no specifications for secondary FR Workwear it does contain three references to any clothing worn over a primary FR garment, including: -

5.1.10 "Organizations shall not permit workers to wear non–flame-resistant clothing over flame-resistant garments",

and,

A.5.1.10 ***"Organizations and end users are cautioned that wearing overgarments or other PPE that are not flame-resistant over flame-resistant garments can compromise the performance of the flame-resistant garments".***

NFPA 2113 is clear that any clothing worn over primary FR workwear should be "flame resistant". However, it does not specify any test or standard to define exactly what this means and what is required.

Given this omission, many users in North America have resorted to the NFPA 701 test as an assessment of "flame resistance". However, this standard is specifically designed for drapery and curtain fabrics so has limited value for protective clothing.

A new standard however, ANSI 203(2018), does provide for testing specifically for secondary FR workwear garments.

It contains two tests. First, a flame resistance or flammability test on the fabric according to ASTM D6413 (as used in NFPA 2112), requiring no burning or dripping and maximum char length. Second, it requires a thermal mannequin test on a layered ensemble of the primary and secondary FR clothing.

In this, any clothing intended to be worn over primary workwear (i.e. SFR garments), must be subjected to a thermal mannequin test in the way it is used in the real world – worn over the primary FR workwear: -

1. The primary FR garment is tested to indicate the base predicted body burn
2. The SFR garment is then tested layered over the same primary FR garment to assess how it effects predicted body burn

The key requirements are that the result must: -

a. Produce a predicted body burn of less than 50% (the same requirement for this test in NFPA 2112)
b. Not result in an increase of predicted body burn of more than 2% when compared with the body burn in the test on the primary FR garment alone.

Thus, this new standard, for the first time, provides for a test method that assesses the effect of secondary FR workwear as it is used in the real world and provides assurance that it does not compromise thermal protection.

In European standards however, EN 14116 is intended for assessment of FR fabrics and components and is used for performance of Secondary FR clothing. It features a single vertical flammability test, ISO 15025. (The same test referenced in EN 11612 but with slightly different requirements).

The requirements defined in EN 14116 for Index 3 in the vertical flammability test are the same as the minimum requirements defined for this test in EN 11612 for primary FR workwear.

ISO 15025, as defined in EN 14116 for SFR workwear, applies a small flame to the centre of a vertically suspended fabric sample (160mm x 200mm) for 10 seconds. Minimum performance requirements are: -

- the fabric must not ignite and burn to any edge
- the fabric must not drip molten debris
- any afterglow must last no more than 2 seconds

The standard classifies results according to three "Indexes'": -

- **Index 1**: no ignition or burning to any edge, no molten or dripping debris, afterglow time no greater than 2 seconds
- **Index 2**: as 1 above plus no hole formation greater than 5mm
- **Index 3**: as 2 above plus after-flame time no greater than 2 seconds

Secondary FR workwear should meet at least the lowest, Index 1, which essentially requires the fabric does not ignite and continue to burn or drip.

An important step forward was taken with this standard in the 2015 version which as well as a minimum Index 1 performance on the fabric, added a requirement that testing on components such as zip assembly and seams, and with the same minimum performance – no ignition, no dripping etc. – required.

This vertical flammability test is similar to the flame resistance test, ASTM D6143 required in the NFPA 2112 and in the new ANSI 203 standard. In that case the sample size is different (12" x 3") and the burn time slightly longer (12 seconds rather than 10). The requirements, however, are essentially the same; no ignition and no melting or dripping.

The addition of the ANSI 203 standard in 2018 however, changes the baseline for assessment of Secondary FR clothing, by providing a performance standard using thermal mannequin testing to predict likely body burn in layered ensembles, as it is used in the real world.

Secondary FR Workwear Standards: Conclusion

EN includes a specific standard for secondary FR workwear (EN 14116) requiring flammability testing of both fabric and components. In the USA, the new ANSI 203 standard provides for thermal mannequin testing of the layered primary and secondary FR clothing as they are worn in the real world, and, ensuring the secondary does not compromise the primary FR layer.

Users can therefor look to these two standards to ensure their SFR garments of choice do not constitute a hazard.

Conclusions: Real-World Use is Different to Laboratory Tests

Both EN and NFPA standards feature effective and quite similar testing of primary FR workwear. EN 11612 and NFPA 2112 include tests for flame resistance (or vertical flammability), heat transfer resistance, thermal shrinkage resistance and a thermal mannequin test, though the EN standard is weakened by the fact that this last is optional. There are shortcomings and benefits to both (users in Europe could look to the US requirement for a mandatory thermal mannequin test, whilst users in North America might look to the various tests in Europe for resistance against different forms of heat energy transfer).

In the case of secondary FR workwear, in Europe, the EN 14116 standard offers flammability testing of fabric and components to ensure it will not ignite and

burn, but EN standards include no requirement for flash fire thermal mannequin testing of layered ensembles of primary and secondary FR clothing.

In US standards, the omission of testing for secondary FR workwear has been recently addressed in the 2018 standard ANSI 203. This provides for thermal mannequin testing of layered ensembles, with the primary FR workwear tested first, and the ensemble after to ensure that no degradation of thermal protection results from the layered system.

The entire point of SFR workwear is that it is worn OVER primary FR workwear. And whilst EN 14116 at least offers flammability testing of an SFR layer fabric and components, only thermal mannequin testing can advise users of how FR workwear performs as it is worn in the real world. By subjecting layered ensembles to a controlled, simulated flash fire, and calculating predicted body burn, *it is the only practical method of ensuring secondary FR garments do not compromise the thermal protection offered by primary FR garments worn beneath.*

Thus, the new ANSI 203 standard should constitute the minimum required testing of SFR clothing. As with all US standards however, it is optional, so many SFR garments on the market have not been subjected to it. And in Europe, whilst limited flammability testing is required by EN 14116 (and, like other EN standards, but unlike US standards, is legally required), there is no thermal mannequin testing of secondary FR garments *required* at all.

Yet there is a further complication. SFR workwear is specifically designed to protect against liquid or dust chemicals, or even simply to keep the primary FR garment beneath it clean. So, what happens when the SFR garment becomes splashed with dirt, oil, or other contaminants? Especially if the fabric fails to effectively repel it or even absorbs it. Clearly, a flammable contaminant such as oil could have a dramatic effect on overall performance and thermal protection, so the SFR fabric must effectively repel liquids as well as resist ignition and burning.

All this would be very difficult to incorporate into a meaningful laboratory test (what contaminant would be used and how much of it?) However, in a risk assessment, in addition to only specifying secondary FR clothing that has been thermally mannequin tested in a layered system, as described in ANSI 203, users should take account of what contaminants may be in the work environment and how they might affect overall thermal protective performance. As a safety measure, a good rule of thumb is to not continue to use contaminated SFR workwear, but to replace it with clean garments regularly.

A video, showing the relative performance of different SFR fabrics when contaminated with a light oil, can be viewed here.

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