Technical Textiles
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Lecture No-23
Extreme Heat Protective Clothing (contd…)

Now, we will start discussing different standards for fire protective clothing and different test methods.

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To design fire protective clothing, National fire protection association, they give guidelines for fire protective clothing. So NFPA 1971 they in their document they give entire guidelines for fire protective clothing, here are some points;

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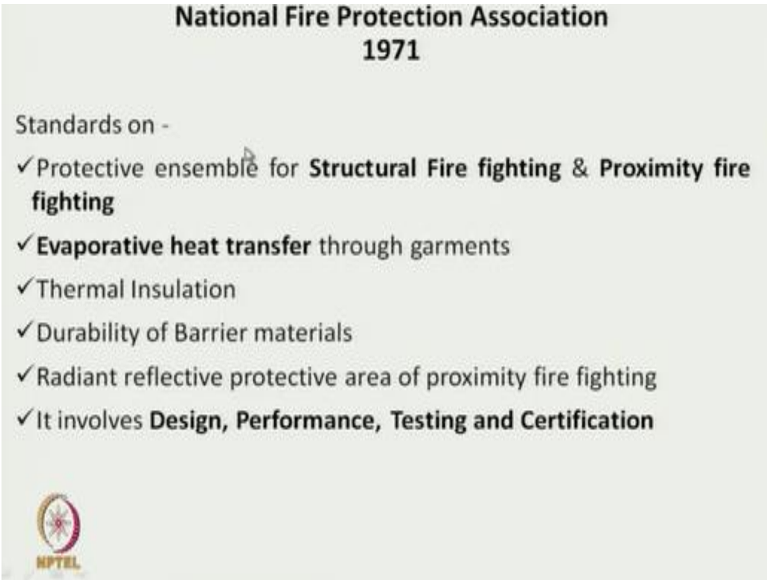

As per their standards the protective ensemble for structural fire fighting and proximity fire fighting. So, this is the standard, NFPA 1971. They give the guide lines; there should be evaporative heat transfer through garments, it should be thermally insulating. They give guidelines about the durability of material. The radiant reflective protective area of proximity fire fighting. It involves design, performance, testing and certification. So NFPA 1971 talks about all these areas.

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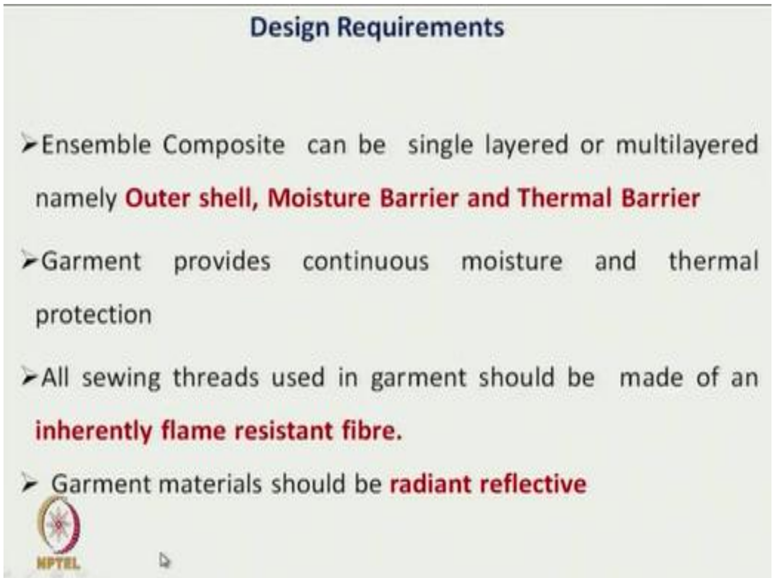

It also mentioned the ensemble composite can be single layer or multilayered that is outer layer, moisture barrier layer or thermal layer, garment, provides, continuous moisture and thermal protection. These are the guidelines. All sewing threads used in the garment should be made of an inherently flame resistant fibre. Garment material should be radiant reflective.

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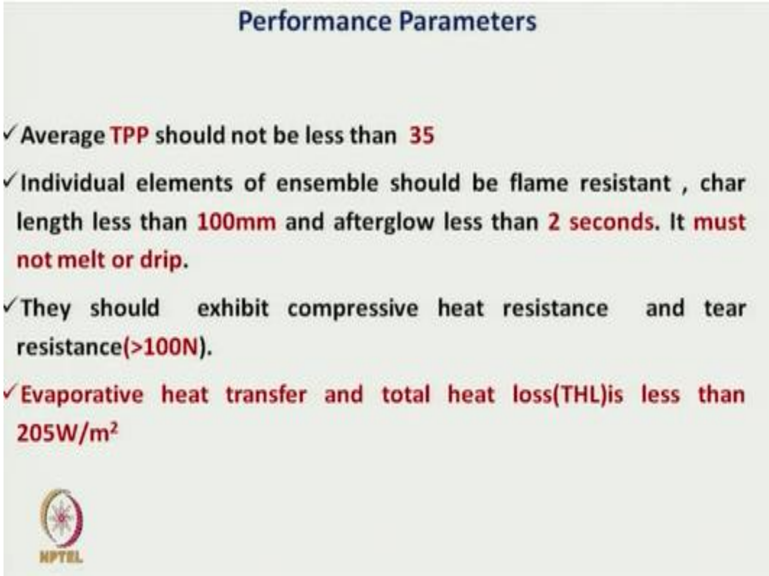

So, apart from the guidelines they also suggest some performance parameters, like average thermal protective performance TPP should be more than 35 it should not be less than 35. Individual garments, that is individual elements of the clothing ensemble should be flame resistant; char length should be less than 100 millimetre, after glow less than 2 seconds. It must not melt or drip.

So we should select such material, even if this material provides the TPP more than 35 but if it fails on all other characteristics or other parameters, and then we should not use in fire protective clothing. Like a material if we produce a thermal ensemble that is clothing ensemble if we produce which has very high TPP, but if it melts or drip then we should reject that material. That is why it has guidelines for performance parameters.

They should exhibit compressive heat resistant and tear resistance should be more than 100 Newton. As per the NFPA guidelines, evaporative heat transfer and total heat loss THL in short is less than 205 watt per square meter. So, these are the performance parameters one should meet before that ensemble is used for fire protective performing.

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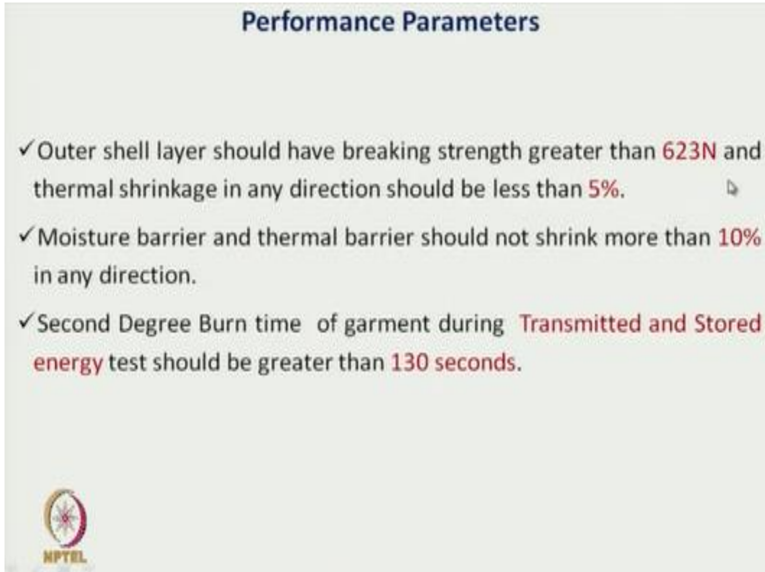

The outer shell layer should have breaking strength greater than 623 Newton, that is the guideline and the thermal shrinkage of the outer layer should be less than 5%. On the other hand moisture barrier layer and thermal layer should not shrink more than 10%. So outer layer the shrinkage characteristic is stringent the requirement is stringent because it is exposed to higher heat the second degree burn time of garment during transmitted and stored energy test should be greater than 130 second that is the second degree burn time for entire assembly.

So the test standards are available, so NFPA talks about only the guidelines and requirement of the fire protective clothing.

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International Standards

Standard	Heat Flux Exposure (kW/m^2)	Apparatus (Sensor/ Heat source)	Sensor	Use	Specimen size (cm × cm)	Result report
Direct Flame Exposure						
ISO 9151	80 ± 4 kW/m^2	One Meker burner with Propane/ Methane gas supply	Copper disc calorimeter	Fire fighters/ Industrial work wear	14 cm × 14 cm	Time for 24 °C temperature rise/ HTI
ASTM D 4108	83 kW/m^2	One Meker burner with Propane/ Methane gas supply	Copper calorimeter	Open flame exposure	10 cm × 10 cm	Burn time based on Stoll's criterion

As far as international test standards are concerned one may follow the ISO standard or ASTM standard. For direct flame exposure, there are three different types of exposure heat exposure one is direct flame exposure, next is radiant heat exposure and third one is both direct flame and radiant heat exposure. For direct heat exposure, as per ISO 9151 standard the heat flux is 80 + - 4 kilowatt per square meter. The apparatus here as it is direct heat exposure, so one maker burner is used the sensor is copper disc calorimeter.

This is used for fire fighter or industrial work wear, on the other hand ASTM it talks about the heat exposure is 83 kilowatt per square meter and maker burner is used and sensor copper calorimeter, open flame exposure is there and the sample size and result is reported in terms of burn time, based on Stoll's criteria and in ISO this actually here the time for 24 degree Celsius temperature rise.

So at the other side the copper calorimeter where the total time required to rise temperature by 24 degree Celsius and in ASTM we use the Stoll's criterion.

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Standard	Heat Flux Exposure (kW/m^2)	Apparatus (Sensor/ Heat source)	Sensor	Use	Specimen size (cm × cm)	Result report
Radiant Heat Exposure						
ISO 6942	Low level: 5 & 10 kW/m^2 Medium level: 20 & 40 kW/m^2 High level: 80 kW/m^2	6 silicon carbide heating rods of total length 356 ± 2 mm and diameter 7.9 ± 0.1 mm	Curved copper plate calorimeter of dimension 50 × 50.3 mm and thickness 1.6 mm	Industrial worker or firefighter exposed to low or high level heat flux	23 cm × 8 cm	Method A: visual assessment Method B: Heat Transmission Factor (TF) and Radiant Heat Transfer Index (RTHI)
ASTM F 1939	Method A: 21 kW/m^2 Method B: 84 kW/m^2	Five 500 W infrared translucent quartz lamp	Copper slug calorimeter	Workers exposed to radiant heat exposure (work wear)	25 cm × 10 cm	Radiant Heat Resistance (RHR) rating

In radiant heat exposure test in ISO as per ISO 6942 here we use the lamp that is 6 silicon carbide heating rods are used and in ASTM quartz lamps are used.

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Standard	Heat Flux Exposure (kW/m²)	Apparatus (Sensor/ Heat source)	Sensor	Use	Specimen size (cm × cm)	Result report
Combined Convective and Radiant Heat Exposure						
ISO 17492	80 kW/m² (50 % Convective & 50 % radiative)	2 Meker or Fisher burners fixed at 45 ° from vertical and 9 quartz T- 500 infrared tubes	Copper disk calorimeter of diameter 40 mm and thickness 1.6 mm	Emergency firefighter exposure and moderate exposure of industrial workers	15 ± 0.2 cm × 15 ± 0.2 cm	Thermal Threshold Index, TTI (= heat flux exposure × heat transfer burn time determined using Stoll's criterion)
ASTM F 2700	84 ± 2 kW/m² (50 % Convective & 50 % radiative)	2 Meker or Fisher burners with Propane/ Methane gas supply and Nine 500 W T3 quartz infrared lamp	Copper slug calorimeter	Fire fighters/ Industrial work wear	15 cm × 15 cm	HTP value

Combined convective and radiant heat exposure both Meker burner and the quartz tubes are used for both ISO and ASTM methods.

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Full Scale - Manikin Testing

- Realistic flash fire exposure conditions.
- Controllable heat flux and exposure time.
- Full size instrumented manikin with 122 heat sensors (for measuring heat transfer through garment).
- Amount, degree and location of predicted burn injury can be calculated from measured sensor data.

Another technique is that full scale Manikin Testing, were Manikin is covered with the protective clothing and it is exposed to flames and the heat flow is measured using different sensors there are large number of sensors used for different types of Manikins.

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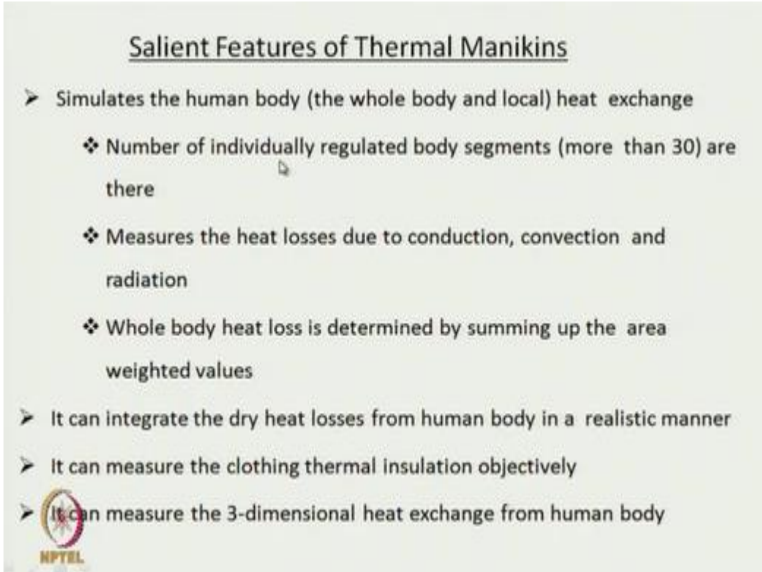

The advantage of Manikin is that it simulates the actual condition and number of individually regulated body segments typically more than 30 body say segments are there, it measures the heat flow in terms of conductive convective and radioactive mode.

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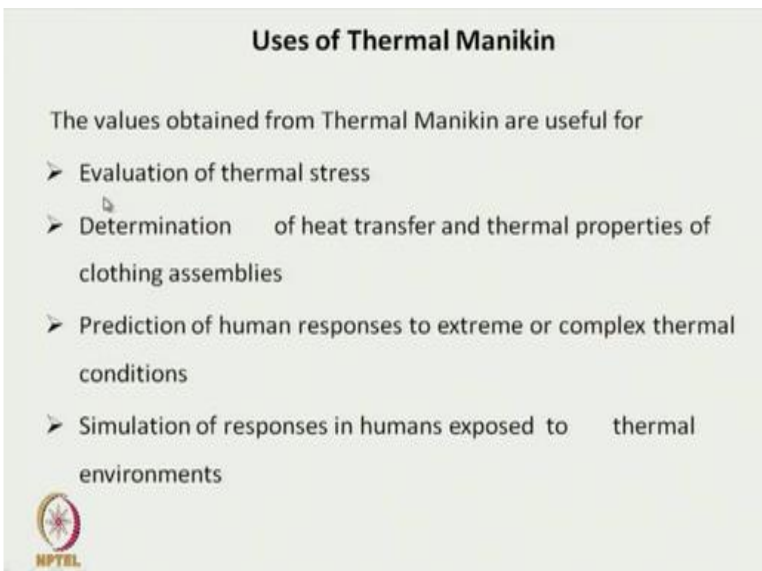

So the value obtained from the Manikin is useful for measuring the thermal stress, determination of heat transfer and thermal properties of clothing ensemble, it is used to predict human response to extreme and complex thermal condition. In addition to the manikin which is measured which measures the heat transmission in three dimensional in actual, simulates actual burning behaviour, but to get idea about the protective performance.

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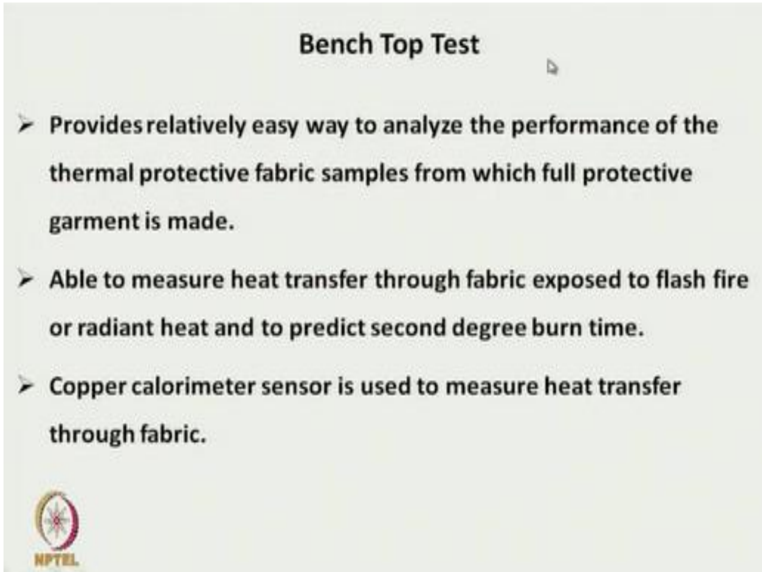

Bench top testing is also useful, it provides relatively easy way to analyze the performance of thermal protective fabric sample, from which full protective garment is made, able to measure heat transfer through fabric exposed in both flash fire or radiant heat or it can be tested both flash fire and radiant combined. So there are different test methods in all this test method the copper calorimeter sensors are used to measure the heat transfer through the fabrics.

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These test methods are flame exposure test, this is by horizontal method or maybe in particle mode. Radiant heat exposure test it is similar to the first one flame exposure test, but only difference is that in place of flame heating source only radiating heating source is there, hot surface contact exposure test this tests simulates the situation where the person is in contact with hot surface and how much heat is getting transmitted that is also measured.

This situation sometime arises during the fire fighting where particularly in structural fire fighting, the portion the position where the fire has taken place, the total building or total structure is hot, so in case of the fire fighter touches any hot surface how much heat is being transmitted from the hot surface to the skin can be assessed using this test. Steam exposure test; so there will be situations where the fire fighter is exposed to steam.

Hot water splash exposure test; so the hot water splash may also occur, so that protection of the fabric from hot water splash is also assessed. Hot water immersion with compression exposure test, so in case of the hot water immersion how much heat is getting transmitted to the body or through the cloth that we can get from this test and flame exposure test or the radiant exposure test in vertical orientation of fabric. These are the different test techniques. Now we will discuss one by one;

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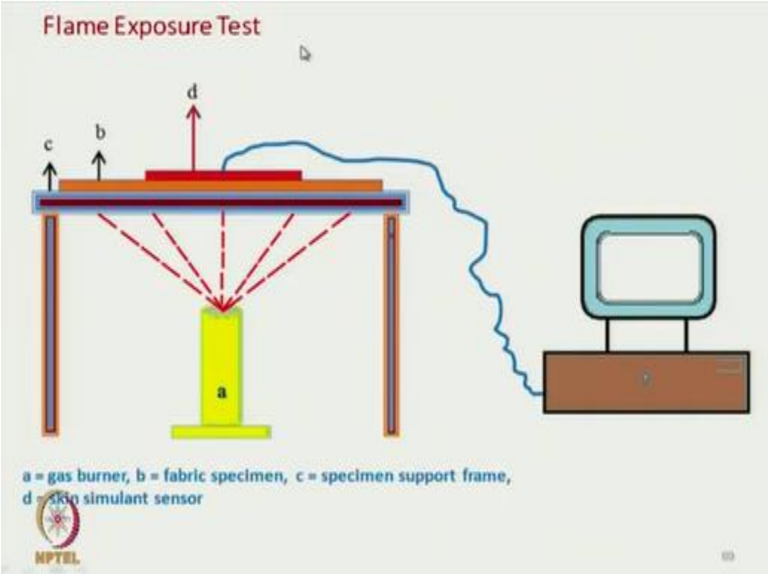

The flame exposure testing, it is horizontal orientation of fabric, this is gas burner which produces flame and fabric specimen this is fabric specimen, c is the frame which holds the fabric specimen and d is the skin simulant that is calorimeter that is a sensor. Once the flame is the fabric is exposed to the flame the heat is transmitted and the time to reach the second degree burn is calculated using the Stoll's curve.

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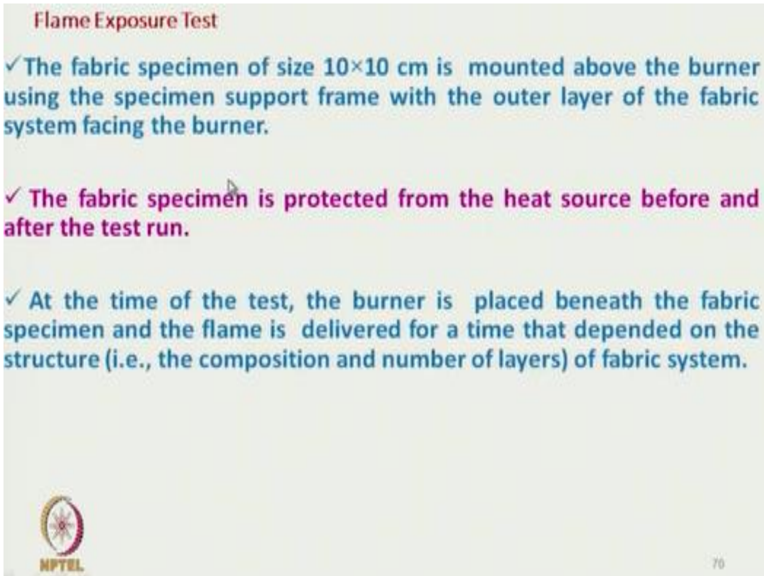

Here, the fabric specimen size 10 by 10 centimetre which is mounted above the burner using this specimen support frame, the fabric specimen is protected from heat source before and after the test by using one extra arrangement of the shield arrangement one plate and once the plate is removed then the fabric will be exposed to direct flame. So at the time of the test the burner is placed beneath the fabric and the flame is delivered for the time that depends on the structure. So thicker fabric for thicker fabric we can have the longer time.

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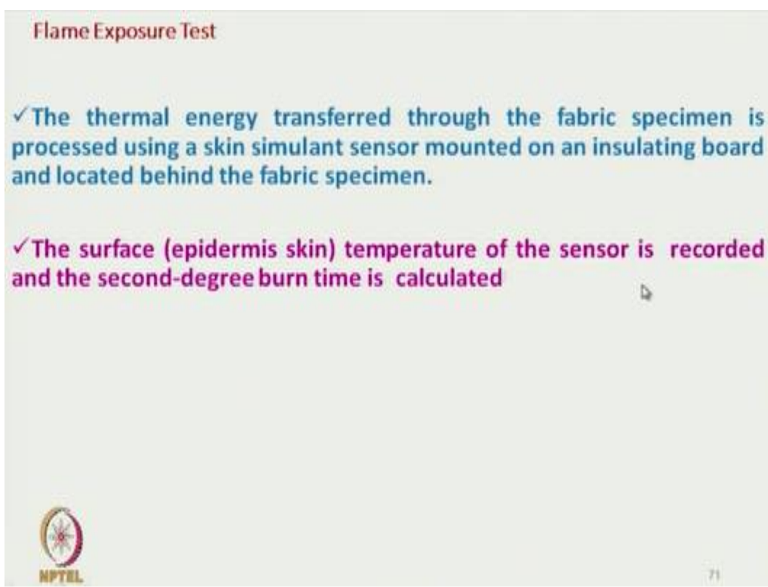

The thermal energy transfer through the fabric is measured through a skin simulant sensor and the surface temperature of the sensor that is, it is skin temperature is recorded and second degree burn time is calculated using Stoll's curve.

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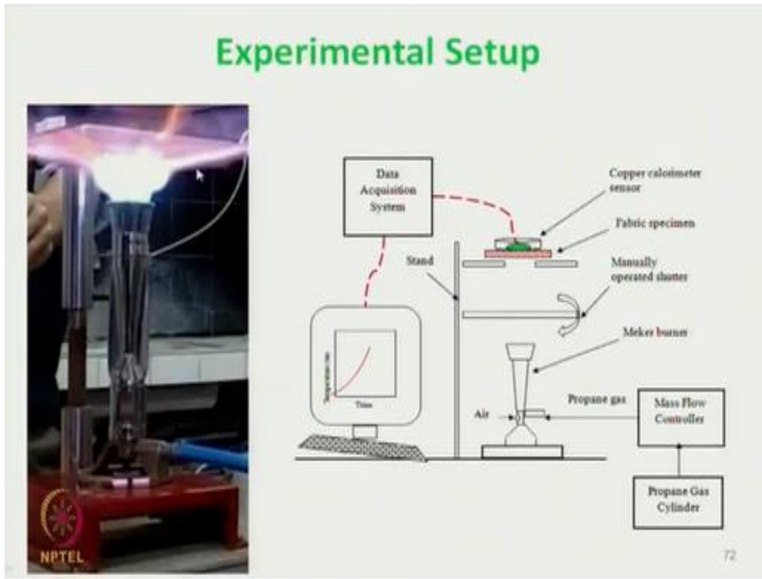

This is the experimental setup here and from there we can calculate the second degree burn time here, this is a shutter which protects the fabric from additional flame once the shutter is removed the fabric is directly exposed to the flame.

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This is the experimental setup.

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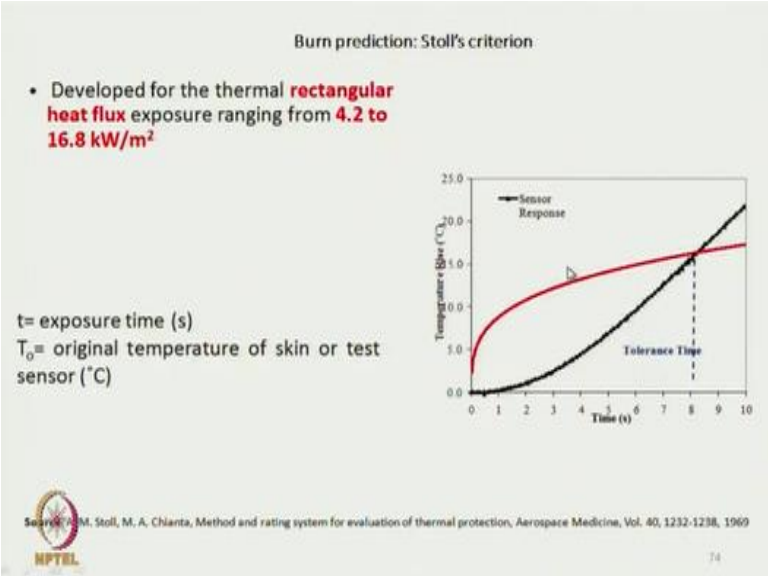

This is the Stoll's curve and here at the point where this curve intersects, that is the second degree burn time as per this graph the second degree burn time is 8 second.

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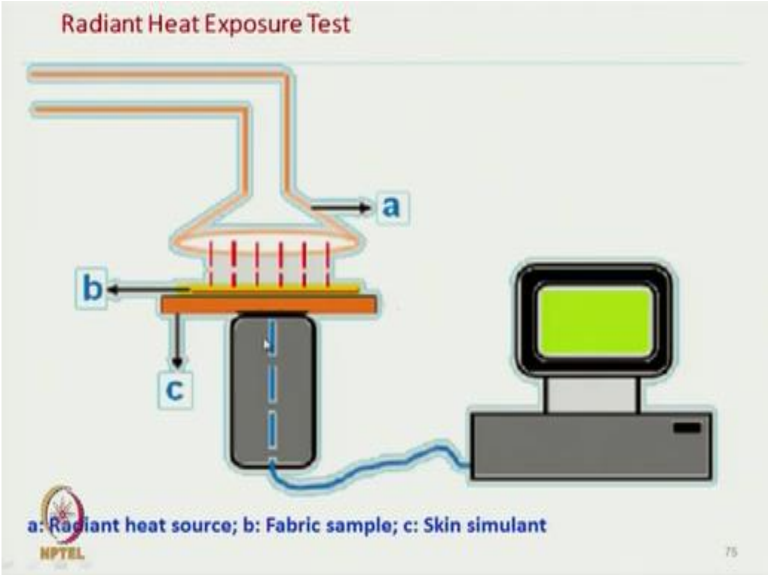

The radiant heat exposure is similar to the flame exposure, but here radiant heat source is from the top and b is the fabric specimen and c the skin simulant is placed beneath the fabric and the temperature is recorded heat flow is recorded here.

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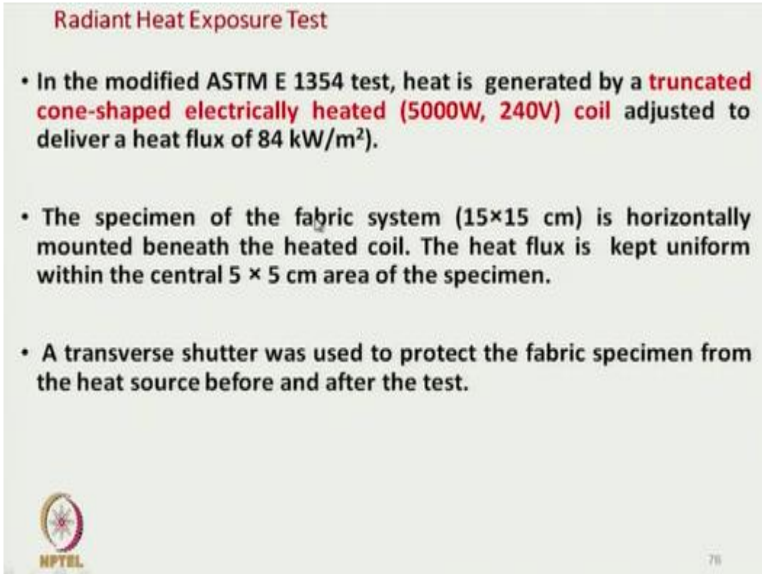

This system works as per the ASTM standard, the heat is generated by truncated cone shaped electrically heated bulb, so it electrically heated coil. So the intensity is adjusted to have heat flux of 84 kilowatt per square meter that is a standard. So the specimen size here is specified 15 by 15 centimetres horizontally it is kept.

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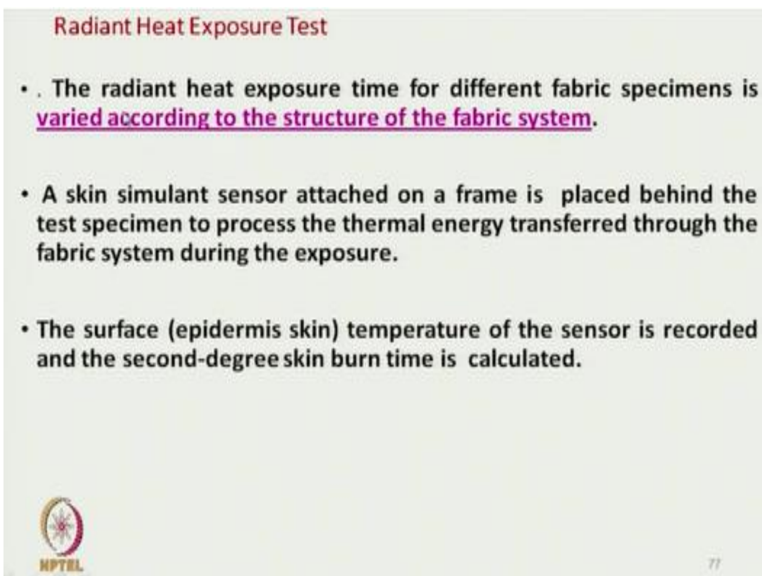

The radiant heat exposure time for different fabric again depends on their structure.

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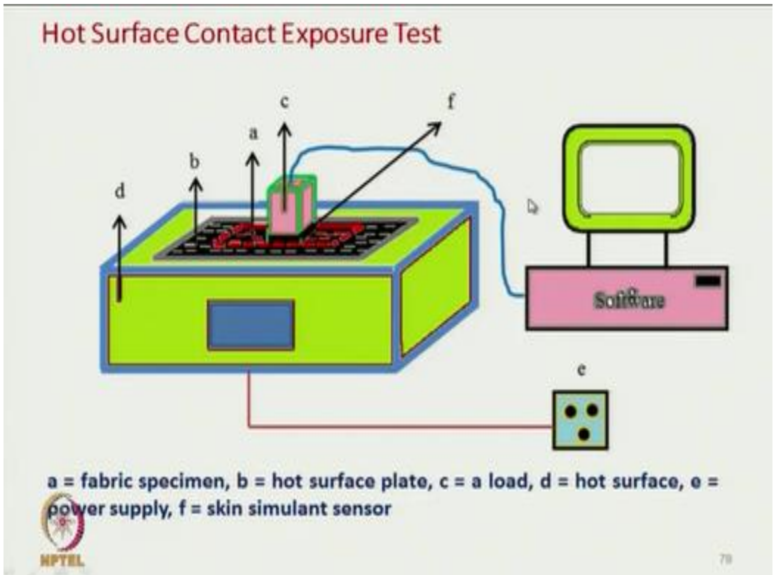

Next test method is hot surface contact exposure test. Here, fabric specimen a, this is a fabric specimen, B is the hot surface this is a hot surface, here load is kept here and d is the this is the hot plate b and hot surface. This is the power supply and here this is skin simulant that is the sensor is here. So when this fabric is placed on the hot surface, the heat is flowing through the fabric and skin simulant. Since the heat flow and we can calculate the second degree burn time.

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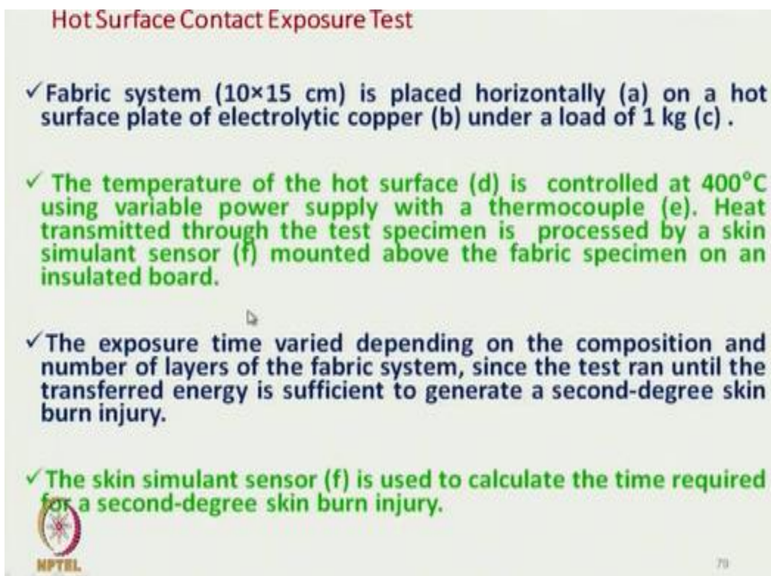

Second degree burn injury time is calculate this is explained here. Here, again fabric specimen size is 10 by 15 centimetre, placed horizontally and a load is placed 1 kg load.

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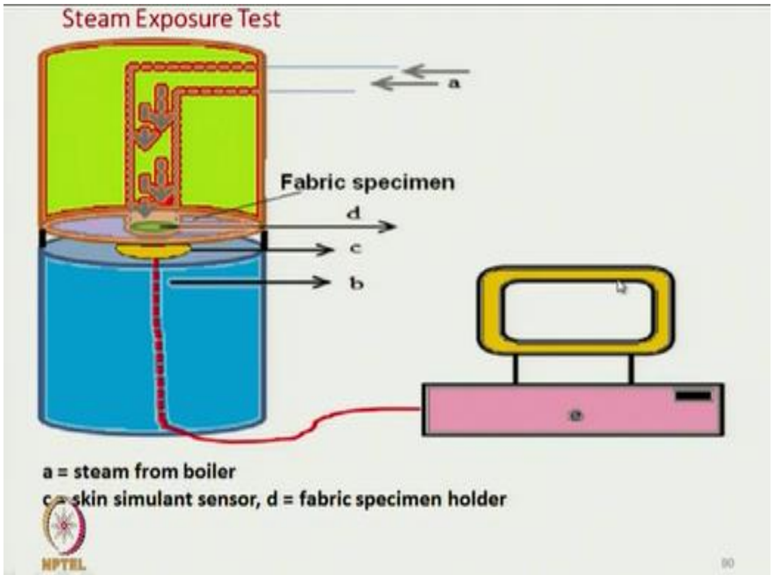

Steam exposure test here, this is the steam from the boiler, steam inlet, this skin simulant sensor above the sensor the fabric specimen is kept, due to the steam the heat flows from the steam through the fabric and the skin simulant that sensor sense the heat transmitted through the fabric.

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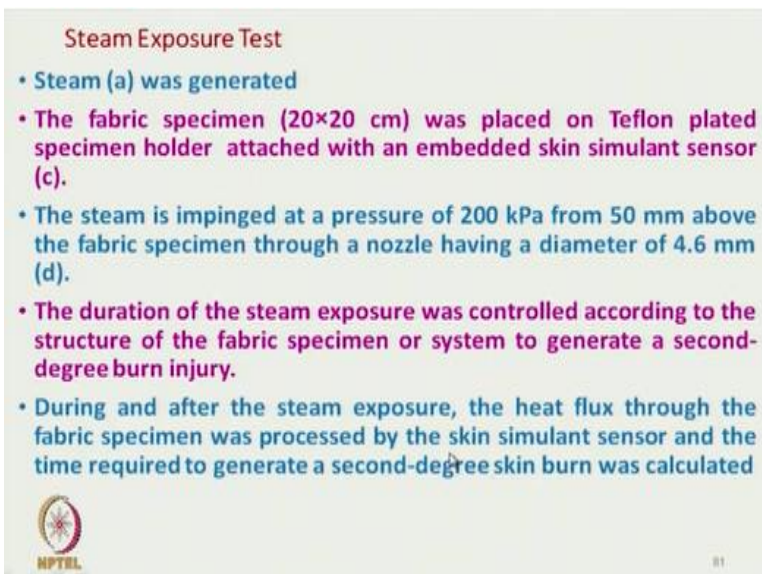

So fabric specimen again, it is 20 centimetre by 20 centimetre here. So there are different standards, the duration of the steam exposure was controlled according to the structure of the fabric specimen or system to generate the second degree burn, so that is why the we can control the level of exposure.

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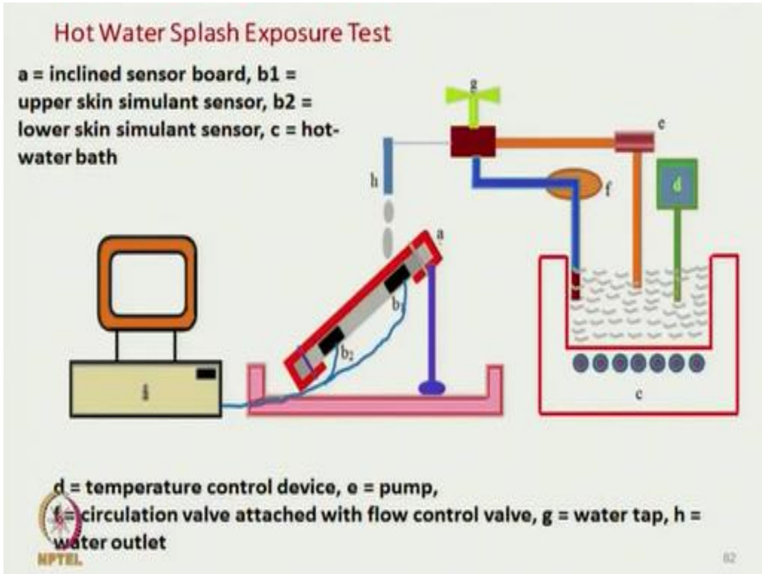

Next method is that it is hot water splash exposure test, so in this method simulates in case of the hot water splashing on the garment how much burn injury will take place, so the fabric is placed on inclined plane. So a is inclined sensor board, b1 and b2 are the skin simulants, there are two skin simulants are there, one is placed directly below the splashing point another is below at certain distance from that point.

So this is the hot water bath and through and here d is the, thermostat control the thermal temperature controller and through pump and control system the hot water is being supplied on the fabric sample.

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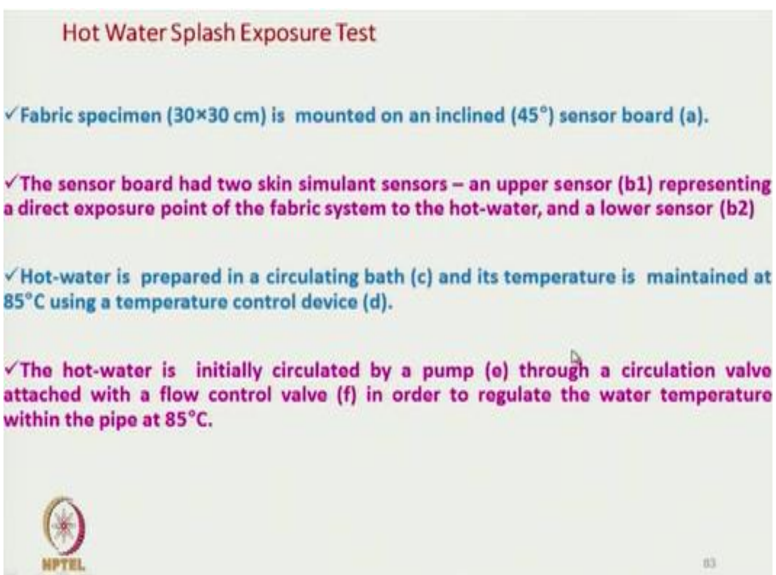

Here, we can measure temperature or heat flow at by two sensors, the water temperature is kept around 85 degree Celsius

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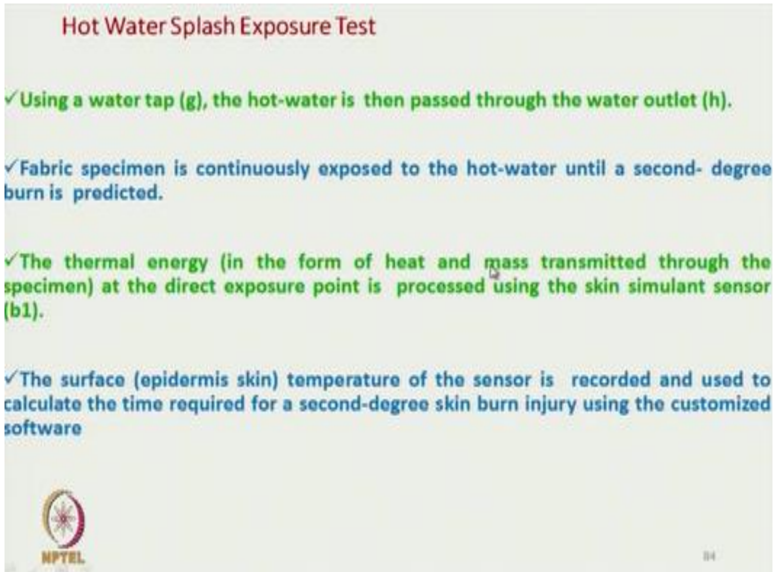

And controlled water is being supplied, the thermal energy in the form of heat and mass transmission here as the water is being dripped, so thermal energy is being transmitted in the form of heat and mass at the direct exposure point is process during the skin simulant sensor. So at b1 and also at b2, which is little bit away from the b1.

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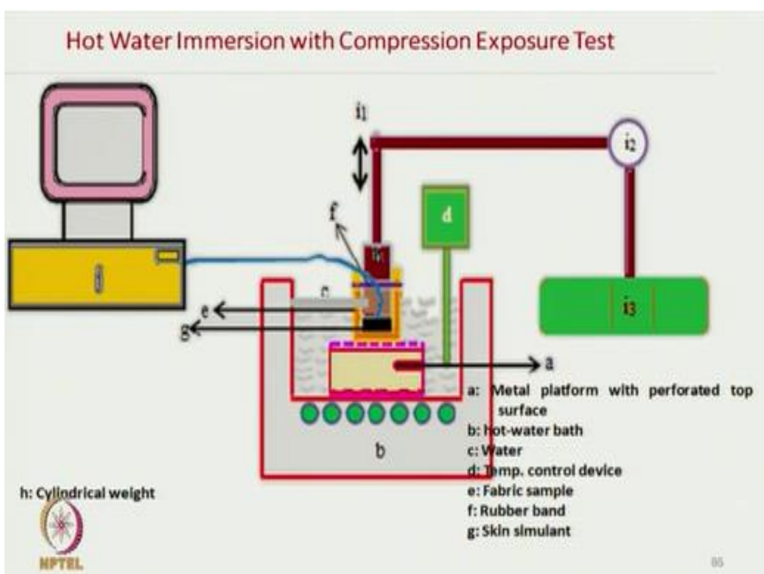

Next technique is that hot water immersion with compressive load. So, this is the there is a compressive load is there and here the heat flow when the specimen is immersed into the water.

So here this is the fabric specimen and f is the rubber band it is a rubber band and inside there is a sensor this is a sensor is there and d is the temperature control device we can control the temperature and once this total ensemble is dipped inside the water, so due to hot water the temperature and the heat will flow through the fabric sample and the sensor will sense that change in temperature and it is recorded by the recording device and cylindrical weight is there, which will actually compress the specimen. So in this case, we get the hot water immersion with compression exposure.

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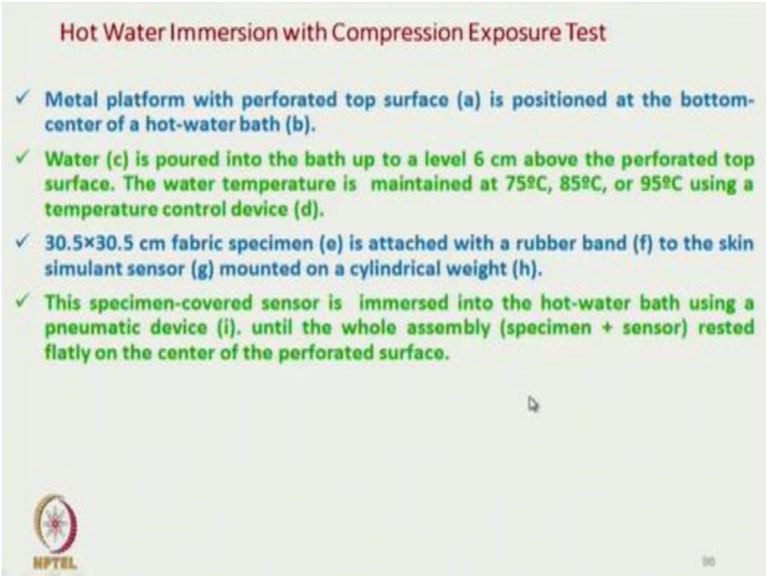

These systems have already been discussed in another course that is the testing of functional and technical textiles.

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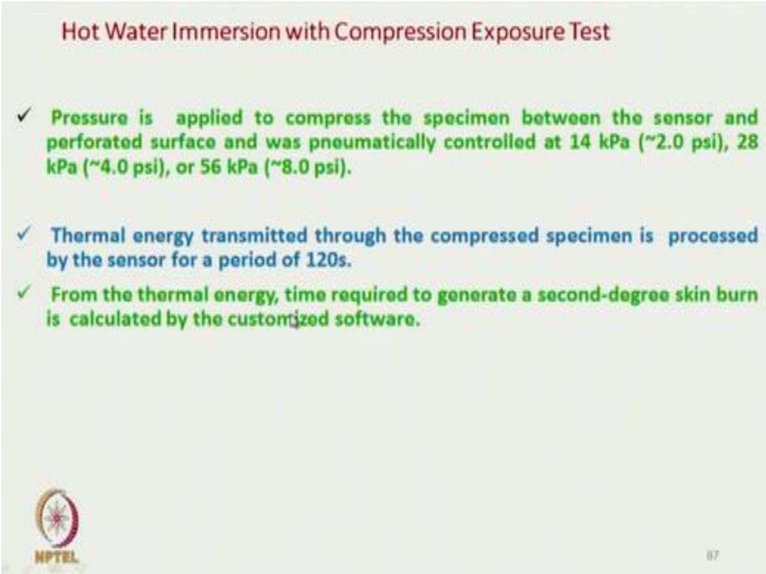

So from the thermal energy the time required to generate second degree burn again can be calculated.

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Our last measuring technique is that the instrument where the vertical orientation of fabrics are there, why vertically orientation? In most of the test methods, we have seen the fabrics are in horizontal orientation, but in actual situation most of the cases the fabrics are in vertical orientation.

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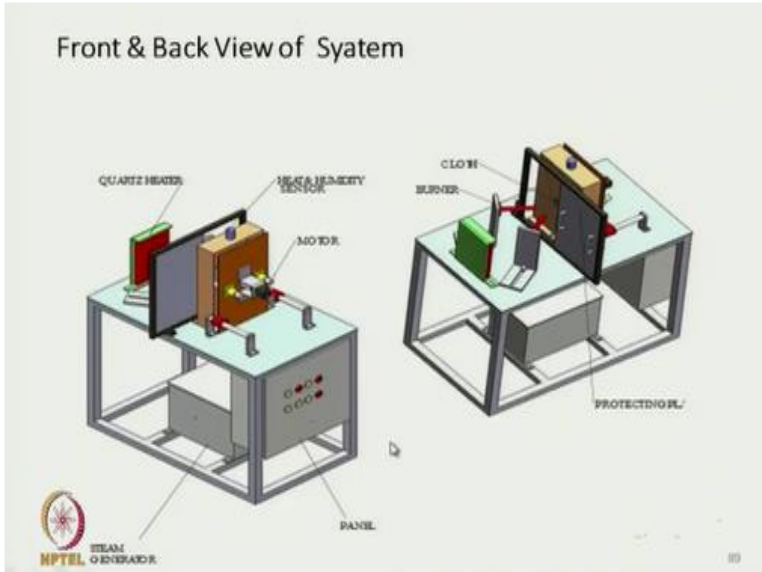

So, this is the diagram of this system this is the quartz heater. If we want the radiant heat on the other direction, this is the quartz heater quartz lamp. In addition to that; there are two maker burners which produce the direct flame and here is the fabric holder with this box here the fabric specimen and this is the shutter. Once we want to start the experiment the shutter is removed the direct flame or radiant heat or may be both together.

It is the fabric is exposed to this direct heat from the flame or radiant heat and on the other side of the specimen, this calorimeter is kept and in this system, another arrangement is there here this box that there is a gap, air gap which simulates the microclimate. We can change the thickness of the microclimate and the steam generators are there which will change the humidity of the microclimate and we can measure the temperature and humidity of the microclimate.

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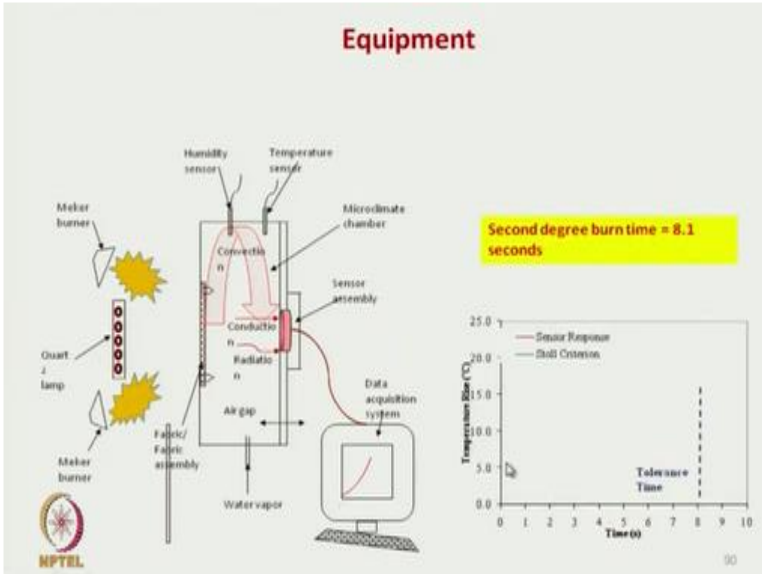

So this diagram will show the instrument, this is Meker burner, these are the Meker burners, this is quartz lamp, here is the fabric specimen, this is the microclimate chamber, air gap, which is variable air gap can be created, here is the sensor assembly which is connected with the computer and the water vapour supply arrangement to change the humidity. So here we can simulate the actual condition during extreme heat condition the wearer can sweat.

So that humidity present in the microclimate between cloth and skin this is a cloth and skin that humidity due to the humidity the thermal transmission behaviour may change, that is also recorded here. So humidity sensor is there and also thermometer is there and this total assembly can move laterally to control the air gap, one shutter is provided between the heat source and fabric.

Just during test the shutter is removed, the flame and here is the quads lamp started, once this quartz lamp and flame started, the shutter is removed and the heat flows through the fabric specimen to the sensor and this is recorded, the second degree burn time is recorded and the heat is flowing and it is recording and recording the second degree burn time.

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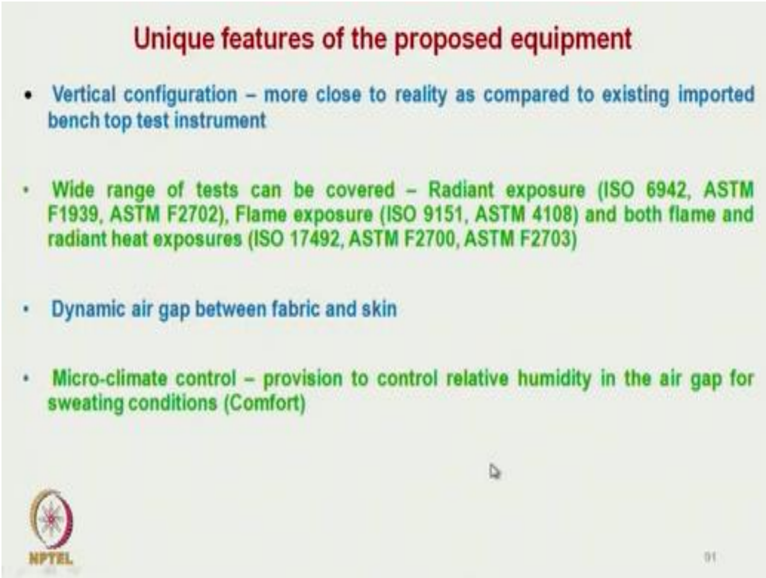

So the main features of this instrument that is a vertical configuration it is more close to reality as compared to existing instrument, this is widely used and for different standards like radiant exposure standard, flame exposure standard and both flame and heat exposure standard, we can work with all this different standards. Dynamic air gap between fabric and skin, microclimate can be controlled by providing the humidity to simulate the sweating condition.

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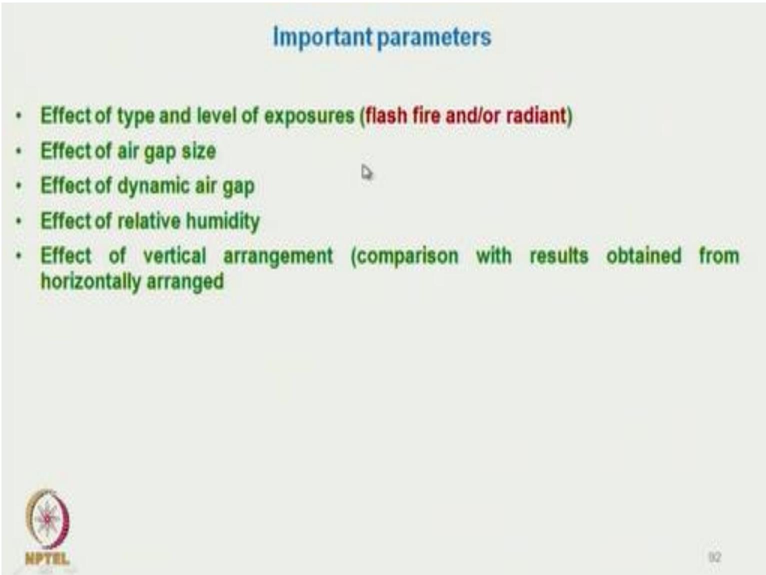

Effect of type and level of exposure can be changed effect, of air gap can be changed. So dynamically that can also be changed air gap can also be changed dynamically, it can move continuous fashion, like if we try to simulate the actual moving condition during movement that also can be simulated here. Relative humidity can be changed that is to simulate the sweating condition. So these are the salient feature of the features of this instrument.

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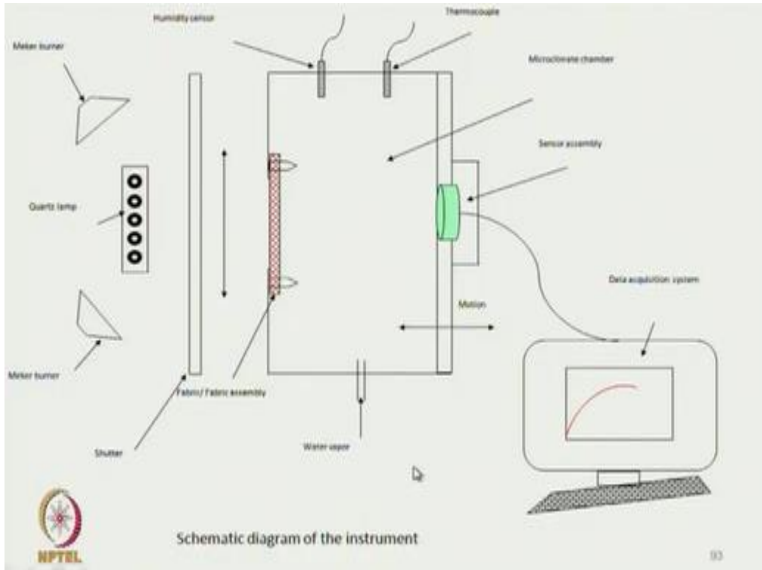

Different diagrams.

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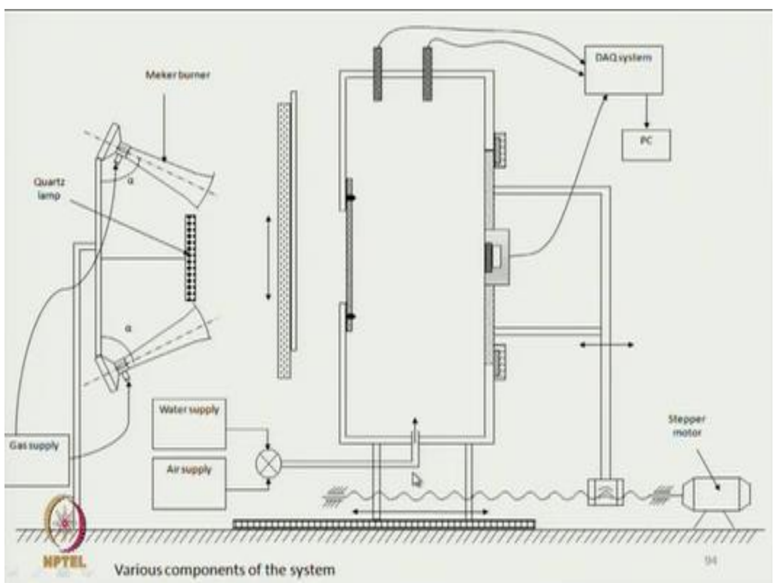

So that is all about the thermal protective clothing. Thank you.