Evaluation of Thermal Comfort on Protective Clothing Worn in an Radiation Power Plant

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Abstract

The purpose of this research was to device thermal comfort model for radiation power plant workers in protective clothing. Three fabrics commonly used in protective workwear were made into coveralls of identical design and were evaluated by adult healthy males in four simulated work environment. It was investigated between the physiological response and subjects comfort according to environmental variance and clothing types. The of simulated work enviro mensent was controlled under four different humidity and temperature of each type.(Temperature 20±1℃, RH 40~70%±5%, Temperature 30±1℃, RH 40~70%±5%) An index of physiological response was connected with the thermal comfort designed. Mean skin temperature, skin temperature, Axillasy temperature ear canal temperature, clothing climate, total sweat, blood pressure, and R-R interval were be evaluated.

Skin temperature difference ocurring during exercise and rest were significant only with respect to time and regions of the body. This despite physical differences in the three coveralls, particulary mass statistically experiment.

Also, an index of subject wearing sensation was designed for thermal comfort after investigation determined the kind of clothes and the type of environment. As a result of this research, two types of multiple regressions was deviced to estimate thermal comfort of the protective clothing..

Ⅰ. Introduction

Potential radiation hazards are present in many different industrial situations.

In general, the major radiation hazards which occur in industry are controlled by shielding the radiation source with leed or concrete rather than by clothing the worker. In order to develop radiation protective clothing the designer must first under stand the hazard work situation present and be aware of the role clothing and play in protection. Clothing can however protect workers from radio substances carried in dust oil and grease in areas where repair and maintenance jabs have to be carried. (Watkins, 1997)

Protective clothing for radio power plant workers generally takes the form of a completely encompassing coverall with intergrated or overlapping gloves, boots and hood. At the present Korean standard established the level of protective clothing: KSP-8153 (Korea standard protective mask for radioactive contamination), KSA-4801 (Korea standard protective footwear for radioactive contamination), and KSA-4052 (Korea standard protective gloves for radioactive

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contamination) that department of radioactive safety industry (Lee Keun-bae, 1986; Inpo, 1989). If workers will wear protective clothing for long time, it will give them to be excessive heat stress and to call uncomfort due to radiate sweat because it is form of coverall that cover the whole body that mean it cannot be ventilate. If workers will be keep working after wearing protective clothing under the environment of high temperature and high humidity, they feel fatigued as well as it makes decreasing ability of working from heavy physiological burden even they work short time about fifteen minutes (Branson., 1982).

But the established studies of thermal comfort of protective clothing in radition power plant : The sunney the Survey of Adiabatic power in the Statical Status(McCullough, 1985), The Survey of Thermal Comfort Wearing(KAERI, 1978; Kim Eun-joo, 1996), Presentation of Environment Numerical Index about Radiation Pwer Plant Environment(Hong Sung-ae, 1986), Contamination Pollutant Decontamination of Thermal Comfort (Norwood, 1995), The Study of Subject Matter Relate to Radioactivity Contamination(Smith, 1980; Orlando, 1981; Branson, 1986; ASTM, 1988), The Survey of nuclear radiation for the Human Body were studied about each factor. (Kweon Sok-keun, 1990; Lee Yong-soo, 1991) So, those studies are insufficient of thermal comfort about each three factors of reciprocal action for working environment, wearing, and comfort.

The purpose of this study is to device thermal comfort model for radiation power plant worker in protective clothing. It was investigated the relationship between physiological response and subject comfort according to environment variance and clothing type.

Ⅱ. Method of Experiment

1. Subjects and Experiment Garments

1) Subjects

Four healthy college students volunteered in the present study. The purpose and possible risks of the study were carefully explained to each subjects before any experimental testing. Subjects were tranned thermal stress for unified with the heat stress.(70~80℃) about two hours per one day, for two weeks. <Table 1> was showed subject's physical characteristics Body surface area calculated according to Fujimotto equation (Fujimotto et al., 1968)

2) Experimental Garments

Experimental garments were composed of mask, gloves, foot-wear and experimental garment coverall with hood. All subjects wore standard cotton under shirts and under pants during each of experimental process. The coveralls were made of a here differental fiber types. - two tyvek : non woven polypropylene(PP), polyethylene(PE), one reused after washing polyester/ cotton(T/C) woven fabric as shown in <Table 2>, the physical properties of experimental garments and thermal properties.

<Fig. 1> shown in experimental garments design details.

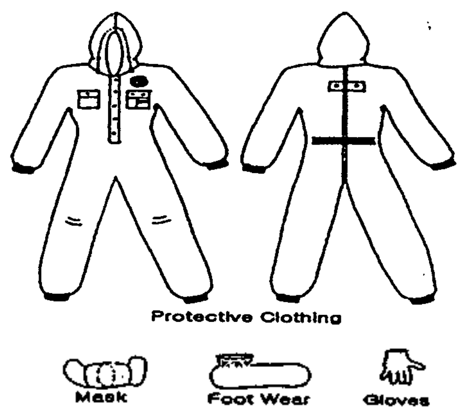
2. Enviromental Condition and Experimental Protocol

<Table 1> The physical characteristics of Subjects

Subject code	Age (years)	Height(cm)	Weight(kg)	Body surface area (m^2)
A	20	179	64	1,763
B	20	178	63	1,748
C	20	176	65	1,735
D	20	174	56	1,623

<**Table 2**> Physical characteristics of Coveralls and Fabrics Thereof

Garment code	PP	PE	T/C	Test method
Fiber(%)	Polypropylene 100	Polyethylene 100	Polyester/Cotton 66.7 × 33.3	KS K 0210
Air permeability (cm^3/minute/m^2)	761	14	312	KS K 0570
Water absorption(%)	44.7	19.4	21.2	KS K 0339
Fabric thickness(mm)	0.293	0.132	0.301	KS K 0506
Waterrepellency (%)	70	70	80	KS K 0590
Water vapor transmission rate ($g/m^2/h$)	244	189	253	KS K 0594
Density(g/cm^3)	0.283	0.328	0.630	KS M 0511
Disposition of warmth	42.6	32.9	34.4	KS K 0560
Fabric construction	non-woven	non-woven	3/2 woven	KS K 3015



<Fig. 1> Experimental equipments.

Experiment was operated type of environment that Fanger(1967) present comfort under the environment and under the environment of indoor working place in real adminstration limit at a radiation power plant such as in summer season(Kim Eun-joo, 1996). Also, it was operated four different types of temperature, humidity, and an air movement was kept less than 0.25 m/sec.

A: Temperature 20±1℃, RH 40%±5%

B: Temperature 20±1℃, RH 70%±5%

C: Temperature 30±1℃, RH 40%±5%

D: Temperature 30±1℃, RH 70%±5% (henceforth A, B, C, D)

Before dressing, subjects were instrumented with equipment. Tests and rests were carried out in a climate chamber at A, B, C, D. Subjects then attempted the following protocol : After 20 min stability, 10 min ergocycling, 10 min rest were two times repeated. It was designed to accomplish target task about 3,200kcal in radiation power plant works had done.

Test measuring times were 60minutes to tally such procedure as shown in <Table 3>. experimental schedul. The subject entered the experimental room after of support in two hours after the meal and rest over one hour began.

The exercerise of ergo cycling were performed 60rpm speed after a 20 stability. 10minutes exercise and 10minutes rest was repeated two times. (Tamura, 1985)

3. Measurements

The subjects physiological response of were measured for skin temperature, mean skin temperature axillary/ear-canal temperature and total sweating weisht blood pressure and were researched for R-R, subjective sensation.

Skin temperature in seven location were moitored (forehead, upper arm, hand, chest,

<Table 3> Experimental schedul

	First stability (10 minutes)	Second stability (10 minutes)	First ergocycle (10 minutes)	First resting (10 minutes)	Second ergocycle (10 minutes)	Second resting (10 minutes)
Skin ear cana timperaturel	00000	00000	00000	00000	00000	00000
Eardrum/armpit/axillary temperature	0	0	0	0	0	0
Temperature & humidity of clothing climate	00000	00000	00000	00000	00000	00000
Quantity of partial sweating insensible sweat	0	0	0	0	0	0
Weight of paper guzz	0	0	0	0	0	0
Weight of cloth sweed rate	0					0
Blood pressure of high/low	0					0
Interval of R-R	00000	00000	00000	00000	00000	00000
Comfort·	0	0	0	0	0	0
Thermal sensation	0	0	0	0	0	0
Humidity sensation	0	0	0	0	0	0

0: It means first experiments.

thigh, leg, feet) continually using digital thermister K730 (Takara Inc, Co. Janpan Range 0.1℃) The siter of recording skin temperature and procedures for calculating the mean skin temperature chosen by Handy & Du Bois equation (Winslowetc., 1938)

Ear-canal temperature measured by an digital ear thermistor. Clothing microclimate (temperature and humidilty within clothing) was measered using thermo-hygrometer (Shinyei, Inc Co. Japan) at chest between under wear and coveralls.

Local Sweat Rate was measured before and after the change in filtering paper weight (55 mm, rounded, 4). Filtering papers were dried in microoven during hours. Measurements of body were forehead, chest back, right arm, left leg. The change in pre vss post clothing weight, guzze weight(flowed sweat rate) was used to determine Total Sweat Rate of human balance (10g, Poong Kwang PKS-1007). R-R(Electrocardiograph) were measured using a 64K Byte Type (Takei Kiki Koyto Co., Japan).

Subjective sensations were mode into thermal sensation by ASHRAE with seven scales, humidity sensation with seven scales and thermal comfort sensation with four scales (see Table 4)

4. The Analysis of Statistics

The statistical evaluation of thermal comfort between the physiological response and subjects comfort according to environmental variance and clothing types was assessed using a three-factor analysis of variance.

The statistical significance between the parameters was paired T-test, data from each experiment were analyged by ANOVA Test adjusted for multiple comparisons.

It was T-test for looking through relation items and put in multiple comparison test of Duncan. On the background of those, regression equation used for the statistical evaluation of

<Table 4> Scales of subjective sensation

Sensation rute	Thermal sensation	Humidity sensation	Comfort sensation
1	Very cold	Very dry	Very comfortable
2	Cold	Dry	
3	Cool	A little dry	Comfortable
4	Not both	Hot	A lettle uncomfortable
5	Warm	A little hard	
6	Hot	Hard	Very uncomfortable
7	Very hot	Very hard	

thermal comfort model. All statistics were analyzed using a SAS Package.

Ⅲ. Conclusion and Discussion

1. Physiological Response and Subject Wearing Sensation

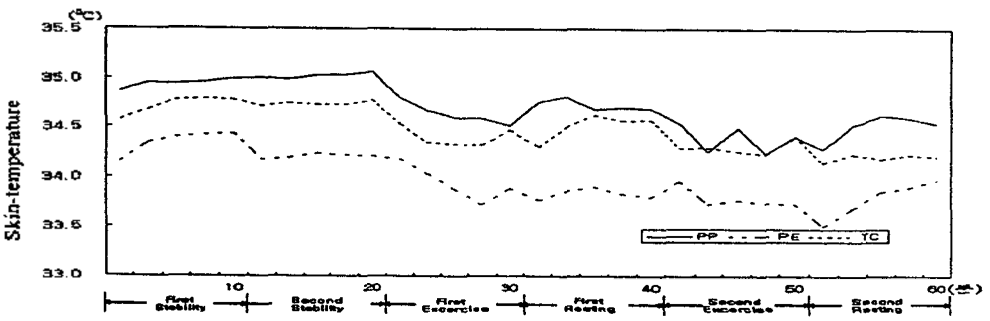
1) Physiological Response according to Environment

Skin temperature was showed significant conclusion from under the environment of C, D that was high temperature and humidity. Under the environment of D such as real under the environment of working was proved clothing PP > T/C > PE as difference temperature average of skin temperature. This is agree with PP > T/C > PE on the absorption of clothing material, transmission of air, and comfort.

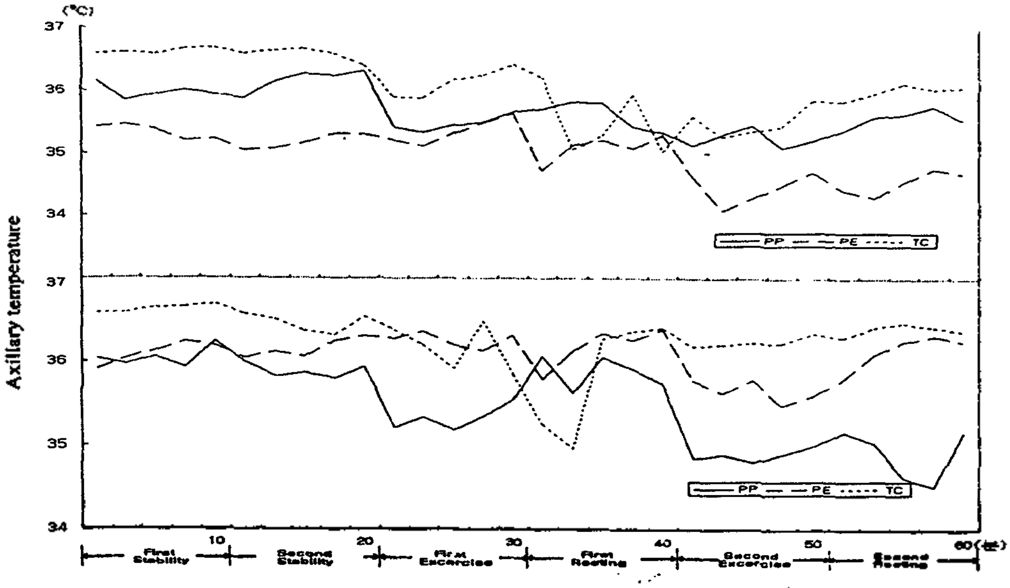
According to <Fig. 2> temperature range of axillary temperature was showed range of 34.98 ℃~36.9℃. Before, axillary temperature was showed the lowest distribution as clothin T/C > PP > PE in A, B and C. this showed unity with conclusion that clothing kinds skin temperature average was the lowest.

According to <Fig. 3> Ear-canal temperature was high as clothing T/C > PP > PE in under the environment A, and PP > T/C=PE in environment of high temperature. Ear-canal temperature of PE was showed the lowest from the both environment. This result was showed tendency such as changing of Ear-canal temperature.

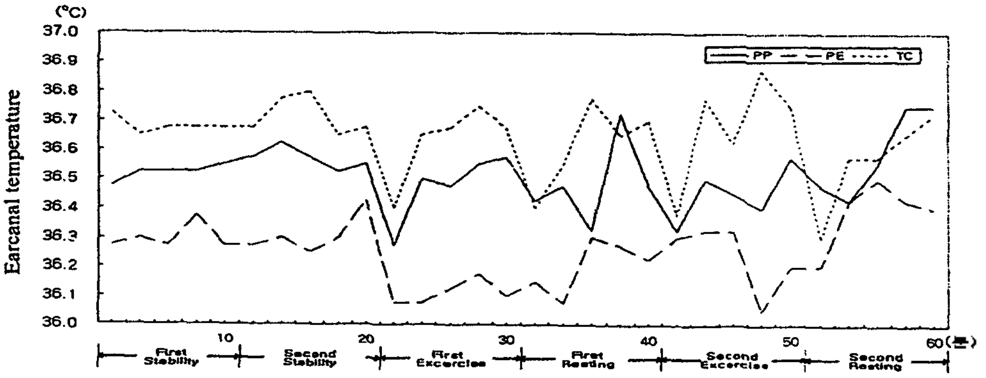
According to <Fig. 4> it was showed inside of clothing temperature was high as clothing PP > PE > T/C in A under the environment,



<Fig. 2> Skin temperature change during exercise and rest by environmental condition of coveralls.



<Fig. 3> Axillary temperature changes during exercise and rest according to environmental condition for coveralls.

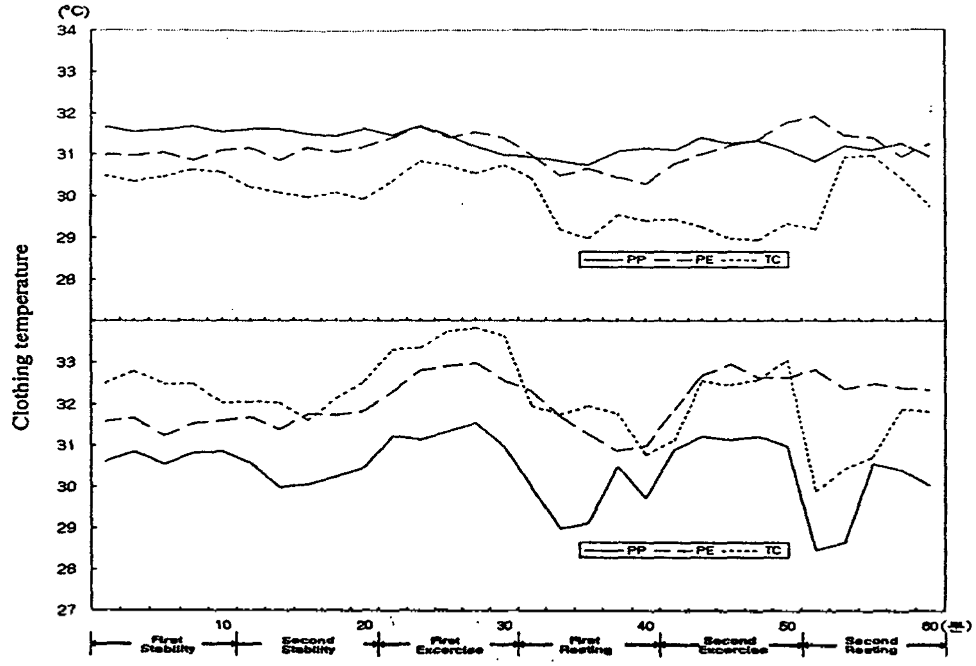


<Fig. 4> Ear-canal temperature changes during exercise and rest according to environmental condition for coveralls.

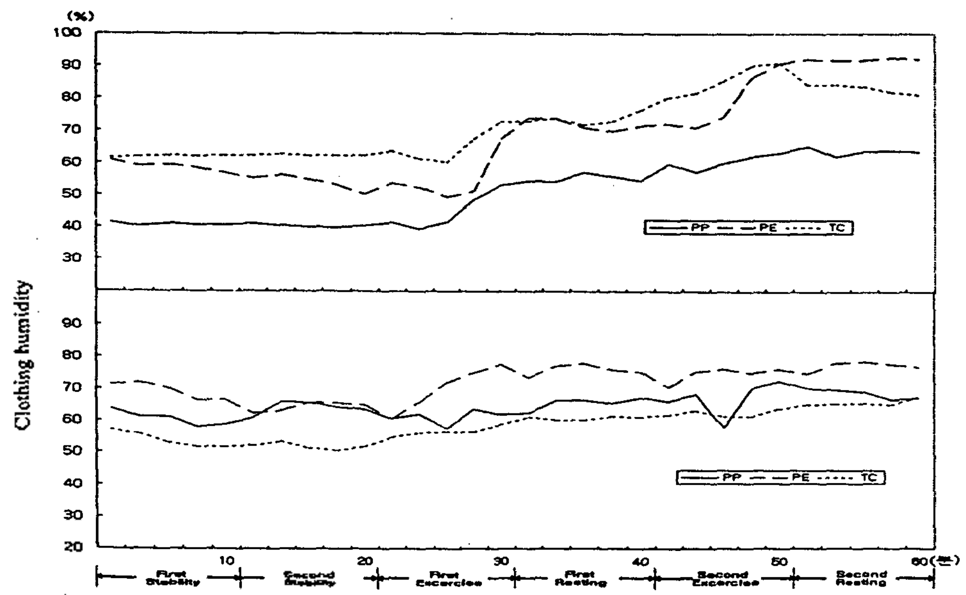
clothing T/C > PE > PP in B. Opposite conclusion of result could think influence according to difference humidity as the same temperature.

Inside clothing humidity of under the environment D was higher than three environments. This was related to evaporation of the human body. It was showed changing of humidity, and quantity of sweating clothing PE=T/C > PP in under the environment A, PE=P/C > PP in under the environment B, PE > PP > T/C in under the environment C, and PP > T/C > PE in under the environment D.

According to <Table 5> under the environment A, B are showed significant difference statistically from relation with total sweat and under the environment C, D here no movement rate. It showed high sweat from all clothing. There are not differences between clothing in



<Fig. 5> Clothing temperature changes during exercise and rest according to environmental condition for coveralls.



<Fig. 6> Clothing humidity changes during exercise and rest according to environmental condition for coveralls.

<Table 5> Total sweating weight for coveralls and environmental condition (unit:mg)

Coveralls \ Environmental condition	A	B	C	D
PP	2275.5	3029.8	3871.5	5922.0
PE	2980.0	3334.5	4136.3	6346.5
T/C	2416.3	3322.50	3939.5	5940.8
F Value	16.89**	5.26	1.76	0.45

* : p<0.05, ** : p<0.01, *** : p<0.001
a, b, c is the result of multiple test of Duncan.

such environment of high temperature and high humidity. Under the environment A was showed clothing PE > T/C >= PP. Therefore, PE was showed the largest sweat.

Clothing type of R-R interval, under the changing of environmental condition of clothing type, there is no distinction, but under the environment C and D there is distinction between the clothing type. It means the R-R interval clothing type PE is longer under environment C and D than the other.

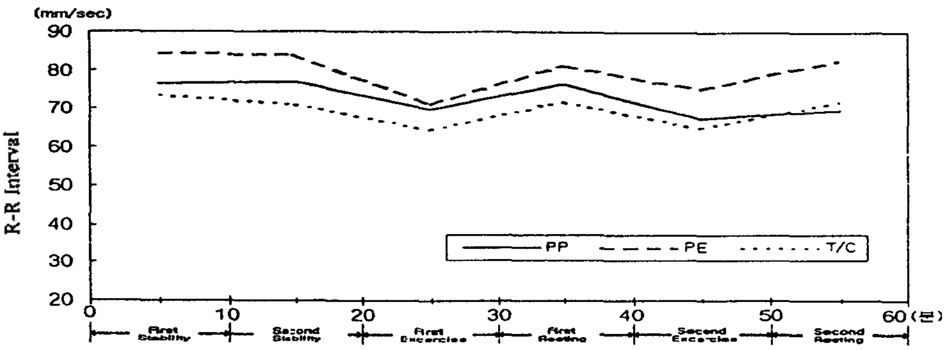
The distinction of the lowest blood pressure and clothing type is P<0,05 under the environment A and B, but there is no distinction under the high temperature and humidity environment. Under the A, B there is the highest the lowest blood pressure of clothing PP and clothing PE is the lowest the lowest blood pressure. The more temperature and humidity the lower the high blood pressure. Especially the more humidity the more distinction. The blood pressure is clothing PP > T/C > PE under all the environmental condition.

2) Subject Sensation according to Clothing and Environment

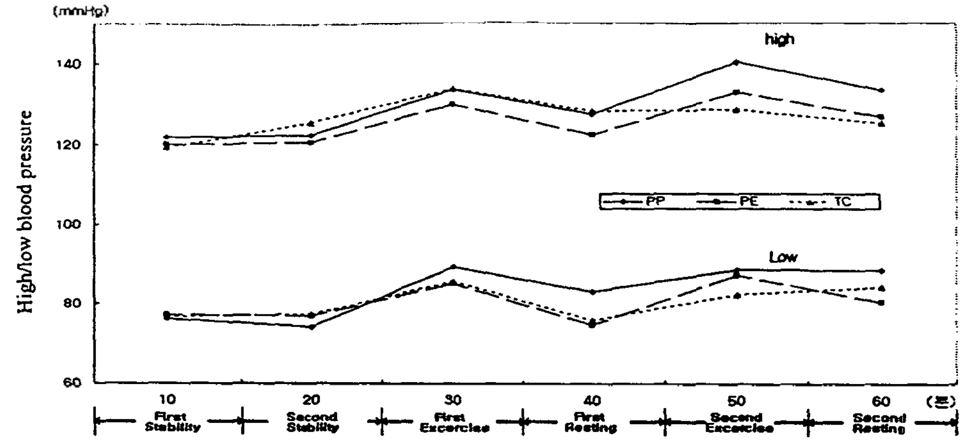
In part of clothing material properties, thermal sensation inter-related with air permility and humidity sensation inter-related absorbed water properties, comfort sensation was thickness.

2. The Relation of Subject Sensation and Physiological Response

In physiological response and subject wearing



<Fig. 7> R-R Interval change during exercise and rest according to environmental condition for coveralls.



<Fig. 8> High/low blood pressure change during exercise and rest according to environmental condition for coveralls.

sensation was correlation with MST and total sweat period and subject wearing sensation was bi-interrelated MST, clothing climate and total sweat rate.

3. Estimate Model for Thermal Comfort

It is found the relationship between mean skin temperature, total sweat rate, blood pressure, clothing climate and R-R interval.

As a result of this study, two types of multiple regression as a function of thermal sensation, humidity sensation and comfort sensation are modelled in order to estimate thermal comfort ot the protective clothing.

Ⅳ. Conclusion

This study was designed for to device thermal comfort model for radiation power plant worker in protective clothing. It was investigated the relationship between physiological response and subject comfort according to environmental variance and clothing types.

The result was as follows;

1. Under the higher temperature and humidity, MST was higher. Under the environment of type D, the type of clothing PP was higher in MST.
2. The local sweat rate is higher in order of forehead, breast, upper arm, hand, thigh, leg and foot. Each type of clothing has a different total sweat rate. The type of clothing PE, total sweat rate was highest.
3. In R-R interval, during the working and under the environment of types A, B was faster than rest period.
4. Under the environment of A, B, subject wearing sensation was significant change rate in during the resting and working. Under the environment of C, D. have non significant change rate, specially under the environment of D. Clothing type of PE was revealed 'most hot', 'most humidity', 'most uncomfortable' in subject wearing sensation.. The Clothing type of PP is the most comfortable in subject thermal comfort sensation..
5. In part of clothing material properties, thermal sensation inter-related with air permeability and humidity sensation inter-related absorbed water properties, comfort sensation was thickness.
6. In physiological response and subject wearing sensation was correlation with

MST and total sweat period and subject wearing sensation was bi-interrelated MST, clothing climate and total sweat rate.

7. It is found the relationship between Mean Skin Temperature, Total Sweat Rate, Blood Pressure, clothing Climate and R-R interval.

As a result of this study, two types of multiple regressions are modelled in order to estimate thermal comfort ot the protective clothing as follows;

The thermal comfort evaluation model according to physiological

Comfort =

$$-3.6172-0.00022a+0.07104b-0.01400c-0.10511d-0.192809e-0.450589f-0.014162g+0.40109h-0.013614j \quad (R^2= 0.7829)$$

a: total sweat, b: high blood press., c: low blood press., d: mean skin tem., e: armpit, f: clothing tem., g: lothing humidity, h: eardrum, I: R-R

The thermal comfort evaluation model according to clothing materials

Comfort =

$$227.8313-0.00242j-0.138741k+526.044772Ll-1.19739m-0.97118n-39.882560o+0.47165p-0.009627q-0.01538r \quad (R^2= 0.7726)$$

j: Ratio of Blends., k: Air Permeability., L: Water Absorption., m: Thickness., n: Waterrepellency., o: Waterresistance., p: Density., q: Thermal Resistance., r: R-R

These results suggest the usages of thermal comfort evaluation model can easily evaluated heat load in the thermal comfort and improving subjects wearing sensation in the protective clothing.

Therefore, in order to get more precise results, more studies under the diversity of clothing types, and environments should be done.

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