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A Case Study on Designing a Console Design Review System Considering Operators' Viewing Range and Anthropometric Data

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Objective: The aim of this study is to introduce an operator console design review system suitable for designing and evaluating consoles based on human factor guidelines for a digitalized main control room in an advanced nuclear power plant which has a requirement for anthropometric data usage.

Background: The system interface of the main control room in a nuclear power plant has been getting digitalized and consists of various consoles with many information displays. Console operators often face human-computer interactive problems due to inappropriate console design stemming from the perceptual constraints of anthropometric data usage.

Method: Computational models with a process of visual perception and variables of anthropometric data are used for designing and evaluating operator consoles suitable for human system interface guidelines, which are used in an advanced nuclear power plant.

Results: From the computational model and simulation application, console dimensions and a designing test module, which would be used for designing suitable consoles with safety concerns in a nuclear power plant, have been introduced.

Conclusion: This case study may influence employing a suitable design concept with various anthropometric data in many areas with safety concerns and may show a feasible solution to designing and evaluating the safety console dimensions.

Application: The results of this study may be used for designing a control room with the human factors requiring a safe working environment.

Keywords: Console, Anthropometry, Visual perception, Interface, HSI guidelines

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1. Introduction

As the main control room interface has been recently digitalized in a nuclear power plant (NPP), the safety and reliability of the use environment of digital devices including a console are emphasized more than any other systems. The interface of NPP's main digital control room consists of various operators' workstation consoles in addition to a large display panel (LDP) and a safety console. The hierarchy and shape of the working environment and the flow of movement are major working environmental factors. The shape design of a control room is a key working factor to

operators, and thus it is important to identify correlations between physical characteristics and devices' mechanical characteristics in a broad context of human-machine manipulation.

Cognitive load increases due to more information in a hybrid NPP in the digital environment than the analog environment, although physical burden has decreased. Since the possibility of causing human errors is high because of massive amount of operation information even in the case of highly skilled operators, it is critical to convey the relevant information clearly. Concerning the main control room of an existing NPP where the control of operations, such as operation, suspension, emergency, and abnormal operations, is carried out, installed indicators and control devices are over 2,000. Since surveillance using the large display panel (LDP) and control and information indication using operator consoles are conducted, it is critical to design the console shape and layout through which information identification within visual perception range is easy in order to manipulate actual devices.

However, actual design of ergonomic interface considering numerous consoles' shapes and layout is not efficiently carried out due to the lack of a comprehensive system analysis and evaluation system (Ra and Cha, 2013). This study aims to analyze the sensitivity of many independent variables according to recent anthropometric data for console design in order to optimize the operating environment from the cognitive ergonomic perspective. Ultimately, this study aims to introduce a case study on a console design evaluation system currently under development using effective viewing angles helpful to the layout of operators' directing and controlling facilities within the range of operators' information processing capabilities (Cha, 2013).

2. Method

2.1 Background research on viewing angles

Vision is a key sensory organ to the extent that about 90% of the information taken from the surroundings by humans is acquired by human's vision. Humans recognize or perceive information taken through the eyes via information processing. Visual information means information changing through human's vision, and the visual information can be understood with three characteristics: The first is sensible characteristic. When an image is formed on the retina, after light passes through each part of the eye, the sensory receptor and nerve system accept spatial physical energy; namely, light, converting it into neural information. The second is perceptive characteristic. Human's efficient visual processing area is more than 180° horizontally and 130° vertically, and there is optical illusion in which a subject's shape or form changes according to visual angle. The third is cognitive characteristic. After visual information arrives at the brain, the visual information, such as shape, color, or motion, is recognized through different channels. Further, knowledge is stored in the form of representing or symbolizing external objects or relationships between objects (Cha, 2016).

Humans have a certain range of field of vision, and it is defined according to visual angle identifying the outline of a subject. The cognitive level differs depending on the distance from a subject and its size. If a subject is at the same vertical side as a human, Table 1 shows human's visual relationship according to the size of a subject.

Human's useful field of view (UFOV), generally known in the ergonomics guidelines, are shown in Table 2, when a human deciphers letters, sees symbols, and distinguishes colors.

2.2 NPP guidelines' application for viewing angles

There are three types of guidelines used by applying to a digital NPP with regard to console viewing angle as shown in Figures 1, 2, and 3, and they are offered to actual ergonomic design (KEPCO E&C, 2008, 2016; NRC, 2002).

Table 1. Calculations on visual angles

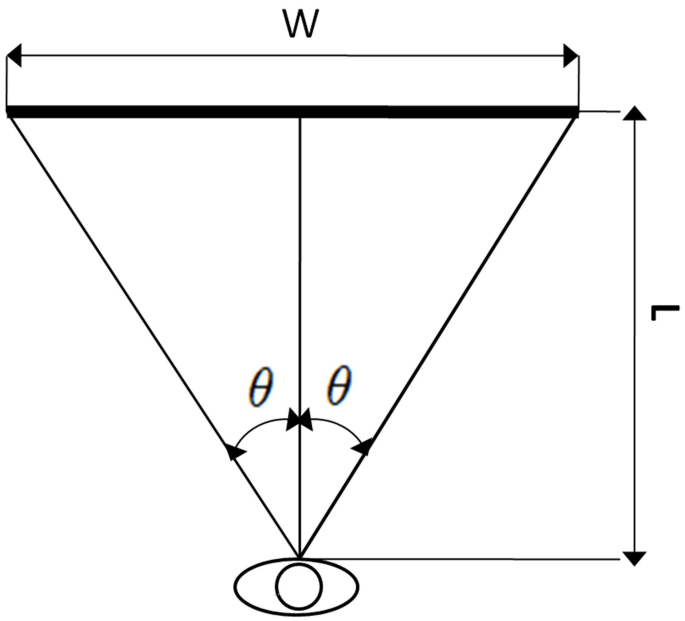
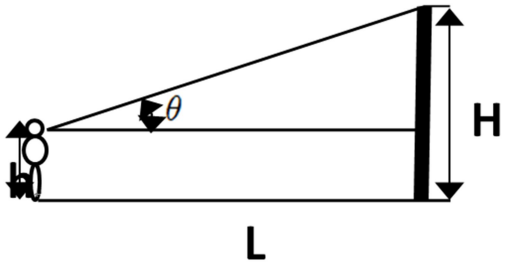
Horizontal	Vertical
	
W = 2tanθ θ : Left and right side angles W : Subject's length L : Distance from a point to the subject	H = h + L*tanθ θ : Vertical angle W : Subject's height L : Distance form a point to the subject

Table 2. Guidelines on visual

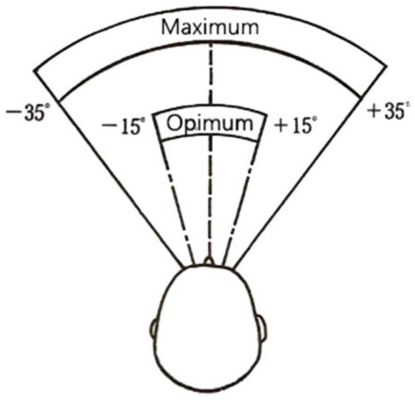
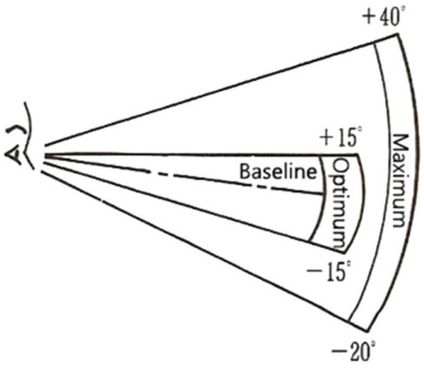
		
	Horizontal visual field	Vertical visual field
General range	The visual field range through which a subject can be viewed is 1° (left and right, each), when central vertical axis is set up between the left and right eyes.	In the vertical direction, visual field tilts downwards more. At the usual time, the direction of visual field is placed at 10° downwards.

Table 2. Guidelines on visual (Continued)

	Horizontal visual field		Vertical visual field	
Range in deciphering letters	Same visual field axis	5~10° (left and right, each)	Centered on visual height horizon	Desirable upward visual field limit is 15°
Range by which a symbol can be seen		5~30° (left and right, each)		Upper limit: 20° Lower limit: 30°
Range by which colors can be distinguished.		30~60° (left and right, each) from the central axis		Upper limit: 30° Lower limit: 40°

2.2.1 Horizontal space standard of the control and display devices of a sit-down console

All the control and information display units used for main jobs of a sit-down console should be placed within the maximum values of viewing range and extended reach of a user in sit-down position (NUREG-0700(Rev.2) 11.1.2-9).

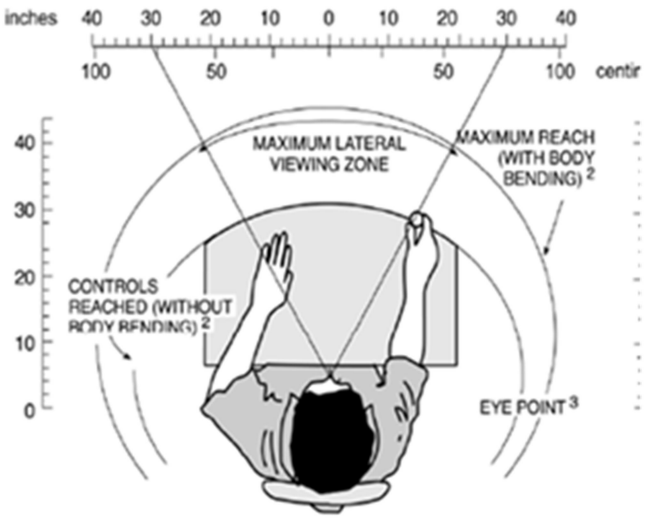


Figure 1. Horizontal viewing range on NPP sitting console

2.2.2 Standard of console VDU's vertical UFOV

In stand-up and sit-down consoles, all information display units, including an alarm indicator, need to be offered within the 5th percentile of a female's field of view measurement (75° from horizontal field of view), and the angle that the field of view and a visual display unit (VDU) forms needs to be maintained higher than 45° (NUREG-0700(Rev.2) 11.1.2-5).

2.2.3 Actual layout range standard of VDU information

When main information display units were placed in a sit-down console, horizontal layout range was within 35° (left and right, each) centered on line of sight (LOS) by using actual console shape data, with vertical layout range designed to make LOS 40° downwards.

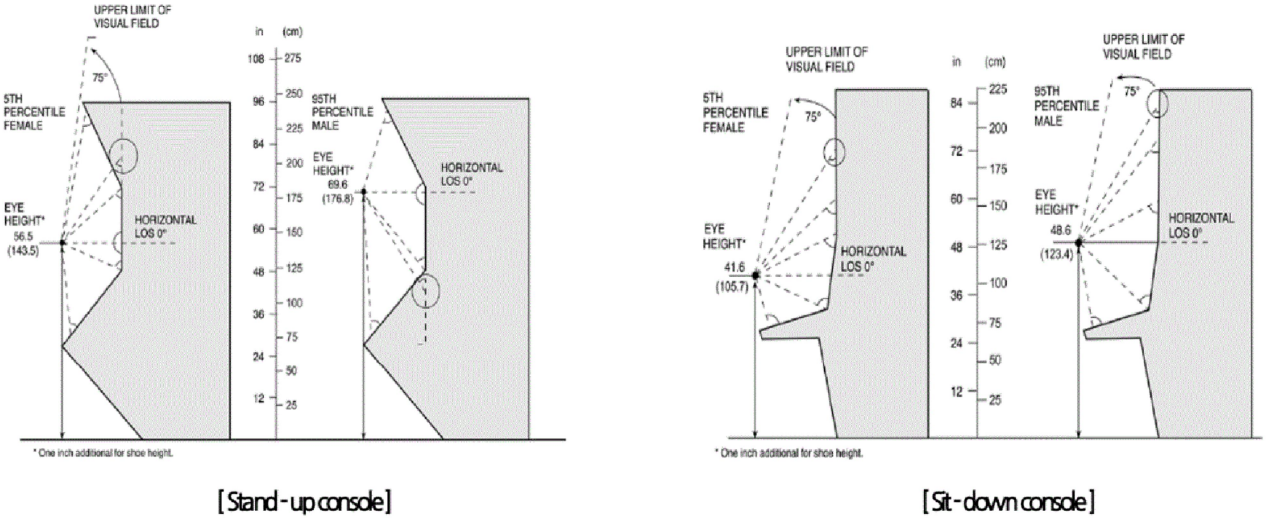


Figure 2. Vertical viewing range of NPP consoles

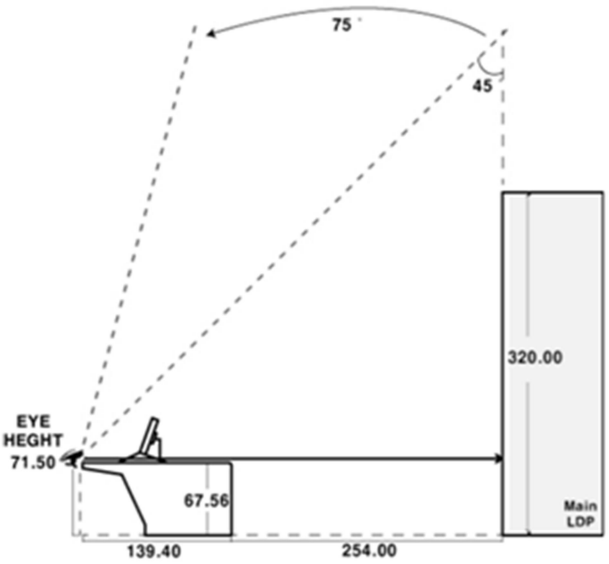


Figure 3. VDU layout design

2.3 Anthropometric data for NPP console design

The Korean Agency for Technology and Standards' SizeKorea 7th Anthropometric Data of Koreans, which measured and investigated Koreans' anthropometric data and human shapes (KATS, 2016), were collected by console design factor item in this study for 10 months from March to December 2015. The anthropometric data of operators, aged 25-50 in NPPs required for sit-down console evaluation, were sorted out and arranged by referring to the NUREG guidelines (Table 3).

Table 3. 2015 Korean anthropometric data for console design (unit: cm)

Standing	Measured data (cm)	
	5th percentile of adult females	95th percentile of adult males
Height	150.2	181.4
Eye height	139.5	169.7
Shoulder height	120.2	147.6
Elbow height	91.2	111.8
Grip reach; forward	59.9	75.4
Viewing distance from the body	7.6	8.6
Popliteal height	34.2	43.9
Sitting height	82.2	96.2
Eye height, sitting	71.5	86.9
Shoulder height, sitting	52.3	64.8
Elbow height, sitting	21.9	30.7
Thigh clearance	12.9	18.0
Buttock-popliteal length	41.2	51.3
Knee height, sitting	44.4	55.4
Grip reach; forward, sitting	59.9	75.4

2.4 Intelligent design review system

To efficiently carry out console design review and evaluation feedback, an intelligent design review system (IDRS), which is an intelligent decision making system module, was developed in a demonstrative manner (Figure 4).

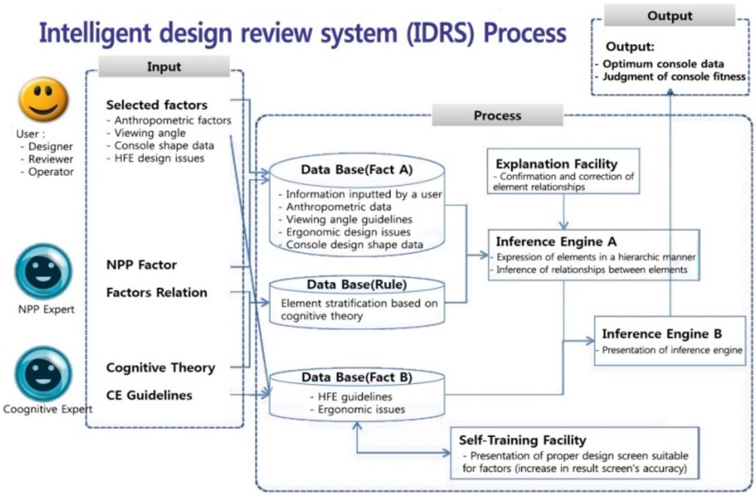


Figure 4. Intelligent design review system architecture

IDRS complies with the structure of an intelligent system. When a user (console designer or evaluator) asks a question or in puts the details concerned through the given interface, an inference is made using the details in the database and rules, and the result is conveyed to the user through the interface again. This study implemented an intelligent system by which data can be more easily collected by adding a knowledge acquisition facility, a self-training facility, and an explanation facility to the architecture.

3. Results

3.1 Console design computational model

Figure 5 shows the variables and fixed values to be inputted, and also the resulting values when the system is implemented. By fixing VDU's size and the distance, L, between an operator and VDU, according to the design plan of an NPP as they are inputted as variables, each operator's eye height, popliteal height, and shoe thickness are treated as input values. For each independent variable's sensitivity analysis, the SizeKorea 7th Anthropometric Data were used.

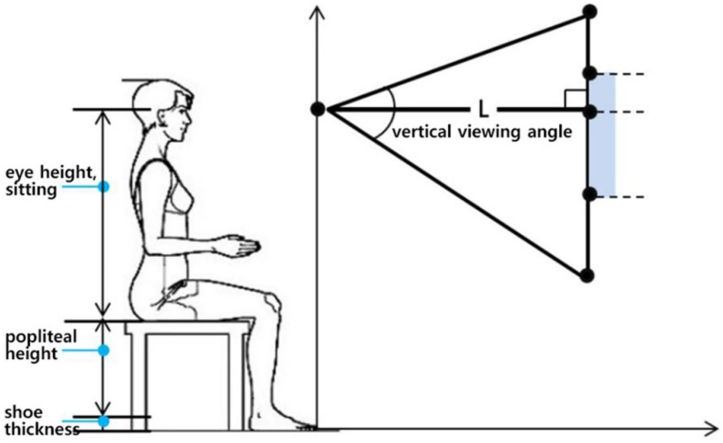


Figure 5. Console design with anthropometric data usagerm

When the program is executed, vertical viewing angles are computed according to anthropometric data. If the vertical viewing angle is set as a fixed value by referring to the guidelines, whether a VDU is within the operator's viewing angle or not is displayed as Yes/NO. Therefore it helps to generate an optimum design plan upon designing an NPP, and also an evaluation on whether the design is made well can be carried out.

When the main information display units are placed in a sit-down console in the NPP guidelines related with VDU information layout range where NUREC-0700 Rev.2 becomes the basis, the horizontal layout range is 35° (left and right, each), centered on LOS. The vertical layout range is indicated as within 20° upwards and 40° downwards, centered on LOS. Based on this, if calculation is conducted using an example of 5^{th} percentile of males through a trigonometrical function and vertical viewing angle formula, the following result values are generated: sit-down console's height, H, is 1093.5mm; distance from VDU is 535.2mm; and distance from floor to eye, h (5^{th} percentile of males' eye height, sitting + popliteal height + shoe's thickness), is 1353mm. Also, the maximum height and minimum height of effective viewing angle can be calculated.

3.2 Suitability analysis with parameters

A sensitivity analysis on whether parameter values affecting console design are suitable for the design and evaluation guidelines was undertaken by substituting the parameter values.

3.2.1 Design sensitivity analysis (male)

Using the SizeKorea 7th Anthropometric Data, when each percentile value of males aged 25-50 was substituted, height (h) from floor to eye height was calculated. According to the result values, Figures 6 and Table 4 show the values calculating the maximum h at 20° upwards, and the minimum h at 40° downwards.

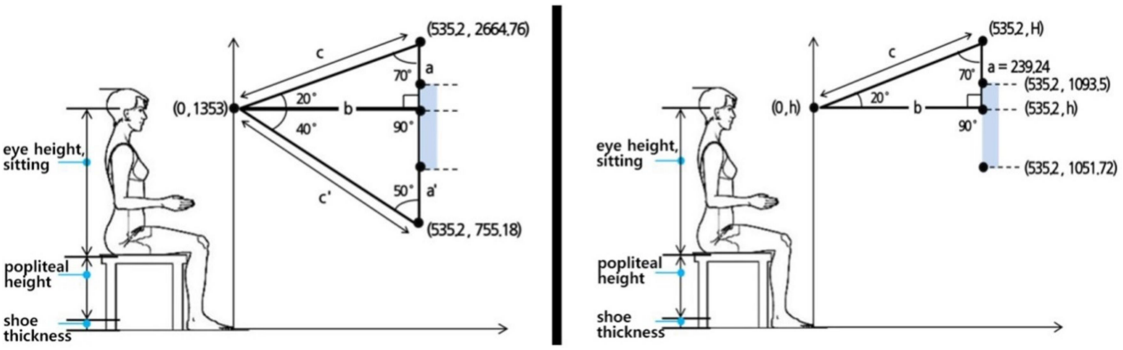


Figure 6. Console design suitability (max., male) and console design suitability (min., male)

Table 4. Calculated figures for console design (male)

	1st percentile	5th percentile	25th percentile	50th percentile	75th percentile	95th percentile	99th percentile
h	1155.5	1195.5	1241	1272	1303	1353	1388.5
H (max.) =h+a*tan20	1394.74	1434.74	1480.74	1511.24	1542.24	1592.24	1627.74
H (mim.) =h-a*tan40	676.36	716.36	761.86	792.86	823.86	873.86	909.36

3.2.2 Design sensitivity analysis (female)

Using the SizeKorea 7th Anthropometric Data, height (h) from the floor to eye can be calculated, respectively, by substituting each percentile value of females aged 25-50. According to the result values, Figures 7 and Table 5 show the values calculating the maximum h at 20° upwards, and the minimum h at 40° downwards.

3.3 Computational Model-based System Output

Based on the anthropometric data, guidelines, and console shape data, this study presented the suitability of console design results

through IDRS' design process embedded with a decision-making inference model as shown in Figure 8.

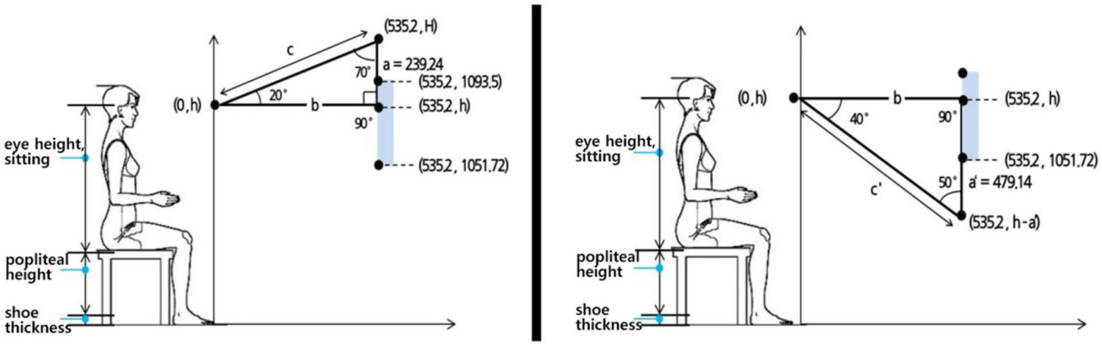


Figure 7. Console design suitability (max., female) and console design suitability (min., female)

Table 5. Calculated figures for console design (female)

	1st percentile	5th percentile	25th percentile	50th percentile	75th percentile	95th percentile	99th percentile
h	1082	1107	1153	1181	1213	1255.5	1293
H (max.) =h+a*tan20	1321.24	1346.24	1392.24	1420.24	1452.24	1494.74	1532.24
H (min.) =h-a*tan40	602.86	627.86	673.86	701.86	733.86	776.36	813.86

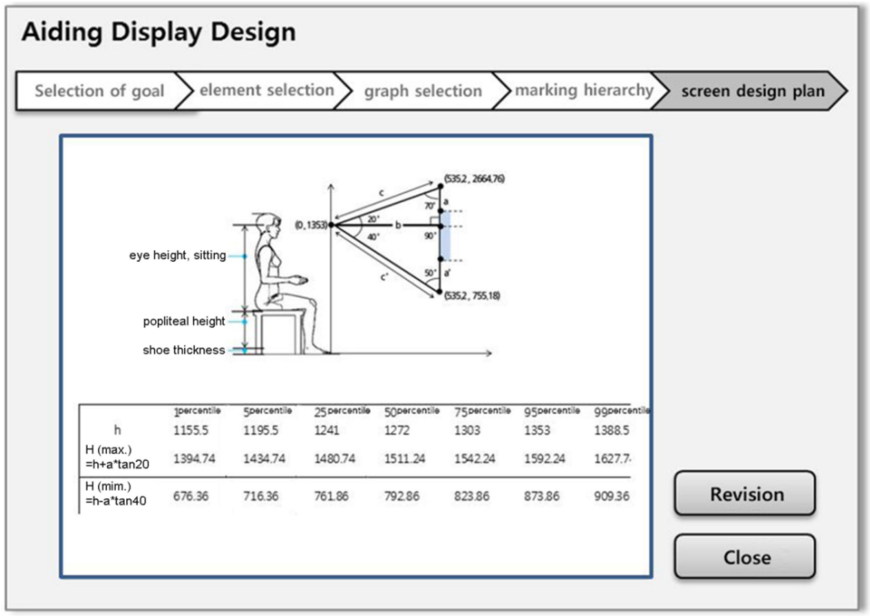


Figure 8. IDRS UI output screen

4. Conclusion

In a nuclear power plant (NPP), safety is regarded as most important. In a digital hybrid NPP, where the possibility of human errors has become higher due to increase in cognitive load by more information, information identification compared to the past needs to be easy for device manipulation above all. Using the viewing angle-based evaluation support system applicable to the main control room design layout in an NPP through the results of this study, whether a console's visual display units are included within the operator's effective visual field according to NPP guidelines, and whether the given information can be clearly recognized can be evaluated. Therefore, work efficiency improvement can be expected, and there can be effectiveness in terms of ergonomics in the optimum design of a console depending on individual anthropometric data to be solved, or depending on the adequate problem solving measure devised upon problems' occurrence in a console related with the viewing angles of the main control room working environment.

The main control room design of a digitalized NPP is currently conducted and evaluated according to ergonomic guideline standards, which cannot promptly cope with the frequently changing digital environment and up-to-date anthropometric data. To improve such inefficiencies of design and rule of thumb evaluation, an intelligent console design review system, which is a currently developed design evaluation support system, will make contributions to efficient console design and the evaluation of digital NPPs by continuously embedding updated intelligent modules.

Acknowledgements

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