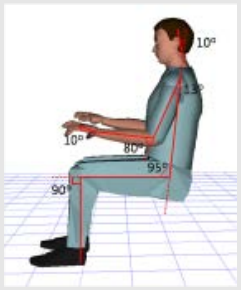
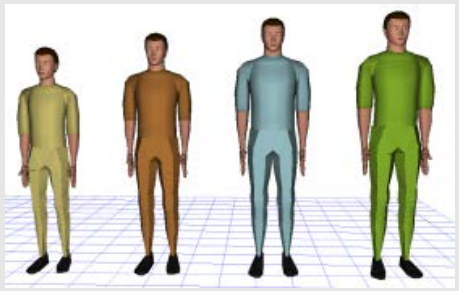
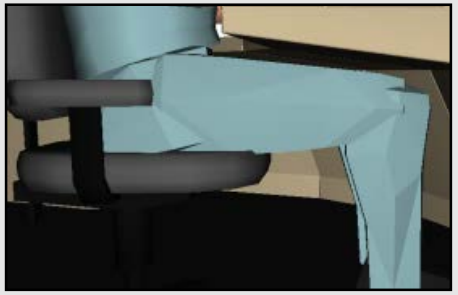
포항공과대학교
산업경영공학과

Ergonomic Design Technology Lab

Ergonomic Evaluation of a Main Control Room Design of Radioactive Waste Facility Using Digital Human Simulation

POSTECH

2012. 10. 25

KOPEC

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Agenda

- Introduction
  - Background
  - Objective of the Study
- Approach
- Evaluation & Improvement
- Discussion

Radioactive Waste Facility (RWF)

- **Intermediate- and low-level wastes (I&LLW)**
  - ✓ From where: hospitals and industries as well as the nuclear fuel cycle
  - ✓ Examples: paper, rags, tools, clothing, filters, and other materials which contain small amounts of mostly short-lived radioactivity
- **Saturation of I&LLW in Korean nuclear power plants (NPP)** (KRMC, 2009)

Radioactive wastes

Radioactive wastes stored in silos of NPP/RWF

⇒ Plan approved to construct a **new RWF for I&LLW** by 2012 in Gyeongju

Main Control Room (MCR) at RWF

- **Area for main operation and control of RWF**
  - ✓ Many displays and controls for situation recognition, control, and safety management
  - ✓ **Continuous monitoring and operation by operators**

Main control room of RWF

⇒ Need to provide comfortable work environments for operators

Existing MCR Studies

- Few studies related to ergonomic design of NPP/RWF MCR last 20 years
- Ku et al. (2007) evaluated existing MCR designs

  ⇒ Not easy to correct identified design problems due to MCR operation
- Hwang et al. (2009) identified design problems of an MCR by observation and interview ⇒ No solutions for improvement

Example of problem list of an MCR (Hwang et al., 2009)

The priority of display in terms of emergency by operators	The possible situations and the latent human errors
1	*Situation*: The image of LVD projection was blurred. *Latent errors*: It might be difficult for the operator to read.
2	*Situation*: The value of water level on WDP was a rough average instead of precise value of specific alarm. *Latent errors*: It might cause operator to make a wrong decision by reading the water level bar directly.

Situation

Problem

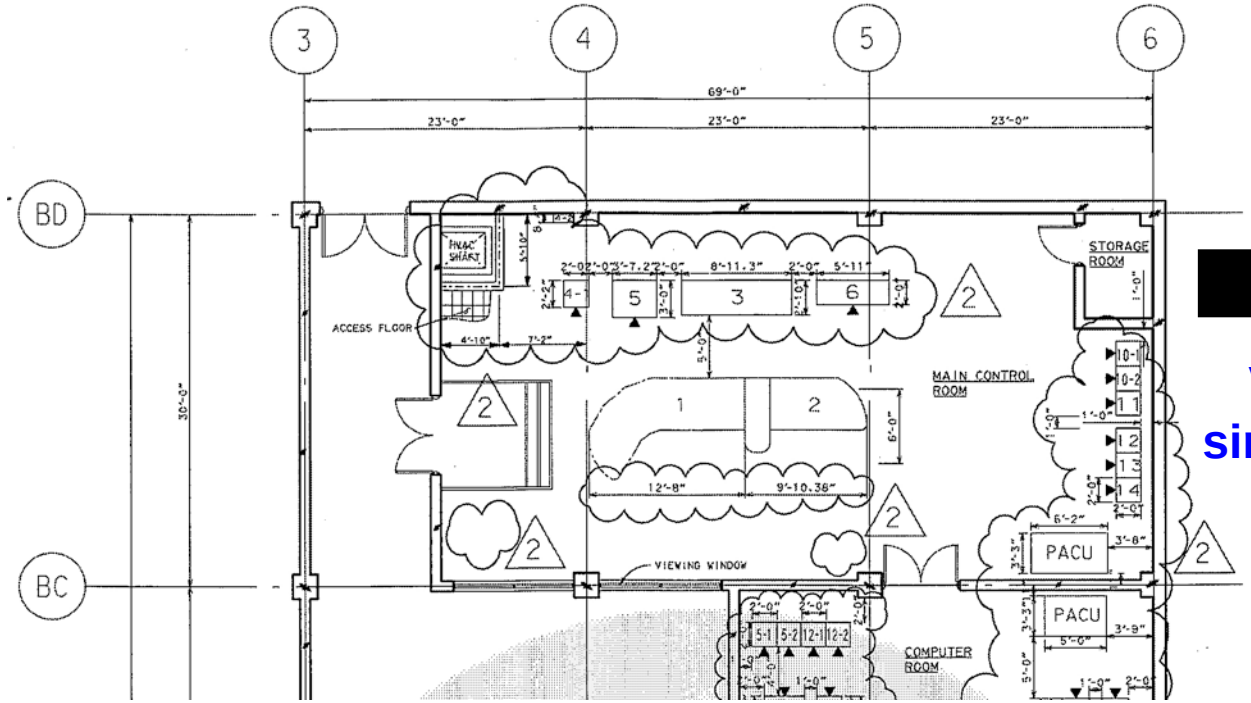
But, no solutions

⇒ **Need to evaluate an MCR at the planning stage of facility construction and provide ergonomic solutions for potential design problems**

Request for Research

- **Evaluation of a preliminary MCR design** requested by KOPEC
  - ✓ **No physical mockup**: 2D drawings of a preliminary MCR design

⇒ Need to apply a digital human modeling and simulation system (e.g., Jack®, RAMSIS®) for ergonomic assessment



Preliminary MCR drawing

Virtual simulation

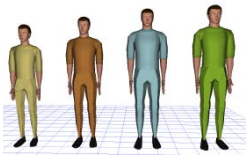
Research Objective

Ergonomic Evaluation of
a Preliminary Main Control Room (MCR) Design
using Digital Human Simulation

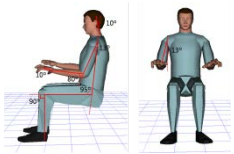
- **Ergonomic evaluation of an MCR design using digital human simulation**
  - ✓ Generation of humanoids for operators and a 3D digital mockup of the MCR
  - ✓ Evaluation based on NUREG-0700 (U.S. design guideline for NPP)
  - ✓ Evaluation from ergonomic aspects (postural comfort, reachability, visibility, clearance)
- **Suggestion of ergonomic solutions**
  - ✓ Search for potential solutions for identified problems for improvement
  - ✓ Validation of suggested solutions

Research Protocol

Generation of **humanoids** considering operators in the MCR



Determination of a **reference posture**

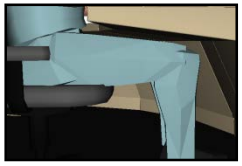


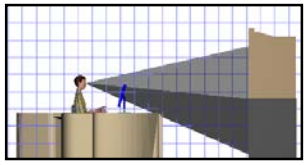
Construction of a **digital mockup** for the MCR

Analysis of **NPP regulations** and **MCR design characteristics**

No.	Design component	Postural comfort	Reach-ability	Visib-ility	Clear-ance
1	Console	O	X	O	O
2	Large display panel (LDP)	O	X	O	X
3	LCD	O	X	O	X
4	Security access control sub-console	O	O	X	X
5	CCTV master control rack	O	O	X	X
6	Main fire control panel	O	O	X	X
7	Printers	O	O	X	X

Ergonomic design **evaluation**

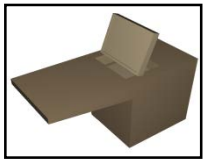




Problem detection

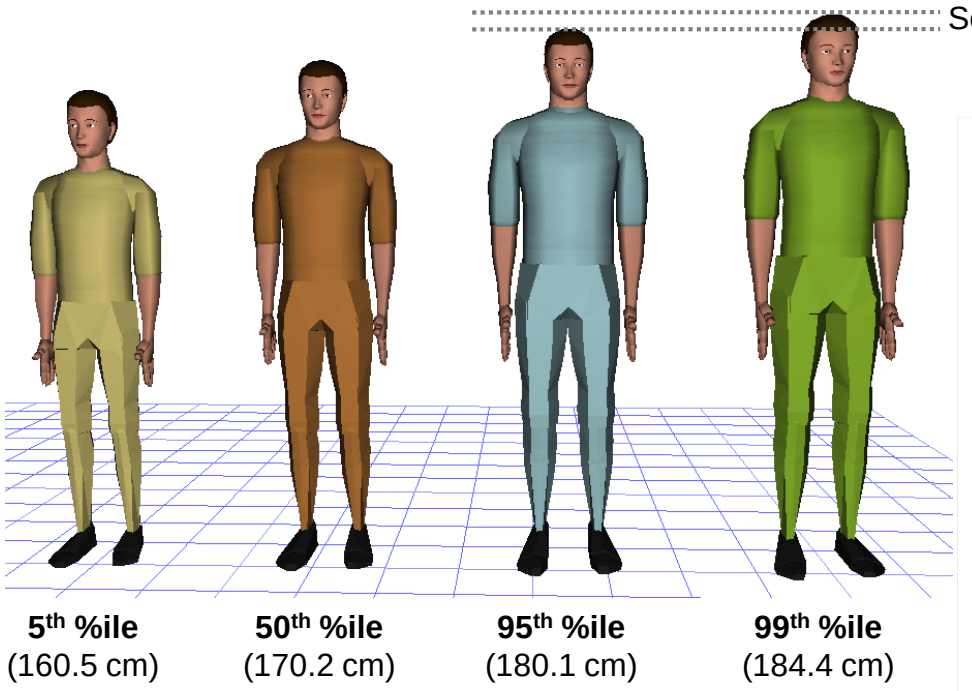
Validation

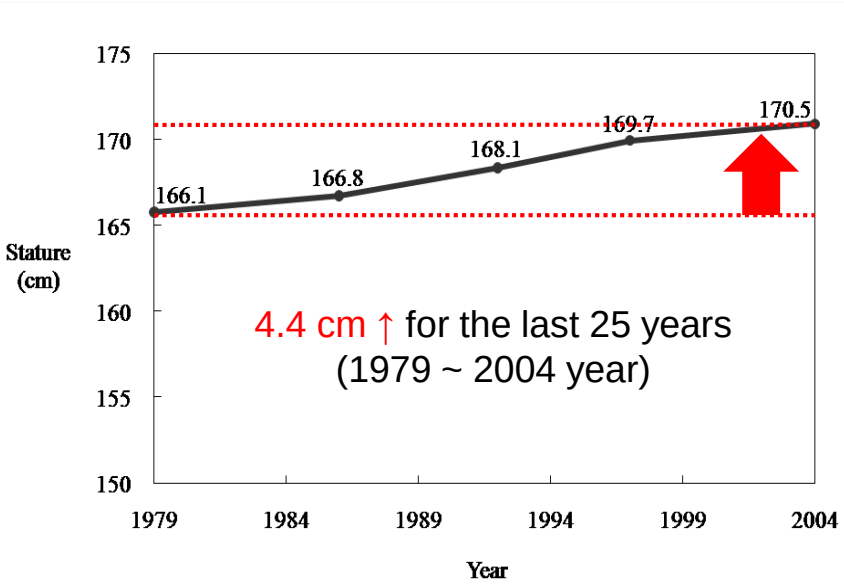
Design **improvement**



Humanoids

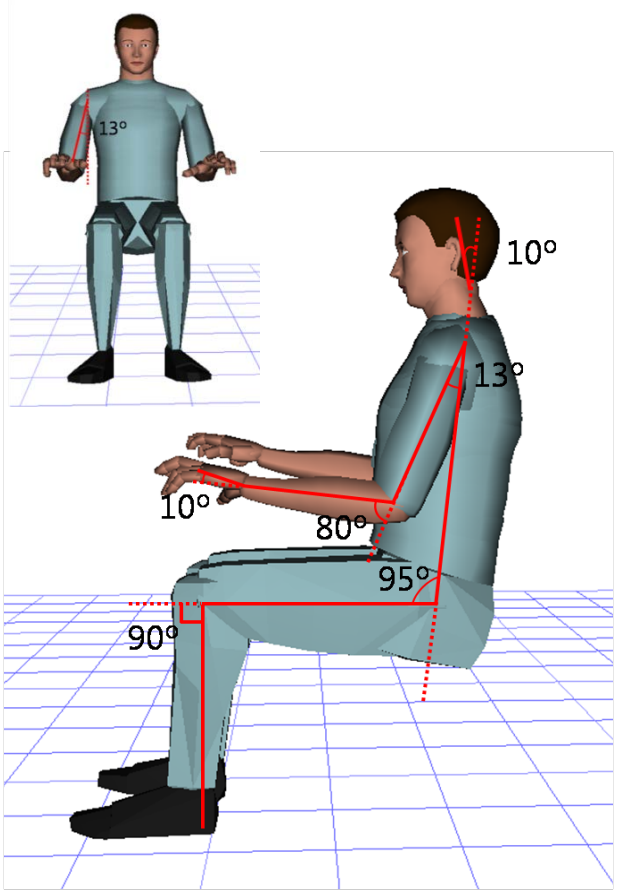
- **Four representative human models** considering **actual operator's body sizes**
  - ✓ 20s ~ 50s, males (Size Korea, 2004; *n* = 1,992)
  - ✓ **5th, 50th, and 95th percentiles**: accommodation of 90% for stature
  - ✓ **99th percentile**: generation considering MCR's life cycle (20 years)





Reference Posture

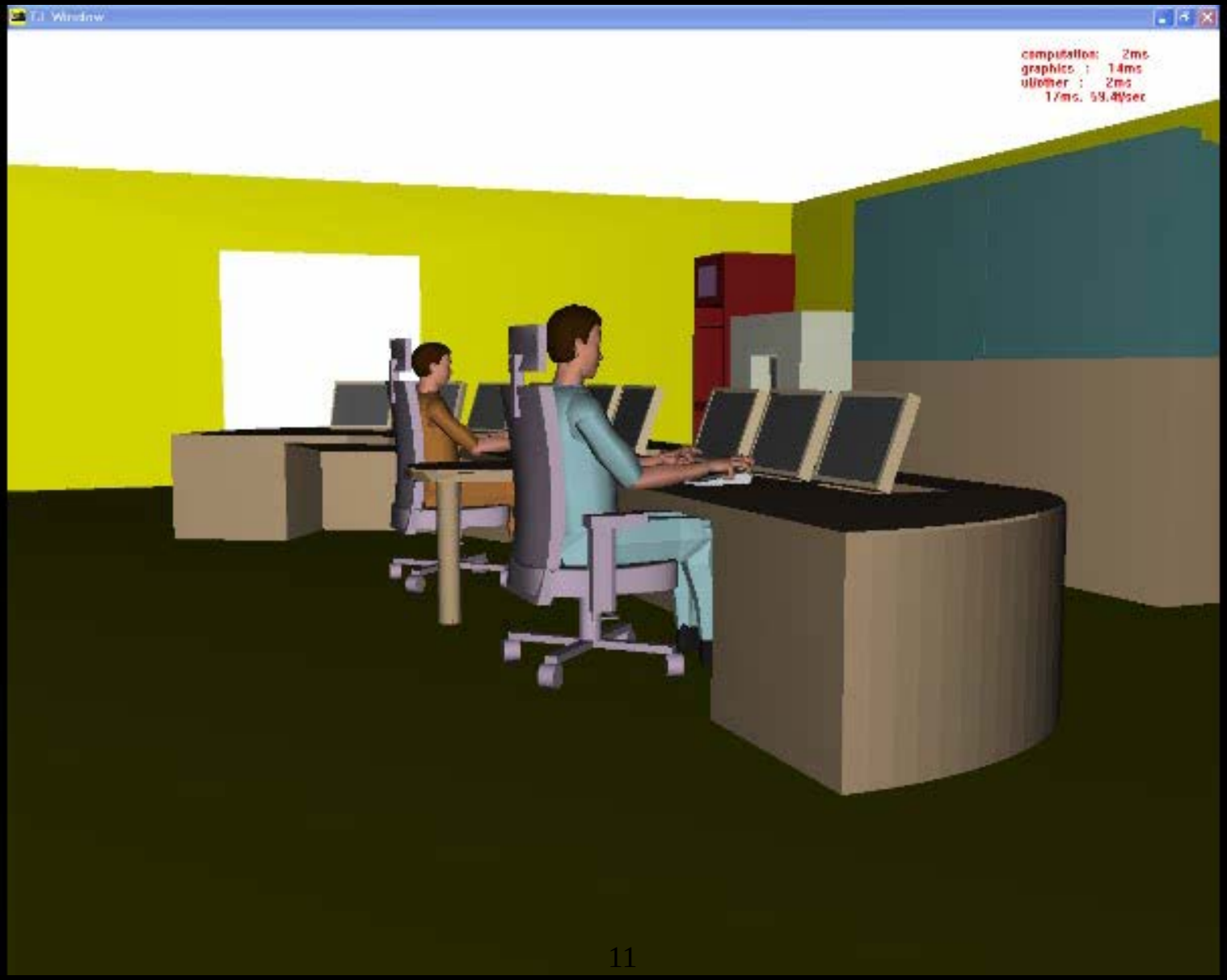
- **Establishment of a posture for evaluation referring to 14 existing studies related to computer workstation posture**



Body part	Motion	Posture recommecdation (°)	References	Recommended posture range (°)	Determined posture (°)
Neck*	Flexion (+)/extension(-)	34 ~ 65	Grandjean et al. (1983)	24.5 ~ 65	35
		24.5 ~ 65	Kim et al. (1991)		
Shoulder	Flexion (+)/extension(-)	0 ~ 25	Chaffin and Andersson (1984)	0 ~ 25	13
		0	ANSI/HFES (2007)		
		13	Geandjean (1987)		
		23	Salvendy (1987)		
	Abduction(+)/adduction(-)	0 ~ 25	Chaffin and Andersson (1984)	0 ~ 25	13
		8 ~ 23	Salvendy (1987)		
Elbow	Flexion (+)/extension(-)	70 ~ 135	Cushman (1984); Grandjean et al. (1983); Miller and Suther (1981); Weber et al. (1984)	70 ~ 135	80
		90	ANSI/HFES (2007)		
		99	Salvendy (1987)		
		75 ~ 125	Grandjean et al. (1983)		
Wrist	Flexion (+)/extension(-)	-10 ~ 30	Hedge el al. (1995); Keir et al. (1995); Rempel and Horie (1994); Weiss et al. (1995)	-10 ~ 30	10
Trunk**	Flexion (+)/extension(-)	≥ 90	Chaffin and Andersson (1984)	90 ~ 110	95
		104	Geandjean (1987)		
		100 ~ 110	Salvendy (1987)		
		90	ANSI/HFES (2007)		
Hip**	Flexion (+)/extension(-)	0	ANSI/HFES (2007)	0	0
Knee**	Flexion (+)/extension(-)	90	ANSI/HFES (2007)	90	90

* Angle between vertical line from cervical and line linking cervical and tragion
** Angle between transverse plane and corresponding body part

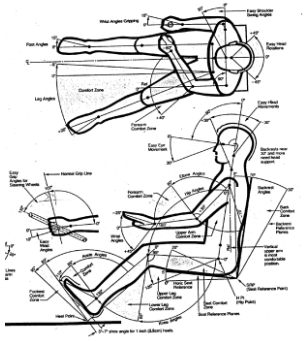
Digital Mockup

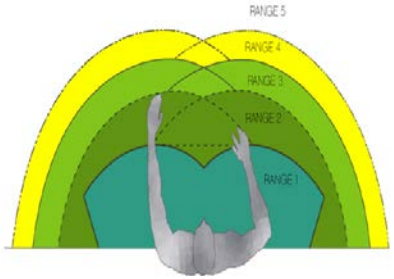


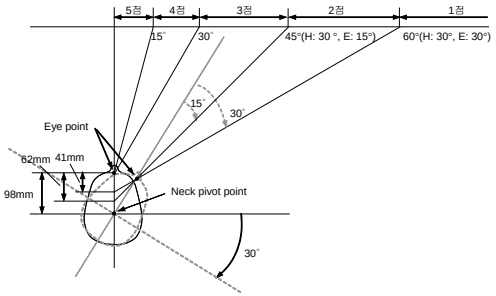
Ergonomic Evaluation Criteria

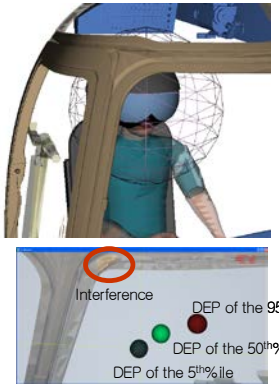
- **Application of four ergonomic aspects referring to existing DHS studies**

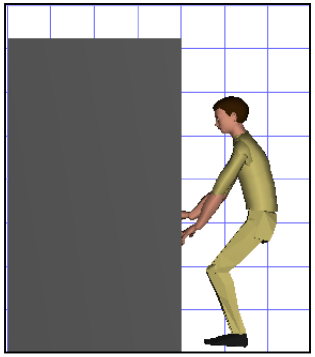
  (Bowman, 2001; Nelson, 2001; Park et al., 2008)

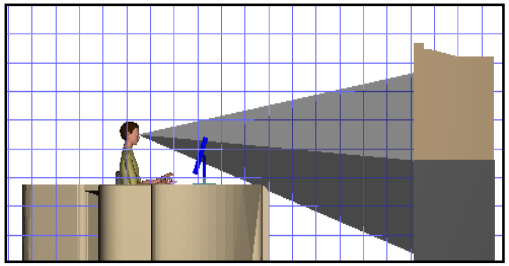


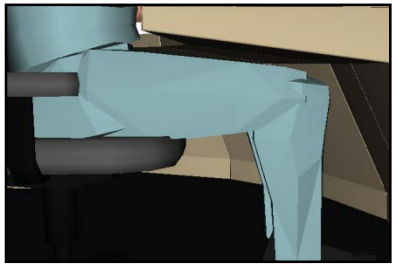












Postural Comfort **Reachability** **Visibility** **Clearance**

Design Component vs. Evaluation Criteria

- **Evaluation criteria: selectively applied with target design components**

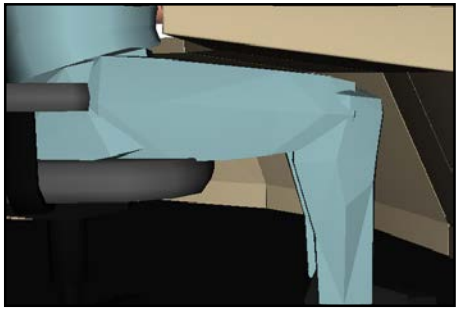
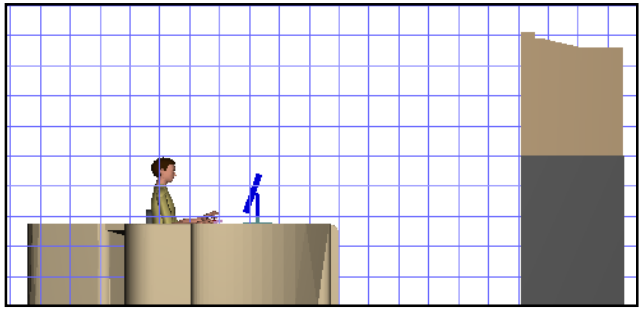
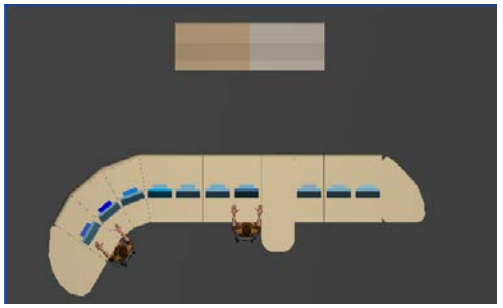
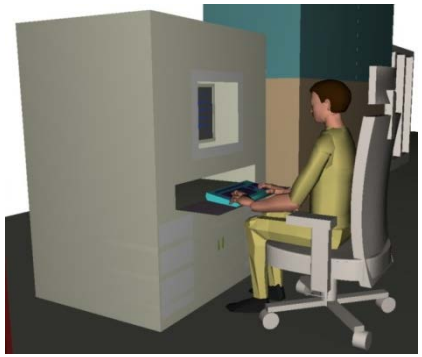
No.	MCR design component	Postural comfort	Reachability	Visibility	Clearance
1	Console	O	X	X	O
2	Large display panel (LDP)	O	X	O	X
3	LCD monitor	O	X	O	X
4	Security access control sub-console	O	O	X	X
5	CCTV master control rack	O	O	X	X
6	Main fire control panel	O	O	X	X
7	Printers	O	O	X	X

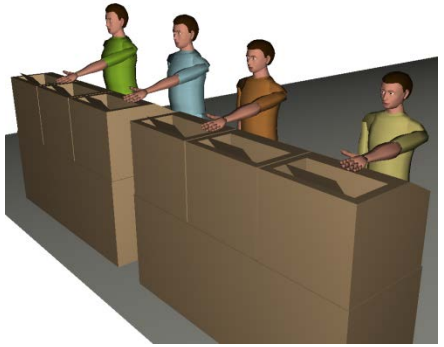
NPP Design Guideline

- **Extraction of relative regulations from human-system interface design review guidelines (NUREG-0700, O'Hara et al., 2002)**

Component	Criteria	Recommendation	Target %ile
Console	Clearance	Should provide adequate height, depth, and knee clearance for the 5th to 95th percentile adults(p. 426, 11.1.5-4)	95th & 99th
Large Display Panel (LDP)	Visibility	Permit operators at the consoles full view of all display panels(p. 459, 12.1.1.3-1)	5th ~ 99th
		Be able to view information from multiple locations(p. 327, 6.3.1-1)	
		Horizontal viewing angle requirement: Acceptable limit is within 30° from the centerline of each display(p. 329, 6.3.2-4, 6.3.2-5)	
	Location	Centrally located in the control room(p. 311)	5th ~ 99th
		Viewing distance - Minimum: Not closer to any observer than half the display width or height, which is greater(p. 329, 6.3.2-3) - Maximum: Able to resolve all important display detail at the Maximum viewing position(p. 329, 6.3.2-2)	
	Character size	Character height (cm) = 6.283×D×(MA) / 21600(p. 47, 1.3.1-4)	5th ~ 99th
		Minimum of minutes of arc (MA): 16'	
		Recommended MA: 20'~22'	
		Character height-to-width ratio should be between 1:0.7 to 1:0.9(p. 47, 1.3.1-5)	
LCD	Visibility	Vertical viewing angle requirement: Not more than 20° above and 40° below the user's horizontal LOS(p. 419, 11.1.2-6)	5th ~ 99th
		Viewing distance: 33~80cm with 46~61 cm preferred(p. 420, 11.1.2-8)	

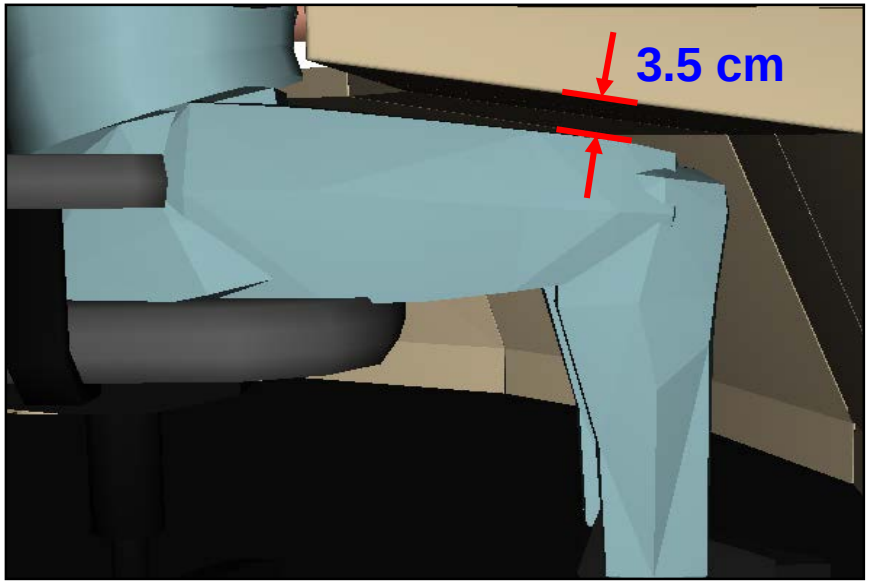
Ergonomic Design Evaluation

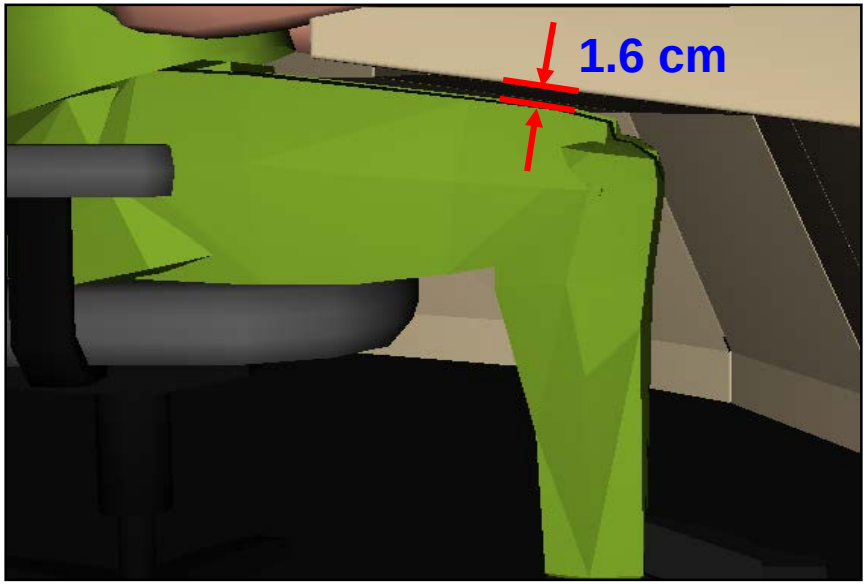



Evaluation for 7 MCR design components
(console, LDP, LCD, security access control sub-console, CCTV master control rack, main fire control panel, printers)
in terms of **4 ergonomic evaluation criteria**
(postural comfort, reachability, visibility, clearance)

Result: Console



95ththo%ile

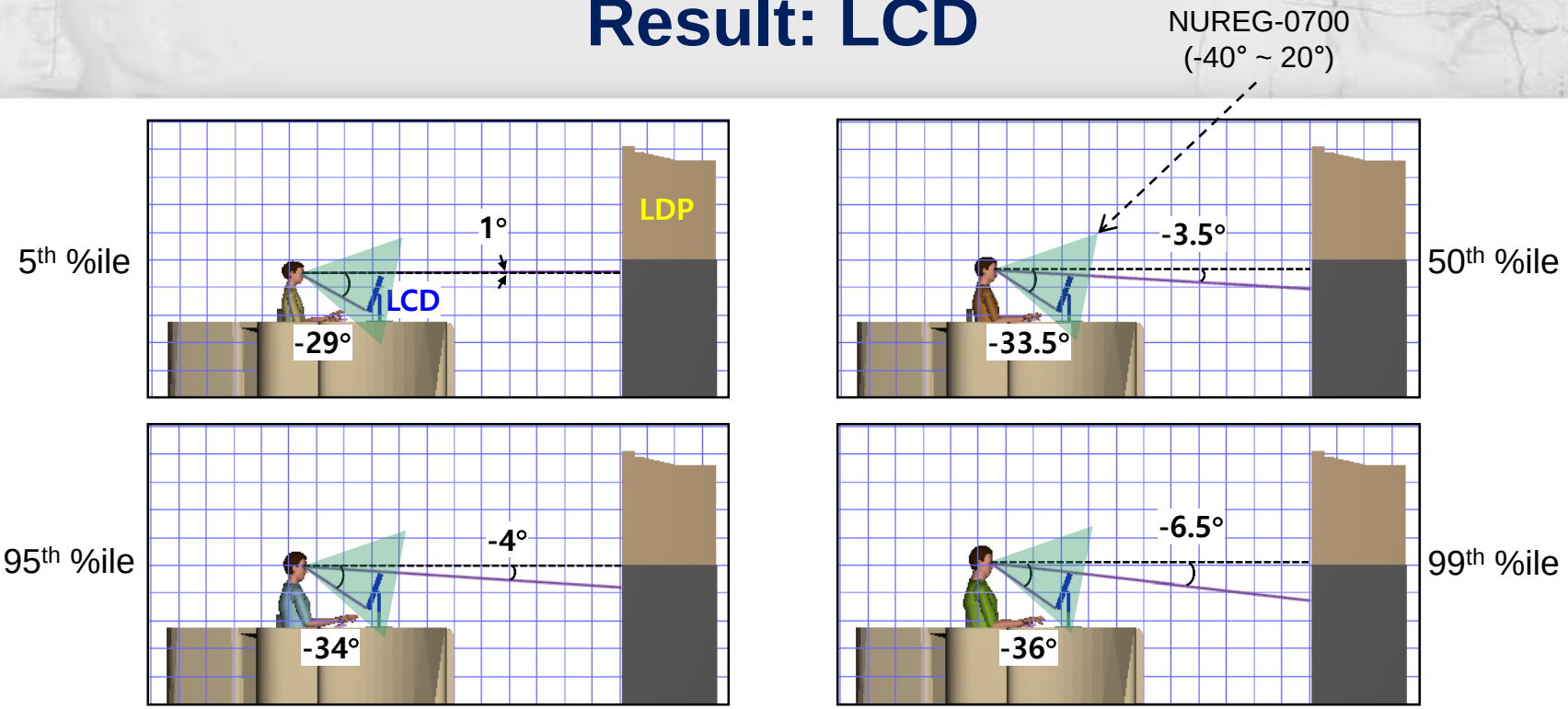


99ththo%ile

- Ergonomic evaluation criterion: **minimum knee clearance**
  (least distance between humanoid's leg and the console)
  - ✓ Humanoids: 1.6 ~ 6 cm
  - ✓ NUREG-0700: adequate knee clearance (11.1.5-4)

⇒ **Satisfied** (for 5th to 95th percentile as well as 99th percentile)

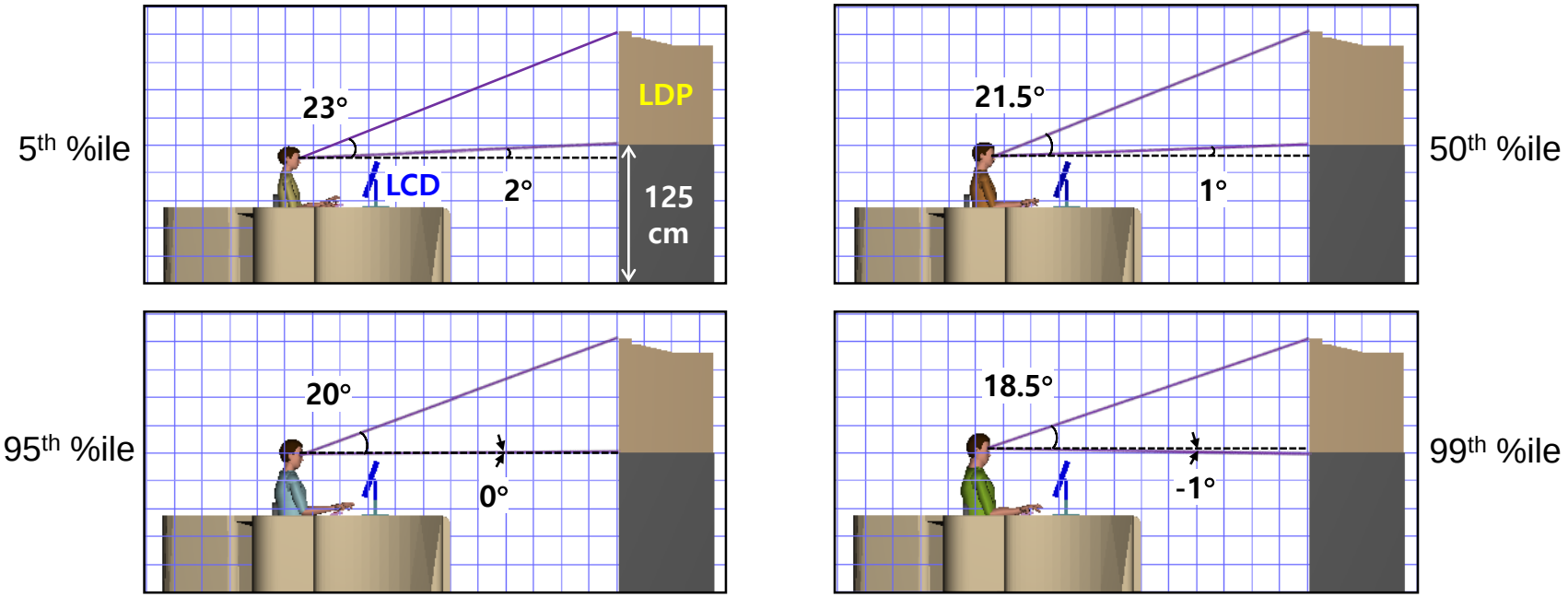
Result: LCD



- Ergonomic evaluation criterion: **vertical gaze range (VGR)**
  (gaze range when operators see the lowest to highest point of LCD)
  - ✓ Humanoids: -36° ~ 1°
  - ✓ NUREG-0700: -40° ~ 20° (11.1.2-6)

⇒ **Satisfied** (for 5th to 95th percentile as well as 99th percentile)

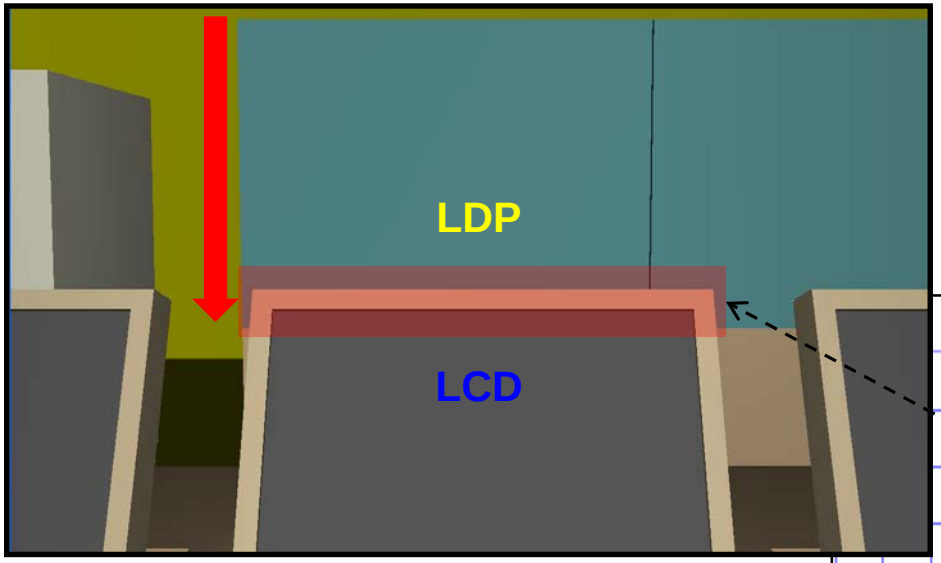
Result: Large Display Panel (LDP)



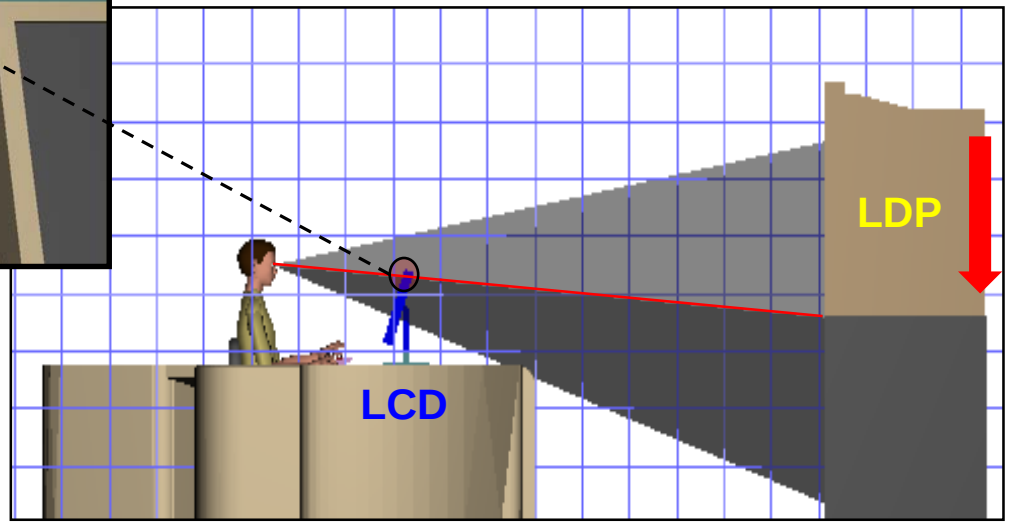
- Ergonomic evaluation criterion: **vertical gaze range (VGR)**
  (gaze range when operators see the lowest to highest point of LDP)
  - ✓ Humanoids: -1° ~ 23°
  - ✓ NUREG-0700: permit full view of all display panels (12.1.1.3-1)
  - ✓ Recommended display's VGR: -26° ~ 2° (Grandjean et al., 1983), -56° ~ -1° (Kim et al., 1999)

⇒ Could **cause** **postural discomfort** and **fatigue** during the long monitoring task

Relationship bwn. LDP's & LCD's Heights



Vision interference



- Only LDP's height ↓: vision interference by the upper area of LCD

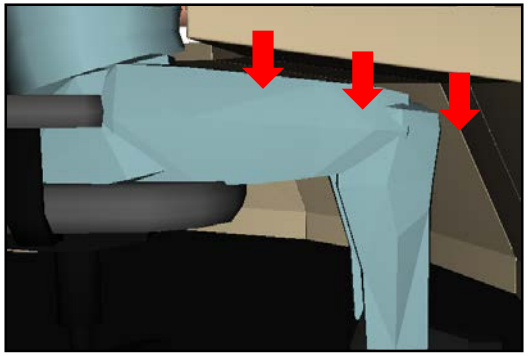
⇒ To improve LDP's VGR → LCD's and LDP's heights ↓ **together**

Improvement Idea: LDP's VGR

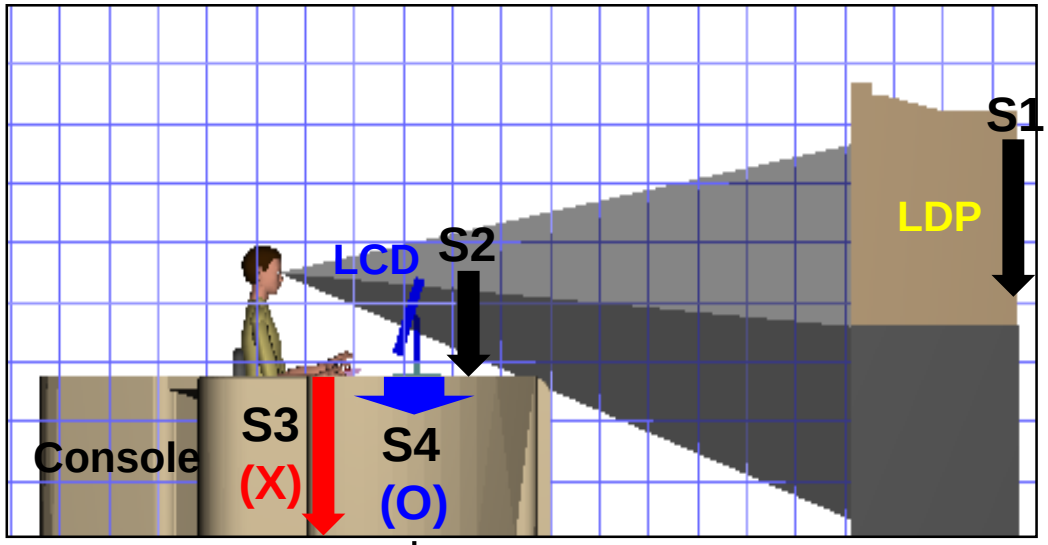
S1. LDP's height ↓

S2. LCD's height ↓

S3. Console's height ↓



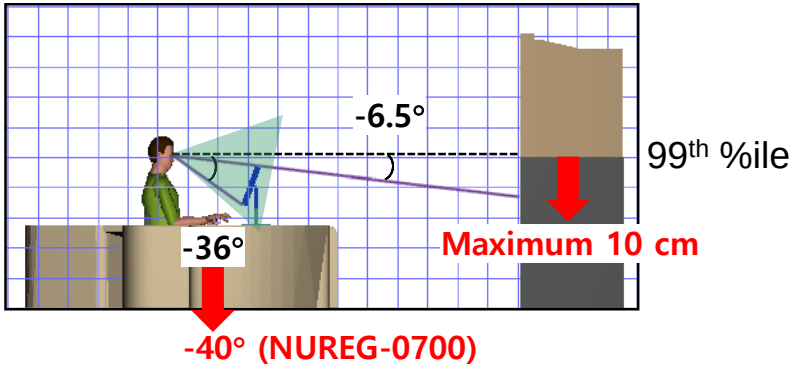
Clearance? ☹

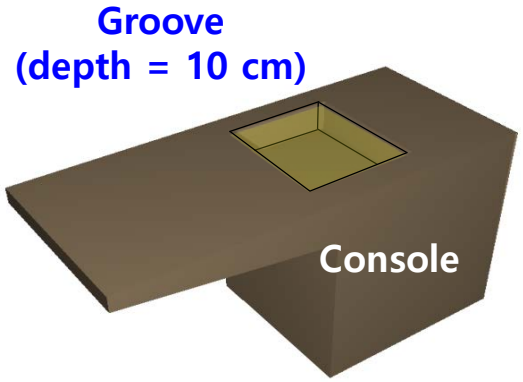


S4. Console's height only for LCD ↓

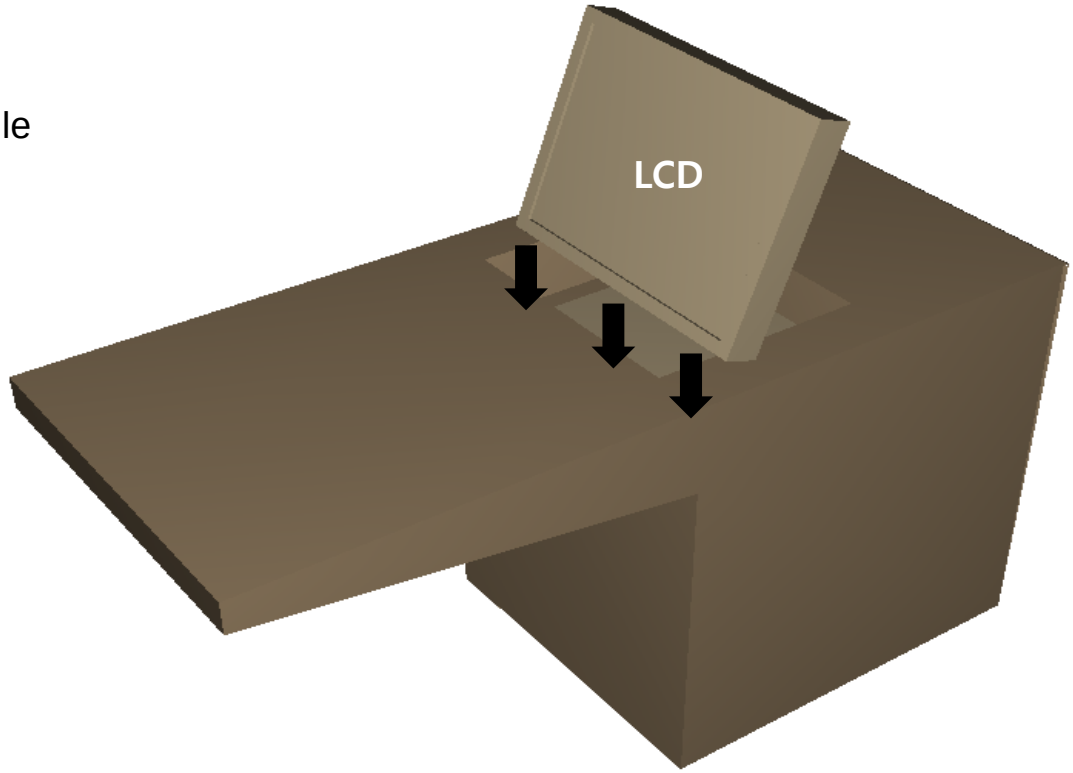
Improvement Result: LDP's VGR

- **Creating a square groove on the console's surface for LCD installation**
- Depth of groove: determined by considering LCD's VGR for 99th%ile



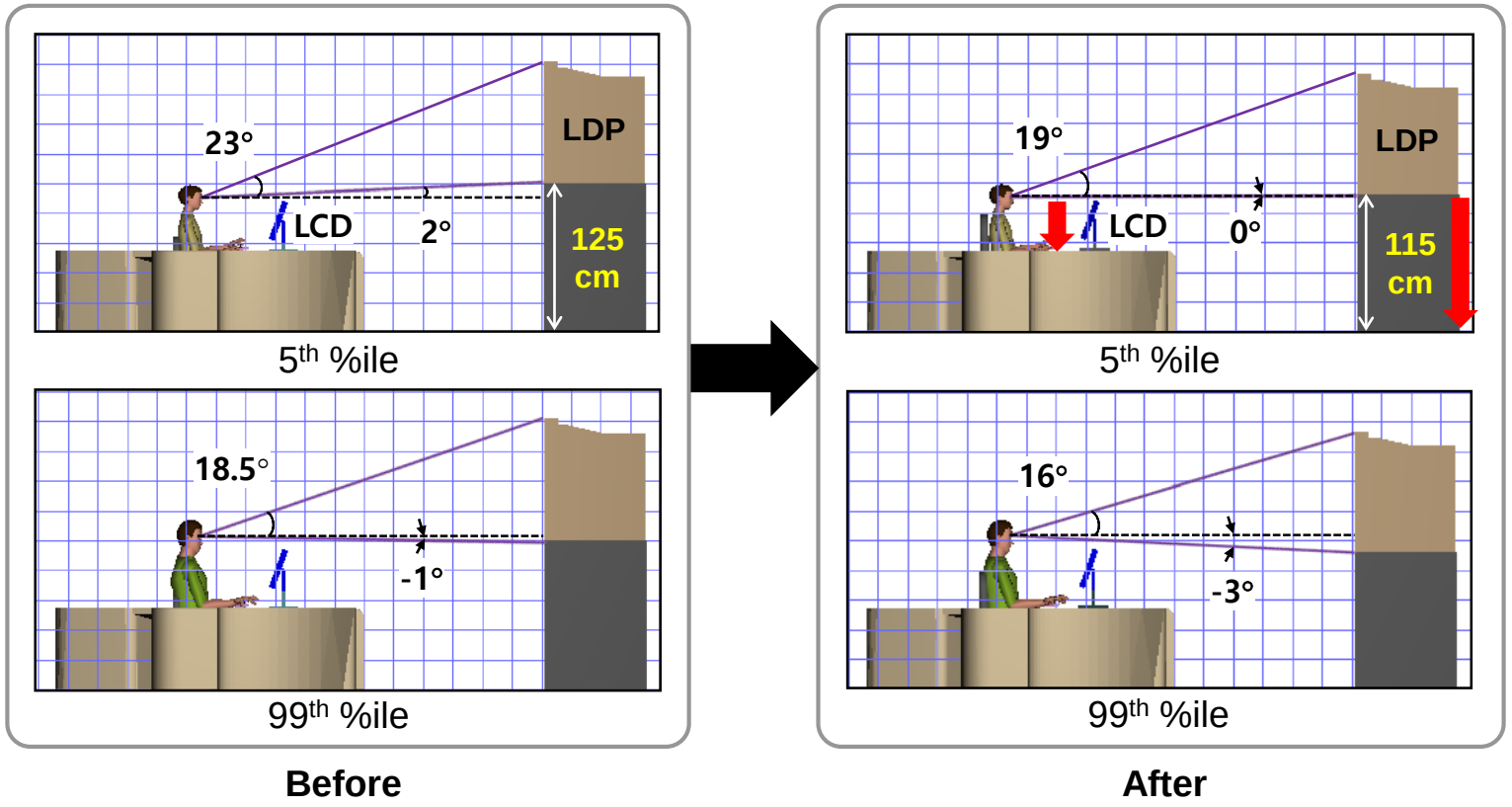


Groove for LCD installation



Installed LCD

Improvement Evaluation: LDP's VGR



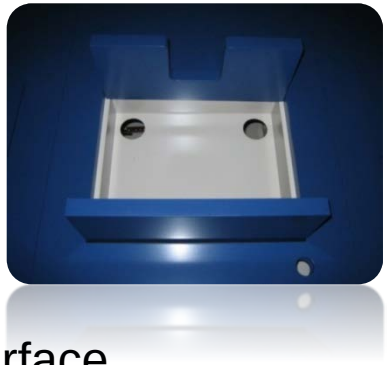
- **Improvement of LDP's VGR: -1° ~ 23° → -3° ~ 19°** (< 20°; NUREG-0700)

  ⇒ Partially **physical fatigue alleviation** during the long monitoring task

Discussion

- Proper sizes of MCR design components for Korean operators
  - ✓ Console's height: around body > 65 cm, around knee > 55 cm
  - ✓ LDP's height for VGR < 20°: 115 cm (3 m from operators)

  ⇒ Can be applied to **MCR design guideline of RWF/NPP**



- Improvement of console for LDP's VGR: maximum 4° ↓

  ⇒ Contribute to provide **more comforts for operators**

- Application of square groove for LCD installation to console surface

  ⇒ Can be an **effective method** for **reducing LDP's and LCD's height together without problems for console's clearance**

- Limitation: use of the posture for computer workstation

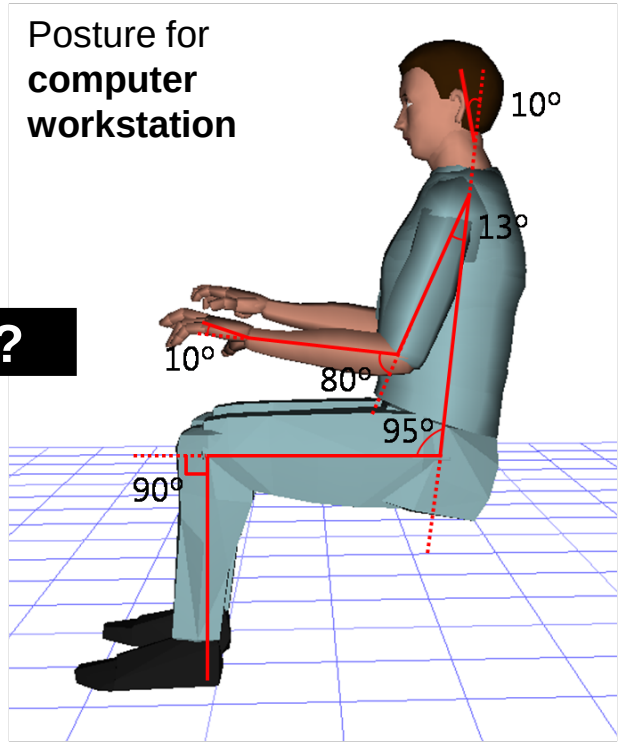
Future Study

- **Need a study for dual display: LDP & LCD**
  - ✓ Lack of recommended vision angles about dual displays
  - ✓ Posture for computer workstation ≠ posture for dual displays?

⇒ Need **recommended postures and vision angles for dual displays**

Dual displays

?



Q & A

Thank You ☺