Newly Developed Automatic Control System for Brain Hypothermia Treatment

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Development of Automatic Control System of Hypothermia

- **Accurate Management of Brain Temperature**
  Adaptive and Fuzzy Control Processes
- **Release from Heavy Loads**
  Physical, Psychological & Economic Burdens
- **Improvement of Medical Condition &Treatment**

Based on "System Engineering"

Simulation ⇨ Experiment

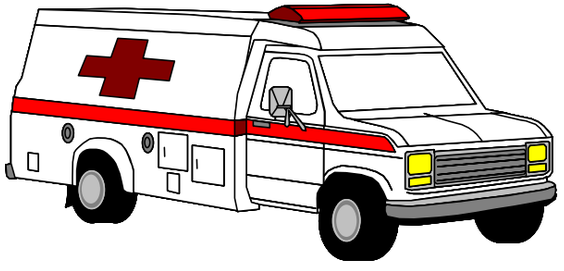
Additional Talk

Concerning Hypothermia Treatment

- Control of Mechanical Respiration
- Optimal Control of Intracranial Pressure
- Monitoring and Determination of Physiological State

Situation

What's matter with him ?
It's awful. It's terrible.
Hurry up! Bring him to hospital !

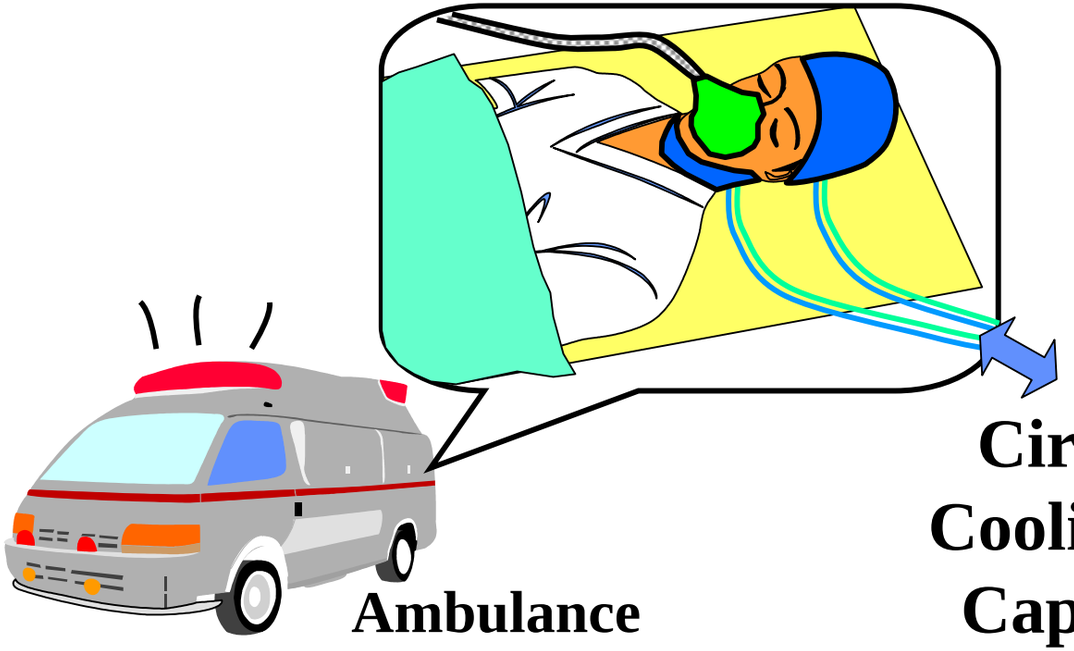


Ambulance

Traffic Accident

Set Quick Cooling Brain Temperature

By Using Cooling Cap and Muffler



Ambulance

Circulation of Cooling Water to Cap & Muffler

Brain Injury and/or Inflammation

Increase of Intracranial Pressure

Prevention of Secondary Damage of Brain Tissue

Bruise on the brain

traffic accident

Ischemic stroke

cerebral infarction

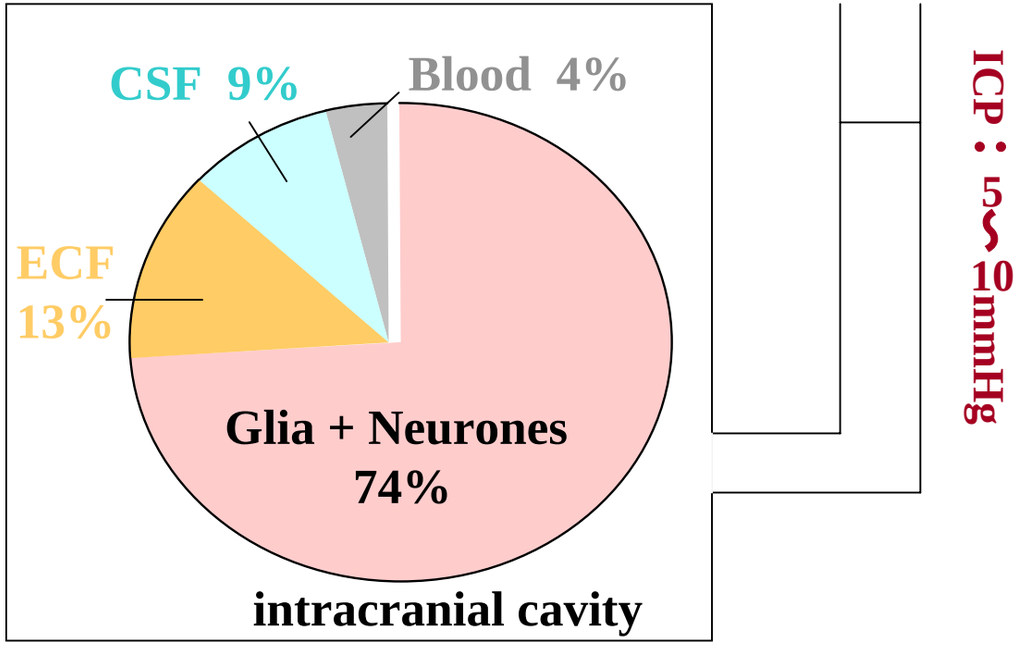
brain hemorrhage (aneurism)

Ischemic heart failure

coronary infarction

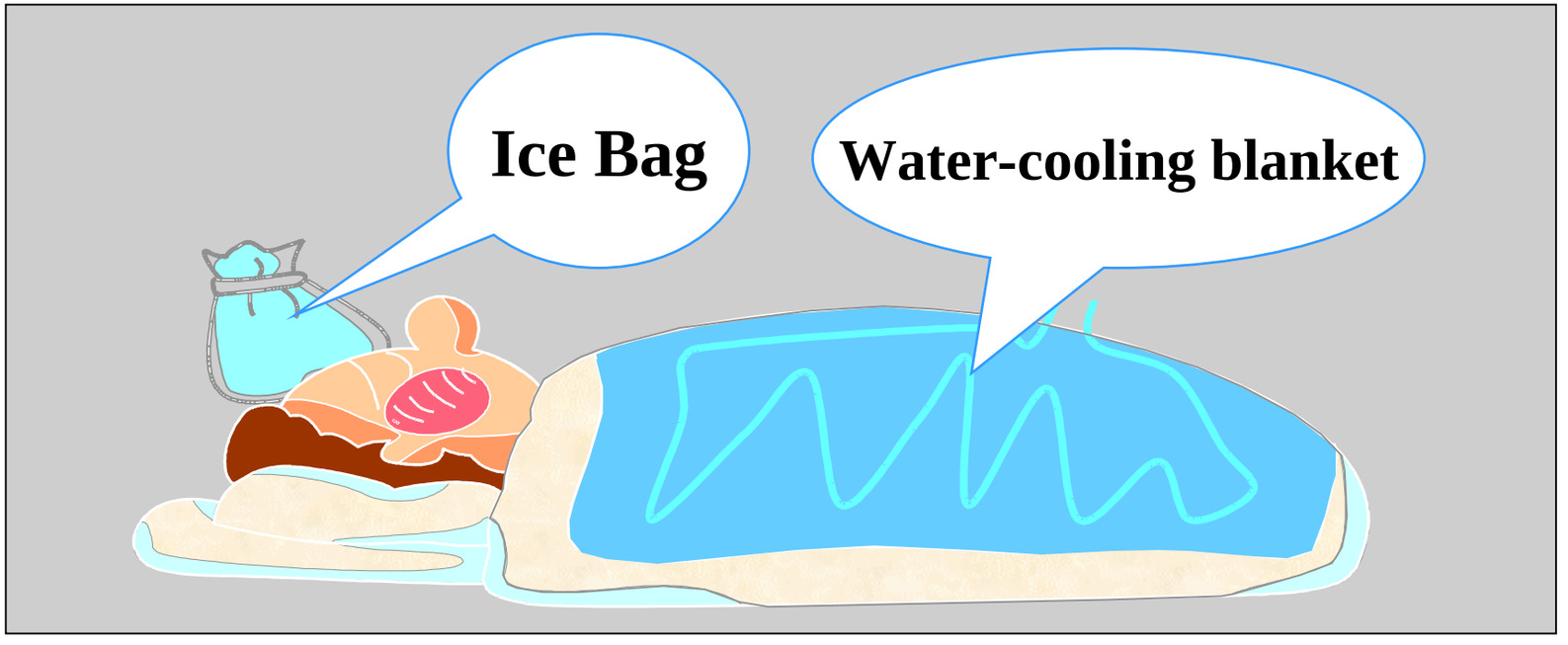
Brain tumor

Cause of Intracranial Hypertension



- ✧ **space-occupying lesions** (hematoma)
- ✧ **brain** volume ↑ (brain edema)
- ✧ **blood** volume ↑ (brain swelling)
- ✧ **CSF** volume ↑ (hydrocephalus)

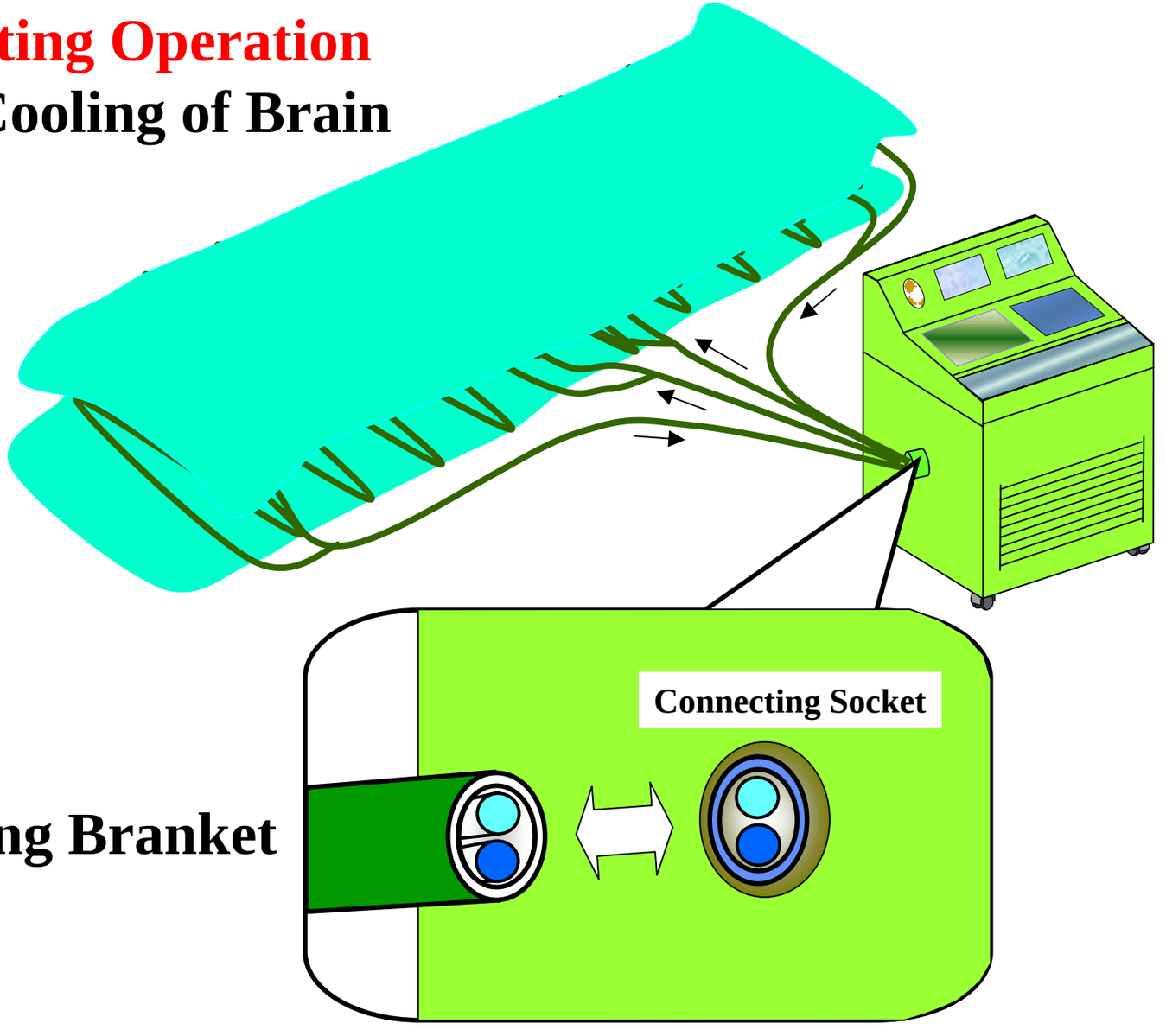
⇨ **＞15mmHg**



- **Whole Body Cooling is Effective**
- **Head Cooling as Assistance**

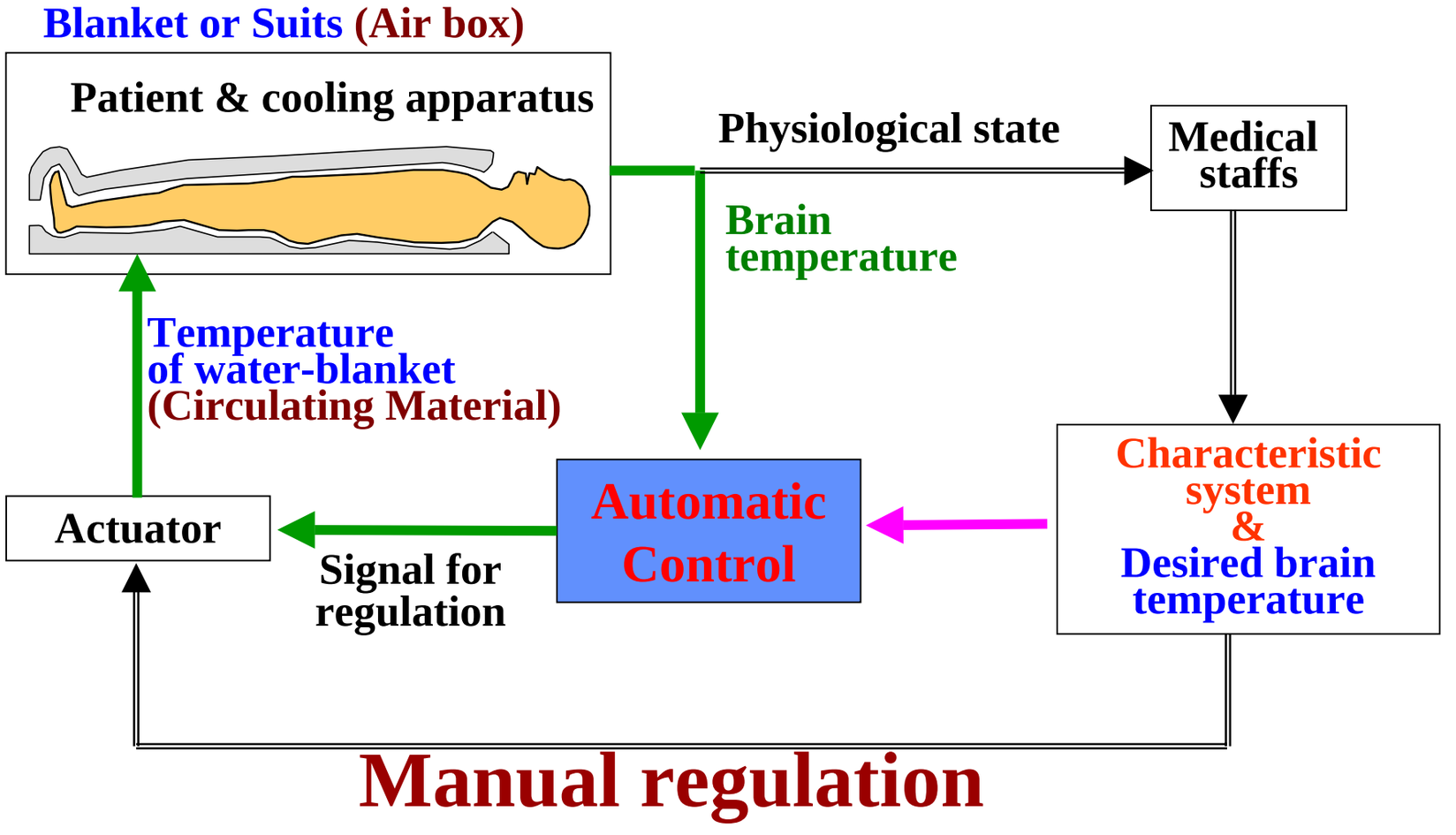
Simple Connecting Operation

Begins Quick Cooling of Brain

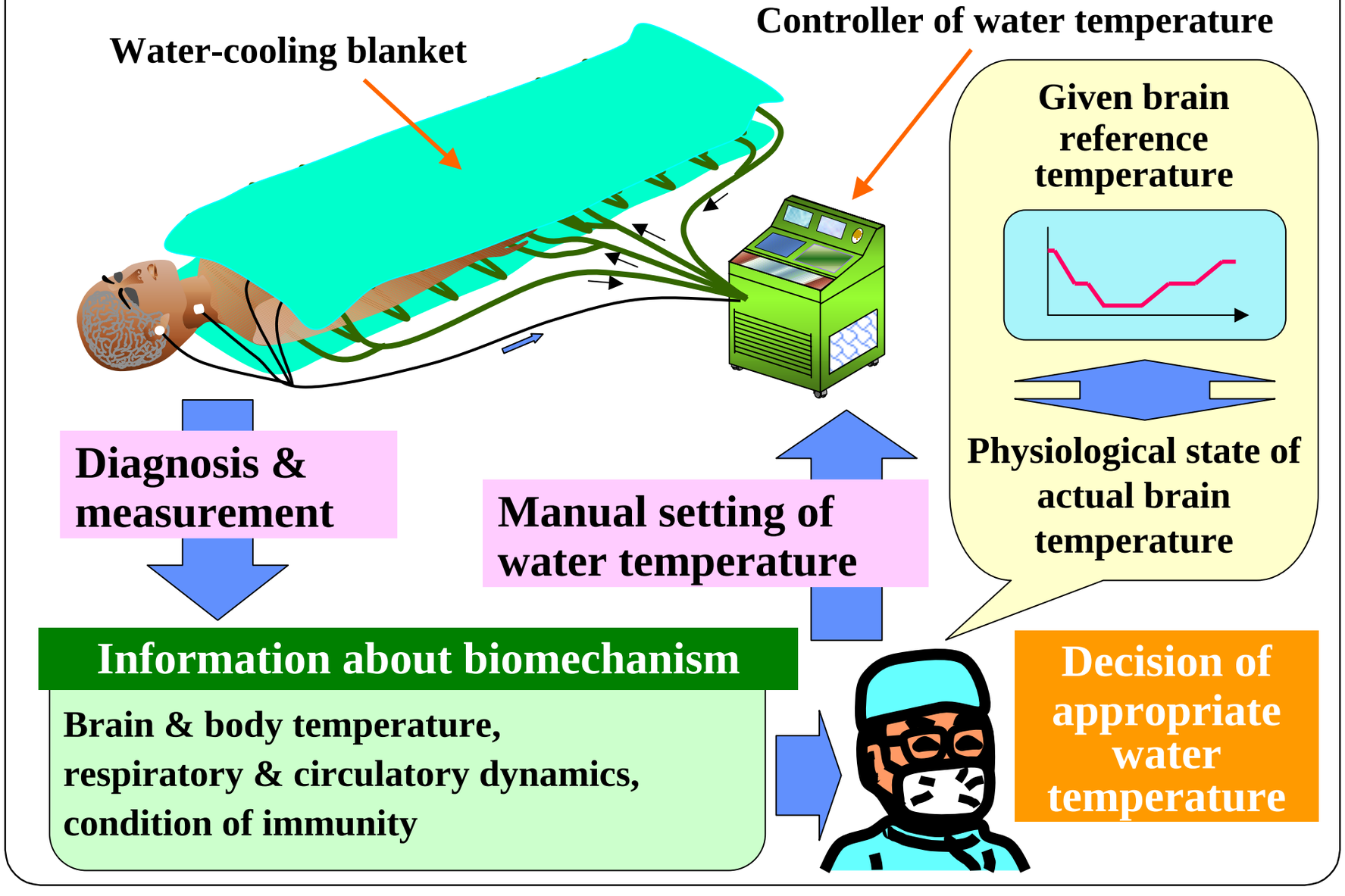


To Cooling Branket

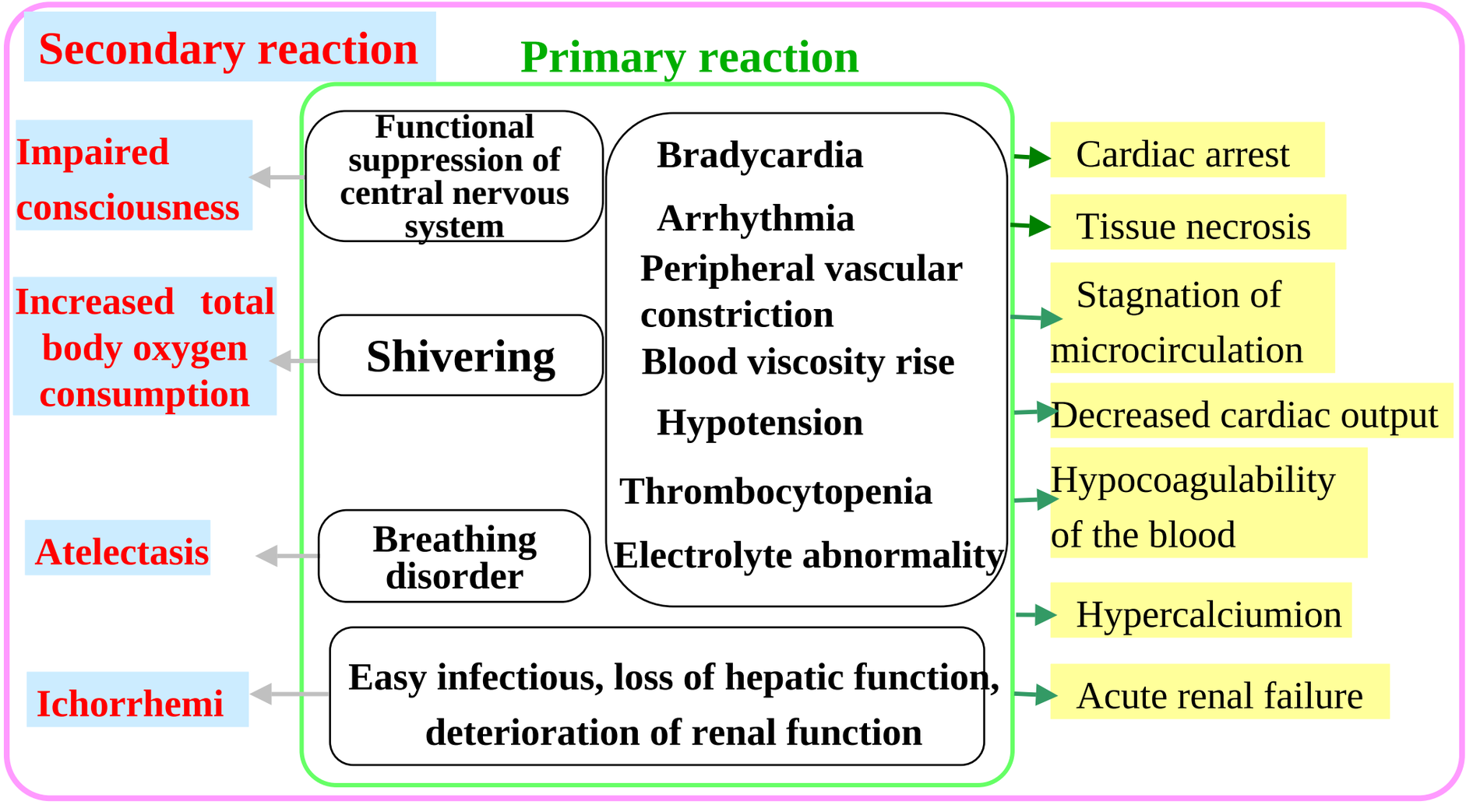
Automatic Control of Brain Temperature



Manual Regulation of Brain Temperature in clinics



Hypothermia under 32 °C Biological Reaction

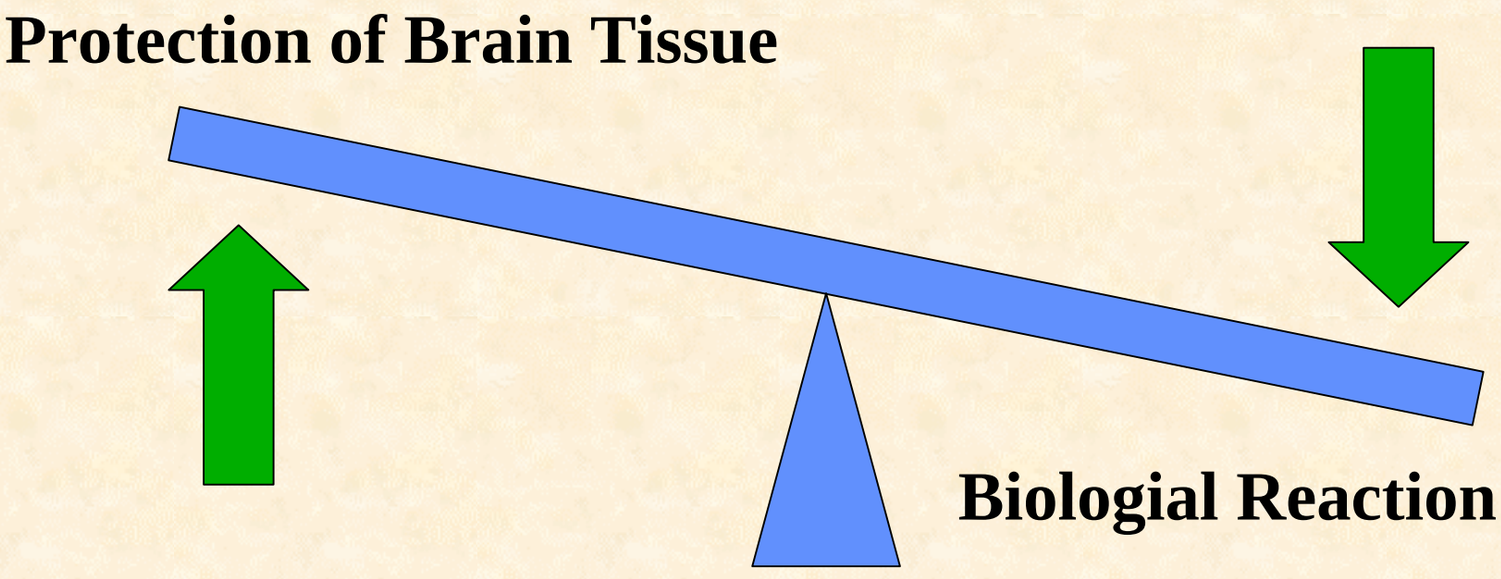


Bad effect on circulation, respiration, immunity & nervous function

Protection of Brain Cells by Brain Hypothermia

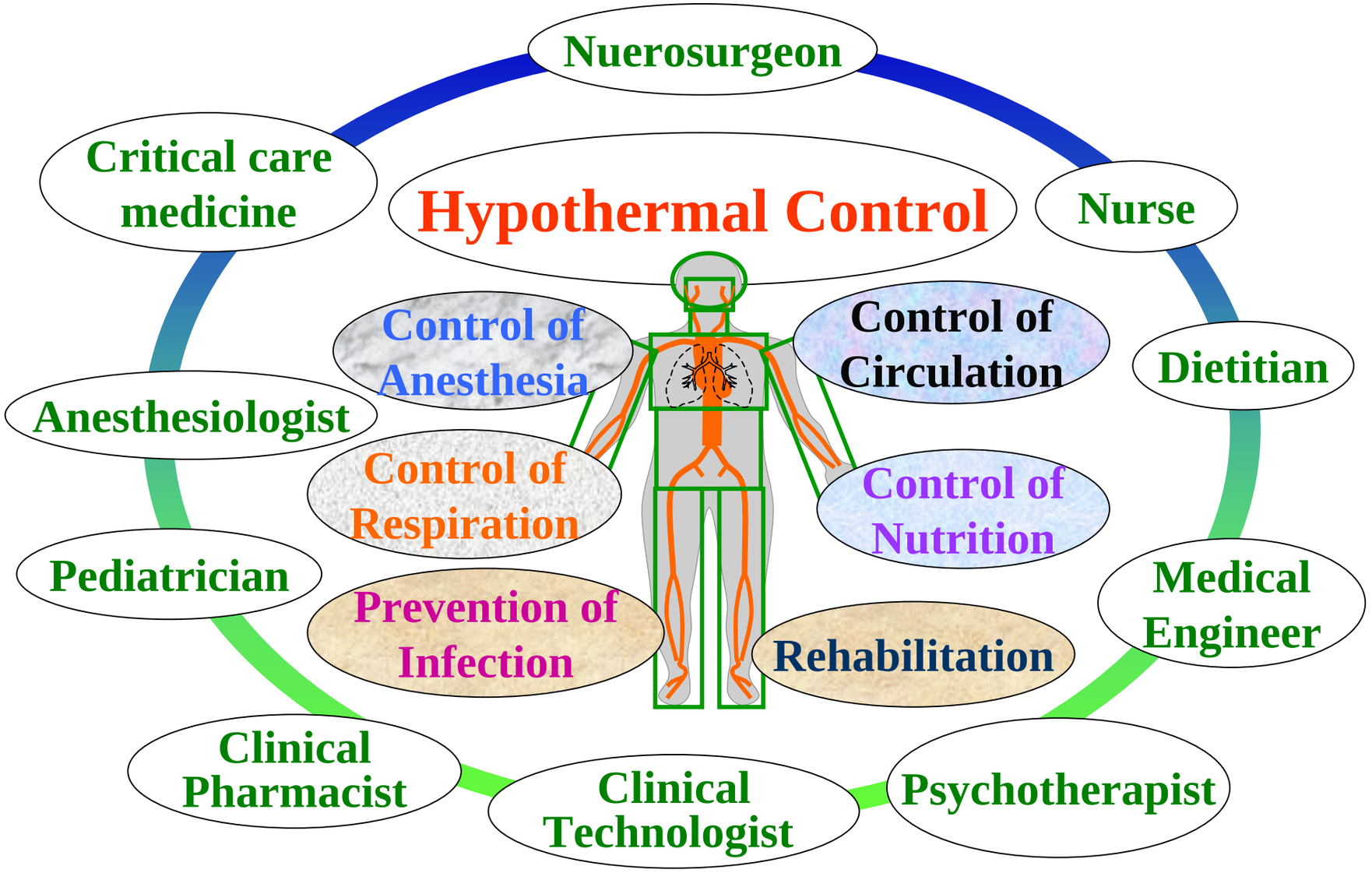
- **Suppression of Damage caused by Energy insufficiency**
  - Improvement of Ca^{2+} homeostasis
  - Suppression of oxidation by free radicals
  - Activation of antiapotosis substance
  - Suppression of dopamine A10 neural groups
- **Suppression of Hyperfunction of Endocrine System**
  - Suppression of cathecholamines hypersecretion

Trade off in Hypothermia

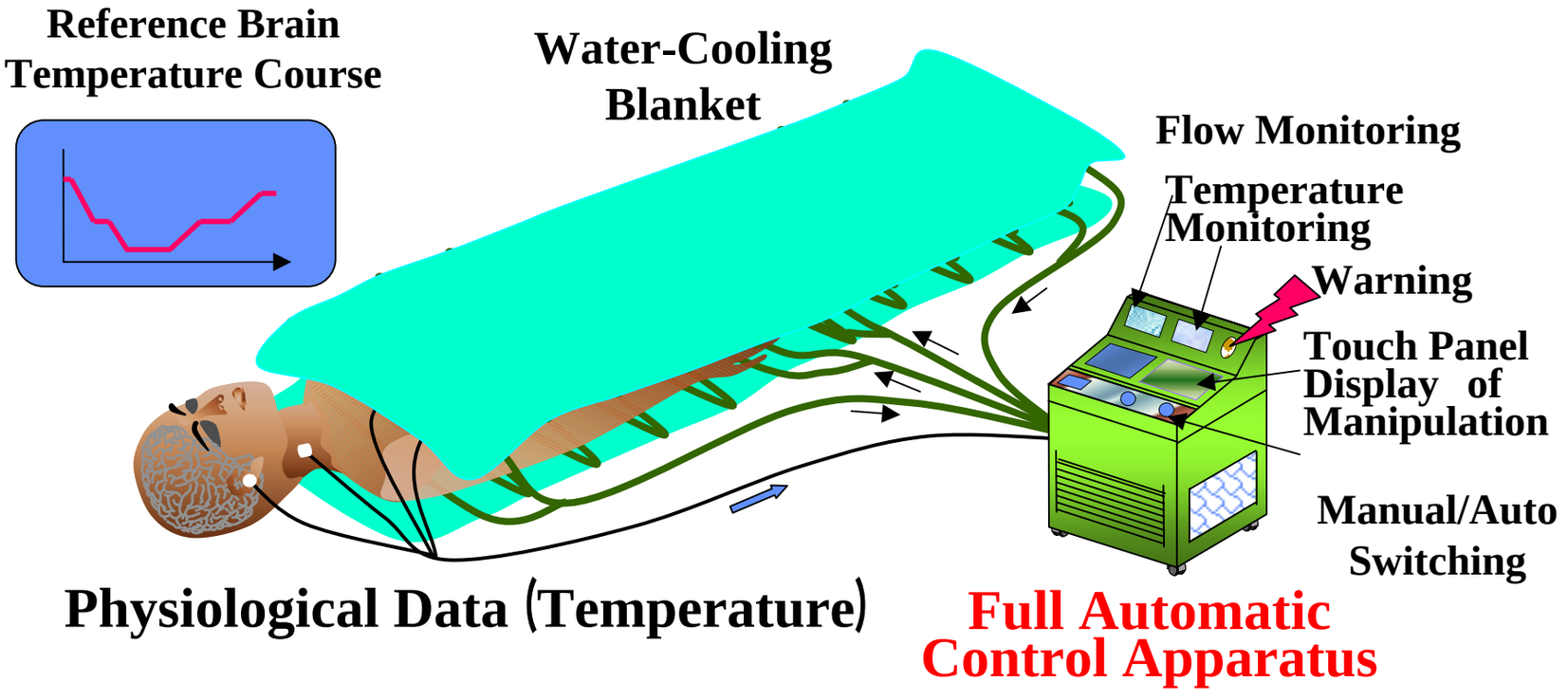


Necessity of precise and accurate control of brain temperature **!**

Hypothermia Treatment in ICU

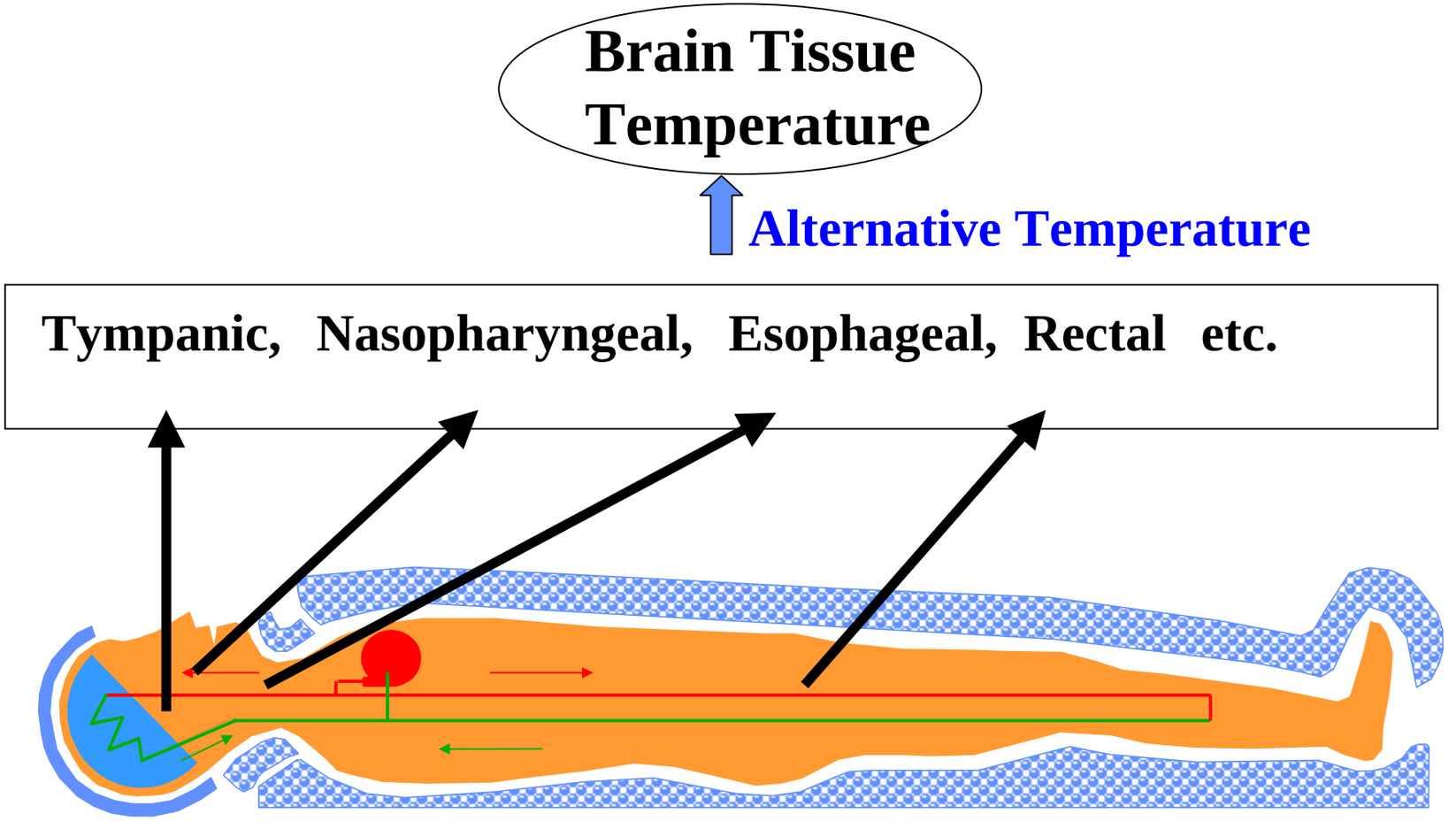


Automatic Control Apparatus of Brain Temperature



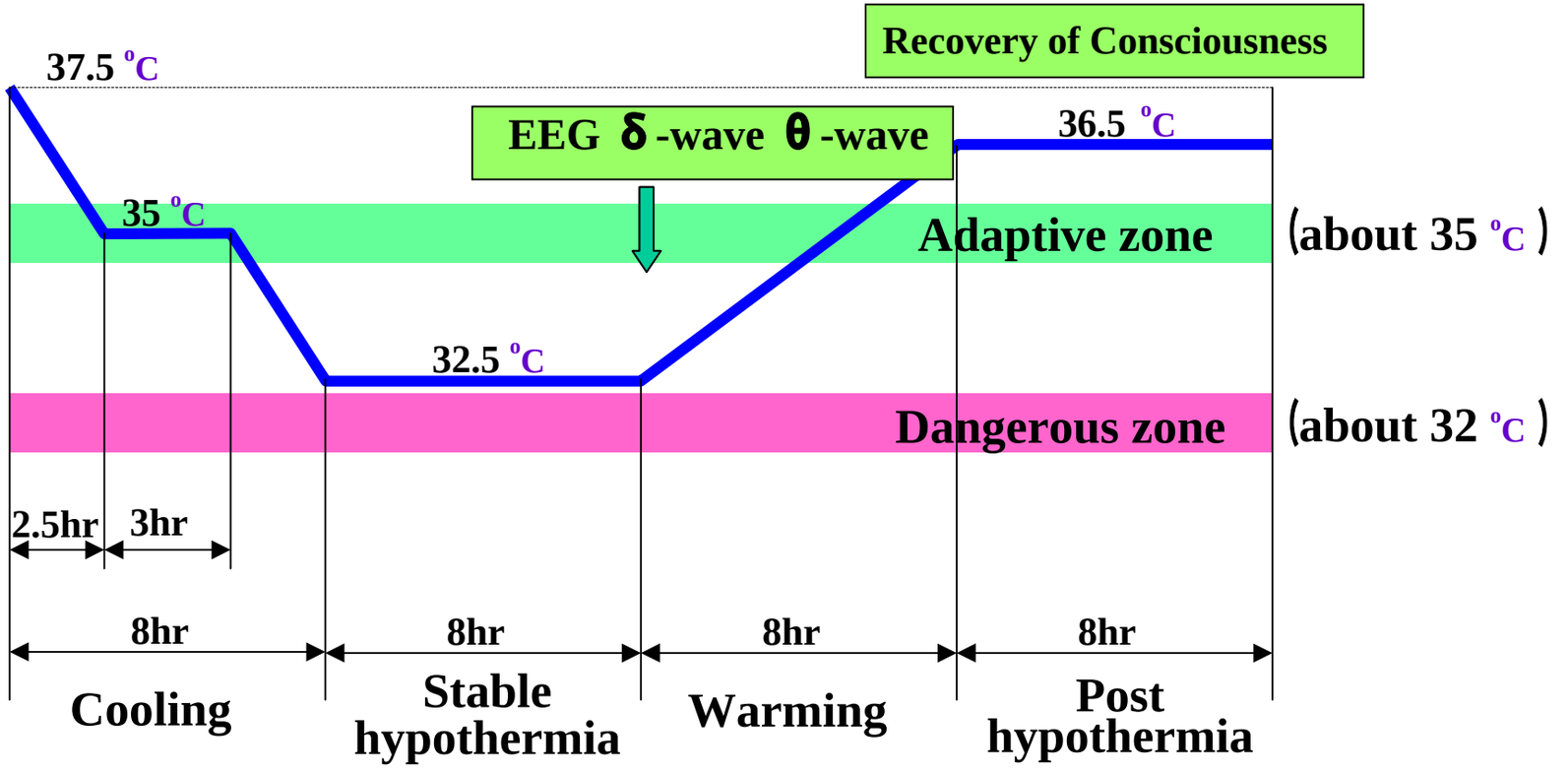
Calculation & Regulation of Water Temperature

Measurement of Temperature in Hypothermia



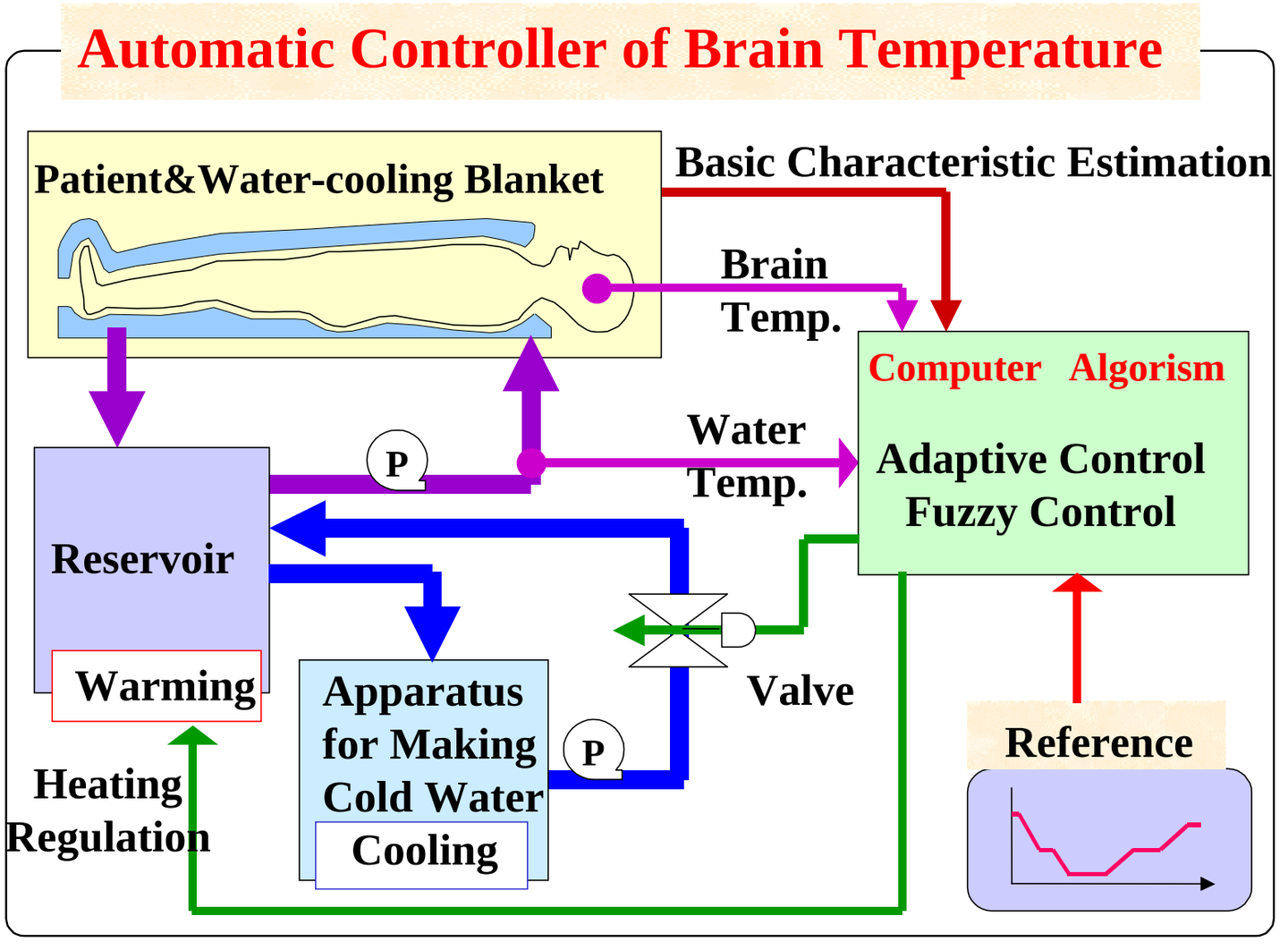
Control of Brain Temperature by Water-Cooling System

Schematic Desired Brain Temperature



Step-by-step Management of Body Temperature

Automatic Controller of Brain Temperature

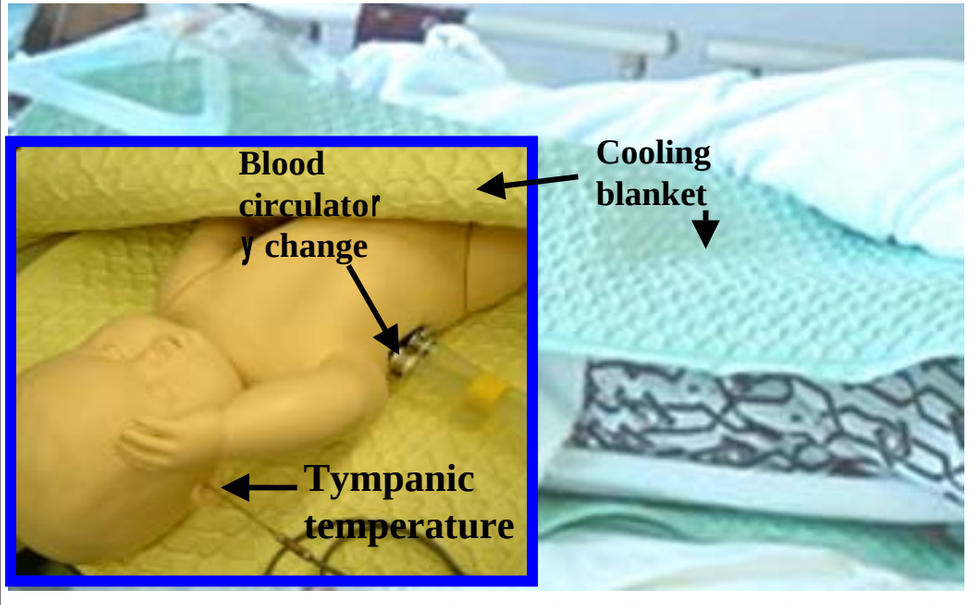


Concept of Adaptive Control Engineering

Different regulation

Various kinds of medical treatment

Change in external environment



Change in internal environment

- Circulatory change
- Metabolic change

etc.

Unknown thermal characteristic

Patient under the brain hypothermia treatment

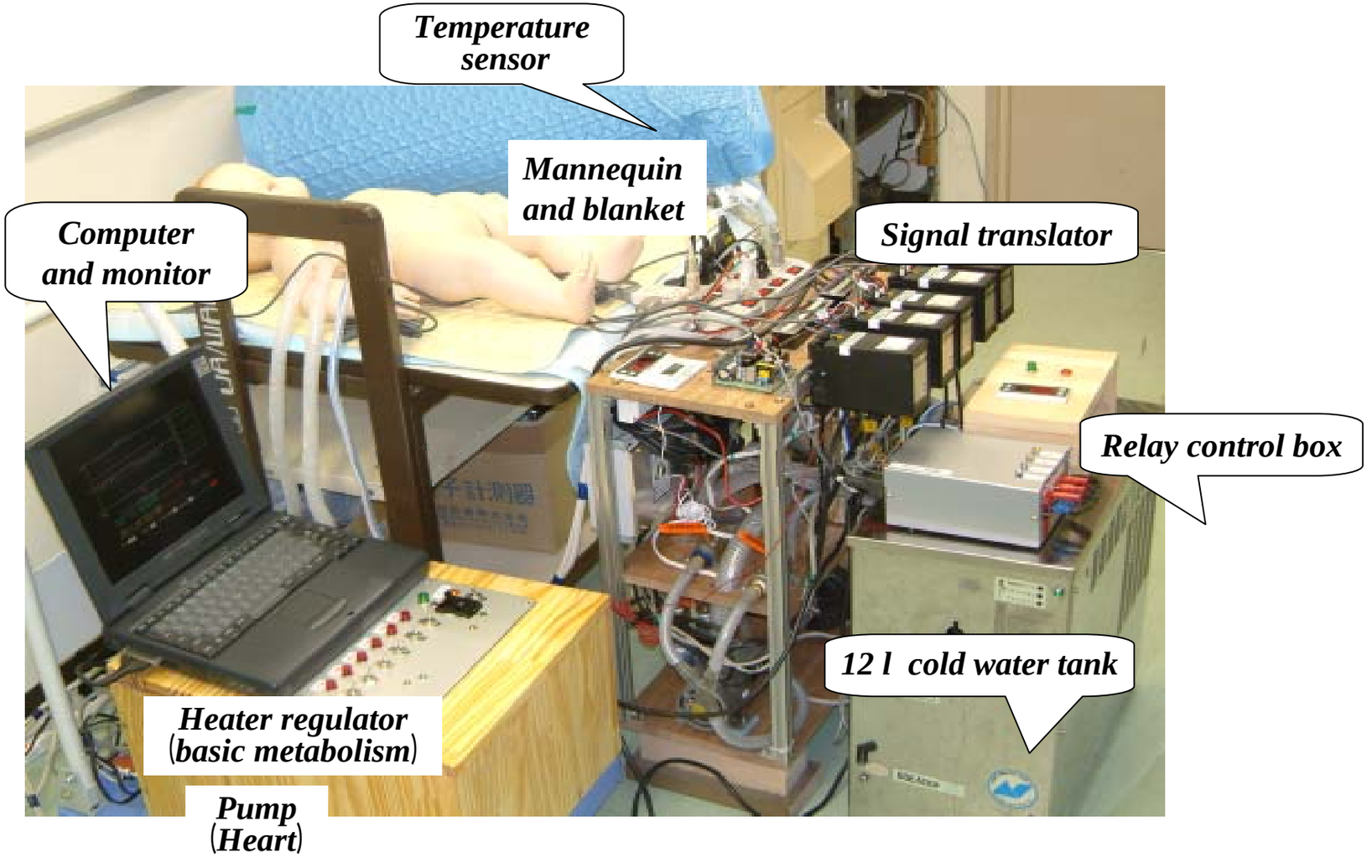
Adaptive control

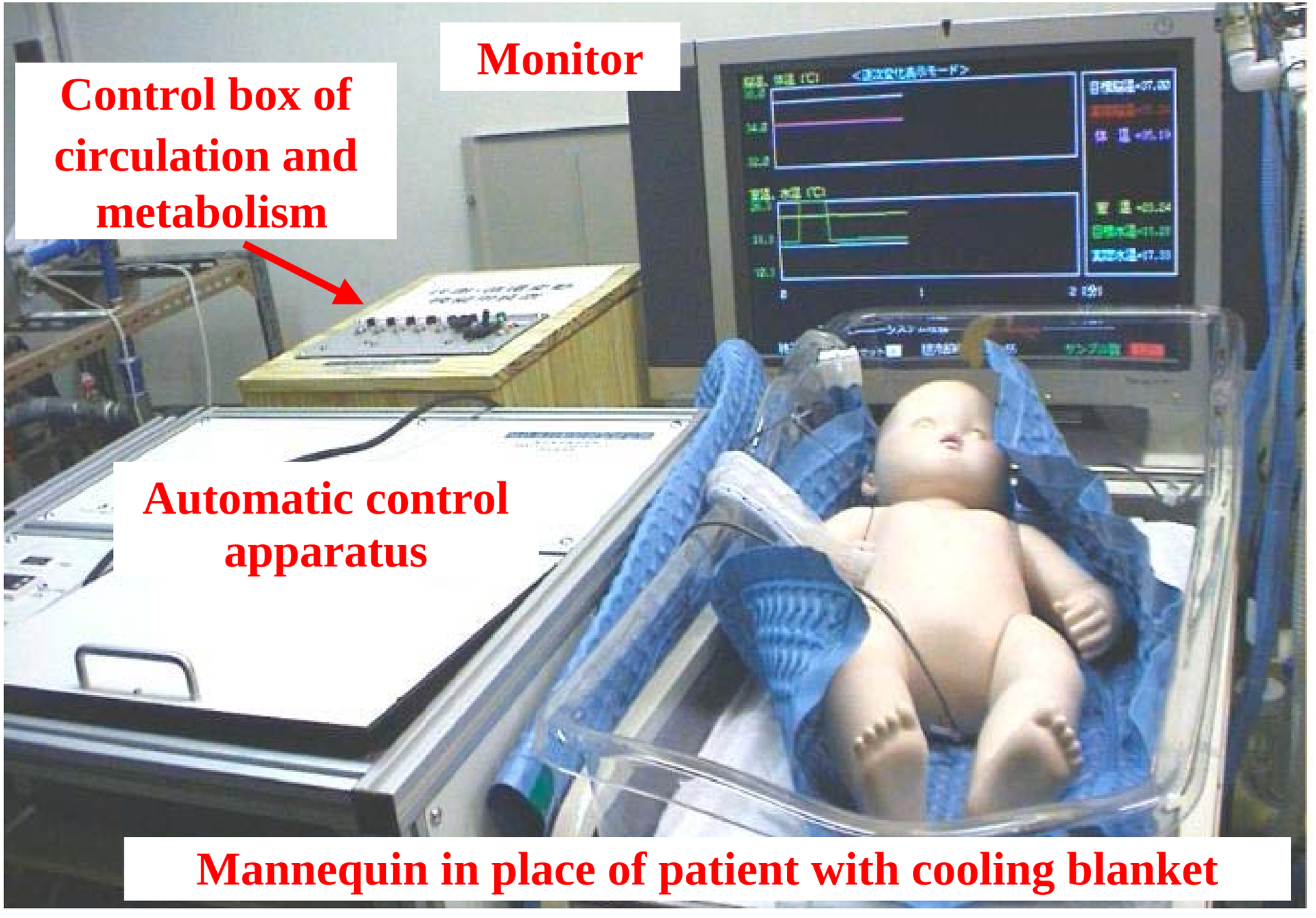
Realization of desired brain temperature

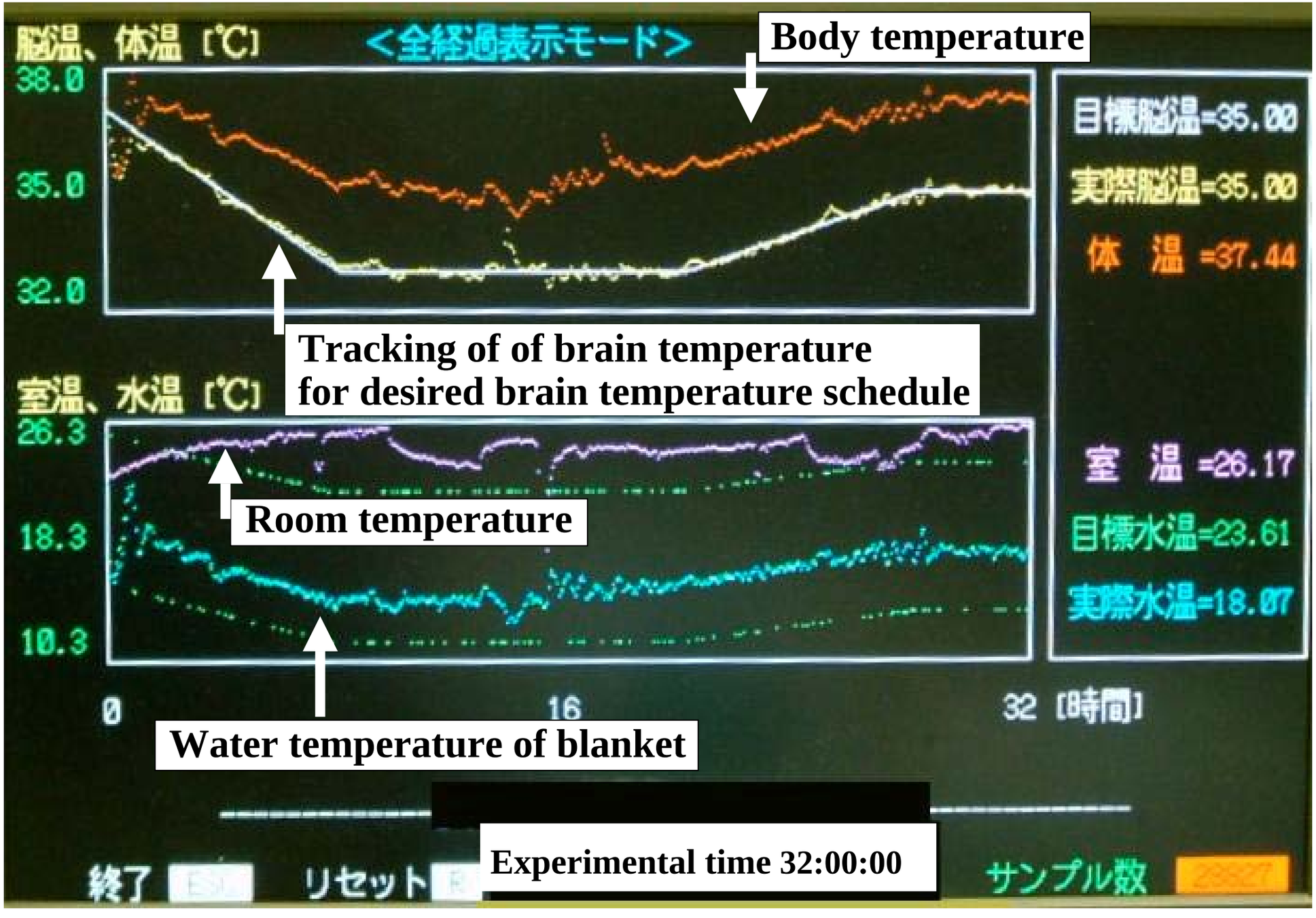
Brain Hypothermia Treatment Using Thermal Mannequin

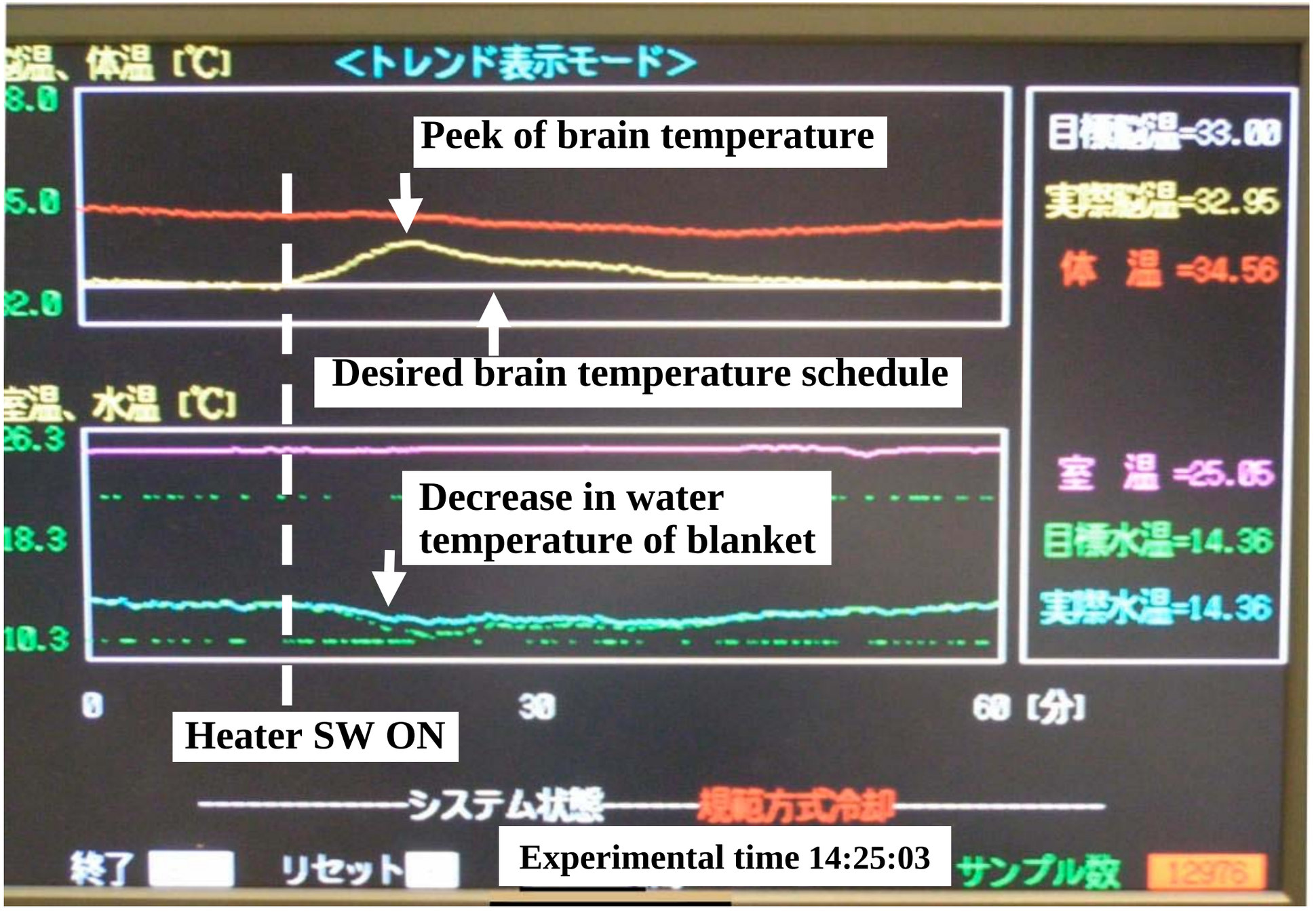
Mannequin controlled by water circulation (blood flow) and heater (metabolic heat)

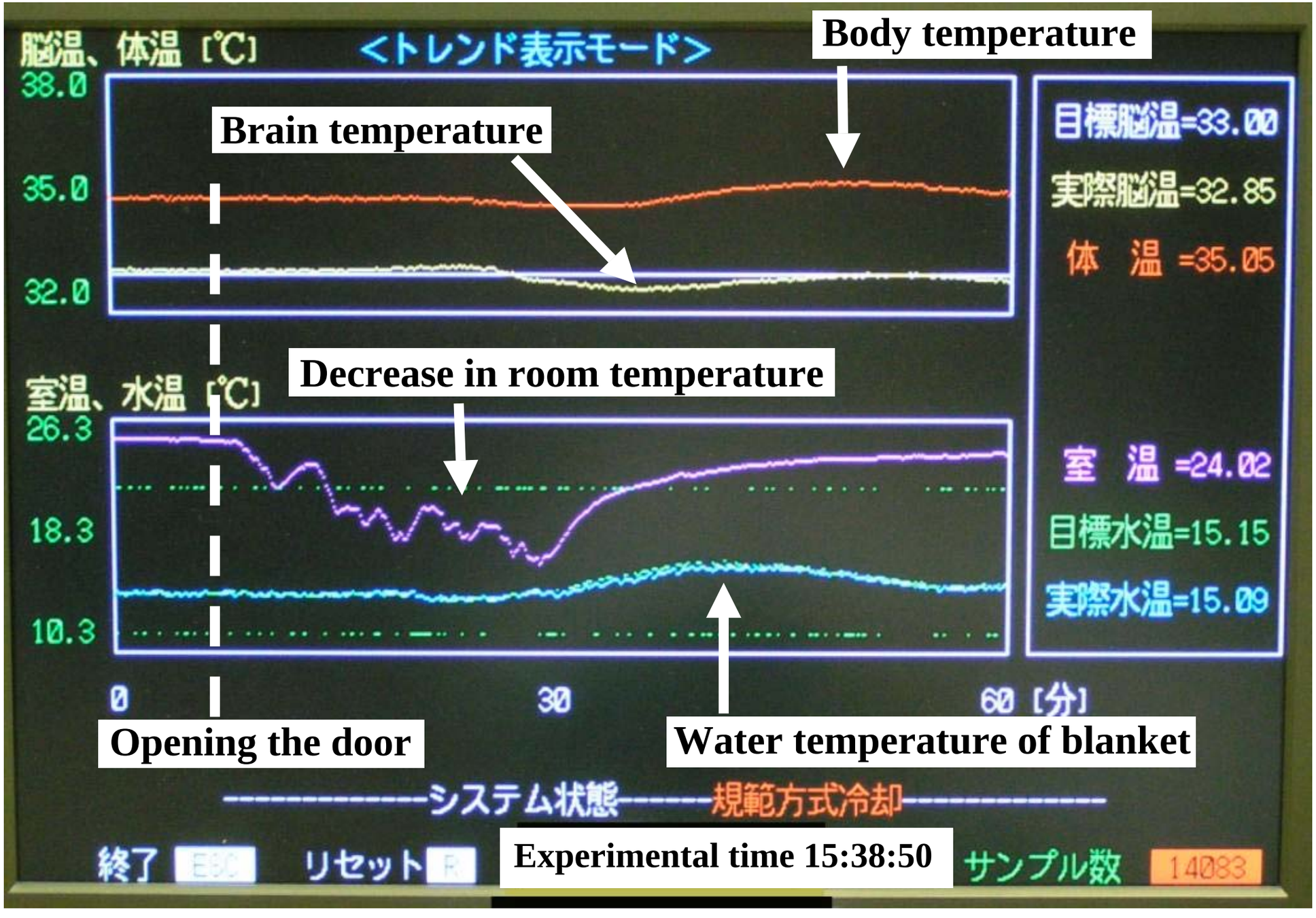
Overview of Experimental Equipment




Monitor
Control box of circulation and metabolism
Automatic control apparatus
Mannequin in place of patient with cooling blanket


脳温、体温 [℃]
<全経過表示モード>
Body temperature
38.0
35.0
32.0
目標脳温=35.00
実際脳温=35.00
体 温 =37.44
Tracking of of brain temperature
for desired brain temperature schedule
室温、水温 [℃]
26.3
18.3
10.3
Room temperature
室 温 =26.17
目標水温=23.61
実際水温=18.07
0
16
32 [時間]
Water temperature of blanket
Experimental time 32:00:00
終了
リセット
サンプル数


温、体温 [℃]
<トレンド表示モード>
8.0
5.0
2.0
Peek of brain temperature
Desired brain temperature schedule
目標脳温=33.00
実際脳温=32.95
体 温 =34.56
室温、水温 [℃]
26.3
18.3
10.3
Decrease in water temperature of blanket
室 温 =25.85
目標水温=14.36
実際水温=14.36
0
30
60 [分]
Heater SW ON
システム状態
規範方式冷却
終了
リセット
Experimental time 14:25:03
サンプル数


脳温、体温 [℃]
<トレンド表示モード>
Body temperature
38.0
Brain temperature
35.0
32.0
目標脳温=33.00
実際脳温=32.85
体 温 =35.05
室温、水温 [℃]
Decrease in room temperature
26.3
18.3
10.3
室 温 =24.02
目標水温=15.15
実際水温=15.09
0
30
60 [分]
Opening the door
Water temperature of blanket
システム状態
規範方式冷却
終了 ESC
リセット R
Experimental time 15:38:50
サンプル数
14083

Fuzzy Control of Brain Temperature by Water-Cooling System

Membership functions and Fuzzy rule

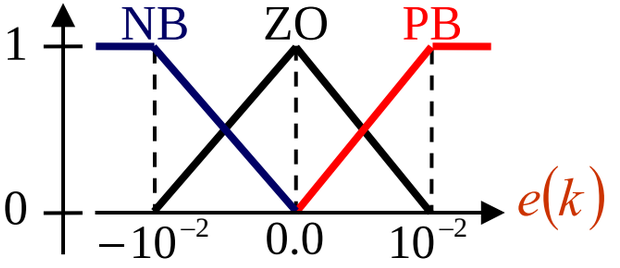
For fuzzy controller-1

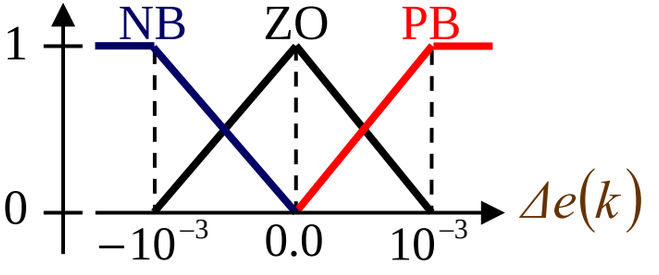
The antecedent

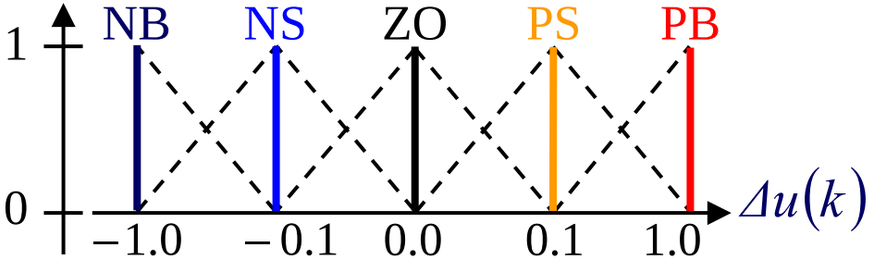
The antecedent

$\Delta u(k)$		$e(k)$		
		PB	ZO	NB
$\Delta e(k)$	PB	PB	PS	ZO
	ZO	PS	ZO	NS
	NB	ZO	NS	NB

The consequent







Membership functions and Fuzzy rule

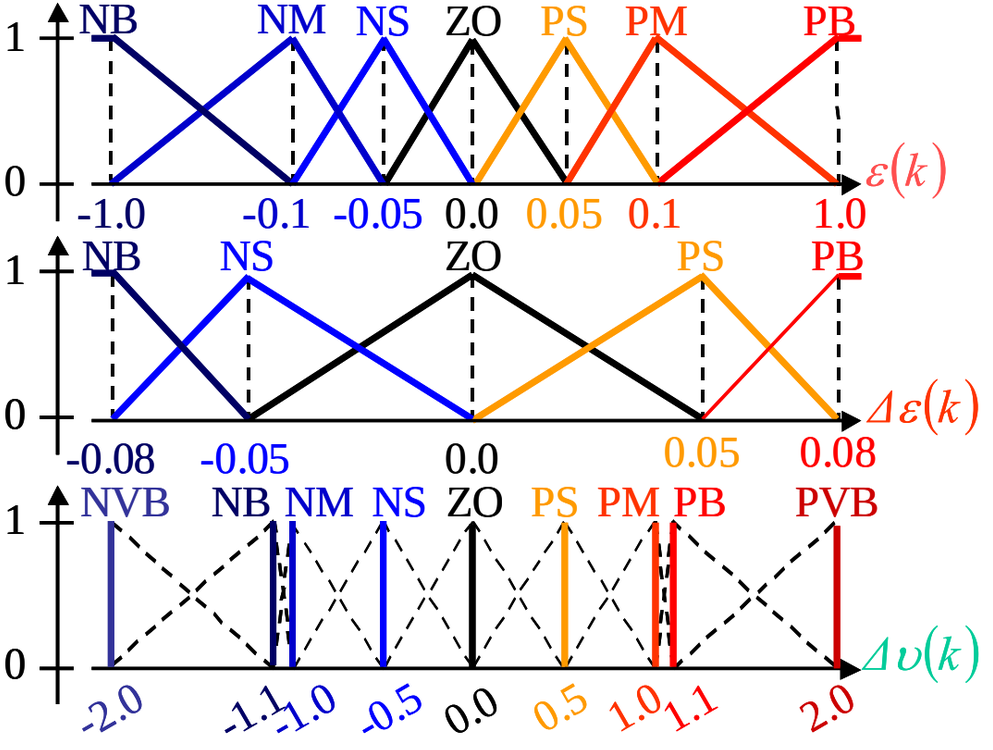
For fuzzy controller-2

The antecedent

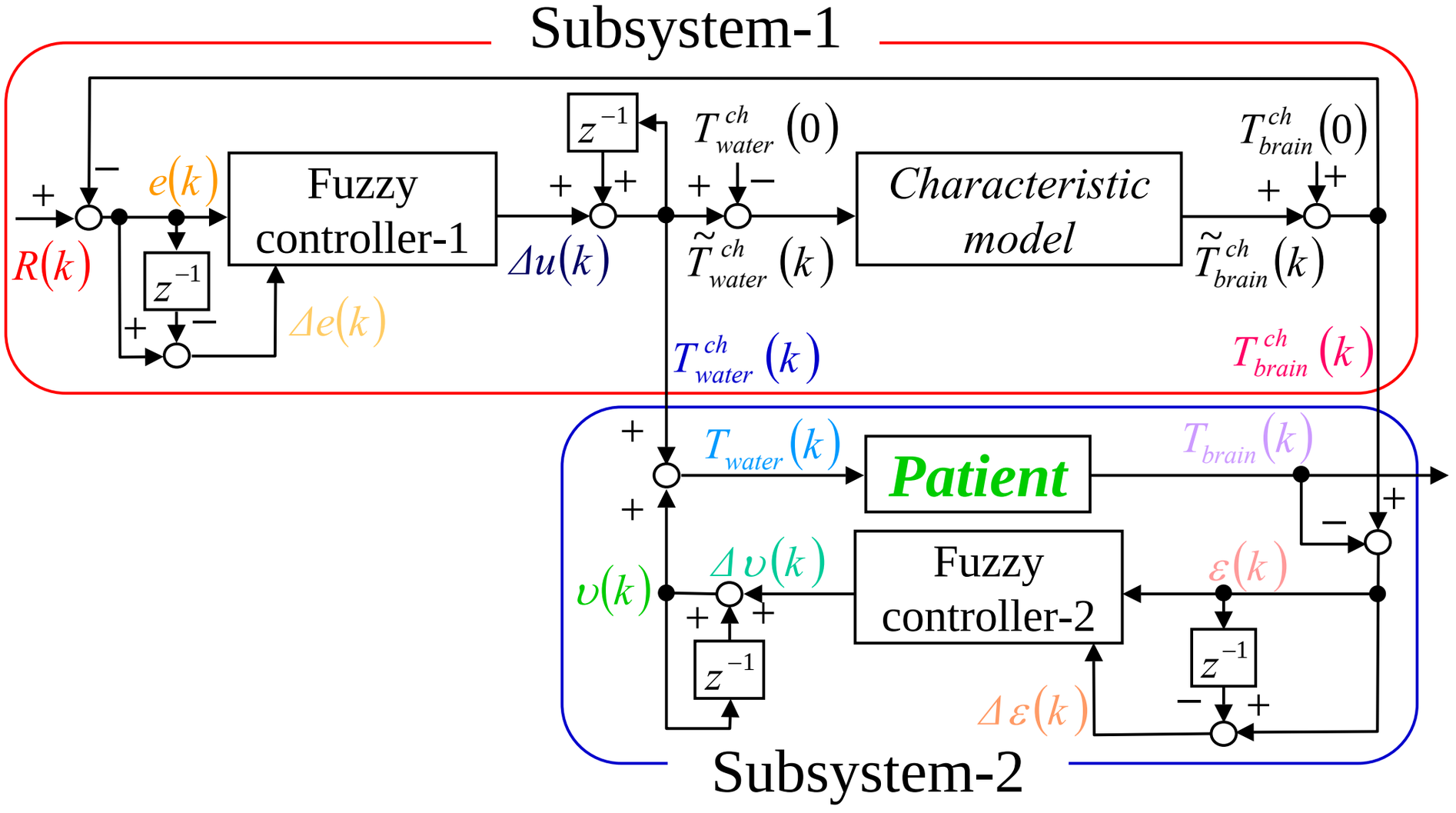
$\Delta\upsilon(k)$ \ $\varepsilon(k)$	PB	PM	PS	ZO	NS	NM	NB
PB	PVB	PVB	PS	ZO	PVB	PVB	NM
PS	PVB	PVB	PS	ZO	PM	PB	NB
ZO	PVB	ZO	ZO	ZO	ZO	ZO	NVB
NS	PB	NB	NM	ZO	NS	NVB	NVB
NB	PM	NVB	NVB	ZO	NS	NVB	NVB

The antecedent ($\Delta\varepsilon(k)$)

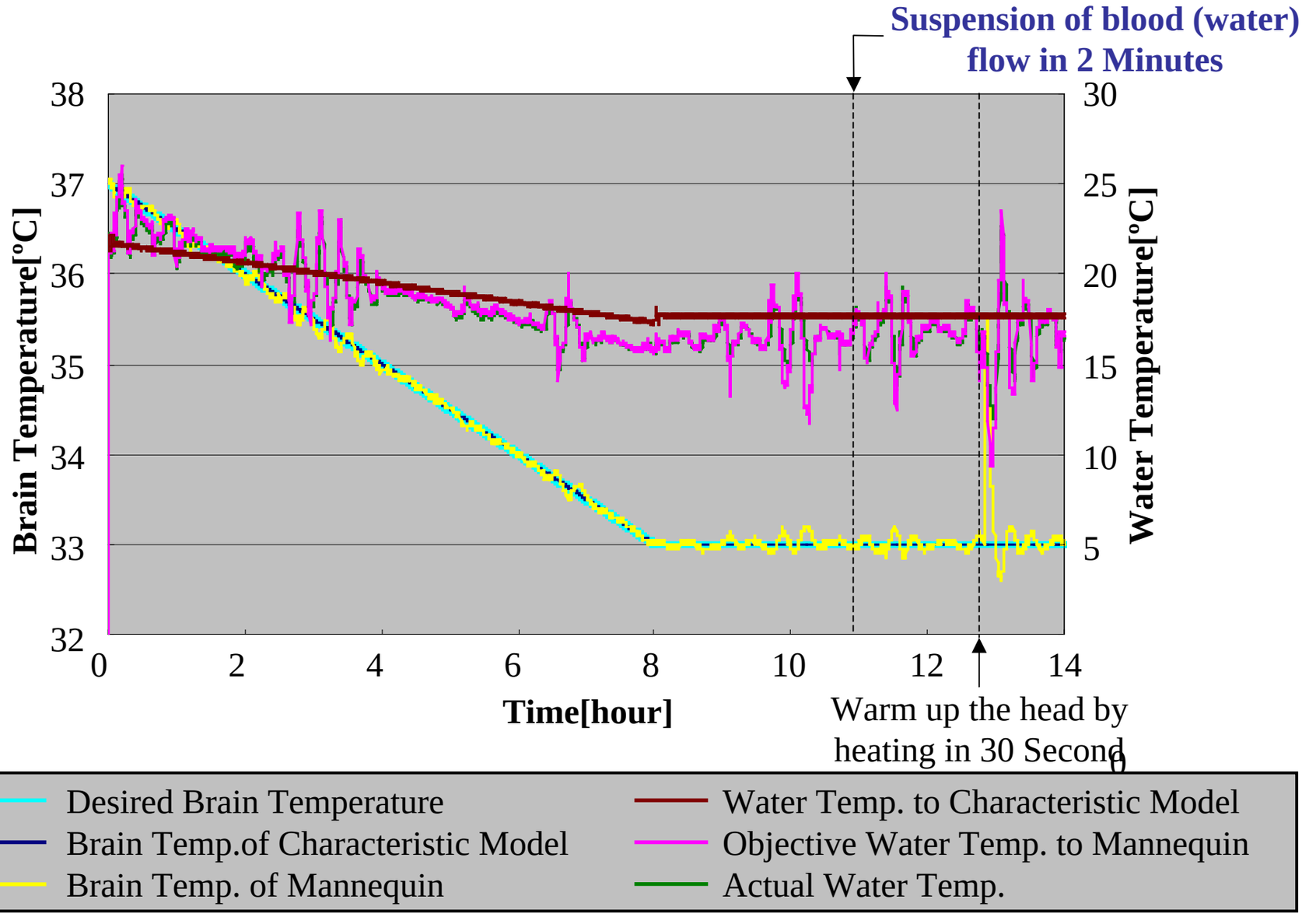
The consequent



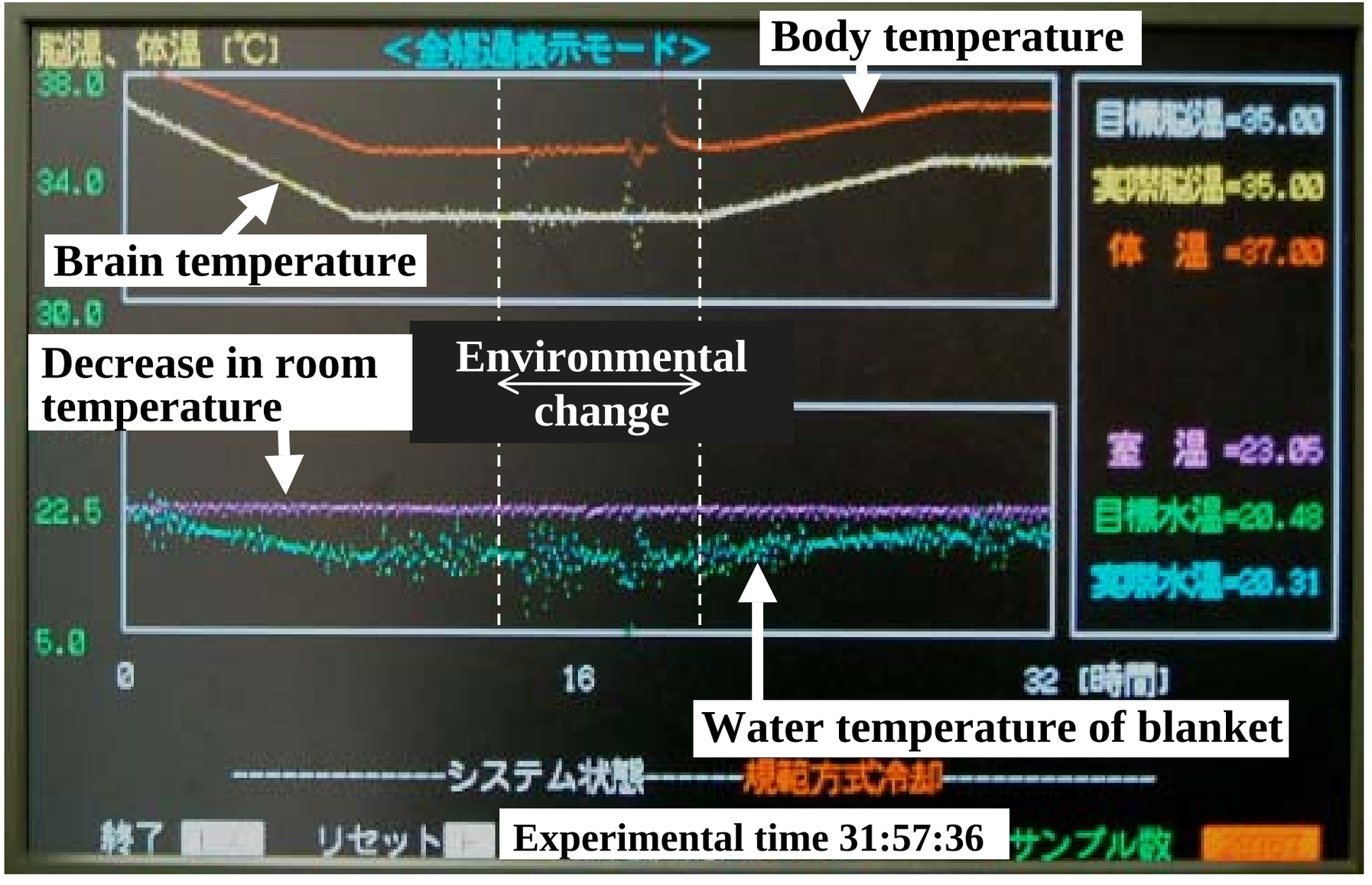
Block Diagram of Fuzzy Control System



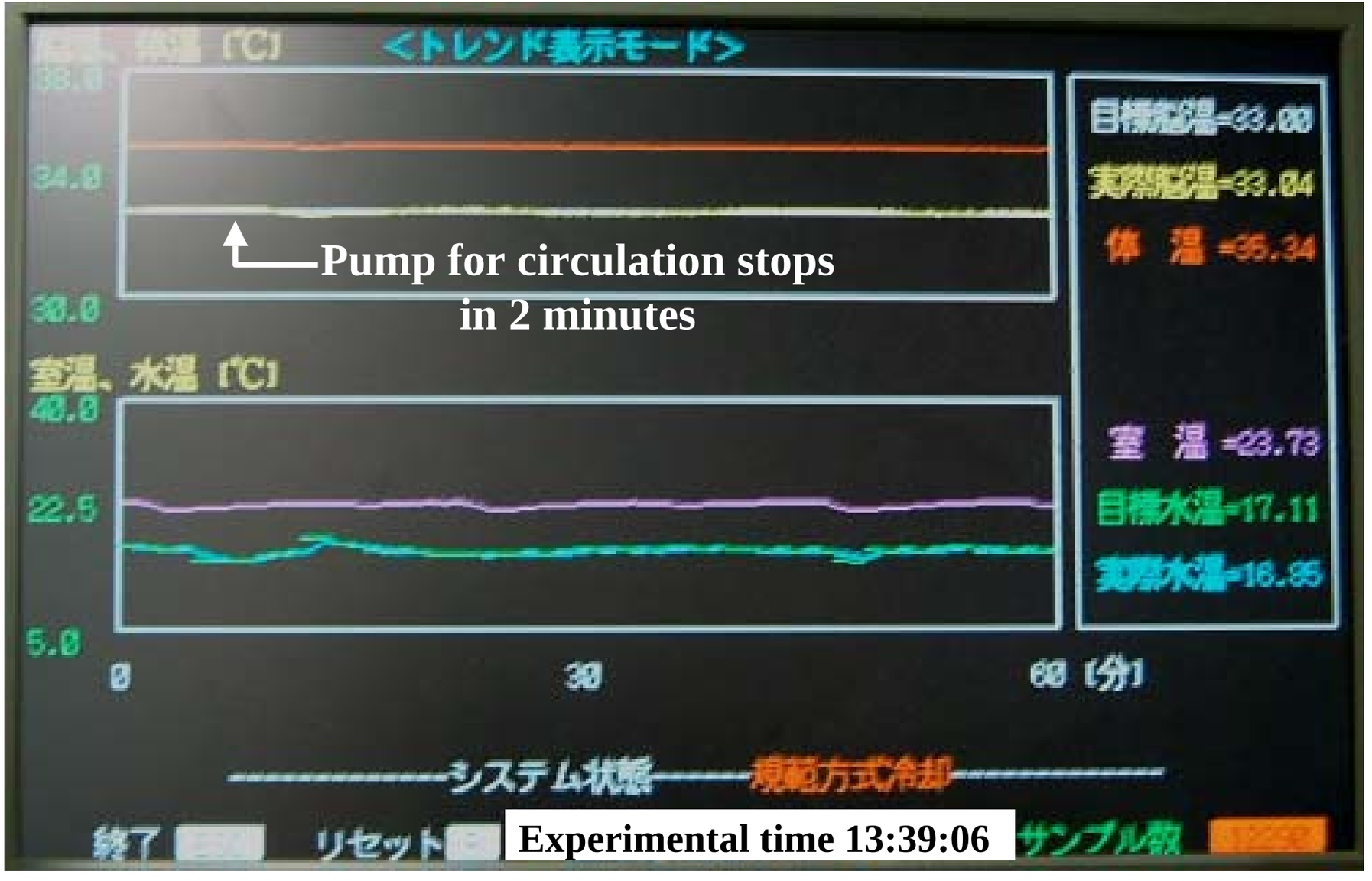
Experimental Result during Cooling and Stable Period



Whole Experimental Result

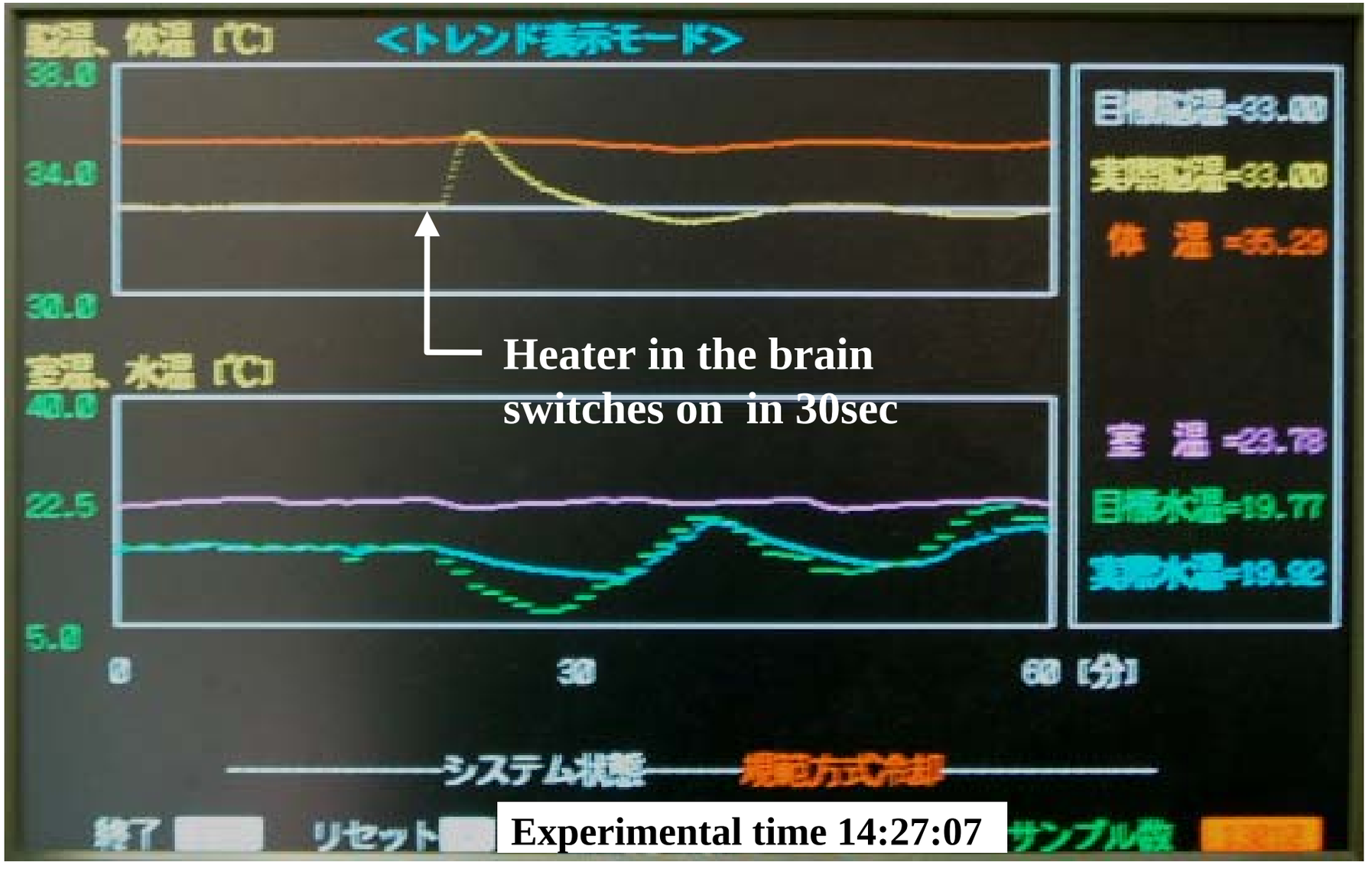


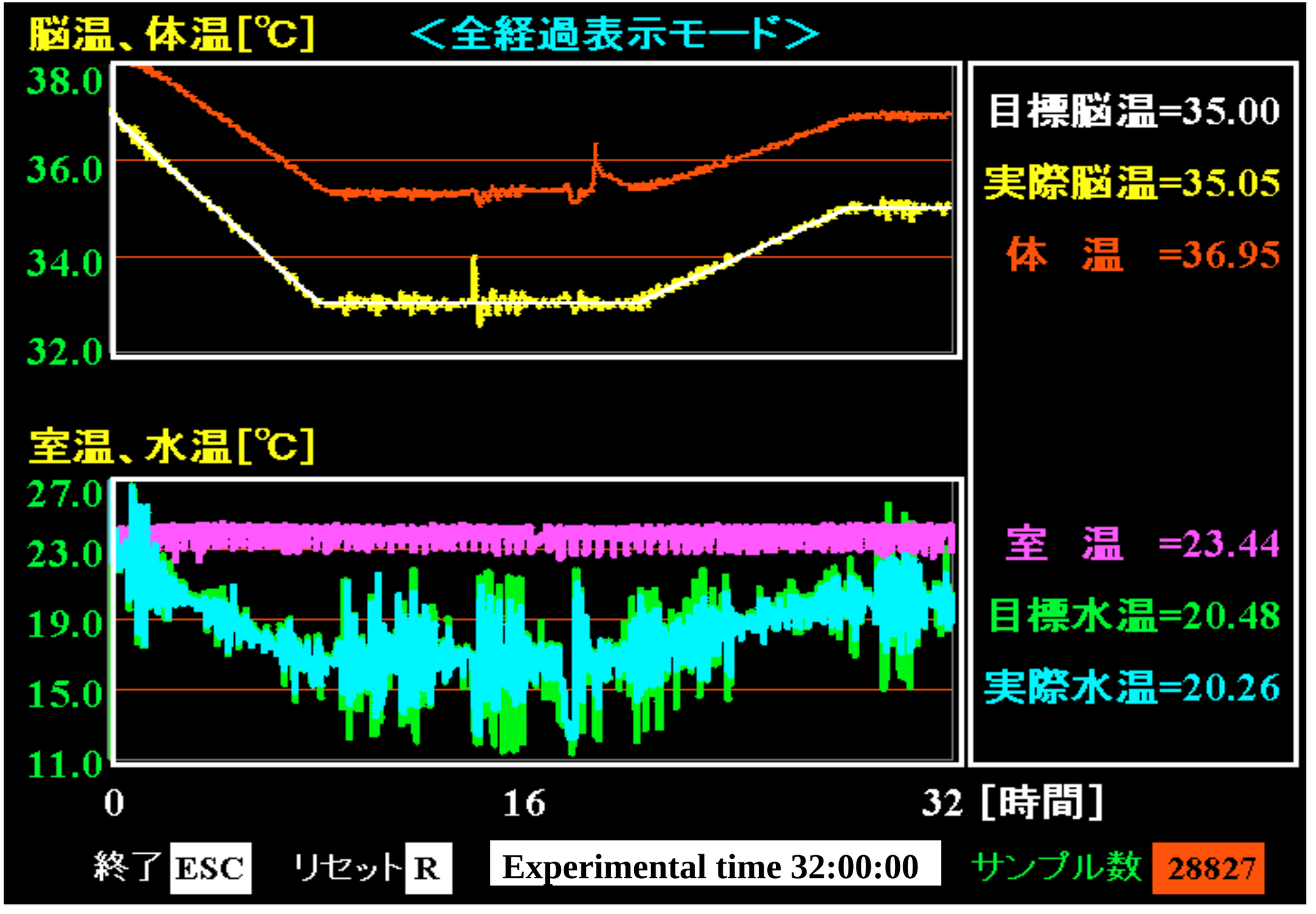
Blood Flow Change

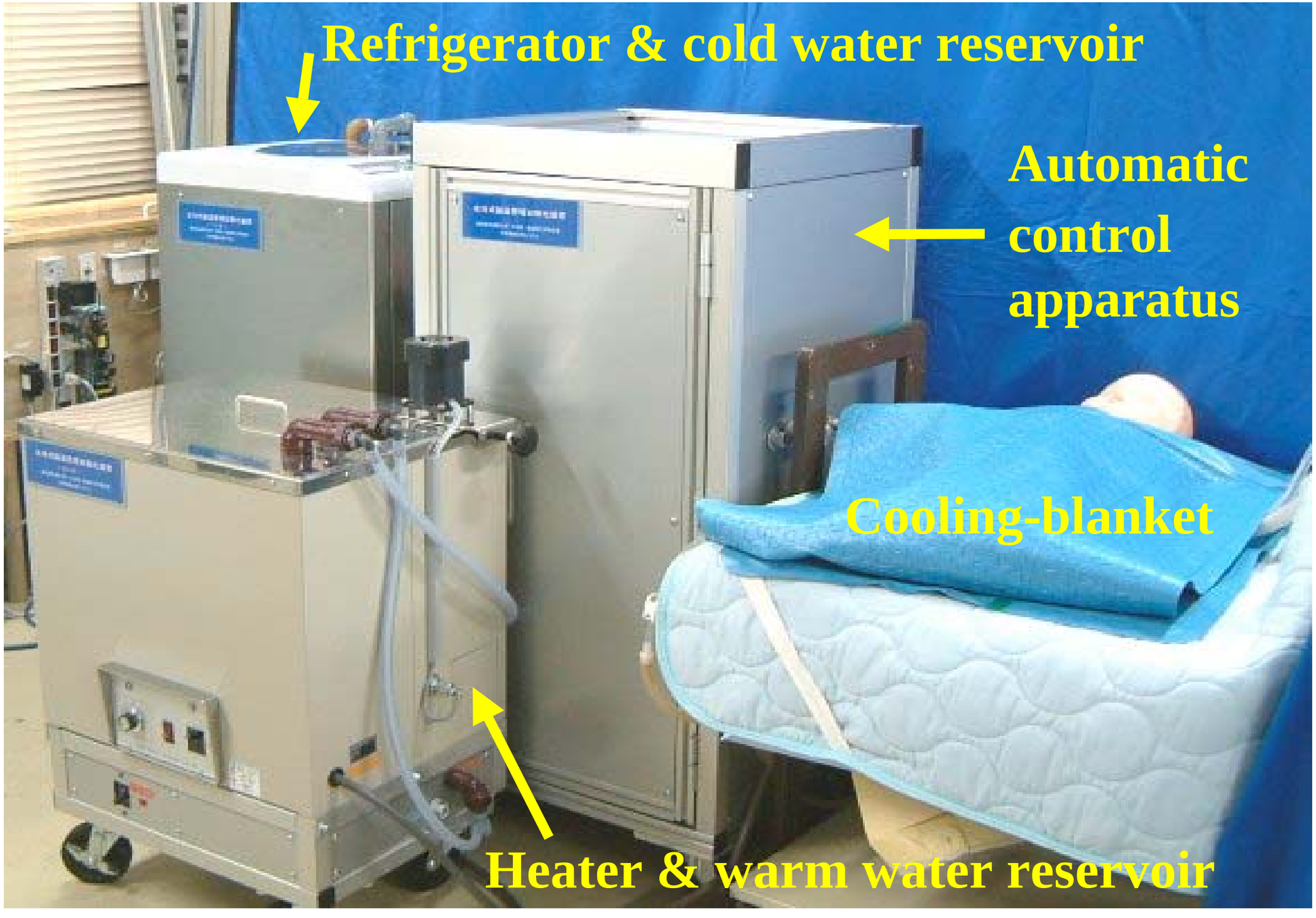


Experimental time 13:39:06

Metabolism Change in Brain

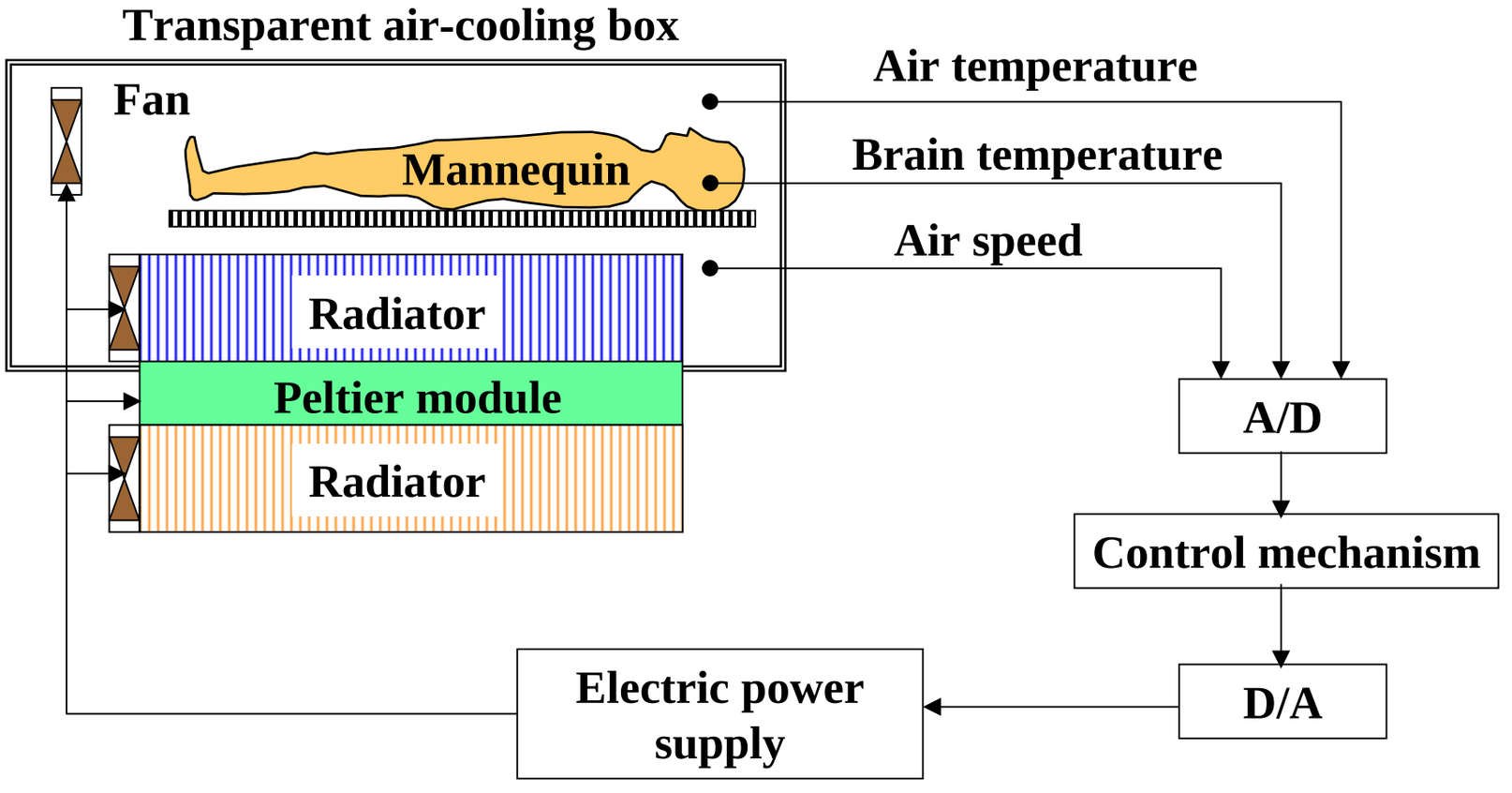



脳温、体温[℃]
＜全経過表示モード＞
38.0
36.0
34.0
32.0
目標脳温=35.00
実際脳温=35.05
体　温　=36.95
室温、水温[℃]
27.0
23.0
19.0
15.0
11.0
室　温　=23.44
目標水温=20.48
実際水温=20.26
0
16
32［時間］
終了 ESC
リセット R
Experimental time 32:00:00
サンプル数 28827


Refrigerator & cold water reservoir
Automatic control apparatus
Cooling-blanket
Heater & warm water reservoir

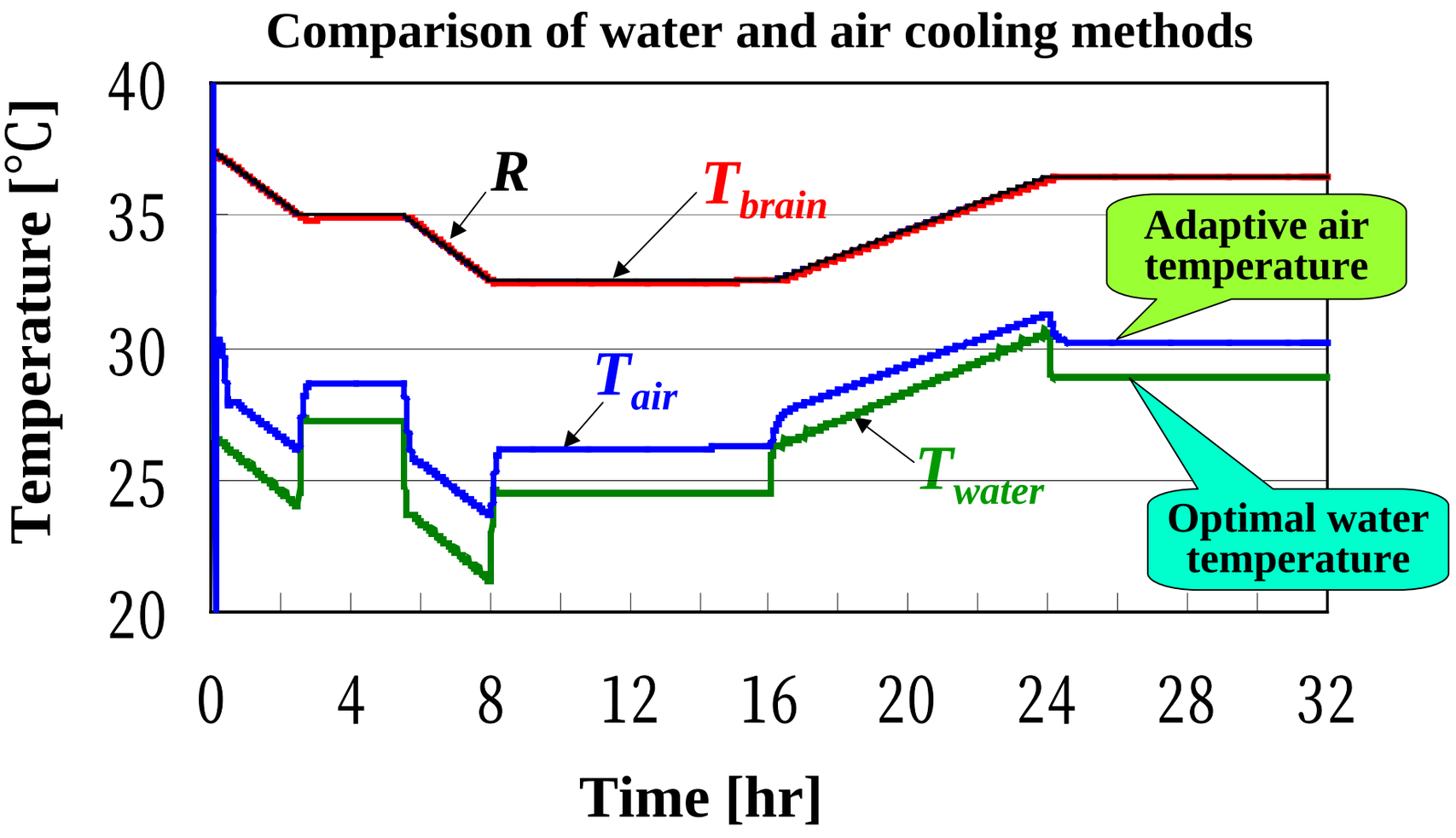
Control of Brain Temperature by Air-Cooling System

Air-cooling Incubating System

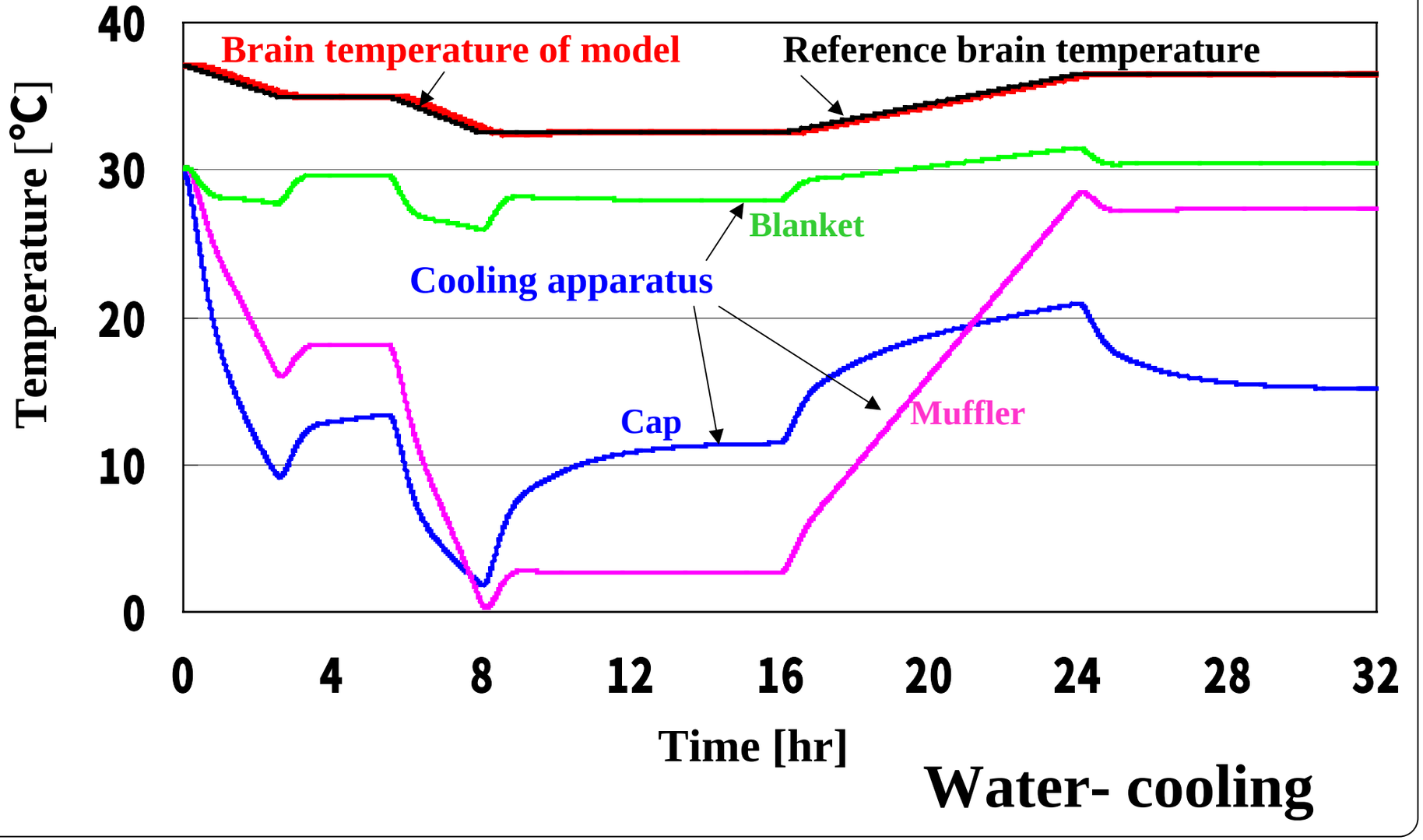


Automatic Air-Cooling Incubating System for Brain Hypothermia Treatment

Simulation Result

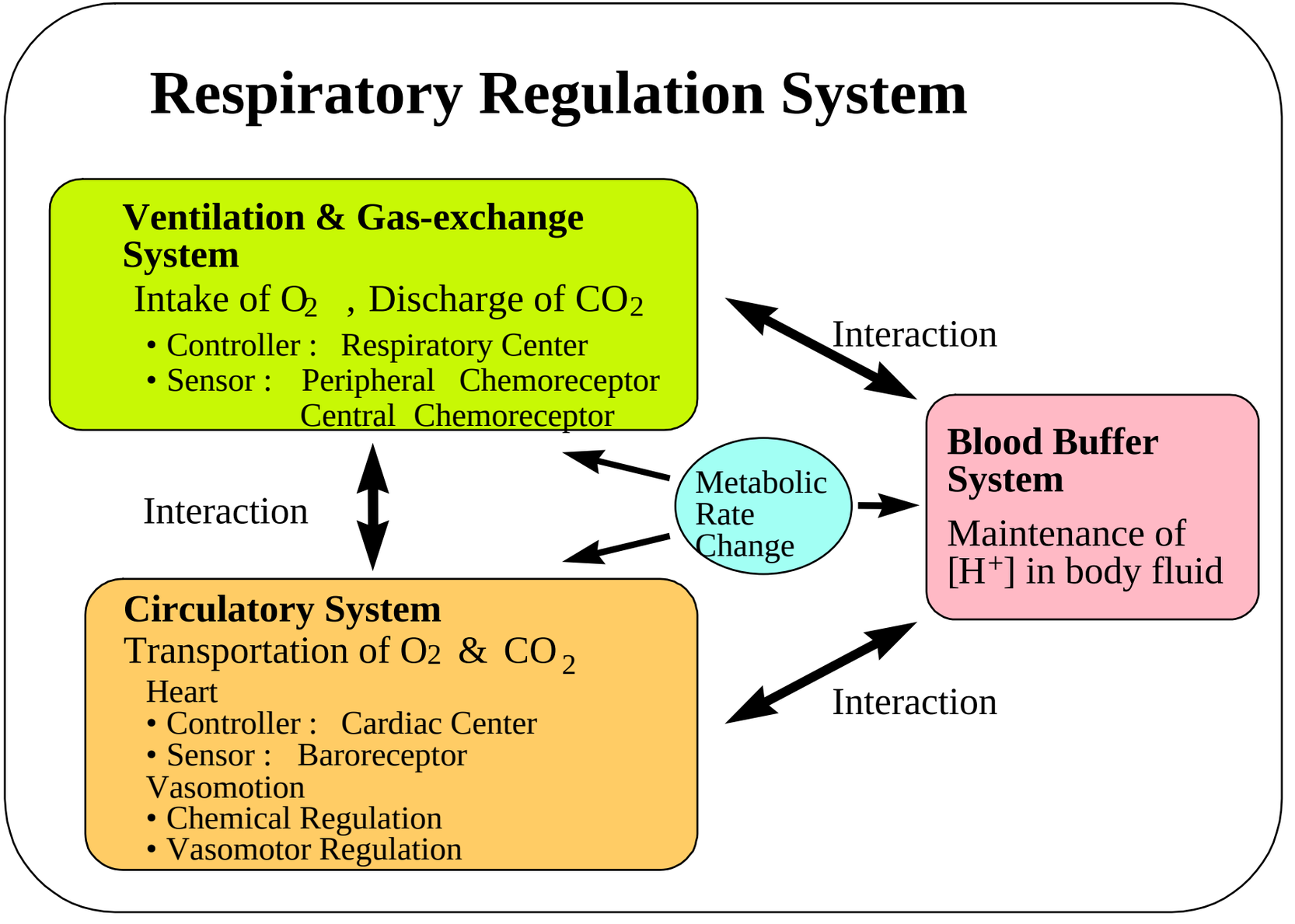


Control using Solution by Optimal Calculation



Automatic Control of Respiration to Deal with Difference of Individual Characteristics

Respiratory Regulation System



Points of Design of the Control System

Respiratory Regulation System

- Non-linearity
- Chronic Change
- Individuality
- Change of Environment

⇩ In order to control

- Understanding by Detection of Its Characteristics
- Design of Control System based on Detected Characteristics

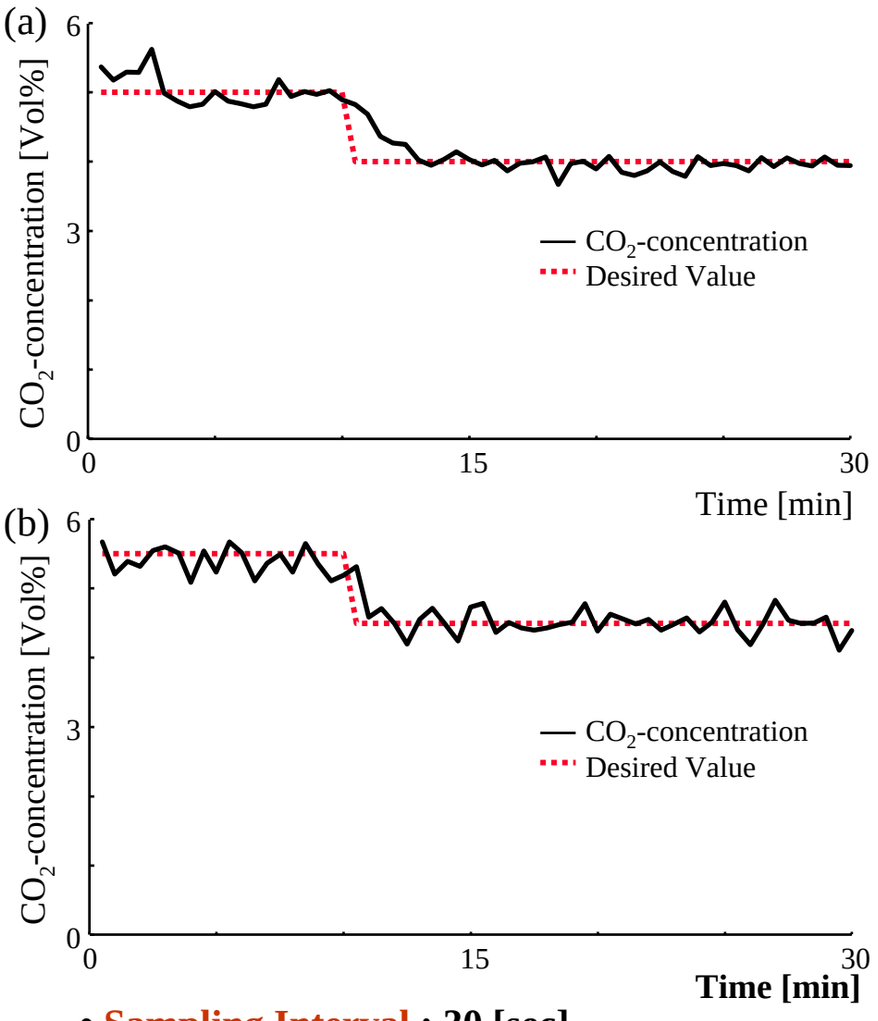
Deviations of the Parameters of the Mathematical Model

Introduction of an "Adaptive System"

Interior view of the all-built-in-one type respirator

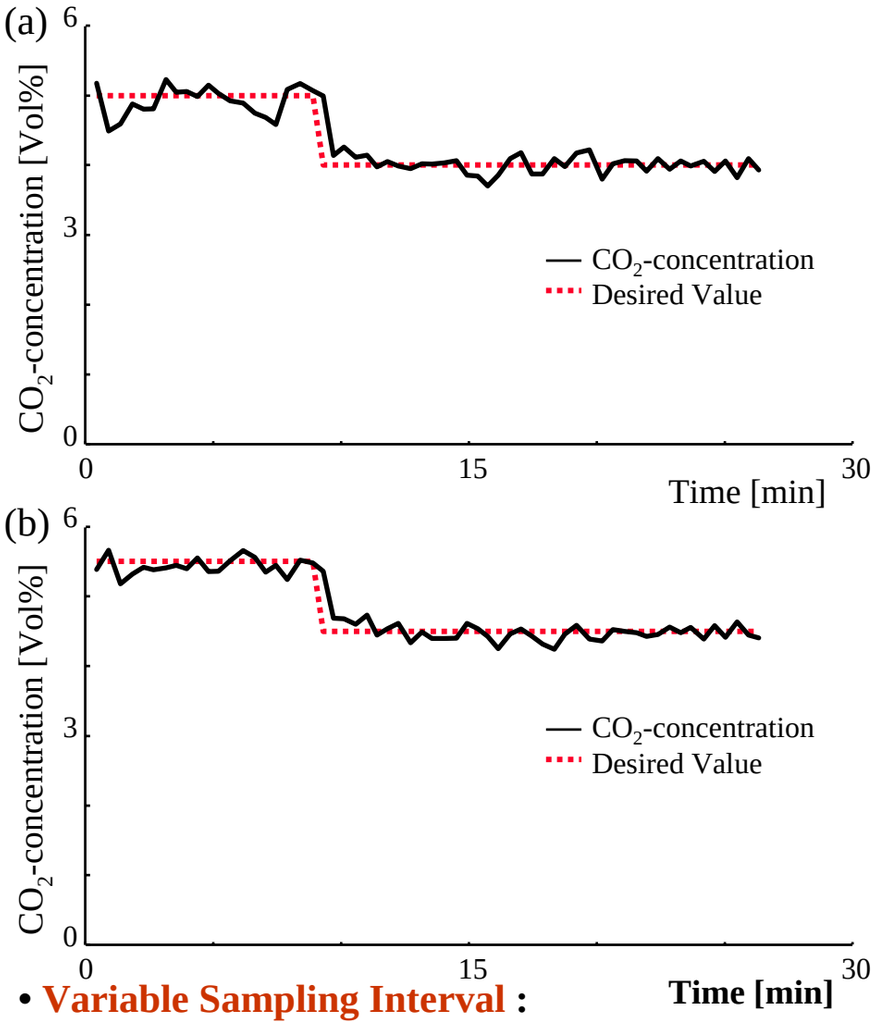
Developed all-built-in-one type respirator

Controlled Respiration



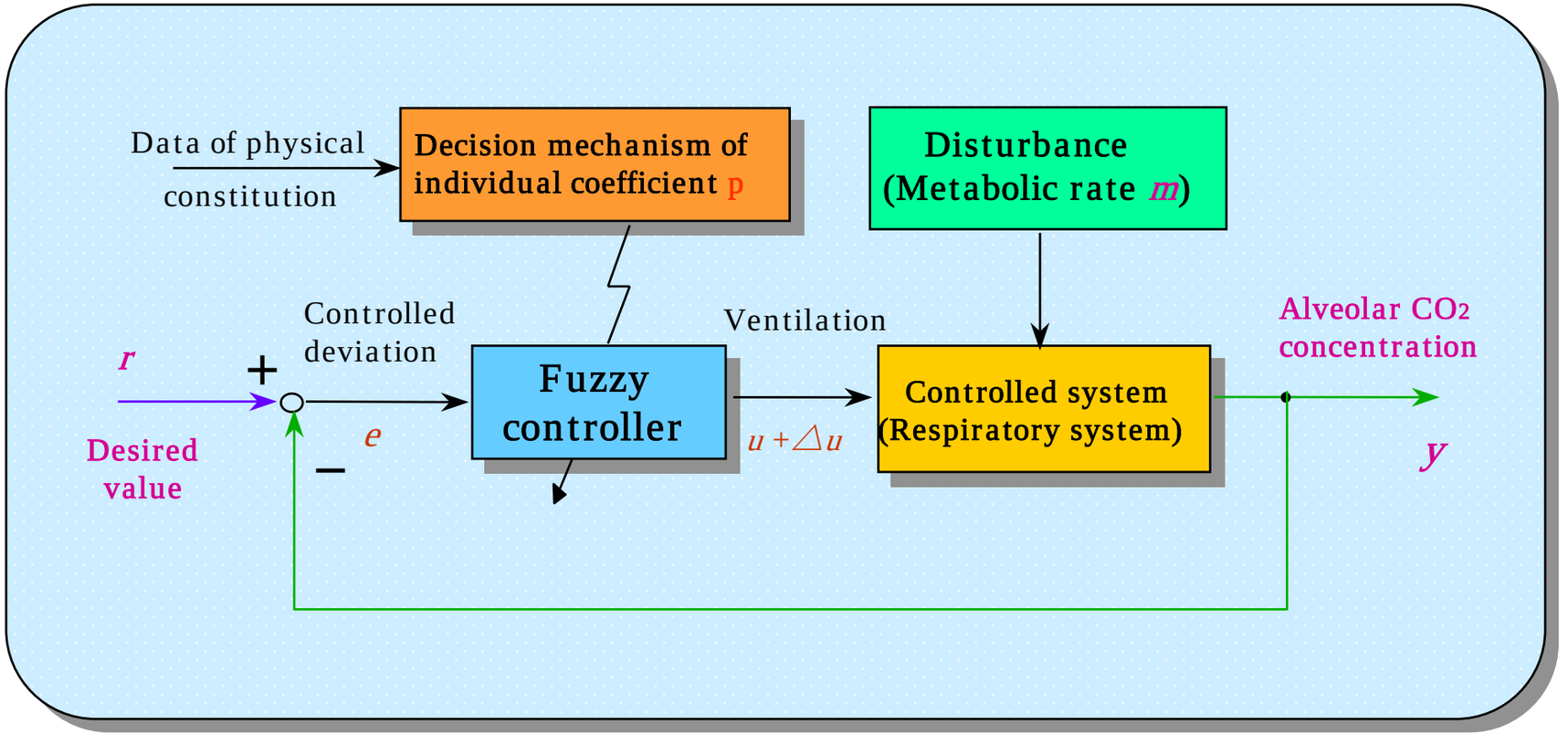
- **Sampling Interval : 30 [sec]**
- **Respiration Rate : 16 [times/min]**
- **Period of Experiment : 30 [min]**

Assisted Respiration

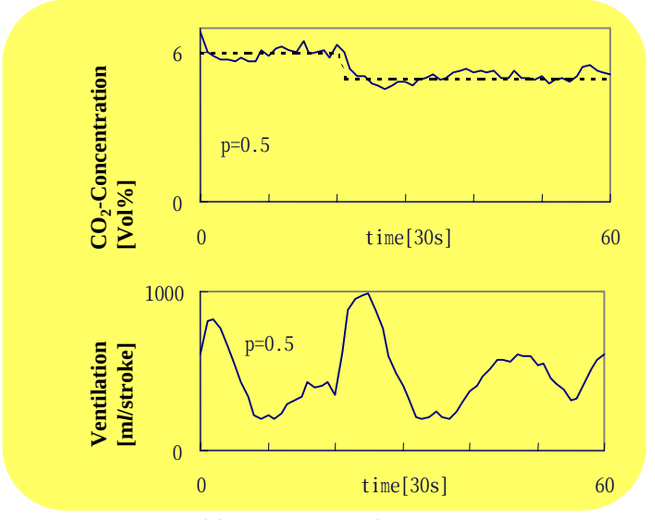


- **Variable Sampling Interval :**
  Every 7 Ventilatory Periods (23.3～30.0 [sec])
- **Respiration Rate :**
  Changed at Random from 14 to 18 [times/min]

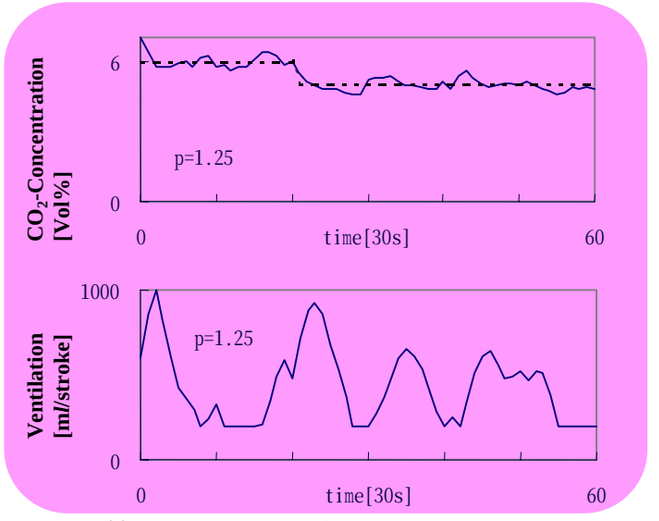
Fuzzy respiratory control system with respect to difference of individuals



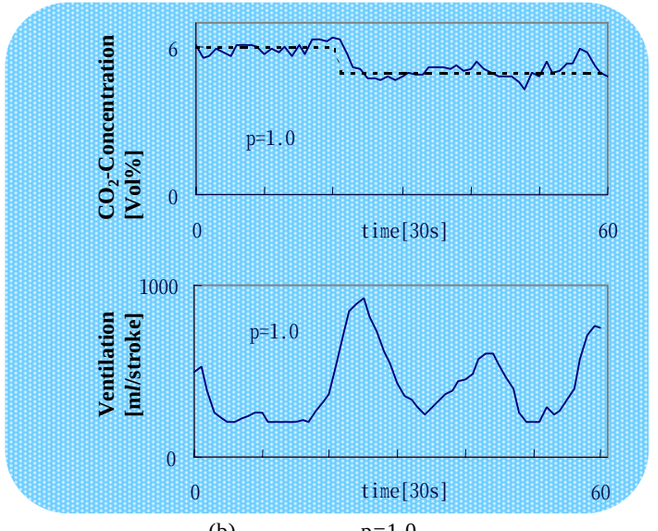
Fuzzy control of the same subject with different constitutional coefficients



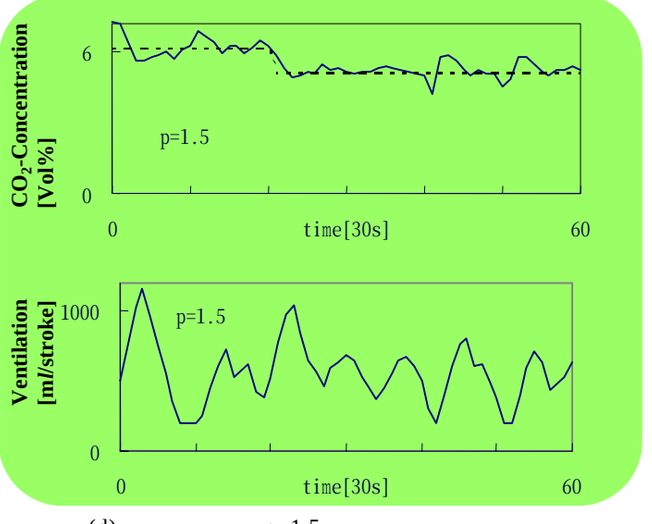
(a) p=0.5



(c) p=1.25



(b) p=1.0



(d) p=1.5

Control of Intracranial Pressure by Administration of Mannitol based on Mathematical Model

Background and Aim

（Traumatic brain injuries，brain tumors, etc.）

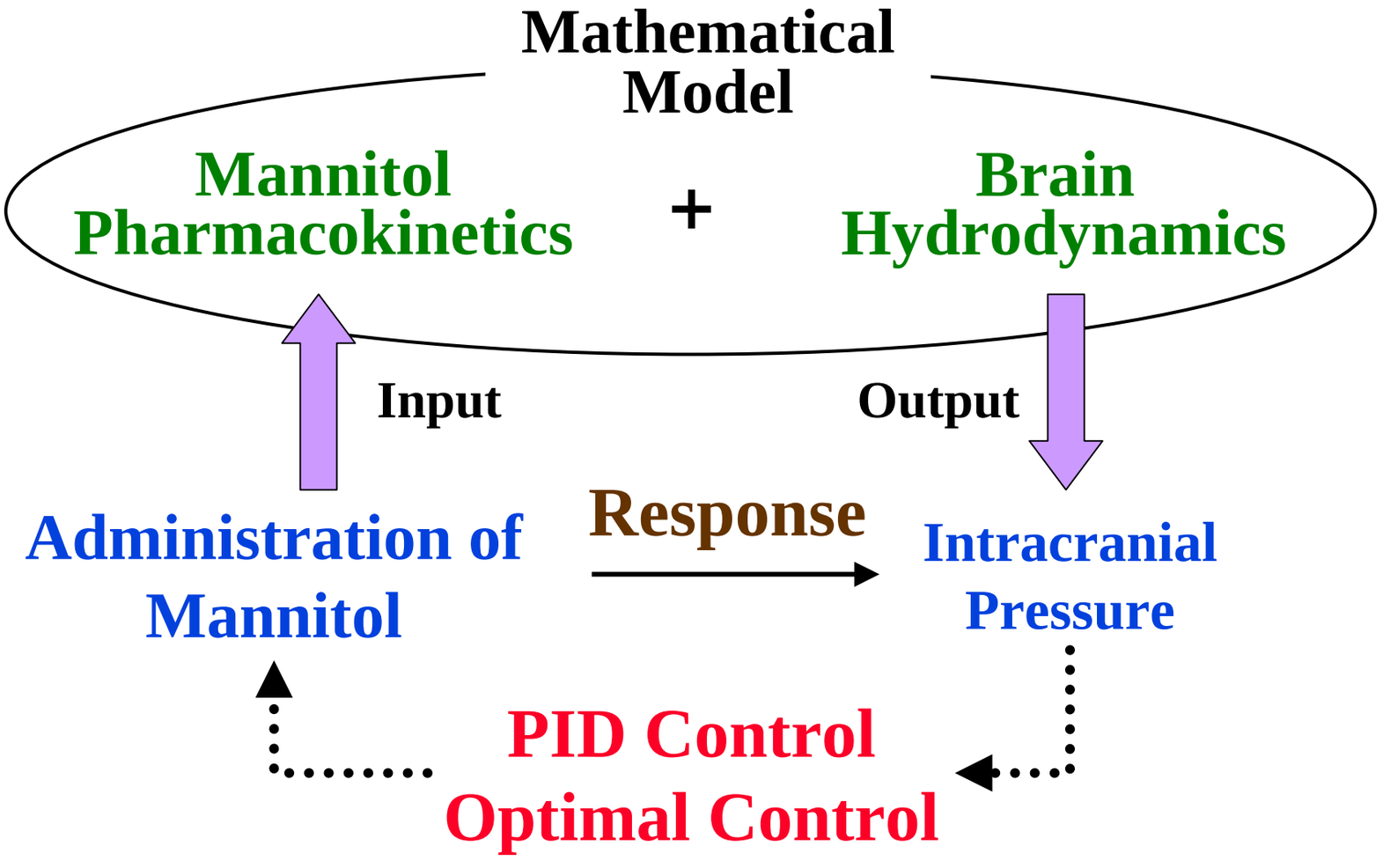
Intracranial hypertension caused by brain edema

Iterative administration based on experience of doctors

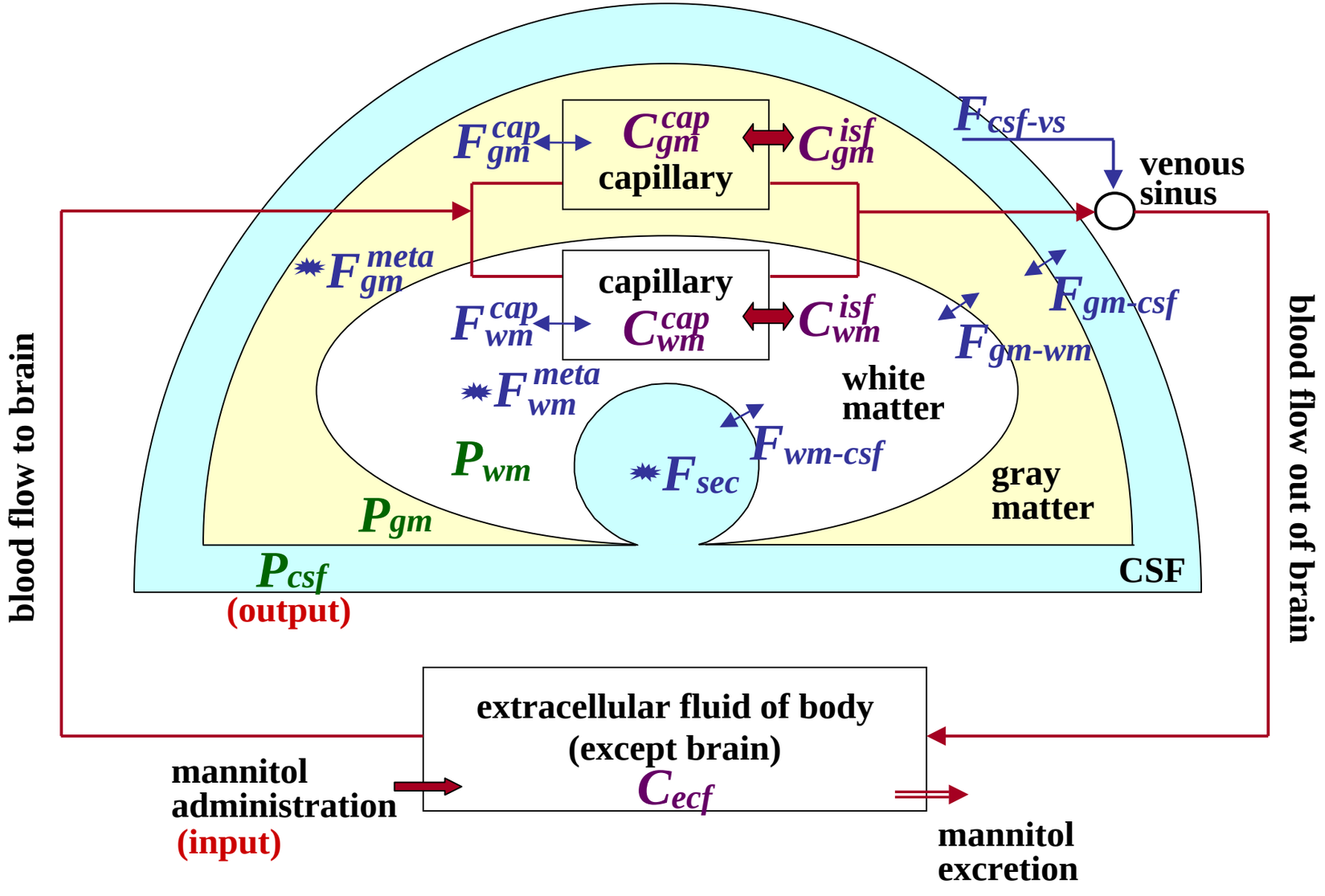
Theoretical Analysis

- **Detemination of most effective administration process**
- **Dynamical prediction of intracranial pressure**

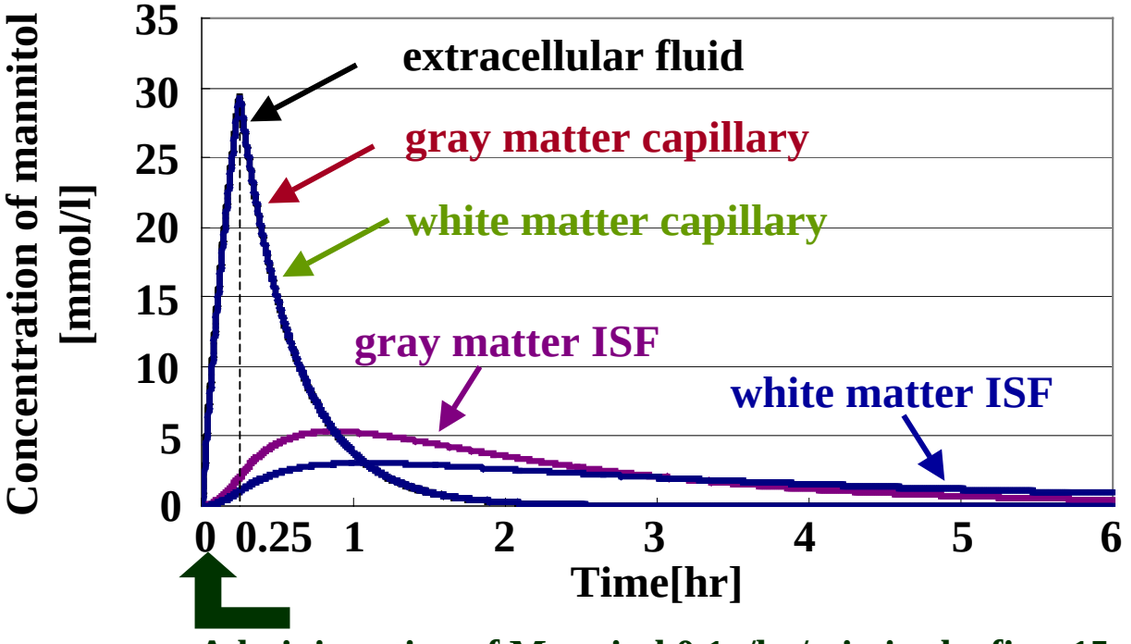
Method


Mathematical Model
Mannitol Pharmacokinetics
+
Brain Hydrodynamics
Input
Output
Administration of Mannitol
Response
Intracranial Pressure
PID Control
Optimal Control

Schematic Representation of Model



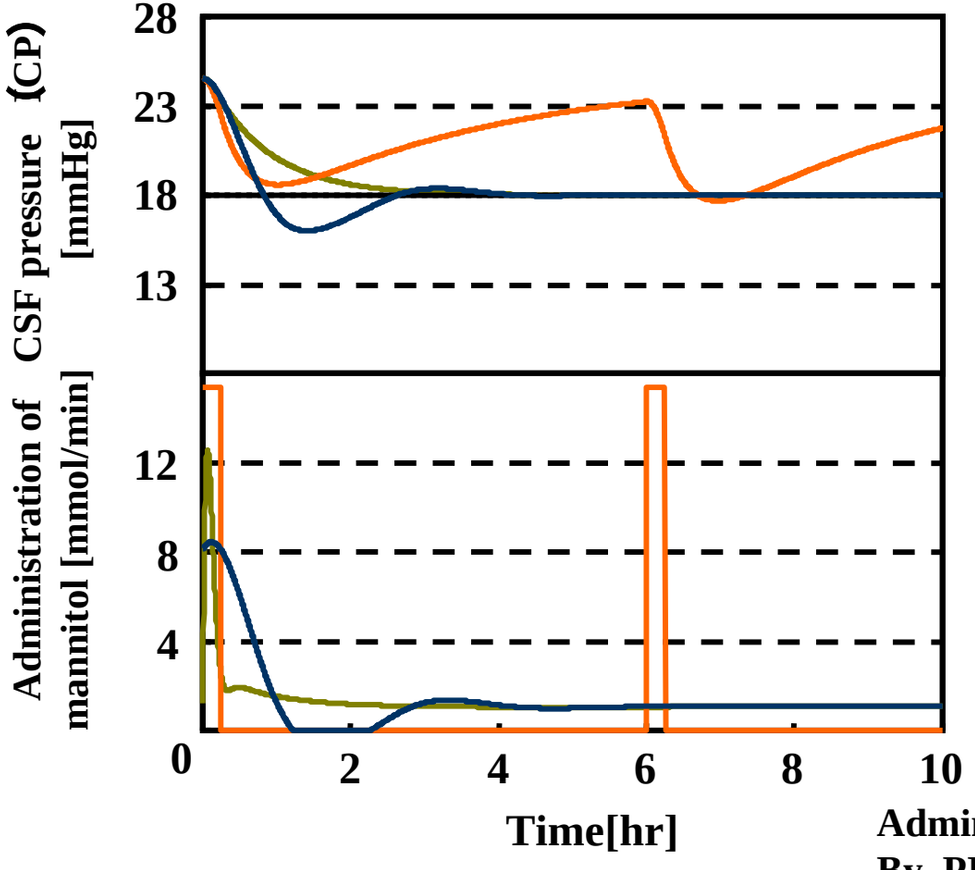
Dynamics of Mannitol Concentration in a Bolus Administration



Administration of Mannitol 0.1g/kg/min in the first 15min

Mannitol concentration of extracellular fluid, gray matter capillary and white matter capillary. They decreases exponentially after their peak on the last moment of infusion.

Comparison of Different Methods by Simulation



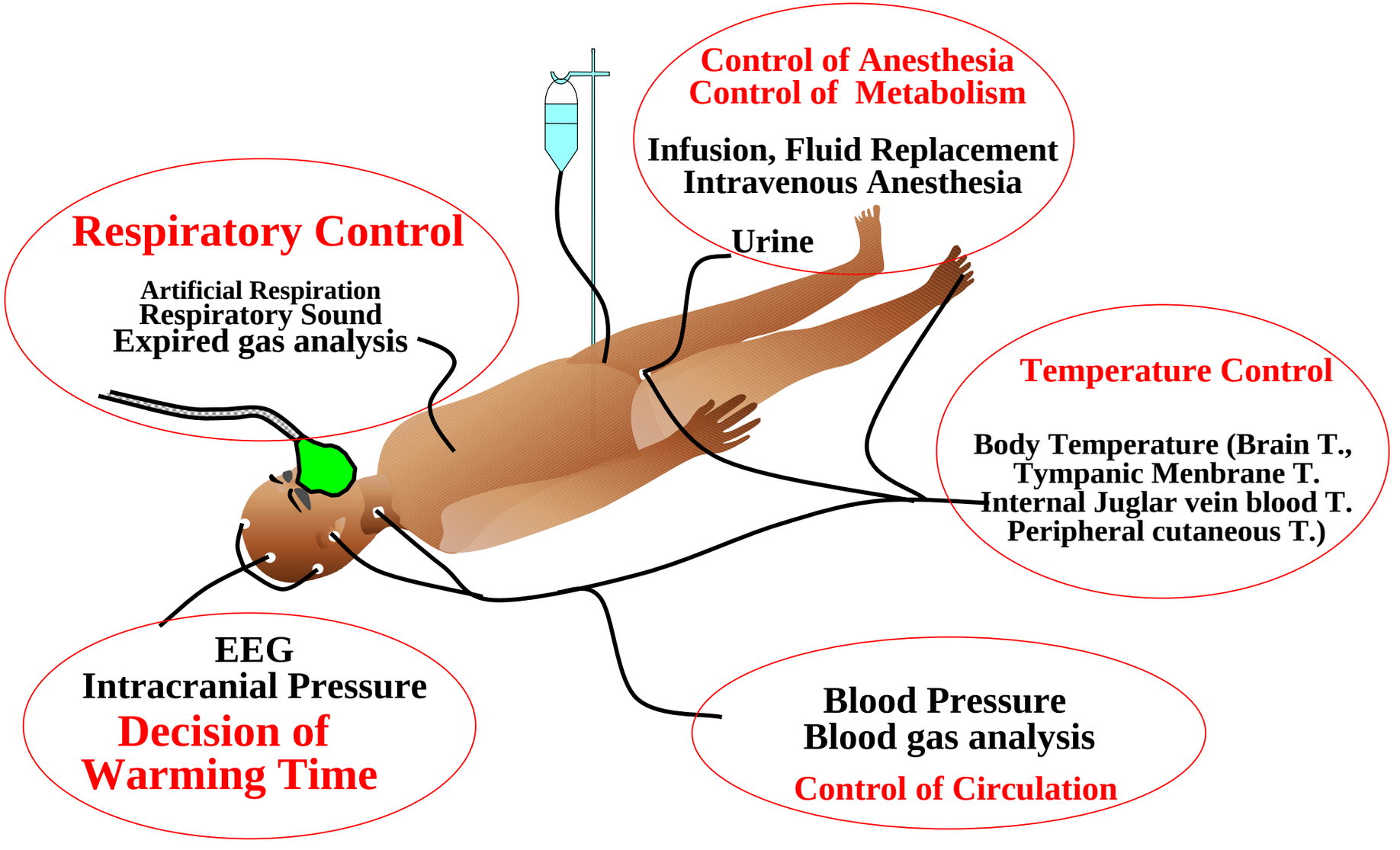
Decrease of ICP by Less Amount of Mannitol in a Optimal Control Process

Administration of Mannitol
By PI-Control
Optimal Control
&Intermittent Control

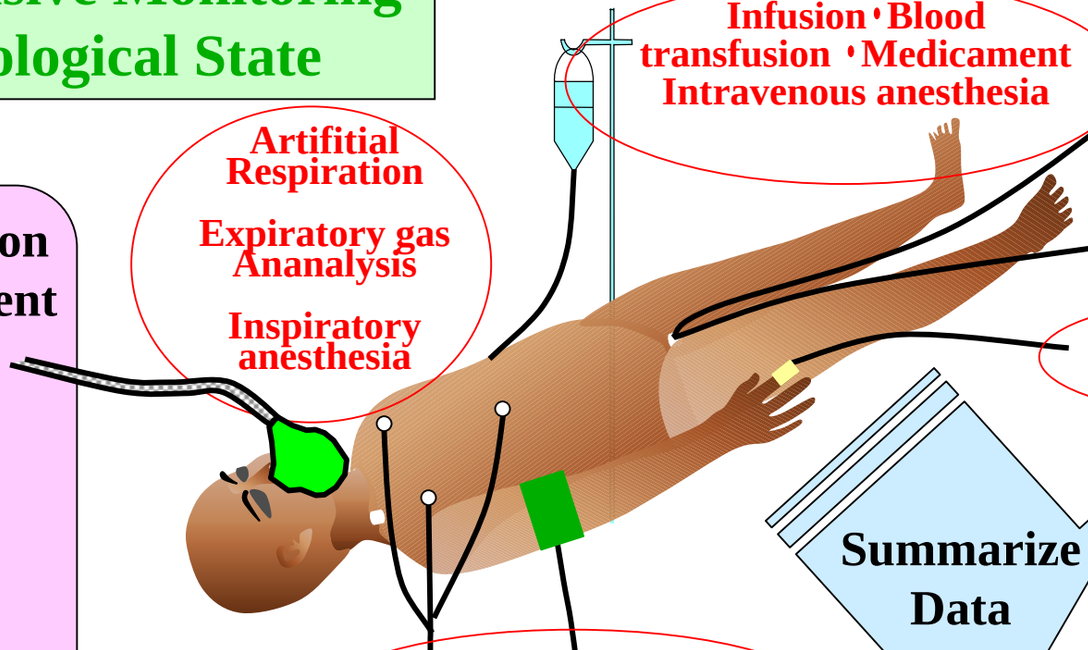
On-line Monitoring of parallel Physiological Data

Monitoring System of Parallel Physiological Data

Conventional Monitoring of Physiological State



Comprehensive Monitoring of Physiological State



Infusion・Blood transfusion・Medicament Intravenous anesthesia

Urinary analysis

Artifitial Respiration

Expiratory gas Ananalysis

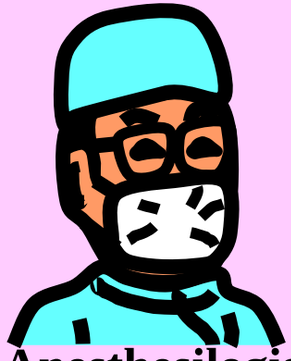
Inspiratory anesthesia

Body, Rectal Temperature

Oxygen saturation

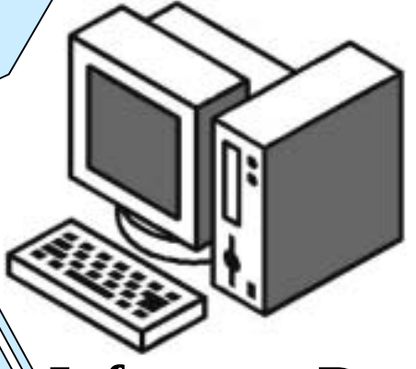
Blood Pressure ECG・Blood Gas

Final Decision and Treatment



Anesthesilogist

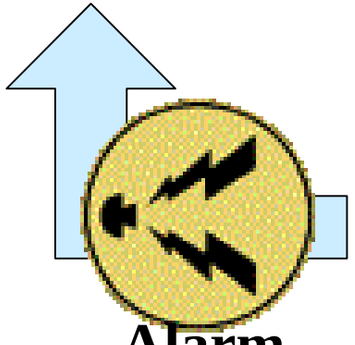
Summarize Data



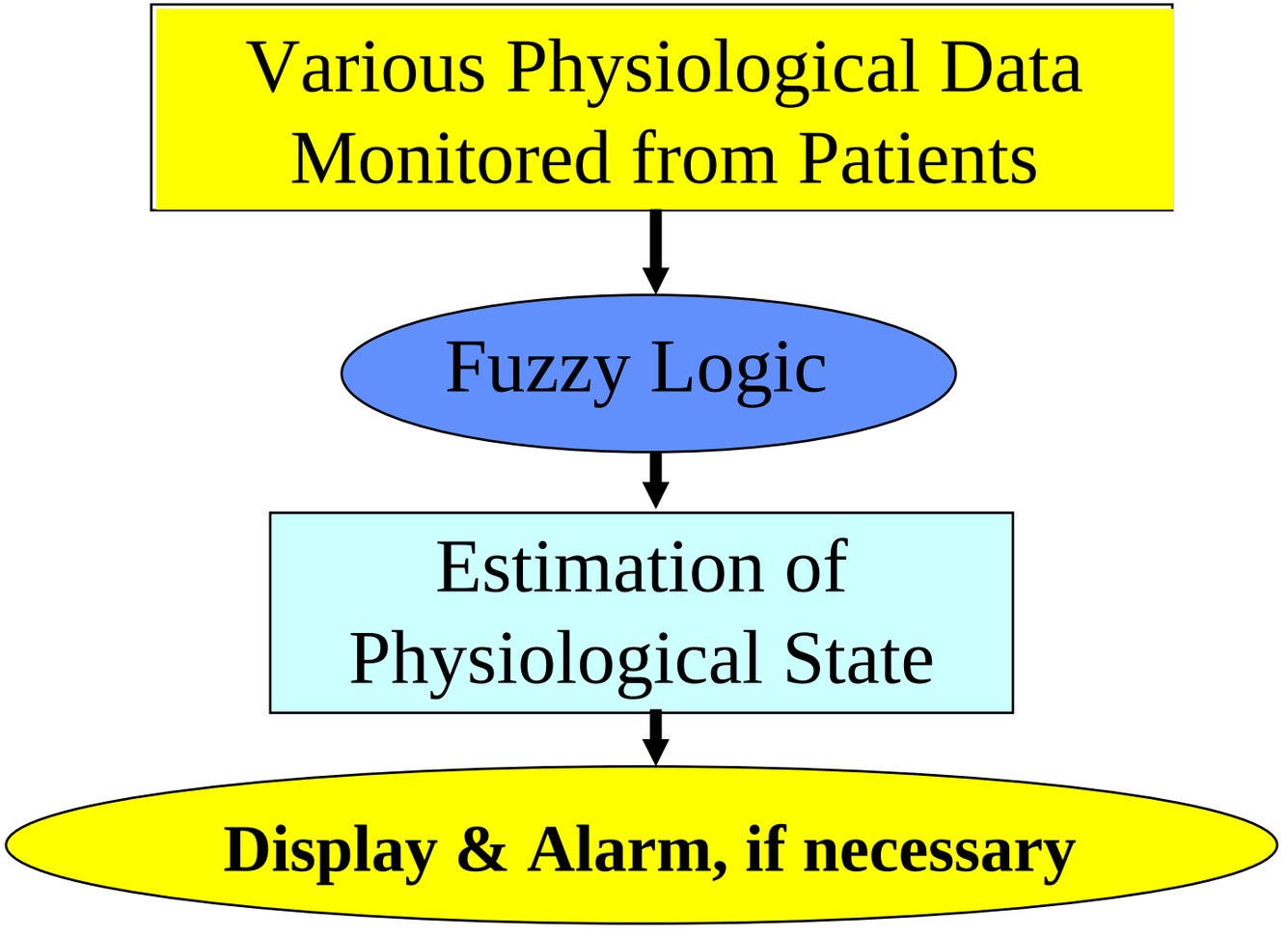
Physio-logical State

Inference, Decision &Description

Indication by Simple Expression



Alarm



Evaluation and Alarming System