Functional Requirement Analysis and Function Allocation for APR 1400

Nuraslinda Anuar, Florah Kamanja, Noloyiso Mtoko, Nurhayati Ramli, Eric Ohaga, Bui Hoang Ha, Kim Dongyoung, Arifin M. Susanto, Zulfakar Zolkaffly, Kim Hyejin, Duy Le Duc, *Jonghyun Kim.
KEPCO International Nuclear Graduate School, 1456-1 Shinam-Ri, Seosaeng-Myeon, Ulju-Gun,Ulsan
**Corresponding author: jonghyun.kim@kings.ac.kr*

1. Introduction

The Functional Requirement Analysis (FRA) and Function Allocation (FA) are required by the regulation in the Human Factors Engineering (HFE) program [1]. The FRA defines the functions, processes, and system for plant safety and power generation. The FA allocates the functions to human operator, automation, or a combination of two.

The FRA and FA for APR1400 have been performed in the very early stage of development but only for the plant safety [2]. However, the analysis did not include the goal of power generation and also did not fully satisfy the latest revision of NUREG-0711.

This paper intends to fulfill the FRA and FA of the HFE as required in Chapter 4 of NUREG-0711 rev. 3 for APR1400 to satisfy both plant safety and power generation objectives.

2. Methodology

The flowchart in Fig. 1 summarizes the methodology of performing the FRA and FA developed from the review criteria in NUREG-0711 [1].

The first step is to determine the scope the FRA, which has been defined to be for full power operation (around 100%), with only the primary systems being modeled (supporting and minor systems are not modeled for simplification) for power generation goal. The results of this step would be high-level functions, which are then further decomposed to process functions and systems levels.

The decomposition rules are (1) the functions at the higher level are more general than those at the lower level, (2) the number of functions at the lower levels should be equal or greater than those at the higher levels, and (3) the number of the lower level functions should be sufficient to achieve the higher-level functions. The stopping rule for the decomposition of the function is the decomposition stops when the level contains the representative control of the low level functions, which is at the system level.

The functions are then characterized [3] according to NUREG-3331, which is a guideline for allocating functions to human or automation. The results of function characterization are the technical bases for the assignment of the level of automation (LOA), which will enable for the determination of the LOA at the system level.

The systems are either assigned to have either one of the five controls: (1) Manual (M), (2) Auto/Manual (AOM), (3) Auto and Manual (AAM), (4) Auto XOR Manual (AXM), and Automatic (A). Overall personnel role analysis (OPRA) is then performed by identifying the roles of the personnel for the allocated functions. Finally, verification of FRA and FA are conducted to ensure that all of the review criteria are captured in this work, by using a verification checklist.

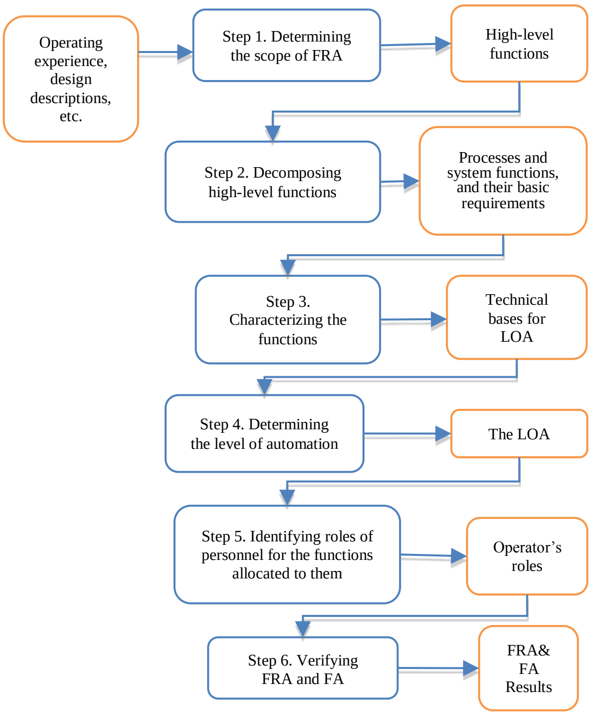

Fig. 1. Methodology for performing FRA and FA

3. Results

The results of FRA and FA are summarized in Table I for power generation goal and in Table II for safety goal. The power generation goal is decomposed into four high-level functions as shown in Table I.

Table I. Function decomposition and function allocation results for power generation goal

High Level Functions	**Process Functions**	**System**	**Control**
Reactor heat generation	Reactor water clean up	Chemical and volume control system (CVCS)	AXM
	Reactor water level control	Pressurizer level control system (PLCS) and CVCS	AOM
	Reactor pressure control	Pressurizer pressure control system (PPCS)	AOM
	Reactor heat control	Power control system (PCS) and CVCS	AOM
	Reactor heat transfer	Reactor coolant system (RCS)	M

Steam production	SG water clean up	SG blowdown system (SGBDS)	AXM
	Feedwater supply	Main feedwater system (MFWS) and feedwater control system (FWCS)	AOM
	SG water level control	MFWS and FWCS	AOM
	Steam transfer	Main steam supply system (MSSS)	N/A
Electricity generation	Steam control	Turbine control system (TBCS)	AOM
	Turbine control	TBCS	AOM
	Power regulation	Excitation system (ES)	AOM
Electricity dispatch	Supply power to houseloads	Main Power System (MPS)	AXM
	Transformation from 24kV to 756kV	MPS (main transformer)	AOM
	Connect to transmission network	Switchyard system	AXM

The safe operation goal is decomposed into nine high-level functions as shown in Table II.

Table II. Function decomposition and function allocation for safety goal

High Level Functions	**Process Functions**	**System**	**Control**
Reactivity Control	Reactor trip	Plant protection system (PPS)	AAM
	Safety injection	Safety injection system (SIS)	AXM
	Rod control	Digital rod control system (DRCS)	M
	Boration	CVCS	AOM
Maintenance of vital auxiliaries	Supply AC Source	EDG	AXM
		AAC	AXM
		UAT	AOM
		SAT	AXM
	Supply DC Source	Station batteries	AXM
RCS inventory control	Safety injection	SIS	AXM
	Charging and letdown (CVCS)	PLCS	AOM
RCS pressure control	Safety injection	SIS	AXM
	Charging and letdown (CVCS)	PLCS	AOM
	Safety depressurization	Safety depressurization and vent system (SDVS)	M
	RC gas venting	RC gas venting system (RCGVS)	M
	RCS heating and spraying	PPCS	AOM
	SG steaming	Secondary heat removal system	AOM
Core heat removal	Safety injection	SIS	AXM
	Forced circulation	Reactor Coolant Pumps (RCPs)	M
RCS heat removal	Auxiliary feed	Auxiliary feedwater system (AFWS)	AOM
	Feed and bleed	SIS	AXM
		SDVS	M
		SCS	AOM
Containment isolation	Penetration flow path isolation	Containment isolation system (CIS)	AOM
Containment environment	Containment hydrogen control	Hydrogen monitoring system (HMS)	M
		Passive hydrogen recombiner system (PHRS)	Passive
		Containment hydrogen purge system (CHPS)	M
	Containment temperature/pressure control	Containment spray system (CSS)	AXM
		Containment fan cooler system (CFCS)	AOM
Radiation emission	Release path isolation	Radiation monitoring system	AOM
	Release path monitoring and control	Radiation monitoring system	M

The OPRA has also been performed. The operator's roles in the main control room can be divided into three categories: (1) reactor operator, (2) turbine operator, and (3) electrical operator. For local operators, the roles are (1) reactor operator, (2) turbine operator, and (3) auxiliary operator.

Finally, the verification of the FRA and FA has been conducted by using a list of checklist questions that reflect the requirements and criteria from section 4.4 of NUREG-0711. It is confirmed by the verification checklist that all of the criteria have been covered by the results of this work.

5. Conclusions

This paper aims to evaluate the FRA and FA for APR1400. The allocation of function is done at the system level for all processes for both the power generation and safety goals, following the NUREG/CR-3331 guideline. As a conclusion, this paper has successfully implemented the requirements and methodology specified in NUREG-0711 for APR 1400.

REFERENCES

[1] U.S. NRC, "Human Factors Engineering Program Model", NUREG-0711, Rev. 3, 2012.

[2] KEPRI, "Functional requirement analysis and function allocation report for Korean Next Generation Reactor Man-Machine Interface – Standard Issue".

[3] U.S. NRC, "A Methodology for Allocating Nuclear Power Plant Control Functions to Human or Automatic Control", NUREG/CR-3331, 1983.