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Safety System in a Heavy Water Detritiation Plant

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ABSTRACT

In a CANDU 6 type reactor a quantity of $55 \cdot 10^{15}$Bq/year of tritium is generated, 95% being in the D_2O moderator which can achieve a radioactivity of $2.5 \div 3.5 \cdot 10^{12}$Bq/kg. Tritium in heavy water contributes with 30÷50% to the doses received by operation personnel and up to 20% to the radioactivity released in the environment.

The large quantity of heavy water used in this type of reactors (500 tones) make storage very difficult, especially for environment.

The extraction of tritium from tritiated heavy water of CANDU reactors solve the following problems: the radiation level in the operation area, the costs of maintenance and repair reduction due to reduction of personnel protection measures, the increase of NPP utilisation factor by shutdown time reduction for maintenance and repair, use the extracted tritium for fusion reactors and not for the last, lower costs and risk for storage heavy water waste.

Heavy water detritiation methods, which currently are used in the industrial or experimental plant, are based on catalytic isotope exchange or electrolysis followed cryogenic distillation or permeation. The technology developed at Institute of Cryogenics and Isotope Separation is based upon catalytic exchange between tritiated water and deuterium, followed by cryogenic distillation of hydrogen isotopes.

The nature of the fluids that are processed in detritiation requires the operation of the plant in safety conditions. The paper presents the safety system solution chose in order to solve this task, as well as a simulation of an incident and safety system response. The application software is using LabView platform that is specialised on control and factory automation applications.

1. INTRODUCTION

In heavy water circuits from CANDU reactor, tritium is generated through the following reactions:

- neutrons activation;
- fission of ^{235}U, ^{233}U and ^{239}Pu in rods;
- ^{3}He disintegration.

Tritium concentration in primary circuit is lower than the concentration from moderator, as long as just a small quantity of heavy water is exposed to neutrons flux (<5%).

The equilibrium value is about $1 \div 2 \cdot 10^{12}$Bq/kg, depends by the heavy water quantity which is used in common in primary circuit and moderator, at an increase rate by $148 \cdot 10^{9}$Bq/kg/year.

As the tritium inventory in a CANDU reactor can be bigger than $2 \cdot 10^{17}$Bq (tritium oxide in heavy water circuits), result that a detritiation plant is a necessity.

Solving these problems means that a heavy water detritiation plant must be built and linked to the moderator circuits of the CANDU type. This type of plant is a nuclear facility, involving special regulation and safety systems, respecting the nuclear laws of ROMANIA and international safety regulations, including IAEA Vienna specifications. Like any nuclear facility, a special safety system is provided, with special hardware and software that supervise the technological process and safety equipment.

The complexity of both new and existing safety systems has grown in the last decade as a result of increased safety requirements and demands for higher performance. Like a result, safety system cost rises and maintenance become more expensive. Increased use of automation reduced these costs and frees plant staff from repetitious tasks and enables operators to concentrate on more strategic operations, giving them time to think before taking action. Thus, increased automation results in higher plant performance and enhanced safety through reduction of human errors.

ICIT trying to develop a new safety system, increasing the automations by replacing the original hardware with more reliable and flexible digital systems.

2. ICIT Heavy Water Detritiation Plant

The tritiated heavy water is received from nuclear power plant and introduced in the process. The output result is a heavy water with low concentration of tritium. This water is returned to the moderator circuits and so the safety regarding the tritium level is re-established.

The ICIT plant for tritium and deuterium separation is an experimental project for extraction of the tritium from heavy water, based on catalytic exchange followed by cryogenic distillation (figure 1). ICIT institute intends to develop another experimental plant based on direct electrolysis and cryogenic distillation.

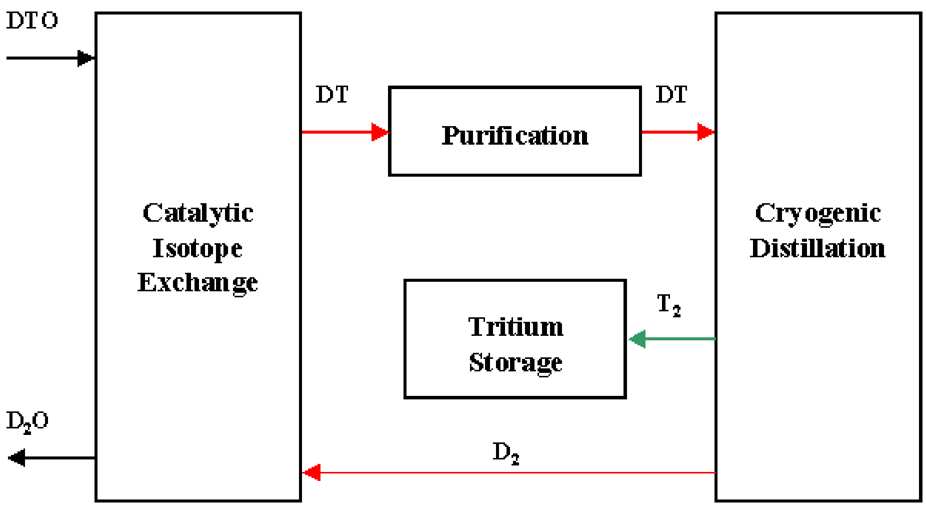

Figure1: Block diagram for ICIT detritiation plant

In the case of normal operating conditions, no operating personnel are allowed to enter into the technological area. Therefore, the monitoring, analysis and safety systems must be remote controlled. The plant include a control room which contains the monitoring, control and safety station and a data acquisition chamber with monitoring and protection loops.

3. Safety system objectives and design

The purpose of the safety and control system is to ensure for population an irradiation risk under the prescription limits and to obtain a lower possible risk The safety system architecture must assure an active and passive, direct and indirect protection

This objective is fulfilled in three stages:

1. Identification of some obstacles against the radioactive material leakage (the structure of the pipes and equipment which have contact with the fluid process; precinct installation must be built like an envelope; the quantity of radioactive material from plant must be limited).
2. Design of system with security roll; part of this system ensure the shutting down and emptying by process agent from the plant (blocking and interplay process system dosimetry, survey system for operationally-exposed persons, for liquids and gaseous effluents and monitoring of the leakage to the exhaust stack; recovery and treatment system for HT and HTO mixture in emergency case; the emergency emptying of isotopic exchange and purification modules; the management system of the radioactive waste; the storage system for tritium or process fluids; the management system for tritiated water; the ventilation system); another part of system manage the control access system, fire alarm system and building integrity system (card access doors, infrared detectors, flue detectors, armoured doors and shell-proof windows, video surveillance, PIR detectors, military guard);
3. Design of the safety system in order to manage credible accidents and design basis accidents (to define the radiation fields in the case of normal operating and credible accident; the limits of the process impose by the results of the analyses). The basis accidents have on the basis the criterion by alone defect (the leakage from pipe or other components). The credible accidents are: the individual damages of isotopic exchange and purification modules, with completely loss of the radioactive inventory, the accidents such as simultaneous or consecutively damage of isotopic exchange and purification modules. The damage of modules can be provoked by external causes: earthquake, fire, and explosion. Because the biggest radioactive inventory is in cryogenic distillation module, this module was build to resist an earthquake with big magnitude.

The concept for security system design is based upon basis and credible accidents that can appears in operation (figure 2). These categories of events comprise leakage from pipes and equipment and partial or total failure of the plant modules.

The security components are divided into two groups: active and passive elements. The active elements can have direct or indirect action.

At ICIT experimental detritiation plant, control and safety systems has different signal loops and these are using different type of equipment. Safety system are designed in respect with "defence in depth" concept [1], which includes the use of redundancy, diversity, separation and failure to safety behaviour for system and its components. Equipment that compounds the safety system has different design and origin, and sometimes uses two different mechanisms to initiate an action. Two or more similar or not measure channels and protection loops are used to perform the same function, in order to provide protection against independent single failure. Also, a highly number of parameters are monitoring in respect with control and monitoring system in order to prevent any equipment fault which can have bad effect in process techniques and rise the damage risk.

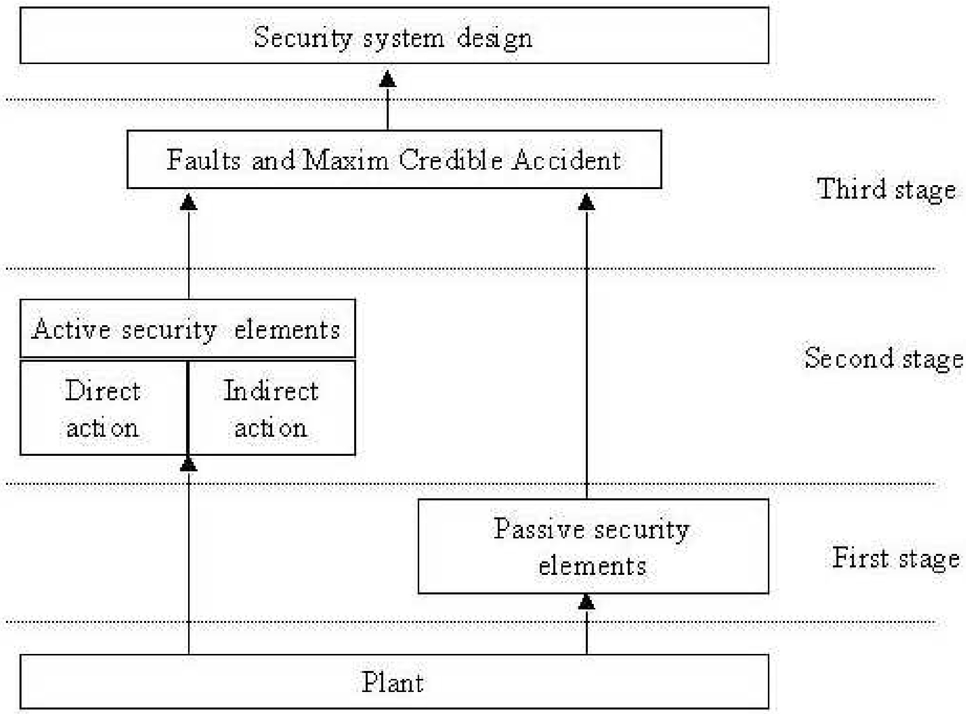

Figure 2: Design tree for safety system

Safety system design makes possible different type of actions as well as the incident is smaller or bigger. Thus, the technological process will not be stopped if the equipment faults are not rising the safety risk, even if the efficiency of the plant will be lower.

The main objective of safety system is to control the ventilation system, which exhaust the air from the plant and auxiliary facilities (tritiated storehouse, the dosimetry laboratory, locker rooms, access area) to the stack [2] through a collector. The air that is exhausted through stack is continuously analysed by a tritium monitor (proportional counter) who is the main security equipment. By the other hand two tritium monitor (ionisation chambers) are placed inside the plant. These two monitors from inside the plant have the auxiliary role for the main monitor and can initialise the stopping procedures for some parts of a plant. These three monitors are playing a principal role in security system which shutdown the plant and starts the emergency ventilation and tritium recovery unit.

4. Connection with plant control system

The connection between both systems, safety system and control system, is made at device control level (figure 3). In vertical direction, the right hand side of figure 3 shows how measurement information picked up by sensors flows to the system control level and plant control level. On the left-hand side, the figure shows how information and actions are transmitted to security system or to the plant. The security system provide alarm signals and data reports from all his components (safety system, fire system, limitation system) in control room.

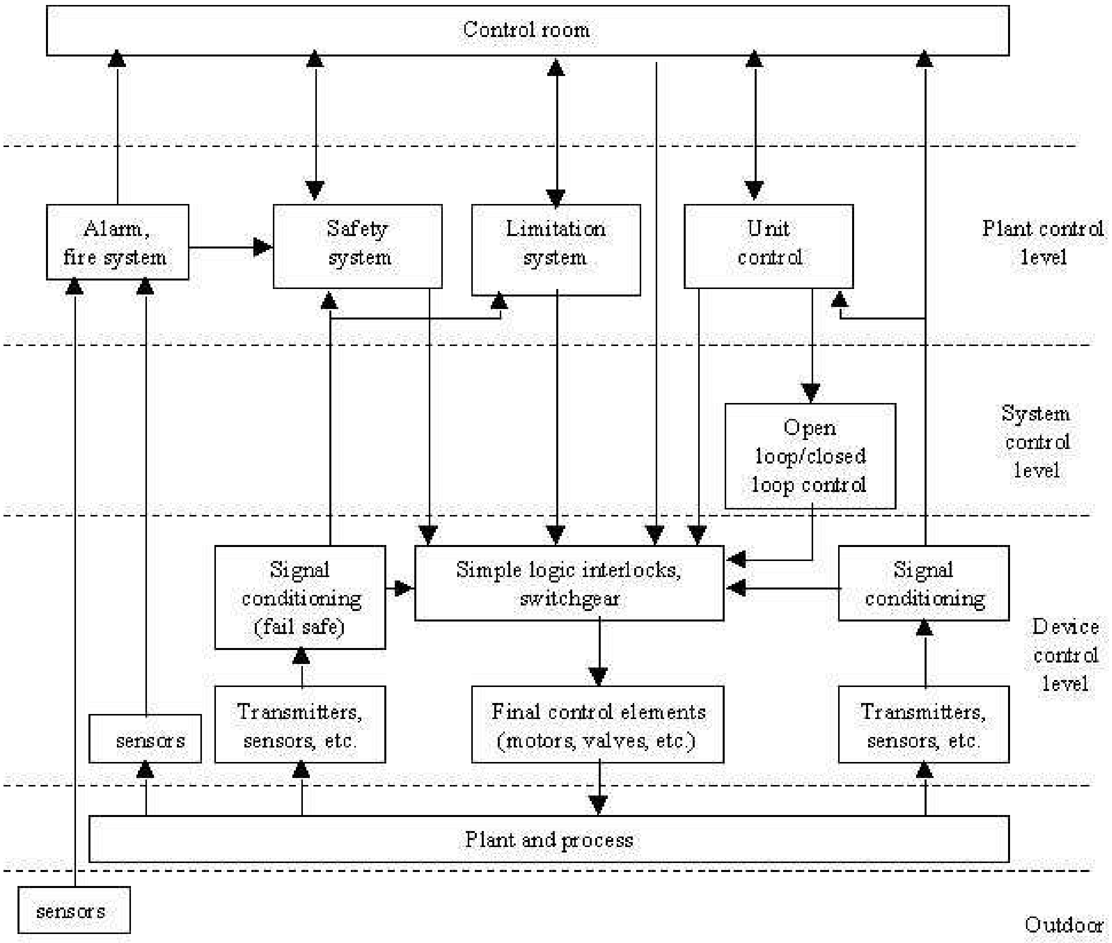

Figure 3: Safety and control system interconnection

5. Virtual Safety System

In present, our laboratory from ICIT Institute develops a highly integrated safety system for Pilot Plant - Virtual Safety System (VSS). This system is working in the same time with the hardware safety system and has on basis data acquisition and software applications [3]. The number of equipment which are used for this system are significant reduced, with benefits in maintenance and operation plant. In figure 4 is showed the interconnections diagram between hardware and virtual safety systems.

At this moment, virtual safety system has operational the part which monitoring the parameters limits, the equipment state, fire and integrity sensors and generate the specific procedure for each type of events. The part, which regards the action that must be taken by safety system, is in tests. This means that the outputs from virtual system achieved in data files, and later analysed in respect with hardware safety system actions and operation procedures. In this way, we want to test the viability of the software application and if appears undefined situations.

The virtual system loads the signals from hardware safety system and monitoring system through serial communication. Software applications are developed in LabView and assure signal conversion and comparison, information analysis, event report and select the specific procedure for each type of events. These data are used as information inputs for annunciation system as well as for the actuation of systems important to safety. A "symptom oriented" philosophy software design reach the two goals which are for interest: first, to assure efficiency and viability for safety system and the second, to prevent fault events or major operation errors through alarm procedure and events prognosis.

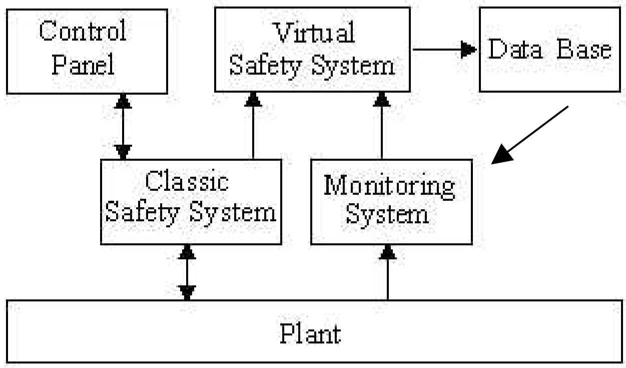

Figure 4: Virtual safety system- block diagram

As well as the computer equipment is used for essential monitoring functions, a dual computer arrangement is used for redundancy [4].

6. Security system actions in case of major damage

In the following we present virtual security system action in case of major damage - completely loss of the radioactive inventory, through simultaneous or consecutively damage of plant modules. In this particular situation the operation procedure impose shutdown of the plant. This action is taken by main tritium monitor or manually (by operator) if local tritium monitors are showing that the alarm limits are exceeded. In the last situation, the plant can be shutdown even if the main tritium monitor still show a normal concentration.

If the limit of radioactivity released in environment is exceeded, the main tritium monitor mounted on the stack gives the following commands:

1. ventilation system is stopped and evacuation stack is shut;
2. the isotopic exchange and purification modules are shut-down;
3. the emergency ventilation and recovery unit are started;
4. the cryogenics distillation module is shut-down sequential;
5. modules are emptying by process liquids;

In case of major damage, is not allowed any start for module plant, because decontamination of equipment and environment inside the plant is necessary.

In figure 5 is shown a print-screen of the front-panel for software application which monitoring the safety parameters in case of major damage (simulated event).

The radioactivity level at tritium monitor mounted on the stack is the only one parameter, which start automatic shutdown of the plant without any confirmation from another parameters. Local tritium monitors needs another parameter for confirmation before to shutdown the modules and the entirely plant. In this way, the risk for release the radioactivity in the environment is lower, even if false alarm can occurred and the plant will be shutdown. Because ICIT plant is experimental one, we prefer to stop the process and take all necessary actions to prevent any unknown leakage.

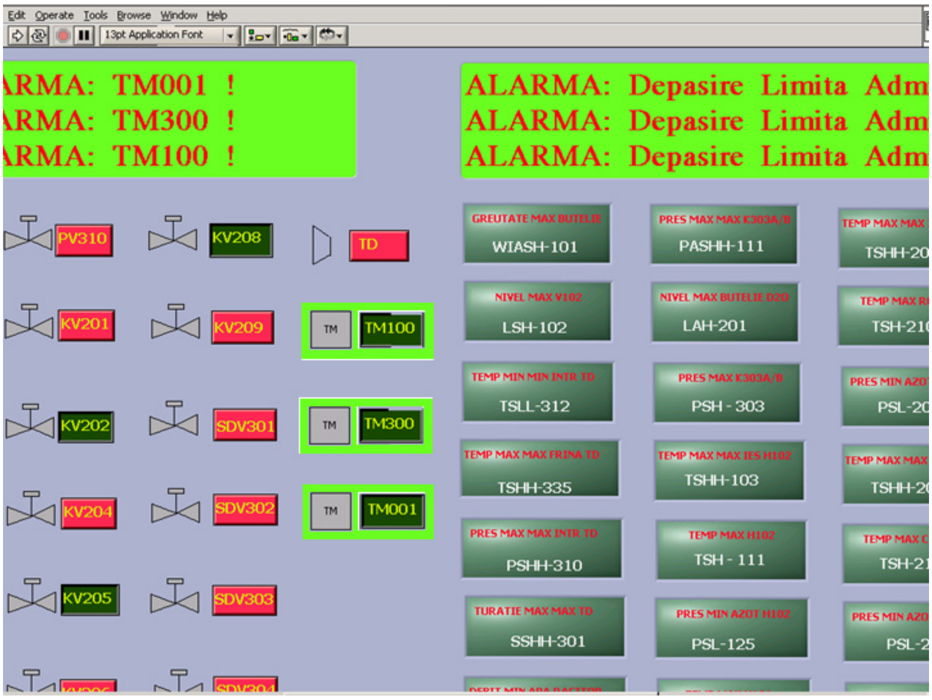

Figure 5: Monitoring station - Alarm parameters

The graphic interface of the software application assure a good plant surveillance and allow sequential monitoring for events and dynamic assistance for each step of specific procedure which must be applied. The operator is informed step by step about the actions that he must make as well as the consequences of his actions.

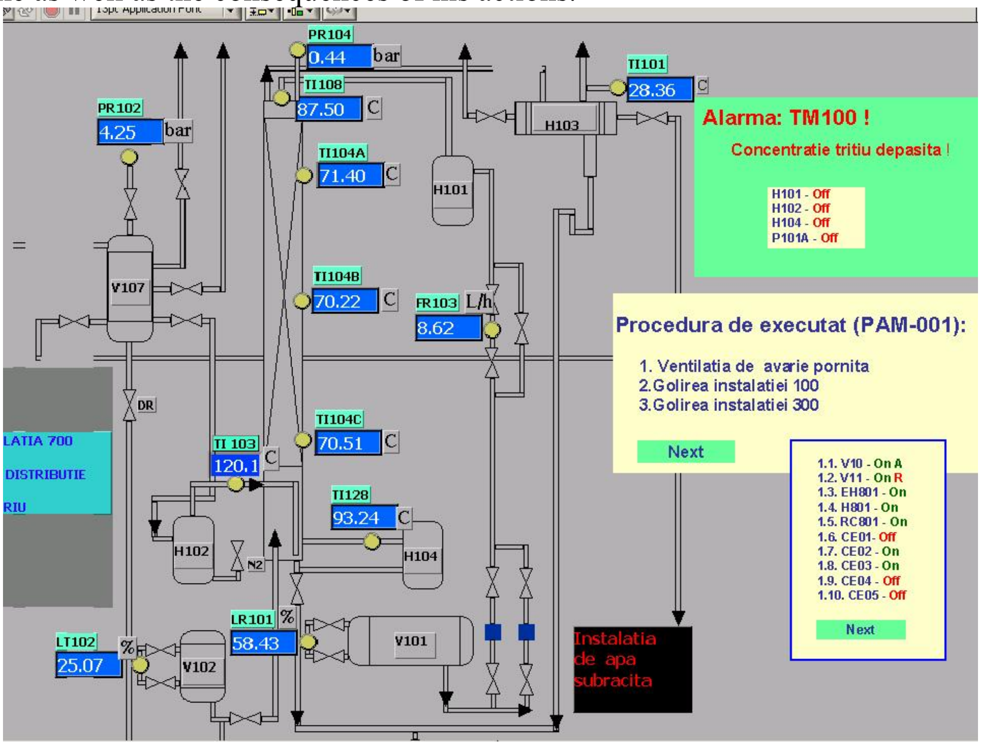

Figure 6: Monitoring station - Alarm to TM100

In figure 6 is presented front-panel application which display an alarm state in isotope exchange module (alarm released by local tritium monitor TM100).

As is shown, are three distinct alarm zones: zone1 - equipment which release the alarm (and also presents the equipment state), zone 2 - specific operation procedure and zone 3 - the state of equipment in each step of the procedure.

7. Results

The system is flexible, easy to use and can be improved in short time and at low costs. Such a system can replace dedicated hardware and software for industrial process, regarding especially the experimental character of this plant. Information on the plant state is essential in the dynamic prioritisation and conditioning of alarm message. Software design assures a friendly human-machine interface.

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