STEAM TURBINE: ALTERNATIVE EMERGENCY DRIVE FOR SECURE REMOVAL OF RESIDUAL HEAT FROM THE REACTOR CORE THAT USE WATER AS COOLANT AFTER FUKUSHIMA

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MOTIVATION

THIS ARTICLE WAS MOTIVATED BY THE LACK OF ELECTRIC POWER FOR MOVING PUMPS TO EXTRACT HEAT FROM THE REACTOR CORES IN THE FUKUSHIMA ACCIDENT

OUTLINE

1. **INTRODUCTION**
2. **METHODOLOGY**
3. **ANALYSIS OF UECCS APPLICATION**
4. **CONCLUSIONS AND FUTURE WORKS**

1. INTRODUCTION

BEFORE FUKUSHIMA

DESIGN BASIS ACCIDENT (LOCA)
+ REDUNDANCY (EQUIPMENT)
+ INSTRUMENTATION (CONTROL)
+ FAULT TREE ANALYSIS (PSA)
+ MAN-MACHINE INTERFACE (ERRORS)
+ CFD (ACCURACY)
+ ETC.

= CLASSICAL REACTOR SAFETY

1. INTRODUCTION

AFTER FUKUSHIMA

NATURAL DISASTER

ZERO x CLASSICAL REACTOR SAFETY

1. INTRODUCTION

NATURAL DISATERS AROUND NUCLEAR POWER STATIONS AFTER FUKUSHIMA

In 2011 after Fukushima accident USNRC (United States Nuclear Regulatory) has reported events related to loss of off-site electricity in some nuclear power plant caused by natural disasters, which could escalate to emergency situations.

1. INTRODUCTION

April 16: Surry Nuclear Power Plant, two PWR of 800 MWe each operated by Dominion Inc. near Surry County in State of Virginia

On that day, a tornado touched down the electrical switching station disabling the primary power to the cooling pumps and causing the actuation of the backup diesel generators

NRC classified as an UNUSUAL EVENT DUE TO LOSS OF ALL OFFSITE POWER FROM TORNADO DAMAGE

1. INTRODUCTION

Yet in April 27, in Browns Ferry Nuclear Power Station, a plant of three PWR of 1,065 MWe each owned by Tennessee Valley Authority (TVA) in the Alabama State, had to shut down when tornadoes and a severe storm damaged transmission lines near the facility and region around

NRC classified as a NOTIFICATION OF UNUSUAL EVENT DUE TO LOSS OF OFFSITE POWER

1. INTRODUCTION

June 2011. The Fort Calhoun Nuclear Power Plant, a PWR of 476 MWe, owned by Omaha Public Power District, was under risk of the Missouri river overflowing, despite it being already in cold shutdown following completion of a planned refueling outage.

The Missouri River flood waters did overflow and reached the containment buildings and the transformers, forcing the shutdown of electrical Power.

1. INTRODUCTION

August 23: North Anna Power Station, two units of PWR producing 1.79GWe in State of Virginia, was declared in Alert due to significant seismic activity onsite. Both units experienced automatic reactor trips from 100% power. All offsite electrical power to the site was lost. Besides all four emergency diesel generators (EDG) automatically started and loaded and provided power to the emergency buses, two of them developed a coolant leak and was shutdown

1. INTRODUCTION

In Brazil, on January 2011, in Rio de Janeiro State, at Angra dos Reis Region, landslides caused by torrential rain have worried about Safety of the Angra Nuclear Power Plant – two PWR of 676 MWe and 1350 MWe each owned by Eletronuclear

1. INTRODUCTION

FUKUSHIMA ACCIDENT BECAME A PARADIGM REGARDING THE SAFETY ANALYSIS IN NUCLEAR POWER GENERATION

ENERGY SOURCE TO COOLING SYSTEMS IS OF PARAMOUNT IMPORTANCE

1. INTRODUCTION

IT IS WELL KNOWN THAT, IN FUKUSHIMA, AN EARTHQUAKE WAS COMBINED WITH THE LOSS OF EXTERNAL ELECTRICITY

DESPITE THESE EVENTS NOT BE THE ROOT CAUSE, THEY WAS THE MAIN CAUSE OF THE DEGRADATION OF THE COOLING SYSTEM, AND CONSEQUENTLY, THE SOURCE OF THE MAIN CATASTROPHE ALREADY SUFFERED BY THE NUCLEAR POWER

AS WE CAN SEE, POWER TO DRIVE THE COOLING SYSTEM IS VITAL IN NUCLEAR POWER PLANT BECAUSE THE RESIDUAL DECAY

FROM FUKUSHIMA, WE TOOK THE LESSON THAT THE CURRENT MODEL OF THE MACHINE DRIVE OF EMERGENCY COOLING OF NUCLEAR POWER PLANTS IS TOTALLY DEPENDENT ON OFF-SITE ELECTRICITY

1. INTRODUCTION

In this paper we propose a concept of Ultimate Emergency Core Cooling System (UECCS) to use in Light Water Reactor based on the decay residual heat to power the cooling pump shaft in case of the degradation of the main emergence cooling system

The system has the advantage of utilizing the proper steam generated by the residual heat

It has the characteristic of working as an ultimate system, that is, it represents the last resource for cooling the reactor core

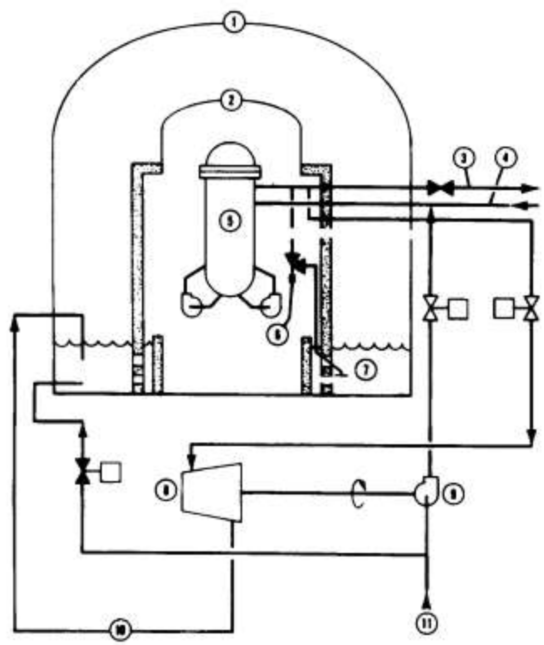
In this way, it is shown that the completion of the cooling system of the reactor can behave as a passive system since it requires no electricity but only the steam generated by residual heat from decay

We propose that UECCS includes the core cooling system and the exhaust heat by using fan system in a closed cooler

2. METHOGOLOGY

IT IS IMPORTANT TO NOTE THAT WHILE OPERABLE THE BWR IN FUKUSHIMA PLANTS RESPONDED TO THE MANAGEMENT OF STEAM (GOOD LESSONS!)

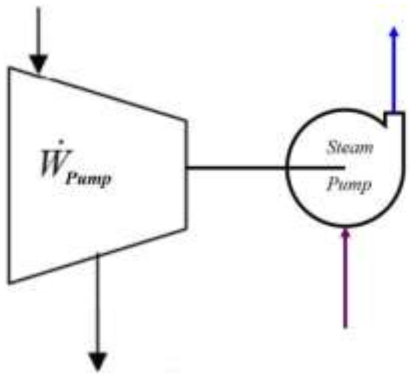
IN FUKSHIMA SOME STEAM TURBINE IS USED TO DRIVE PUMPS

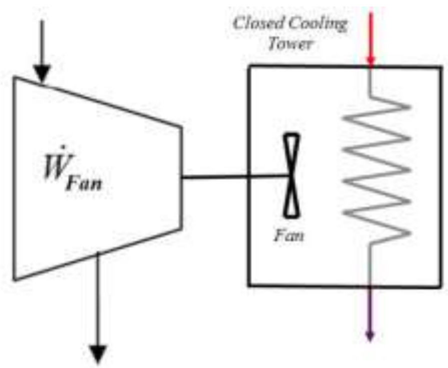


1. CONTAINMENT
2. DRYWELL
3. MAIN STEAM
4. FEEDWATER
5. RPV
6. SAFETY/RELIEF
7. SUPPRESSION POOL
8. TURBINE
9. TURBINE DRIVEN MAKEUP PUMP
10. TURBINE EXHAUST
11. CONDENSATE FROM CONDENSATE STORAGE TANK OR RHR HEAT EXCHANGER

2. METHOGOLOGY

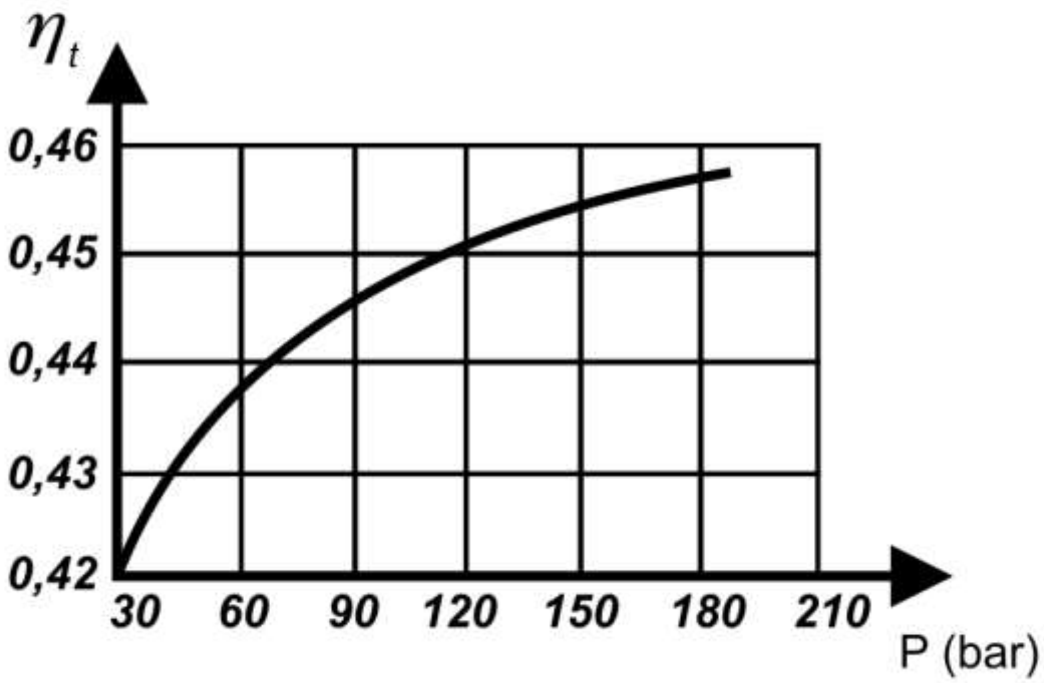
COMPONENTS





2. METHOGOLOGY

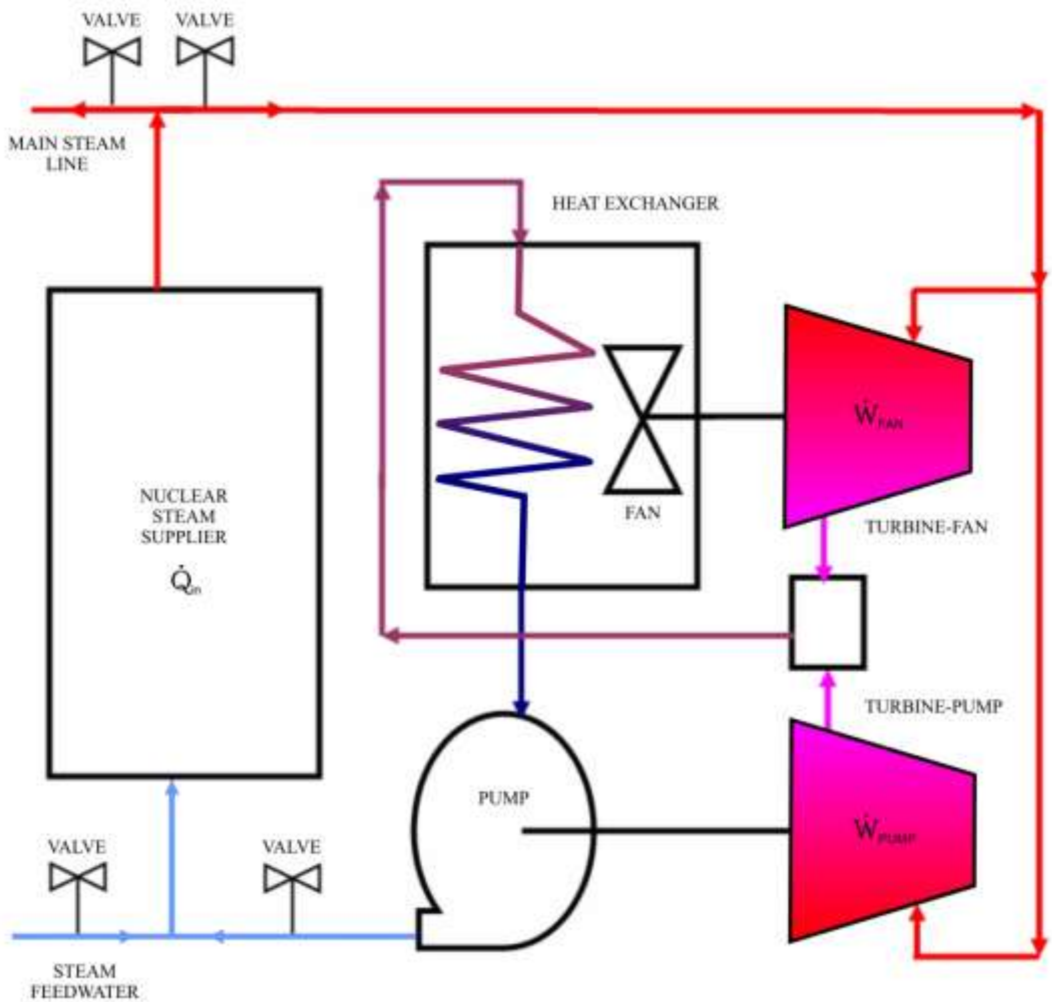
Turbine Efficiency versus Steam Pressure



2. METHOGOLOGY

Passive Ultimate Emergency Core Cooling System for LWR

UECCS



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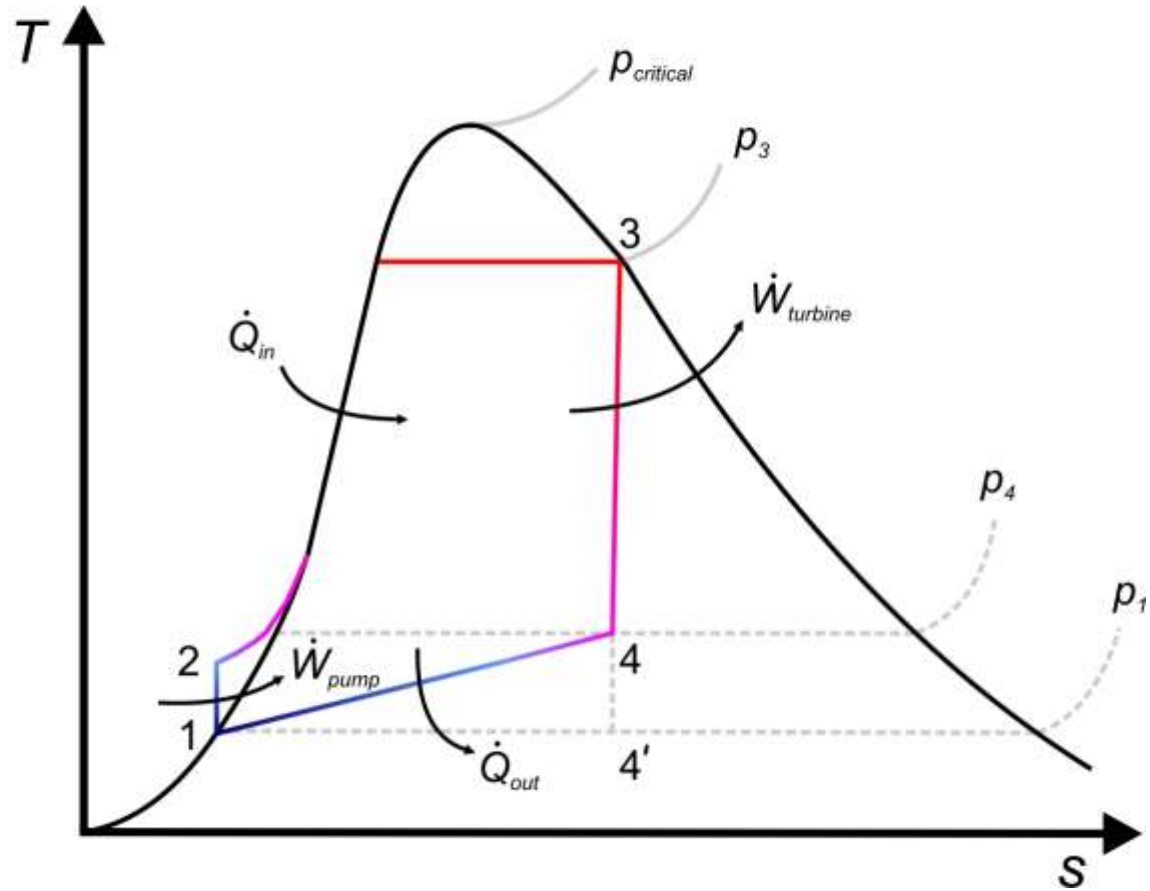
2. METHODOLOGY

Diagram T-s of UECCS



2. METHOGOLOGY

Decay Heat

$$\dot{Q}_{in}(t) = 0.066\dot{Q}_{in}(t_0)\left[t^{-0.2} - (t_0 + t)^{-02}\right]$$

$$10s < t \leq 100days\left(8.6x10^{8}\sec onds\right)$$

Energy Balance

$$\dot{Q}_{out} + \dot{W}_{turbine} = \dot{Q}_{in}$$

Steam Mass Balance

$$\dot{m} = \dot{m}_{Pump} + \dot{m}_{Fan}$$

Turbine Power Balance

$$\dot{W}_{fan} + \dot{W}_{pump} = \dot{W}_{turbine}$$

2. METHOGOLOGY

Fan Power $$\dot{W}_{fan} = \eta_{TF} f \dot{W}_{turbine} = \eta_{TF} f \dot{m}\left(h_3 - h_4\right)$$

Pump Power $$\dot{W}_{pump} = \eta_{TP}(1 - f)\dot{W}_{turbine} = \eta_{TP}(1 - f)\dot{m}\left(h_3 - h_4\right)$$

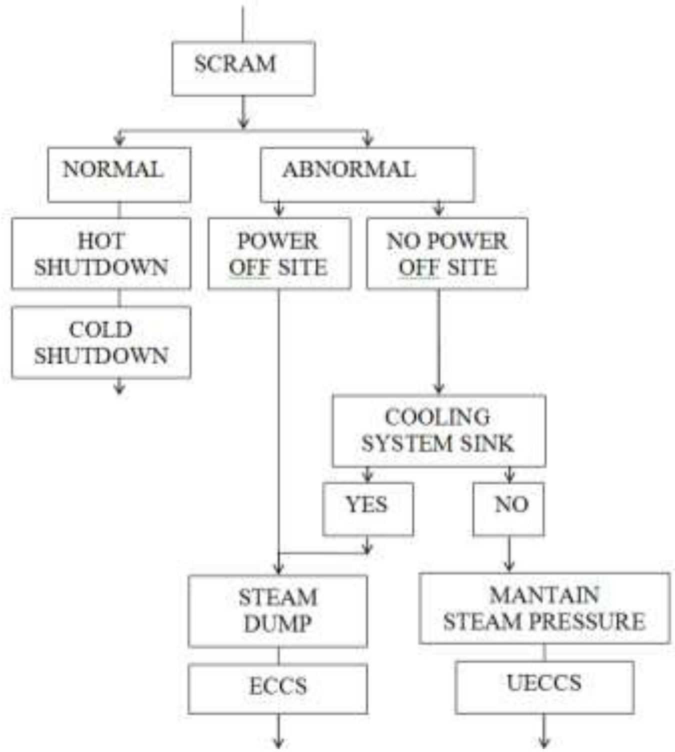
Fan Air Flow $$\dot{W}_{fan} = \frac{1}{2}\dot{m}_{air}v_{air}^2$$

Heat Exhausted at HX $$\dot{Q}_{out} = G_{air}(\overline{T}_{HX} - T_{air})$$

$$\overline{T}_{HX} = \frac{T_4 + T_1}{2}$$

2. METHOGOLOGY

UECCS Control Logic



3. ANALYSIS OF UECCS APPLICATION

The application of UECCS to cooling a reactor core is based on some assumptions. This system has its application in a final stage mode. It actuates after all normal reactor core cooling system are lost. Turbine-fan component can be estimate based on figures of fan cooling systems applied to nuclear generation.

For instance, Chinon Power Plant B in France, 4 PWR of 905 MWe each, utilizes mechanical draft drive fans to exhaust steam from secondary side. Even though that occurs with the circulation water, it also reinforces the approach of fan as a component of cooling. In that plant it is estimated that 1% of power output is spent to exhaust heat by fan system

3. ANALYSIS OF UECCS APPLICATION

Axial fans, the most used in cooler that use tower, as in Chinon, have efficiencies in the range 37%-45%. We can round, for conservative analysis, that the turbine-pump component can consuming 2% of the power output. On the other hand, we consider more 1% for turbine-pump component. It is a conservative approximation, since pump power is much small than turbine power, in a Rankine Cycle.

Thus, a total of 3% of power can be used to drive the UECCS, from heat generated at shutdown regime. Whatever the power generated, this correlation will be maintained. Since the residual decay heat starts of 6.6%, is trivial that the necessary power to move UECCS can be provided from residual source

It is important to point out that the steam generated behaves as in a negative feedback in the sense of exhausting heat. More steam, more power to drive the turbines. Less steam, less heat, and then, low core temperature, supposing the water inventory is maintained.

4. CONCLUSIONS AND FUTURE WORKS

- **An approach that adds up more safety to the LWR fleet was purposed, based on the concept of guaranteeing the cooling power to the reactor core. The system utilizes the steam from the residual decay heat. In conjunction, the loss of sink of the ultimate heat to be rejected, a closed cooling fan system is incorporated to maintain total independence of external power to the plant**

- **The system should be implement, joining a new logical that combines the trip signals to foresee the steam economy during the event of plant shut down**

- **As future work, besides to put in a mathematical basis, this new system requires a minimal analysis of its stability in controlling it. The system is an alternative to use additional backup generators in case of fail of loss of external electric grid**

THANKS FOR YOUR ATTENTION!