SAFETY ASPECTS OF GAS COOLED REACTORS

12/1/2011

INTRODUCTION

Gas cooled reactors are advocated as a way of achieving higher thermal efficiencies in nuclear power generation since they can be operated at higher temperatures than light water reactors. They would allow for the use of the gas turbine or Brayton cycle instead of the steam cycle or Rankine, Joule cycle.

They can provide high temperature process heat needed for high temperature electrolysis of thermochemical processes for the production of hydrogen for a contemplated future hydrogen economy. This makes their safe design and operation of paramount interest.

Air cooling, CO_2 as well as He have been used as gaseous coolants. With a looming shortage of He, nitrogen and dissociating gases are proposed as potential coolants for future gas cooled reactor designs.

DESIGN BASIS ACCIDENT FOR GAS COOLED REACTORS: DEPRESSURIZATION FAULT CONDITION

In a gas cooled reactor, the gas heat transport is directly proportional to the gas density. To enhance the heat transport, the coolant gas is pressurized to increased its density and hence its cooling ability. A loss of pressure thus degrades the cooling ability of the gas coolant.

Depressurization from 40 bars to atmospheric pressure at 1 bar results in a reduction of the gas density by a factor of 40.

If the fission reaction is shutdown, the reduction in the heat removal capacity through depressurization is matched by the reduction in heat generation in the fuel. Thus the fuel temperature does not rise significantly.

If the gas blowers are operative, the cooling would be adequate. If they are not operative, natural circulation should be adequate, provided that the reactor is not depressurized.

If the gas blowers are inoperative and the reactor is depressurized, natural circulation may be insufficient to keep the fuel temperature below the melting point.

At least 4 sets of emergency diesel generators to provide electrical power to the gas blowers need to be installed. The design should allow that the safety of the reactor must be assured with only one of the gas blowers is operational.

If graphite is used as a moderator, its “thermal inertia” should absorb the heat generated from the decay of the fission products. The use of an annular core rather than a cylindrical core and a steel vessel rather than a pre-stressed concrete pressure vessel should radiate the heat away without damage to the fuel.

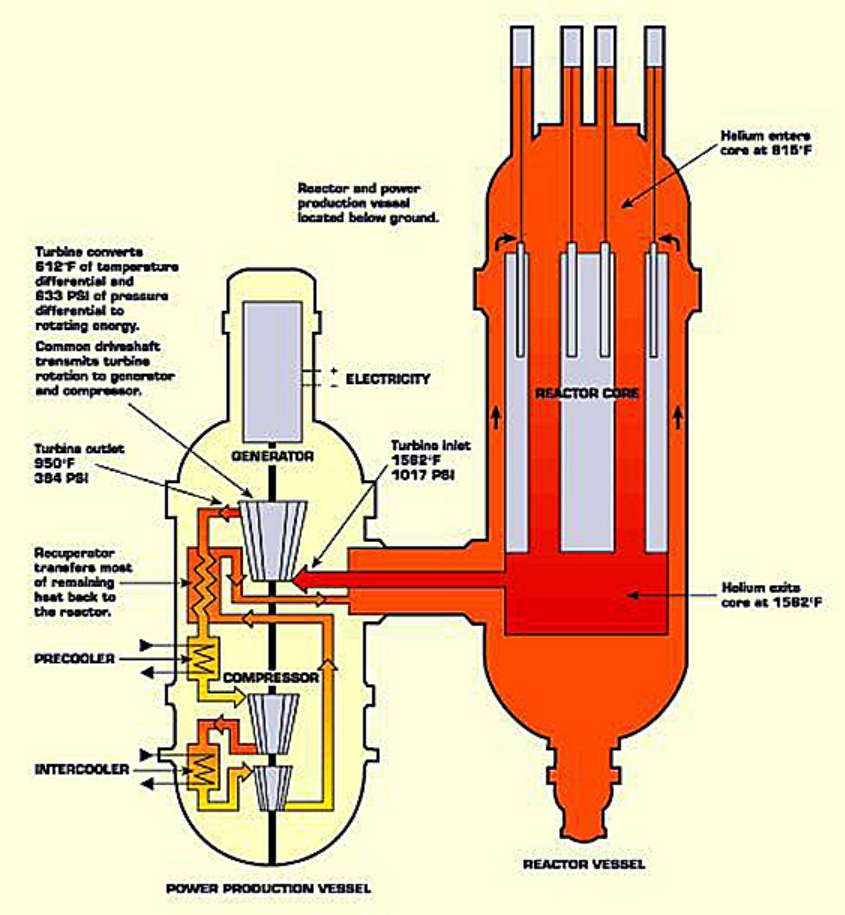

Figure 1. Brayton gas turbine cycle gas cooled reactor configuration.

TRANSIENT BEHAVIOR OF GAS COOLED REACTORS

OVERVIEW

Gas cooled reactors are built with an “integral” type of circuit with the majority of the components enclosed inside the containment vessel.

The diameter of the maximum conceivable pipe break is about 20 cm. Depressurization of the gaseous coolant from a large vessel, that is the equivalent of 30 Pressurized Water Reactor vessels, is very slow: it would take 20-30 hours to depressurize the vessel to atmospheric pressure.

In a depressurization situation, it is still important to keep at least one gas blower in operation for the removal of decay heat and long term cooling. Diversified on-site as well as off-site electricity supplies must be maintained, as well as a supply of cooling water to cool the blower and the oil in the blower seals.

OPERATIONAL TRANSIENTS

In gas cooled reactors, these involve start-up and shutdown problems and load variations during operation. They also involve on-line refueling problems if natural uranium or enrichment fuel is used. The process requires the attachment of a small pressure vessel to the cooling channels, breaking into the primary coolant system and extracting the bundles of fuel into the subsidiary pressure vessel, releasing a new fuel element and sealing the primary circuit before removing the spent fuel element for further processing.

UPSET CONDITIONS

These conditions involve a loss of off-site power, turbine trips, faults on the secondary steam side or a failure of a gas blower.

EMERGENCY CONDITIONS

These include the interruption of the normal electric supply to the power plant. This initiates an automatic reactor trip is initiated by a drop in the gas blowers supply voltage or in the gas blowers rotational speed.

Upon the loss of grid power, the diesel generators are started automatically to extract the decay heat. Heat is removed from the circulating gas using decay heat steam generators.

Gas cooled reactors are to be designed such as natural circulation would represent at least 2 percent of the normal full-power flow. Flow above 0.35 percent of normal flow would be sufficient to maintain the fuel temperature below the maximum allowable critical value of 1,350 ^{o}C.

Other possible emergency conditions include steam generator feedwater faults, steam line breaks, and water ingress into the core. If water ingresses into the core, steam would be generated raising the system's pressure. Protection against this occurrence is through a reactor trip and pressure reduction through the safety relief valves.

LIMITING FAULT CONDITIONS

These conditions involve a gas coolant depressurization followed by a breach of the primary circuit outside the pressure vessel through a safety valve or a break in the pipe works in the gas purification system.

These could also occur as a result of the inadvertent withdrawal of a group of control rods at power or during shutdown.

They could include single channel faults resulting from inlet blockages or fractures of the graphite moderator sleeves surrounding the fuel elements.

PRESSURE VESSEL COOLING

Gas cooled reactors can use a steel vessel or a Prestressed Concrete Pressure Vessel, PCPV.

If a PCPV is used, its temperature must be maintained at less than 100 ^{0}C to protect the integrity of the concrete. For this purpose, cooling water pipes are set into the concrete walls.

Under fault conditions the water cooling must be maintained with reliable auxiliary cooling water supplies available on-site.

Auxiliary coolant supplies must also be available so that the feedwater supply to the decay heat steam generators continues to be maintained.