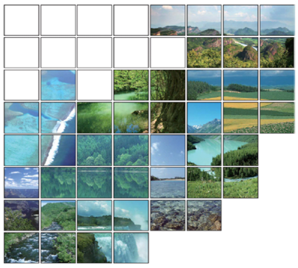
Development of New MHI Neutronics Design Code System GALAXY/COSMO-S

GALAXY//COSMO-S



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This document describes the Neutronics Design Code System GALAXY/COSMO-S (GCS) developed by Mitsubishi Heavy Industries, Ltd. GCS is a computer code system developed for application to the core neutronics design of domestic (Japanese) and overseas pressurized water reactors (PWRs) and is used as a part of the non-LOCA safety analysis code system SPARKLE-2 based on the neutronics and thermal hydraulic coupling method. Multiple core analysis methods based on the latest knowledge are used to ensure the full applicability of the software to PWRs. It has been designed with a focus on user-friendliness and conformity with interface requirements. We plan to license the software.

1. Overview of GALAXY/COSMO-S

The new MHI Neutronics Design Code System GALAXY/COSMO-S or GCS (GALAXY COSMO-S System) has been developed as a part of the next version of the non-LOCA safety analysis code system SPARKLE-2 to be applied to non-LOCA safety analysis of domestic (Japanese) and overseas PWRs. **Figure 1** provides an overview of SPARKLE-2. SPARKLE-2 consists of two parts: a part for core analysis and a part for plant analysis. The latter performs calculation using the transient calculation code M-RELAP5. The core analysis part consists of the three dimensional core kinetic calculation code COSMO-K and the three dimensional thermal hydraulic calculation code MIDAC, and calculates three dimensional power distribution and temperature distribution based on the neutronics and thermal hydraulic coupling method, using the two codes. In addition, it performs a core and plant coupling calculation between COSMO-K/MIDAC and M-RELAP5 to calculate parameters, such as the core flow rate and enthalpy.

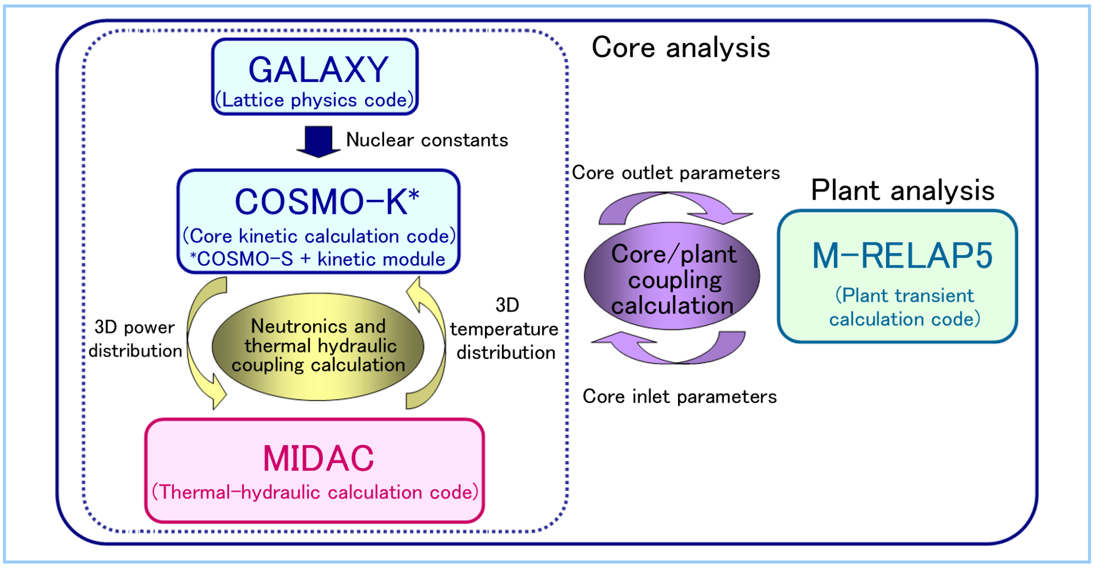

Figure 1 Overview of Non-LOCA Safety Analysis Code System SPARKLE-2

GCS is a three dimensional core static calculation code system developed for application to the non-LOCA safety analysis and core management of domestic (Japanese) and overseas PWR and APWR cores. GALAXY is a two dimensional lattice physics code and performs assembly calculation to generate assembly averaged nuclear constants. COSMO-S is a three dimensional core calculation code and performs core calculation to generate neutronics characteristics, such as the critical boron concentration and the power distribution, using (as input) the assembly averaged homogenized nuclear constants generated by GALAXY and taking into account the fuel assembly arrangement in the core. COSMO-K is a derivative of COSMO-S with a kinetic calculation capability for non-LOCA safety analysis added and fully shares static calculation with COSMO-S. The nuclear constants generated by GALAXY are provided to COSMO-K as well.

GCS is a code system applicable to interfaces at all levels from the fuel pellet to the core. **Figure 2** describes an overview of GCS. GALAXY provides nuclear constants for core analysis and kinetic parameters for safety analysis and allows a wide range of neutronics characteristics calculations, including radial power profile within the pellet necessary for fuel integrity evaluation, basic neutronics design of next generation fuel assemblies and criticality safety analysis. GALAXY-H, a lattice physics code for hexagonal lattices for fast breeder reactors (FBRs), has also been developed as a derivative code, making it possible to explicitly take into account the structure of the assembly inner duct and the lapper tube. COSMO-K (for safety analysis), COSMO-M (for core monitoring) and COSMO-SIM (for a training simulator), which are based on the shared static calculation code COSMO-S, are available for core calculation.

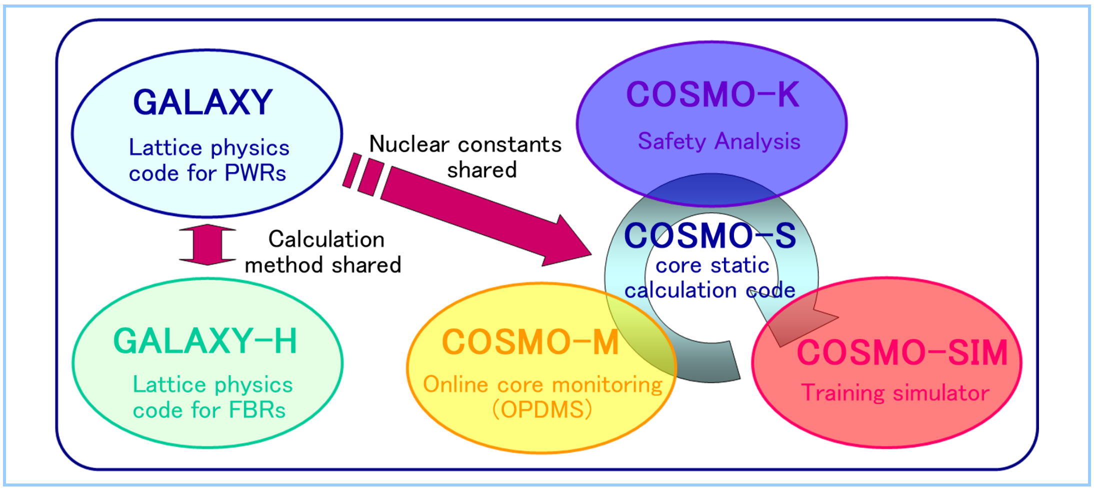

Figure 2 Overview of Neutronics Design Code system GALAXY/COSMO-S and Interfaces

GCS is divided into several modules for easy maintenance. The user interface of this software has been designed with licensing in mind based on our abundant experience in PWR core management and is intuitively understandable. The efficiency and ease of neutronics design has been significantly improved by incorporating the function to automatically calculate core parameters necessary for the design. The automatic calculation function is not included in the source program. It is controlled as input so that automatic calculation is performed in “automatic input generation and implementation of calculation” as much as possible. It is designed to prevent a series of calculations and calculation conditions from being a black box. This makes it easy for the user to check the calculation and the validity of the results of the design explicitly from a quality assurance perspective.

We plan to file application for a topical report to the NRC to apply GCS to non-LOCA safety analysis and core neutronics design for overseas plants and use the “Program for the Technical Review of Topical Reports” of the Nuclear and Industrial Safety Agency for domestic (Japanese) plants. We plan to apply for a technical review of GCS and all of the components of SPARKLE-2, such as MIDAC and M-RELAP5, based on the Topical Report Program. We are preparing for the smooth application of GCS to non-LOCA safety analysis and neutronics design. As described in the next chapter, our proprietary calculation methods and the latest knowledge have been actively used in the development of the codes to make it possible to calculate core neutronics characteristics parameters with high reliability. GCS and SPARKLE-2 make it possible to optimize engineering safety margins in safety analysis and perform design and analysis for reactors that are safer and more economic than conventional models.

2. Calculation method used in GALAXY/COSMO-S

GCS is a neutronics design code system to analyze neutronics behavior in the core and uses a two step calculation method consisting of fuel assembly calculation by GALAXY and core calculation by COSMO-S using the results of GALAXY calculation as input. The calculation methods used in GALAXY and COSMO-S are described below.

GALAXY is a two dimensional heterogeneous lattice physics code that performs a neutron transport calculation, accurately taking into account the heterogeneous structure (pellet, cladding tube and moderator) inside the assembly and the irregular lattice arrangement in the assembly due to the control rod guide tubes and the instrumental thimbles, to calculate the neutron flux distribution with high accuracy. We have developed a method (patent No. 2008-307831) for calculating the neutron flux distribution in the fuel assembly that can consistently calculate the neutron flux in a tiny region using the method of characteristics, which can accurately take into account an arbitrary geometry. The code generates the multi-group effective cross section used as input to this neutron flux distribution calculation using a detailed energy group structure consisting of 172 energy groups and handles neutron production by fission reaction, slowing down process, resonance absorption and the thermalization process in detail. In order to accurately take into account the effect of Doppler broadening of resonances such as for ^{238}U, we have developed a method (patent No. 2010-201387) for calculating the effective cross section that accurately handles actual phenomena in the fuel pellet, such as the effect of the resonance absorption intensity being gray. In order to accurately handle the effect of neutrons not being scattered with equal probability in all directions when colliding with hydrogen and other light atomic nuclei, the code uses a method that uses function expansion for the distribution of flight path directions of the scattered neutrons. It can calculate the neutron flux distribution with high accuracy in systems, such as UO_2 fuel including gadolinium oxide, MOX fuel and reflector regions, where the inflow of neutrons has a significant effect. In burnup calculation to trace changes in nuclide composition associated with fuel burnup, the code handles the decay and production of about 150 different nuclides, including actinide nuclides, such as uranium and plutonium and fission products, such as xenon and samarium. In addition, in order to improve the balance of calculation speed and accuracy for the neutron flux distribution calculations, parallel computing for the effective use of multiple computers and calculation taking into account the symmetry of the system to be calculated are used.

Assembly averaged nuclear constants weighted by the neutron flux distribution calculated by GALAXY are input to the core calculation by COSMO-S. The nuclear constants cannot be calculated for all possible core condition points. Therefore, we have developed a quality engineering-based, highly robust method for representation of nuclear constants (patent No. 2010-107585). The method determines, by an engineering approach, conditions (temperature, boron concentration, burnup, etc.) covering all possible core conditions based on the orthogonal table and expresses the nuclear constants calculated by GALAXY for the conditions determined as a function of core parameters. Core calculation can be efficiently performed by COSMO-S by re-configuring the nuclear constants as a function of the core parameters as the arguments.

COSMO-S is a three dimensional core calculation code that takes into account the assembly array for radial direction in the core and the heterogeneity in the axial direction. In the calculation of the neutron flux distribution in the core, the power distribution is accurately handled by calculating one-quarter of the fuel assembly as the minimum calculation segment using the analytical polynomial nodal expansion method. A detailed pin-by-pin power distribution is calculated by the pin power reconstruction method. In burnup calculation, the decay and production of each nuclide is traced in detail, allowing the annihilation of actinide nuclides, the production of fission products (FPs) and the loss of Boron-10 to be accurately taken into account. Neutronics characteristics parameters in the core necessary for neutronics design, such as three dimensional power distributions, changes in critical boron concentration associated with burnup, control rod worth and temperature coefficients, are obtained by core calculation.

As described above, in the development of GCS, we have developed proprietary technologies and applied the latest knowledge of reactor physics and our abundant experience in PWR core management to allow detailed analysis highly consistent with available computational capabilities. We presented many of the technologies developed in connection with GCS at domestic (Japanese) and international nuclear engineering conferences (8 technical publications for GCS were performed in 2010).

3. Verifications and Validations for GALAXY/COSMO-S

The applicability and applicable range of GCS will be demonstrated by various analyses in the topical reports. We have demonstrated the applicability of GALAXY through major critical experiment analyses (TCA-UO_2, TCA-iron reflector, B&W, KRITZ and VIP) and post-irradiation examination analyses (UO_2 fuel, MOX fuel and UO_2 fuel including gadolinium oxide), as well as comparison with continuous energy Monte Carlo calculation codes. We have also demonstrated the applicability of GCS to core neutronics design and non-LOCA safety analysis by assessing the validity of neutronics characteristics parameter calculation in a comprehensive manner through core analysis of domestic (Japanese) and overseas PWR plants.