CRISTAL: A NEW-GENERATION CRITICALITY PACKAGE

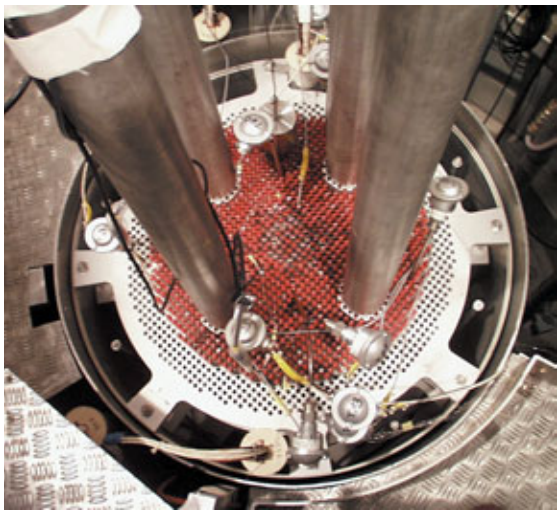
The criticality risk is present in nuclear facilities and transportation containers whenever significant amounts of fissile material are manufactured, stored, transported or processed. Cristal, an integrated set of new-generation computer codes for criticality safety calculations, has been developed to assess this risk.

Criticality conditions

Assessing a system's **criticality** conditions chiefly entails studying the **neutron** population and processing neutron equations, in particular the neutron **transport** equation. The "criticality" physicist is concerned with the **effective multiplication factor** k_{eff}. In order to demonstrate that every step has been taken to avoid criticality, k_{eff} must be less than 1 at all times. Solving a criticality problem or class of problems requires the use of all basic nuclear data, known with varying degrees of accuracy, and a prioritized sequence of models representing neutron phenomena.

Developing a new-generation package

The computer tools available to criticality researchers in the mid 1990's, such as the CEA86 data library and the Apollo1 computer code, used data and **calculation code** developed in the 1970's and 80's, and were unable to meet future requirements. There was no guarantee as to their long-term survival, mainly because their fields of application were too narrow to deal with any new requirements on the horizon, such as **MOX** fuels, high-**burn-up** fuels, or those generated by research on downstream parts of the cycle. It was this state of affairs that motivated the decision in 1995 to develop a new-generation criticality safety **package** called Cristal.



CEA

Experimental programs, conducted in the Eole reactor at CEA/Cadarache, are used in qualifying the Cristal package. This very low power reactor is designed for neutronic studies of moderated lattices (sets of identical elements called "cells"), in particular, those used in pressurized water reactors. Here, we can see the experimental part that can contain different types of cores, together with the four safety rods.

The Cristal package was created and qualified as part of a joint project by IPSN, Cogema and the CEA Nuclear Energy Division (DEN), taking into consideration requirements relating to all possible future applications. The first version (V0.1) of the Cristal package was delivered to users in 1999 following four years of development, validation and qualification work.

The general architecture of the Cristal package (version V0.1), illustrated in Figure 1, is divided into two computing routes that use basic nuclear data taken from the **JEF-2.2** evaluation of the JEF project (*Joint Evaluated File*, European library), supervised by the OECD (Organization for Economic Cooperation and Development) Nuclear Energy Agency. The first route, referred to as the **"standard"** route, implements a formulation of several energy groups of **cross sections** (**multigroup cross sections**) and is used to perform **probabilistic calculations** with the **Apollo2-Moret4** computer codes or **deterministic calculations** with **Apollo2 (Sn modules)**, to determine k_{eff} or geometrical dimensions for a given k_{eff}. The second route, called the **"reference"** route, makes use of the **Tripoli4** code.

Basic nuclear data

Basic nuclear data (cross sections, **resonance** parameters, **fission yields**, radioactive decay constants, etc.) is generated, evaluated and managed on an international level, outside the Cristal package, on the basis of dedicated measurement and interpretation programs (see *Improving and expanding vital nuclear data for neutron physicists*). Apart from a few exceptional cases, the

basic nuclear data currently used by the Cristal package comes from the **JEF-2.2** evaluation.

Upstream from the Apollo2 code, developed by the CEA Nuclear Energy Division for standard calculations, a library must be built containing nuclear data for application to several energy groups. This can be obtained directly from the information contained in the JEF-2.2 evaluation, using the **Themis/NJOY** processing program. The **CEA93** library, based on a multigroup mesh with 172 energy groups, was at first incomplete and not suited to criticality applications, but has now been extended to take in all the **nuclides** essential for criticality studies, such as chlorine, calcium, zinc, and tin.

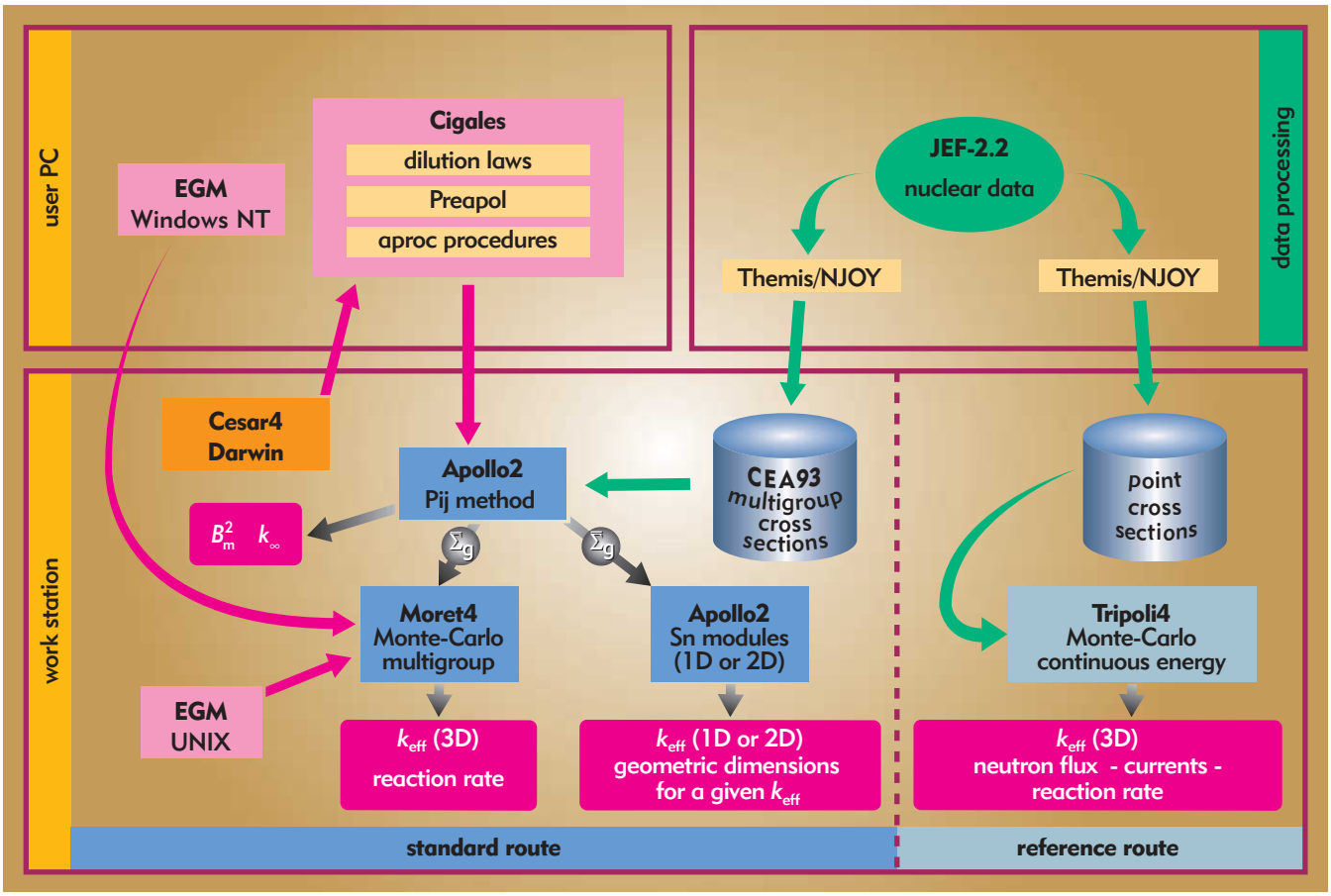
User-friendly interface

In the criticality field, the very wide scope of activities, the variety of geometric configurations and chemical media processed and the wealth of neutron spectra, all call for strong, general formalisms. The user-friendly interface of the Cristal package is designed to minimize the user's workload and allows the use of calculation schemes that have been previously validated and procedures previously optimized (**aproc procedures**) to guide users in their choice of computer codes. The user-friendly interface includes two main tools: the Cigales calculation code and the EGM graphics code.

The **Cigales** computation code (Cristal interface generating Apollo codes relating to criticality safety studies) is an interface designed to determine the atomic composition of criticality **fissile** media (making use of **dilution laws**) and carry out automatic preparation of data files for calculations using Apollo2 (**Preapol**). In addition, Cigales couples with the **Cesar4** program and, eventually, with the **Darwin** system (see *Spent fuel criticality*) that provides access to the material balance of spent fuels.

The **EGM** program (Graphical editor for Moret) is an interface used to build and generate three-dimensional geometries for the Moret4 code. It uses the Cas.cade development platform (3D geometrical modeling, graphical display

Figure 1. Overall architecture of the Cristal criticality safety package.



and input-output module) by Matra Datavision and the Ilog Views graphical interface editor.

The Apollo2-Moret4 route

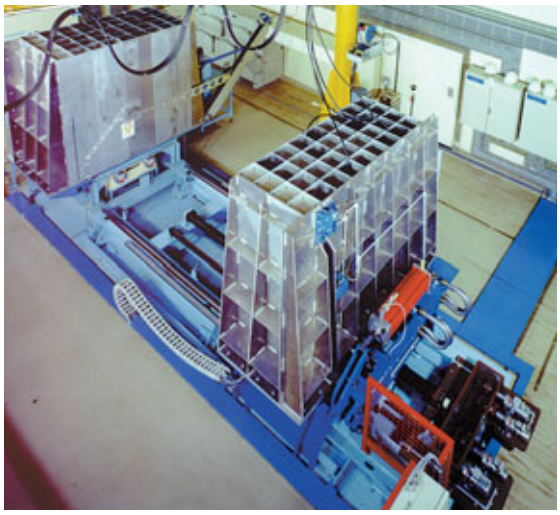
The user first searches for macroscopic parameters defining the media studied. A fine calculation, carried out using Apollo2 (computing neutron flux using the collision probability method (**Pij method**)) is used to determine the neutron characteristics of an equivalent medium. The system studied is described in the Moret4 code as a set of uniform zones characterized by a small number of parameters, such as macroscopic multigroup cross sections ($\bar{\Sigma}_g$) for any type of medium, the **infinite multiplication factor k_∞** and the **material buckling B_m^2** for a fissile medium.

The user's second step is to take the neutron characteristics of the different equivalent media in order to process the whole system in detail in a 3D geometry using the Moret4 neutron simulation program developed by IPSN. This program uses the **Monte-Carlo method** to solve the neutron transport equation and determine the effective multiplication factor k_{eff} of the system being studied.

The Tripoli4 route

The principle of the reference route is to calculate the k_{eff} with as few physical approximation and modeling operations as possible. To follow the reference route, the Tripoli4 code developed by DEN must be used. This calculation code is used to carry out particle transport (neutrons, gamma photons) three-dimensional and **continuous energy** calculations, using the **Monte-Carlo method**. It is used to determine the k_{eff} and neutron flux, the flow of neutrons across a surface, reaction rates and fission rates for example. Tripoli4 includes two types of 3D geometric descriptions and also offers the resources to describe lattices and network of lattices(1). It can operate in parallel mode on a massively parallel computer or a network of work stations.

(1) Seen from the geometrical angle, a lattice is a volume subdivided into meshes.



IPSN

View of Maracas (Closure machine for the solid fuel assembly criticality) at Valduc where criticality experiments were carried out by IPSN, as part of the qualification of the Cristal package. In these experiments, two masses of fissile material are placed on two tables, one moving and one stationary, then gradually moved closer to each other. This reduces neutron leakage, thereby increasing the effective multiplication factor. In this way, the critical value of the distance between the two masses of fissile material can be determined.

Qualification of the Cristal package

Qualification refers to the process implemented to compare the results of the Cristal package with experimental results. By understanding the reasons for differences between calculations and experiments, we can deduce the uncertainty to be applied to the effective multiplication factor k_{eff} calculated for the real situations to be processed.

The Cristal criticality safety package triggered intense qualification work involving the systematic use of critical experiment results obtained from various sources (experimental programs conducted by IPSN, CEA, in the United States, Japan, etc.), and experiments evaluated by ICSBEP (*International Criticality Safety Benchmark Experimental Program*) under the aegis of the OECD. The qualification base contains some 520 experimental configurations representing different media and geometries encountered in fuel cycle operations (plants, facilities, laboratories, transportation).

The experimentation programs relating to spent fuel, carried out by IPSN at Valduc and by DEN in the Minerve reactor at CEA/Cadarache will extend the qualification range of the Cristal package to obtain a more precise assessment of the criticality risk presented by spent fuels. As of 2002, this assessment will be addressed by version V1 of the Cristal package. Among other things, the new version will enable burn-up credit to be taken into consideration (see *Spent fuel criticality*).

Field of application

The Cristal package is designed to meet the requirements of industry and the safety authorities concerning nuclear fuel cycle facilities and the transportation of fissile materials. It applies to criticality studies (design and operation of a wide range of nuclear facilities) and qualification studies (use of experimental results to qualify related computing routes, definition and development of experimental programs, use for international Working Group studies). In the longer term, it will take burn-up credit into consideration.

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