Core Data Viewer

Håkon Jokstad, Michael N. Louka, Makoto Tsuiki
Institute for Energy Technology, Halden, Norway
Tel: (+47) 69 21 22 00 E-mail: hakon.jokstad@hrp.no

Abstract

3D visualisation of reactor core data, such as power density distribution, is a powerful technique for gaining insight into the characteristics of a reactor state. The Core Data Viewer is a software application developed to enable 3D visualisation of core data to be provided on engineers' computers and in classrooms, with appropriate functionality to support meaningful exploration of the data.

1. INTRODUCTION

The Core Data Viewer is a software application that provides the user with an interactive three-dimensional visualisation of reactor core data. 3D data, including power density, xenon distribution, and burn-up distribution, can be visualised and rotated for viewing from any angle, and the user can filter away parts of the core to display only areas of specific interest. For physicists, more detailed information on flux, void, and temperature distribution, can be displayed. Additionally, a 3D representation of a selected fuel assembly is shown in an additional 3D view, integrated into the Core Data Viewer application's user interface, to give a complete view of the data (see Figure 1). The Core Data Viewer enables large amounts of data to be visualised using a compact 3D representation that aids the user in acquiring a rapid overview of the characteristics of the data.

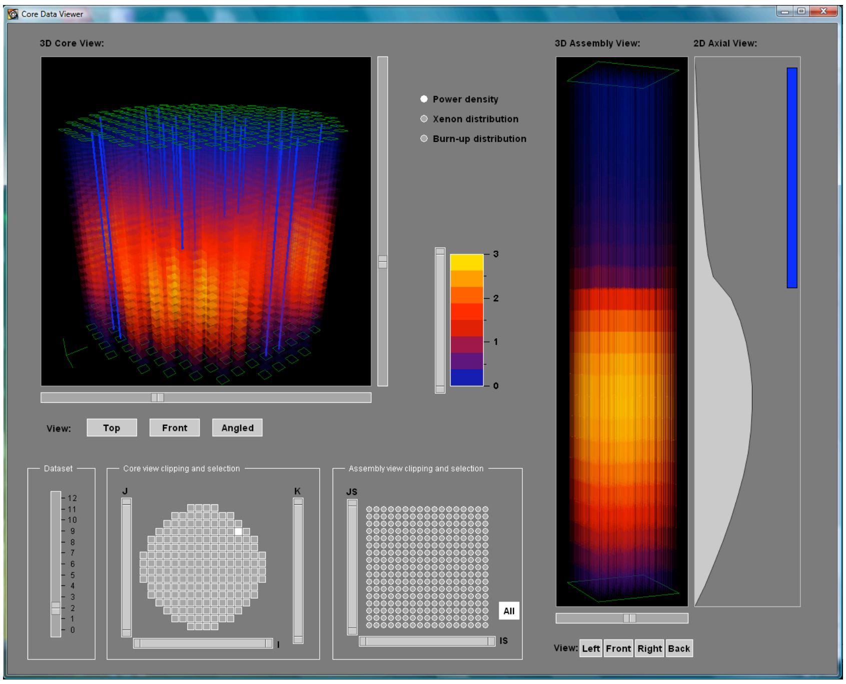

Figure 1. The Core Data Viewer user interface with integrated core and fuel pin views.

2. BACKGROUND

Institute for Energy Technology (IFE) has a long history of process visualisation and reactor core data management that includes the development of graphical user interfaces in the late 1960s and the implementation of the SCORPIO [1] core management system in the 1990s. SCORPIO is typically used as an online core monitoring application, as it combines measurements and simulation to provide a best estimate of the status of a core on a continuous basis. As the reactor core data from SCORPIO is essentially three-dimensional (four, if we include time), but displayed in two dimensions only, it was quickly identified as an application where 3D visualisation could be appropriate.

Although the Core Data Viewer in its current form was implemented in 2008, we first explored the concept through the development of a prototype system, dubbed "Scorpio3D", that was demonstrated by IFE at the OECD Halden Reactor Project's symposium in early 1998. While the 3D visualisation technique used in the Core Data Viewer is essentially the same as that used for Scorpio3D, a significant difference is that in 1998 it was necessary to use a high-end graphics workstation that cost approximately fifty times more than the personal computer hardware that the Core Data Viewer runs on ten years later.

In contrast to the Core Data Viewer, which normally reads data from files, Scorpio3D interfaced directly to SCORPIO, presenting "live" data processed by the SCORPIO system, which otherwise had a 2D user interface that displayed a cross-section of the core. Scorpio3D was therefore strongly coupled to SCORPIO. Data source independence was one of the objectives of the Core Data Viewer, and to test and demonstrate this, we have used files containing data calculated using IFE's VNEM [2] method. VNEM is a nodal expansion method to solve neutron transport equations, developed to increase the accuracy of 3D light-water reactor core analysis, and is typically used to perform calculations for applications of SCORPIO. VNEM is described in a little more detail later in this article.

Both the Core Data Viewer and Scorpio 3D have been implemented using the ProcSee [3] user interface management system (UIMS). ProcSee is a very powerful user interface design and implementation tool, used primarily to implement operator displays for control systems and simulators. It enables us to interface easily to data sources and to rapidly prototype and customise user interfaces. In 1998, the UIMS only supported 2D graphics [4], but it now supports the embedding of 3D graphics into managed displays [5], and the development of the Core Data Viewer, using the Scorpio3D visualisation technique, was proposed when the ProcSee team were looking for a useful application to demonstrate this capability.

3. FUNCTIONALITY

The Core Data Viewer is a visualisation tool that displays a 3D visual representation of reactor core data from calculations. The data visualised can represent various physical phenomena such as power density, xenon distribution and burn-up. While the tool offers a graphical visualisation of users' calculation results, it contains no core data calculation functionality itself, so is open to receive data from a variety of calculation codes.

For the core view visualisation, a 3D model of the core is divided into segments, and a data value is presented for each segment of each fuel assembly (see Figure 2). Furthermore, individual fuel pins of an assembly are shown in a separate fuel pin view, for a fuel assembly selected by the user. In the fuel pin view, a data value is represented for each segment of each individual fuel pin. Control rods and their vertical positions are displayed in both the core and the fuel pin views.

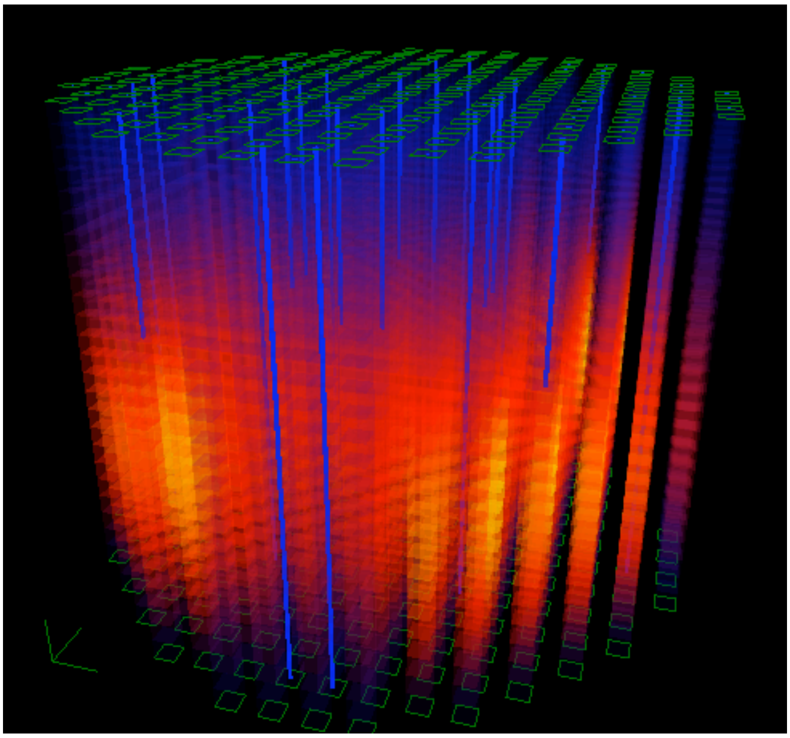

Figure 2. A core view showing the power density per fuel assembly. The colour range used here goes from dark blue (lowest value) via red to yellow (highest value). Control rod positions are indicated by a light blue colour.

Colour coding is applied to the data visualisation according to user-defined settings, where colours can be assigned to ranges of data values. Together with the colour, the user can also specify the amount of transparency to use for a range of values. This enables the user to make the most interesting values appear more solid than values outside the range of interest, and thus emphasise the segments of fuel assemblies that have interesting values.

The user can rotate the core both horizontally and vertically, to view the core from any angle. By cutting planar cross-sections along any major axis, the user can also study interior fuel assemblies or fuel pins anywhere within the core, as shown in Figure 3. Cutting plane can be moved along axes by dragging corresponding slides in the user interface.

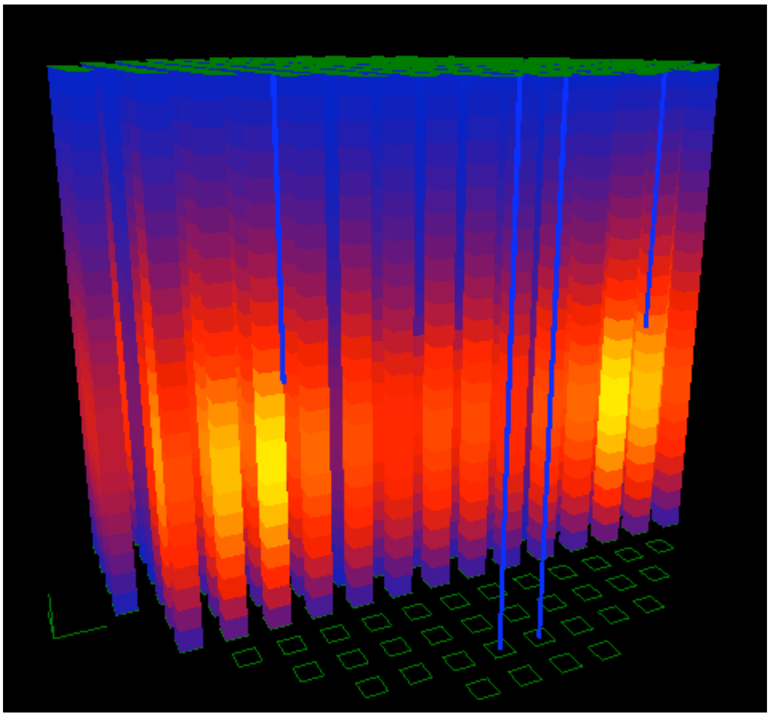

Figure 3. Vertical cross-section of a core at a position with high power values. Transparency has been turned off to focus more clearly on the values at the cross section.

By dragging a slider, the user can specify lower and upper threshold values, visualising only segments of fuel assemblies or fuel pins with data values within those limits. This feature provides a fast way of identifying the most interesting spots. Figure 4 shows an example.

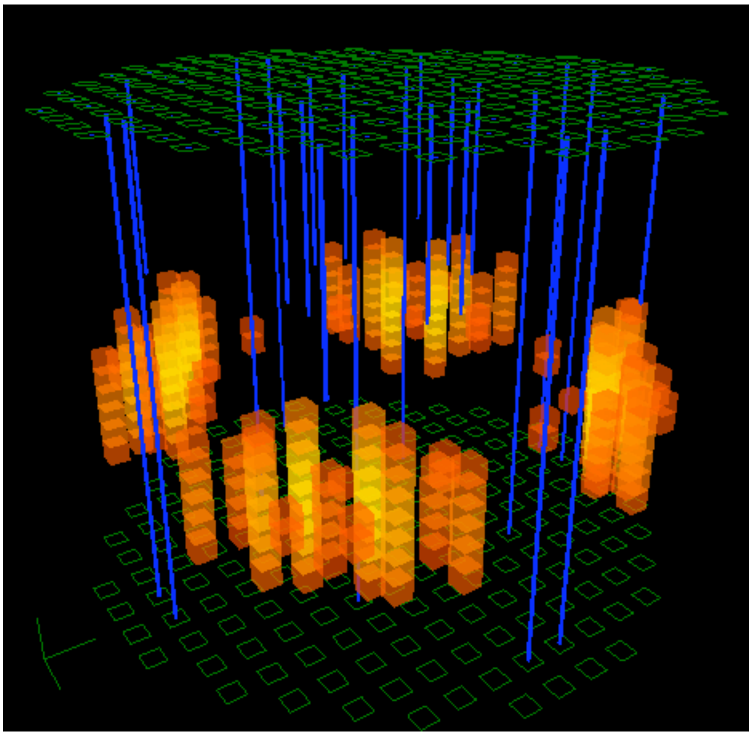

Figure 4. Lower threshold value set to quickly identify hot spots.

Features for rotating the 3Dview, cutting cross-sections, and applying threshold values, are available for the fuel pin view too. Alongside the 3D fuel pin view is a 2D axial view illustrating the data for an individually selected fuel pin, or for the entire selected fuel assembly, as shown in Figure 5.

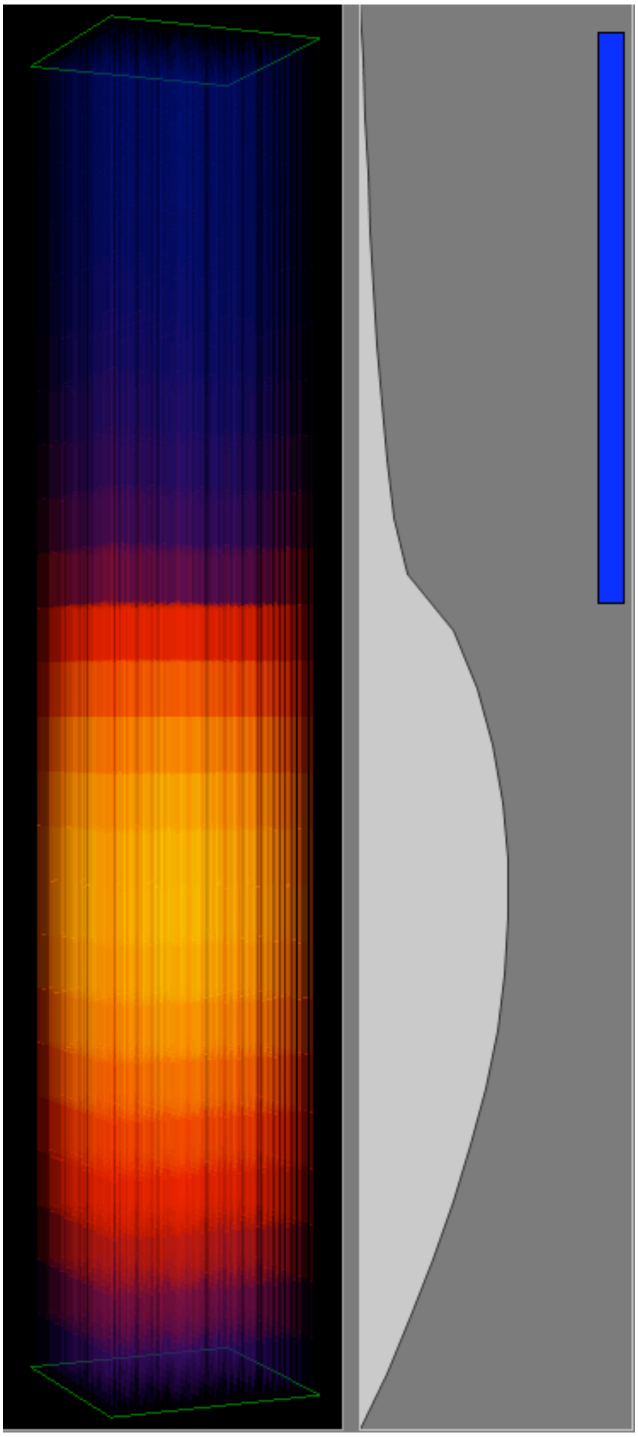

Figure 5. A fuel pin view visualising individual fuel pins of a selected fuel assembly. The 2D axial view to the right represents data for a selected fuel pin. If a control rod is part of the selected fuel assembly, the control rod position is indicated by the blue bar to the right.

The data to be visualised are described in data files, with one file per dataset. A dataset contains values for all segments of all fuel pins and fuel assemblies, as well as vertical positions for all control rods. Furthermore, descriptive data, such as simulation time and various levels of texts, can be included. These descriptive data are presented in the user interface and/or on printed reports so that the user can relate the graphical visualisation output to a description to the data.

The data files are formatted according to the Core Data Viewer's data file format specification. The format is textual to increase portability between systems and ease-of-use. Therefore file contents can be produced easily, given data from simulations, calculation codes, online measurements, pre-recorded data or combinations thereof.

The user can load multiple datasets into the Core Data Viewer at once, and drag a slider to switch between sets. The order of the datasets can be sorted by name, by simulation time, or manually by the user. View settings, including rotation, threshold values, and cross-section cuttings, remain unchanged while switching between datasets. This enables the user to easily make visual comparisons of sets of data.

4. CONFIGURATION OPTIONS

The Core Data Viewer has been designed and implemented as a ready-to-use application that can be adapted to a number of reactor core configurations. BWR, PWR and VVER reactor types are supported, and features required for other reactor designs can easily be added as needed in future. The configurable parameters include the number of fuel assemblies, number of fuel pins per assembly, number of segments along the z-axis, location of control rods, and others.

The required core configuration is described in a user-configurable core configuration file and read by the Core Data Viewer when started. The core configuration file format is human-readable and well defined.

Based on the information in the core configuration file, the Core Data Viewer generates the 3D core and fuel pin views, as illustrated in Figures 2 and 5. Likewise, the user interface controls, for cutting cross-sections and rotating the core, are adapted to the specified core configuration, to provide a user interface appropriate to the given properties of the reactor core.

Colour legends with corresponding value ranges are defined in a separate configuration file. For ease of use, colour legends can also be created, modified, and saved interactively within the Core Data Viewer application itself.

Each data file containing a dataset of values to be visualised refers to an applicable core configuration file. The Core Data Viewer will therefore only load data files that refer to the currently loaded core configuration file, to ensure that the data is compatible with the core configuration in use. Furthermore, in order for loading to be permitted by the software, the contents of a data file must match the specification (e.g. number of values required) given in the core configuration file.

5. APPLICATIONS

Three major application areas have been identified as candidates with best potential for benefiting from using the Core Data Viewer:

1. Core management services, including core design. This is typically an offline activity where fuel vendors' and utilities' reactor physicists discuss and optimise different core loading patterns. Detailed, accurate, and time-consuming calculations produce massive amounts of data, and the Core Data Viewer provides a means to visualise the data and to assist in obtaining a common interpretation of the calculated results.
2. Core monitoring where reactor operators and on-site reactor physicists use Core Data Viewer to visualise data from core simulation codes. On-line measurements can be included in order to compare and verify simulation results. Although the Core Data Viewer currently provides no support for online connection to simulation codes, such features are provided by the underlying technologies used and can easily be incorporated.
3. Training of reactor physicists, instructors, and reactor operators, to better understand reactor core behaviour under various operating conditions.

An important effect of visualisation can be improved communication between experts and non-experts, as effective visualisation can assist users in understanding and interpreting huge amounts of data provided by advanced calculation codes.

The visualisation of power density distribution is a particularly good case that can benefit from using the Core Data Viewer, because it is represented by huge amounts of data, depends strongly on control variables, and is one of the most important parameters calculated in the application areas listed above. For example, it is used to estimate the probability of fuel element failure, including cladding failure, during both normal operation and accident situations. It is also used to estimate the amount of nuclear fuel required by a reactor to produce the desired cumulative energy in a specified period. Thus, it is very important to the field of nuclear engineering from both a safety and an economic point of view.

The power density distribution is calculated by solving equations of the behaviour of neutrons in a nuclear reactor core. The solver is called a core physics simulator. As the power of computers has increased, the calculation methods adopted in core physics simulators have become more precise. An example of a recent higher order method is the VNEM (Variational Nodal Expansion Method) [2] developed by IFE. In this method, rigorous neutron transport equations are solved, in contrast to conventional methods, where approximate neutron diffusion equations are solved. The spatial distribution of neutrons is treated in a very precise manner in the higher order methods, distinguishing each of the fuel rods in an assembly. As a result of precise calculations based on such higher order methods, huge amounts of spatial points are used to represent the power density distributions. For example, more than a million points are used in the case of a medium-sized pressurized water rector core.

For end-users, as the power density spatially distributes within a 3D reactor core in a rather complicated way, its interpretability, as well as the accuracy, is an issue. Reactor engineers have to understand the calculated power density distribution in order to improve the loading pattern of fuel-assemblies in a core, the control-rod insertion depth pattern, the core operating strategy in long or short range, etc., because "improvements" are measured by the suitability of the power density distribution. Also, in reviewing newly designed reactor cores, it is very helpful to see how the in-core power density is distributed.

With this in mind, an efficient visualisation technique is evidently necessary for users to be able to comprehend how power density is distributed. We believe that the Core Data Viewer would be a very efficient tool for this purpose.

Reactor core physics simulators have been integrated into systems for core management tasks. An example is the core management framework SCORPIO [1], which can be interfaced to almost any software modules or tools, including graphical man-machine interfaces, physics simulation codes, optimisation tools, signal validation tools, controllers, etc., to make a complete system for reactor core management. By using a system integration framework, new physics simulators based on higher order methods and the Core Data Viewer could be efficiently utilised in the field of reactor core management.

6. IMPLEMENTATION STATUS

As of October 2008, the Core Data Viewer offers all of the visualisation functions described in section 3 above. It was originally implemented as a visualisation tool for VNEM data, so the current set of configuration options are limited in scope to those needed to import VNEM data from files. The software framework used to implement the Core Data Viewer offers all the functionality required to provide a more comprehensive set of configuration options in future, and additional options will therefore be added when required by customer applications.

A video of the Core Data Viewer in operation can be found on the IFE website (http://www.ife.no/CoreDataViewer).

7. CONCLUSIONS

The Core Data Viewer provides a quick and efficient means of visualising reactor core data that is useful for operators and physicists for interpreting, and communicating, the results of both calculations and data collected online. By providing a 3D overview of the underlying 3D data, the Core Data Viewer provides a very compact visual representation of potentially huge amounts of data. Through an open interface for importing data into the viewer from practically any source, and support for multiple operating systems, including Linux, Apple Mac OS X and Microsoft Windows, we believe that it has a wide potential to provide powerful visualisation capabilities to engineers, physicist, and students, to benefit both the safety and economics of reactor core designs.

8. ACKNOWLEDGMENTS

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