SUnCISTT
A Generic Code Interface for Uncertainty and Sensitivity Analysis

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Abstract: The GRS development SUnCISTT (Sensitivities and Uncertainties in Criticality Inventory and Source Term Tool) is a modular, easily extensible, abstract interface program designed to perform Monte Carlo sampling based uncertainty and sensitivity analyses. In the field of criticality safety analyses it couples different criticality and depletion codes commonly used in nuclear criticality safety assessments to the well-established GRS tool for sensitivity and uncertainty analyses SUSA. SUSA provides the necessary statistical methods, whereas SUnCISTT handles the complex bookkeeping that arises in the transfer of the generated samples into valid models of a given problem for a specific code. It generates and steers the calculation of the sample input files for the used codes. The computed results are collected, evaluated, and prepared for the statistical analysis in SUSA.
In this paper we describe the underlying methods in SUnCISTT and present examples of major applications in the field of nuclear criticality safety assessment:

- Uncertainty and sensitivity analyses applied in criticality calculations.
- Monte Carlo sampling techniques in nuclear fuel depletion calculation.
- Uncertainty and sensitivity analyses of burnup credit analysis.
- Analysis of correlations between different experimental setups sharing uncertain parameters.

The examples and results are shown for SUnCISTT, coupling SUSA to different SCALE sequences from Oak Ridge National Laboratory and to OREST from GRS.

Keywords: Uncertainty and Sensitivity Analysis, Monte Carlo Sampling, Nuclear Engineering, Burnup Credit, Criticality Safety.

1. INTRODUCTION

In recent years, the increase of computational power allowed the development of probabilistic assessment strategies for the field of nuclear criticality safety. In particular, Monte Carlo sampling methods became applicable in different areas of research. These methods use repeatedly calculations of a given model with randomly varied input parameters to determine uncertainties and sensitivities of the model results.
The GRS development SUnCISTT (Sensitivities and Uncertainties in Criticality Inventory and Source Term Tool) is a modular, easily extensible abstract interface program designed to perform Monte Carlo sampling based uncertainty and sensitivity analyses for technical parameters, such as manufacturing tolerances. The methods offer a complement to traditional best-estimate analyses and can help to reduce conservatisms while still keeping the high safety standards required in the field of criticality safety calculations.
For the field of criticality safety, different criticality and depletion codes, commonly used in nuclear criticality safety assessments, have currently been coupled to the well-established GRS tool SUSA [1]. These couplings represent what is called a SUnCISTT application. Among the codes are the CSAS1, CSAS5, CSAS6 and T-NEWT sequences of the SCALE package, developed at Oak Ridge National Lab [2], the MCNP5 code developed at Los Alamos National Lab [3], and the OREST code [4]. OREST is the well-established GRS developed code for a 1 dimensional cell burnup system.
SUSA provides statistical methods for sensitivity and uncertainty analyses, whereas SUnCISTT handles the necessary bookkeeping and provides methods to translate the generated samples into valid computation models of the given problem. It generates and steers the execution of the sample input files of any used code, and collects and processes the computed results.

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In this paper an overview of the major capabilities of SUnCISTT will be presented. In the following chapter the SUnCISTT itself is described in more detail. We explain the core functionalities and the data flow. In chapter 3 we give a short overview of the SUnCISTT's capabilities by summarizing some analyses that have successfully been performed so far. Finally, in chapter 4 we draw a resume.

2. SUnCISTT

SUnCISTT was developed to provide a general analyses tool for uncertainty and sensitivity analysis associated with technical parameters such as manufacturing tolerances. The original goal was to determine uncertainties arising through these manufacturing tolerances in assessments related to the nuclear fuel cycle. However, due to the abstract code concept of SUnCISTT it's use is not restricted to these analyses. It can be used under both, Linux and Windows operating systems and it is, due to its object oriented programming in Python3, easy to extend in its functionalities and fields of applications. SUnCISTT is able to investigate any given mathematic model. Here we describe the couplings of SUnCISTT with the GRS code SUSA, used as pre- and postprocessor, and some specific codes for nuclear criticality and burnup calculations.

The GRS code SUSA (Software for Uncertainty and Sensitvity) is a well-known and for more than 20 years established tool for uncertainty and sensitivity analyses. For example it is also used in combination with the thermohydraulic code ATHLET [5] and with COCOSYS [6], a software designed for the simulation of severe accidents in nuclear power plants.
For the presentation at hand, SUSA serves two purposes: the generation of statistically independent samples of the uncertain input parameters of the model to investigate and to perform the uncertainty and sensitivity analysis of the computational results. Note, that for both purposes the interfaces implemented in SUnCISTT offer the opportunity to apply any other tool with similar features. The approach to couple SUnCISTT to SUSA leads to the following diagram:

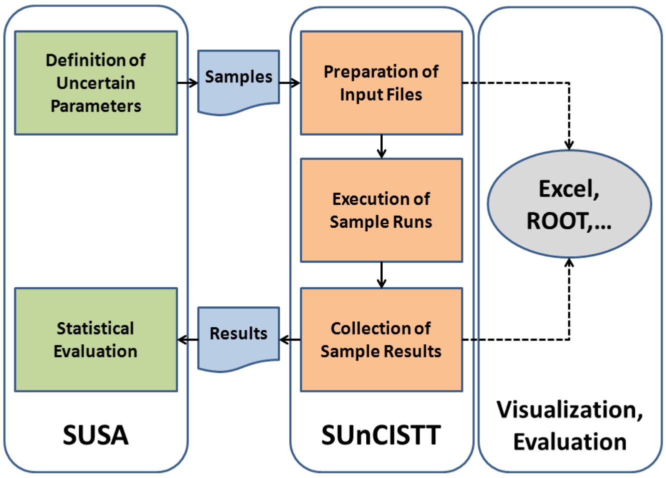

Figure 1: Possible sequence of analyses with SUnCISTT.

In the depicted sequence in Figure 1 SUSA is used for the preparation of the independent Monte Carlo samples, based on the probability density functions of the uncertain parameters. Possible dependencies between input parameters can either be considered in SUSA or using the user interface implemented in SUnCISTT. The result is an ASCII formatted list of independent samples, that is used as input to SUnCISTT.
This list is used in SUnCISTT to convert each generated sample into a valid input file for the applied codes, e.g. the CSAS5 sequence of the SCALE package. SUnCISTT steers the execution of the input files and collects the results for the subsequent statistical evaluation in SUSA. The SUnCISTT modes include mechanisms that allow their visualization, evaluation and supervision by tools like ROOT [7] or Microsoft Excel.

In the approach presented here, the statistical evaluation of the model run results is done with SUSA by calculating mean values, sample standard deviations or perform hypothesis tests. The sensitivity analysis describing the influence of the uncertainty of the input parameter on the uncertainty of the result can be performed by using several sensitivity measures, e.g. ordinary correlation or the correlation ratio.
In the following the SUnCISTT core is described in more detail.

2.1. The SUnCISTT Core

To perform a Monte Carlo sampling analysis of a given mathematical model, SUnCISTT needs information about the generated samples, the computational model to be analyzed and the specific input file requirements of the code to be executed. For the generated samples, the aforementioned ASCII list of the statistical varied input parameter has to be provided. From the input file of the nominal case, a template file is derived in which user defined keywords replace the nominal values of the uncertain parameters. The third file to be provided in the SUnCISTT mode *prepareSamples* is a configuration file that sets the information of the other files into relation. It is prepared in the *.json* format, an exchange format that can be read and written from several programming languages. The user has the opportunity to trigger auxiliary calculations that are necessary to transform the parameters of the generated samples into the parameters needed in the computational model. For example, if samples were generated for the diameter of a sphere but the model requires the radius, this conversion can be triggered from SUnCISTT. If any of the uncertain parameters requires such a conversion, SUnCISTT offers the user the possibility to provide its own Python module, defining the conversion formalism. Note, that this implementation of the user interaction allows the user to easily call any other program from its Python module during runtime. This opens a wide range of opportunities for complex analyses. Besides other configuration options, information about this Python module is also part of the configuration file.

Informations about the executable code to run the sampled input files can be easily implemented in the *runSamples* mode, due to the object oriented structure of the core. With only little extensions, SUnCISTT is capable of performing uncertainty and sensitivity analyses based on Monte Carlo sampling for any given problem, if the executable program to calculate the individual samples is using input files.

With the given information, the mode *prepareSamples* generates the desired number of individual input files with the statistical varied input parameters defined in the sample list. SUnCISTT than steers the execution of the generated files in the mode *runSamples*. With the knowledge about the structure of the provided, individual output files, SUnCISTT also collects the calculated individual result in mode *collectResults* and prepares them for further analysis. In our case files for the postprocessing in SUSA are generated as well as ROOT files or files for Microsoft Excel. For the different SUnCISTT applications this is achieved by overloading only method of the SUnCISTT core with the application specific implementation. For an overview over the whole analysis procedure see Figure 1. Two graphical sketches of the modes *prepareSamples* and *collectResults* with more details are shown in Figure 2 and Figure 3.

The mode *prepareSamples* has the capability to handle additional input variables, if needed. Often, in order to define a valid computation model, model parameters that have a functional dependence on one or more of the uncertain parameters have to be calculated, although these additional parameters are not treated as uncertain parameters themselves. For example, let's assume a material steel with three constituents: iron, nickel and chromium. If the weight percentages of nickel and chromium are defined as uncertain parameters, the contribution of iron has to be derived by subtracting them from 100%. This kind of parameter and its dependencies on uncertain parameters can be defined in the configuration file, mentioned before. SUnCISTT will calculate the final values of these additional parameters based on the user defined Python module. Then, the corresponding keywords in the input files will be replaced, just like for the uncertain parameters. The *prepareSamples* mode includes many check routines for direct feedback that help to reduce potential error sources. For example, SUnCISTT checks if the keywords defined by the user are unique and unambiguous. A bookkeeping method gives the user a quick overview about how often each keyword has been replaces in total and which keywords were replaced in each individual line of the template file. This information can be used to crosscheck the automated procedure with the users' expectation.

Once the sample input files are executed, the mode *collectResults* prepares the result files for further analysis or visualizations. This mode needs to have informations about the structure of the result files and the results of interest. In the development of new SUnCISTT applications, the main task is to implement the parsing of the result files of the codes, searching for the result parameters of interest. By default, SUnCISTT produces a result file that can be transferred to SUSA for the statistical evaluation. For further visualizations and analyses optional files for ROOT or Microsoft Excel can be generated. A graphic sketch is shown in Figure 3.

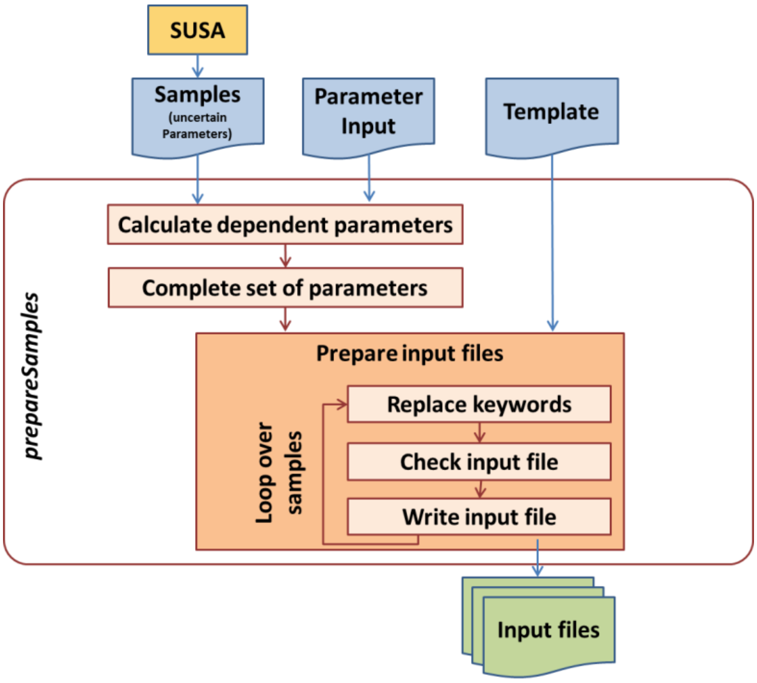

Figure 2: Graphic sketch of the SUnCISTT mode *prepareSamples*.

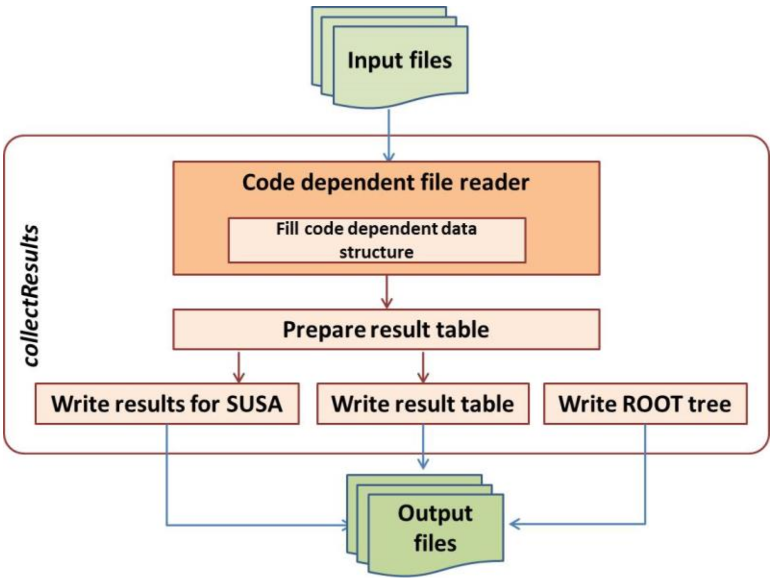

Figure 3: Graphic sketch of the SUnCISTT mode *collectResults*.

The result files obtained from the *collectResults* mode can then be used to assess the statistical quantities of interest and to evaluate the uncertainty and the sensitivity measures. The implementation presented here takes advantage of the numerous SUSA capabilities. However, with the interfaces defined in SUnCISTT, other statistical tools could easily be utilized, too.

3. ANALYSES EXAMPLES OF SUNCISTT APPLICATIONS

The acronym SUnCISTT stands for Sensitivities and Uncertainties in Criticality Inventory and Source Term Tool and as suggested by the name, it was developed to provide a general analysis tool associated with the nuclear fuel cycle. However, providing well defined interfaces to establish the coupling to specific codes, SUnCISTT can easily be adopted to perform uncertainty and sensitivity analyses in any desired field.

In the following we show some results and capabilities of the SUnCISTT in the field of nuclear criticality safety. Since there are numerous applications, all inheriting the same core functionalities and due to the subject of this article, the focus will be to give a general overview. For details about the individual analyses we refer the reader to the given references.

The applications couple specific specialized codes to be used in the calculations with the SUnCISTT. Any new application can be easily implemented by inheritance from the SUnCISTT core functionalities if the underlying code provides ASCII formatted output files. A graphic sketch of the SUnCISTT applications, that have been implemented by GRS so far, is shown in Figure 4.

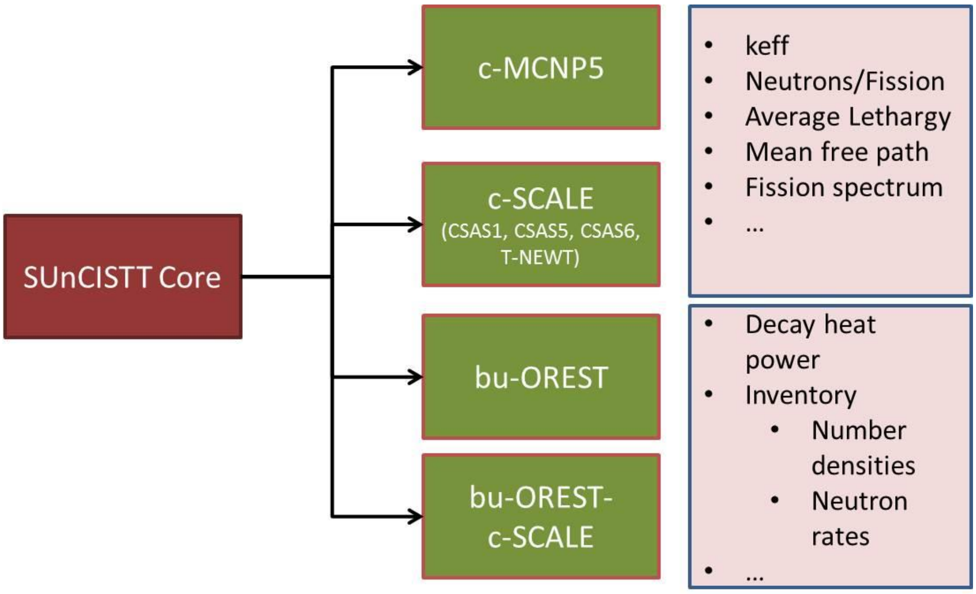

Figure 4: SUnCISTT applications for nuclear criticality safety. Depending on the problem and the physical quantity of interest, the application can be chosen.

The naming scheme for the SUnCISTT applications combines the analysis type to be performed (c = criticality, bu = burnup) with the corresponding code that has been coupled.

3.1. Criticality Assessments with SCALE – the c-scale Application

In the field of criticality safety analyses the main interest is in the determination of the neutron multiplication factor k_{eff}. GRS has implemented several SUnCISTT applications serving this purpose. They are based on the SCALE sequences CSAS1, CSAS5, CSAS6, and T-NEWT, and the MCNP5 application.

We show results for the CSAS5 sequence of the Benchmark Phase IV [8], proposed by the OECD/NEA "Expert Group on Uncertainty and Criticality Safety Assessment" (UACSA), a subgroup of the "Working Party for Nuclear Criticality Safety" [9]. The aim of the benchmark is to determine the impact of correlations between different benchmark experiments on the estimation of the computational bias on k_{eff}. These correlations play a role in the validation of codes for criticality safety assessments, especially in cases where the experimental basis that can be used for the validation is poor and limited to only a few contributing experimental facilities.

To verify a code for a calculated application case, the user can test the code against qualified experimental results. A collection of qualified results for critical experiments is e.g. documented in the "International Handbook of Evaluated Criticality Safety Benchmark Experiments" (ICSBEP) [10] Besides information on the experimental setup it contains additional information about the major sources of uncertainties of each experiment. This can be used to perform Monte Carlo sampling based uncertainty analyses in each experiment of the validation pool. Their results can be used to determine correlation between those benchmark experiments. Since some experimental series share major parts of the experimental setup the manufacturing tolerances of these parts cannot be treated as statistically independent. An add-on of SUnCISTT provides the capability to steer and execute the uncertainty analyses of several benchmark experiments simultaneously. The add-on utilizes the SUnCISTT applications for individual uncertainty analyses, described in the previous chapters. The user can choose if common sources of uncertainties are to be treated identical or individual in the contributing experiments. The results of the uncertainty analyses can be combined and quantities like the Pearson's correlation coefficients can be determined. The benchmark proposed by the UACSA aims to determine the correlation between 21 different criticality experiments, described in the ICSBEP Handbook at LEU-COMP-THERM (LCT) 7, cases 1 to 4 and LCT 39 cases 1 to 17. The experiments share the experimental setup (e.g. fuel rods) and were performed in the same apparatus. An overview of the uncertain parameters common to all experiments are given in Table 1

The experiments consisted of low enriched Uranium in fuel rods with varying pitches and varying formations. The water level in each setup was triggered to ensure a system k_{eff} =1. The water height result is different for each experimental setup and thus the corresponding model parameter has to be treated individually.

Since this articles purpose is to demonstrate the capabilities of SUnCISTT, we will not go into to many details. For an elaborated presentation of the analysis and an interpretation of its results see [11,12,13].

The SUnCISTT add-on is able to steer the uncertainty analyses for the experiments specified in a configuration file at a time. In this case, the file contained 21 entries. For each experiment, the input files necessary for the individual uncertainty analysis has to be provided. The individual uncertainty analyses are then processed corresponding to the description in chapter 2. The add-on provides additional modes, compared to the single-experiment application: a check for missing result files and the possibility to analyze the results for correlation between the individual models. A graphic sketch can be found in Figure 5. The modes marked with an asterisk are those belonging to the single-experiment application that is called from the add-on.

The criticality calculations for the 21 experiments of the UACSA proposed benchmark were performed with the SUnCISTT application c-scale-csas5. It includes the CSAS5 sequence of SCALE version 6.1.2, using the neutron transport code KENO V.a and CENTRM for the resonance self shielding with the 238 group ENDF/B-VII cross section library. Each experiment was sampled 625 times leading to more than 13000 individual calculations. The individual CSAS5 configuration consisted of 100k neutrons per generations and a convergence criterion of $5x10^{-5}$. The first 1000 generations were skipped to ensure source convergence.

Parameter	Distribution Model	Model Parameter	
		a or μ	b or σ
Fuel rod inner diameter	U(a,b)	0.81 cm	0.83 cm
Fuel rod thickness	U(a,b)	0.055 cm	0.065 cm
Fuel pellet diameter	$N(\mu,\sigma^2)$	0.78919 cm	0.00176 cm
Mean linear density of fissile coloumn	$N(\mu,\sigma^2)$	5.0778 g/cm	0.0282 g/cm
Height of fissile column	$N(\mu,\sigma^2)$	89.703 cm	0.306 cm
^{234}U content	$N(\mu,\sigma^2)$	0.0307 At.-%	0.0005 At.-%
^{235}U content	$N(\mu,\sigma^2)$	4.79525 At.-%	0.002 At.-%
^{236}U content	$N(\mu,\sigma^2)$	0.1373 At.-%	0.0005 At.-%

Table 1: Parameters, their distribution models, and model parameters common to all experiments. The distribution U(a,b) represents a uniform distribution between a and b, $N(\mu,\sigma^2)$ represents a normal distribution with expectation value μ and standard deviation σ. Additional to these parameters the water heights were varied independently for each experiment.

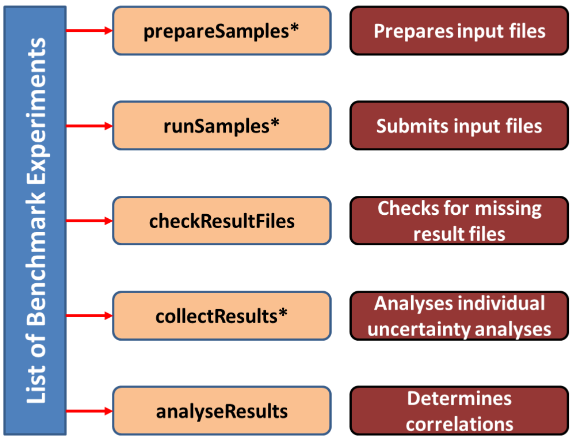

Figure 5: Flowchart of the SUnCISTT add-on for the determination of correlations between calculated k_{eff} values of the benchmark experiments. The asterisks indicate the use of the SUnCISTT core modes.

The mean values and standard deviations calculated for each experiment are shown in Figure 6. Each entry corresponds to the result of one uncertainty analysis as it would have been obtained if the analysis would have been performed with just the c-scale-csas5 application instead of the add-on. The plot was generated automatically in the add-on’s *analyseResults* mode from the ROOT TTree object that is prepared during the *collectResults* mode. The ROOT file containing the ROOT TTree object includes also overview plots of other potential result parameters, like the mean free path of neutrons. With this automated visualization it is possible to obtain a quick overview about the overall results, right after the calculations are finished.
Following the flowchart in Figure 5 for our example of the 21 experiments, SUnCISTT determines the correlations between the calculated k_{eff} introduced by sharing the same experimental setup. The result is shown in Figure 7 as a color coded matrix. It shows the high correlations between the calculated k_{eff} values with coefficients close to 1 for almost all experiments. The exceptions are experiments 2 and 4 from the LCT 7 series. These experiments have a significantly larger pitch which influences the neutron spectra. For a detailed discussion of the results see [11,12].

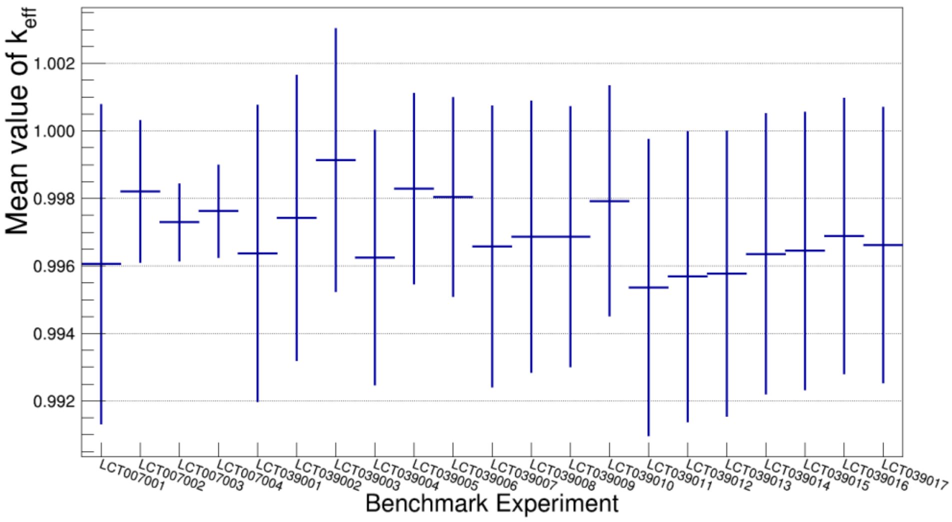

Figure 6: Mean values and standard deviations of k_{eff} of the 625 samples for each of the 21 experiments. All mean values are below k_{eff} of 1.0 and in agreement calculations stated in [10].

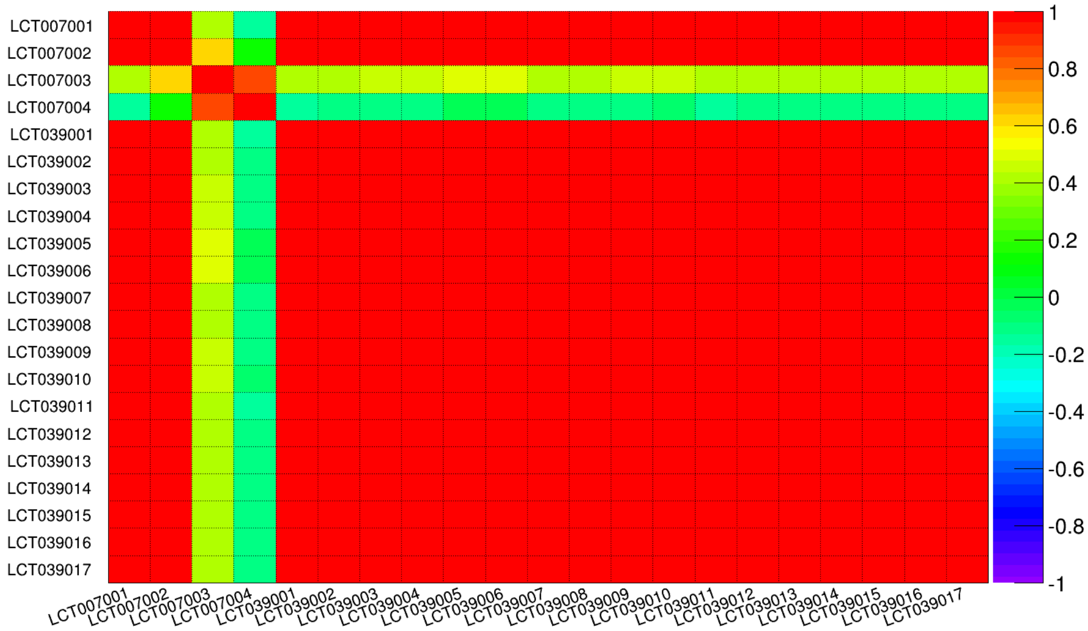

Figure 7: Color coded correlation matrix of the calculated k_{eff} values for the experiments LEU-COMP-THERM (LCT) 7 cases 1 to 4 and LCT 39 cases 1 to 17. All cases are highly correlated, except case number 3 and 4 from the LCT 7 series. These two cases have a significantly larger pitch between the fuel rods, which influences the thermal neutron spectra.

3.2. Burnup Credit Application: bu-orest-c-scale

In the following we show some details of a more complex calculation with SUnCISTT. The goal is to calculate typical physical quantities of interest for a generic transport cask loaded with spent nuclear fuel. The criticality safety calculations include basically two steps: The calculation of the inventory of the spent fuel elements and the criticality calculations of the spent fuel in the cask. In both of these calculations the variation of manufacturing parameters has to be considered in a consistent way. This leads to a complex bookkeeping SUnCISTT needs to handle, in particular the error propagation through the whole calculation chain of burnup and criticality calculation.

When calculating criticality, taking into account the burnup of fuel rods in 3D, one has also to consider axial non-homogeneities in the burnup. Typically, top and bottom of PWR fuel rods are radiated less than the middle leading to axial burnup profiles. The bu-orest-c-scale application is capable of taking these burnup profiles into account.

A schematic overview of the bu-orest-c-scale application, that was developed to perform this type of complex analyses, is shown in Figure 8.

The SUnCISTT application bu-orest-c-scale calculates for each defined axial zone the burnup with OREST. In addition to the generated samples of uncertain parameters, the user has to provide a databank of burnup profiles. The resulting Monte Carlo samples for the nuclides of each axial zone are then transferred into the model for criticality calculations.

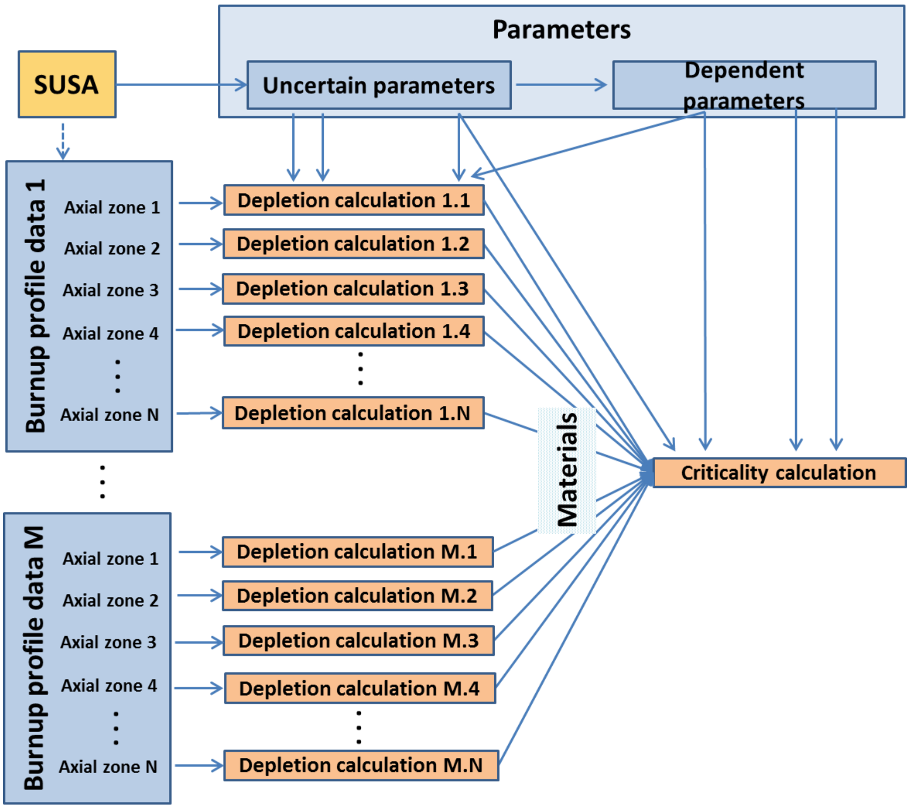

Figure 8: Schematic overview of the SUnCISTT application *bu-orest-c-scale*.

To illustrate the function of the SUnCISTT application, we describe an example calculation of a generic transport cask, loaded with typical irradiated PWR fuel assemblies. This example represents a typical task in the field of criticality safety assessments: the initial enrichment of the fuel assemblies, their average burnup, and their geometry, and the cask itself are known. Criticality safety of the loaded cask has to be ensured for example in interim storage scenarios or for the disposal of cask in a final repository. The Monte Carlo sampling method is an adequate choice for this kind of assessment.

The model of the generic cask used in this example is the GBC-32 transport cask for spent nuclear fuel of Pressurized Water Reactors (PWR) as described e.g in [15]. The design includes a basket with 32 shafts for the fuel elements. Between the shafts neutron absorbers (B_4C/Al) are placed to ensure subcriticality. The whole basket is surrounded by a cylindrical steel body. A horizontal cut through the SCALE model is shown in Figure 9. The fuel elements are modelled in SCALE as 17x17 Westinghouse “Optimized Fuel Assemblies”, shown in Figure 10. In the model, each fuel rod is divided into 18 equal axial zones, indicated in the right picture of Figure 10.

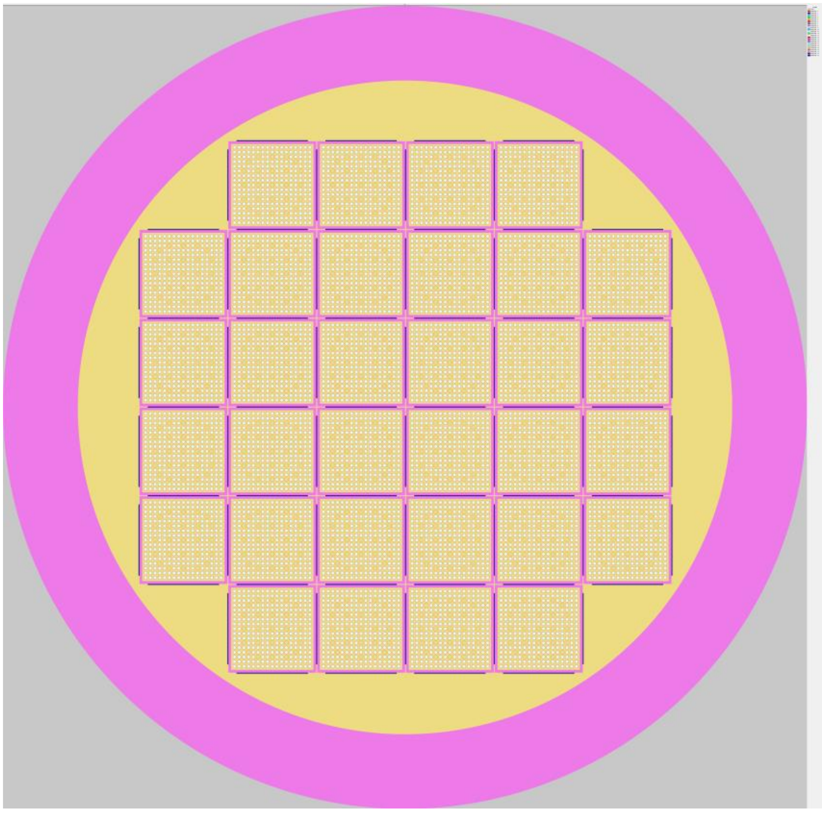

Figure 9: Horizontal cut through the SCALE model of the loaded transport cask GBC-32. Each quadrat represents a complete fuel assembly. For details of the model see e.g. [15]

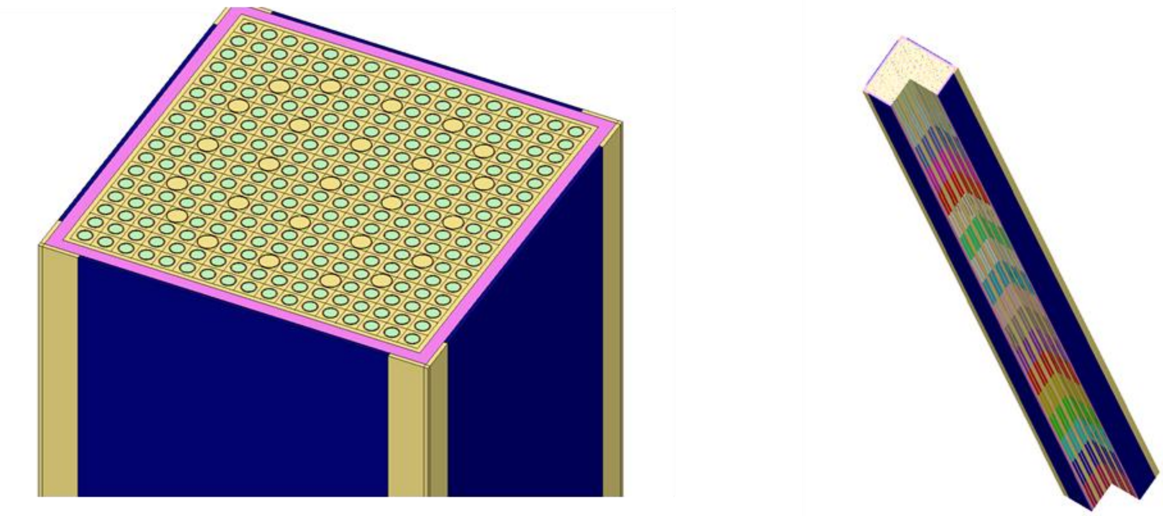

Figure 10: Simulated 17x17 fuel assemblies. On the left a detailed view of a horizontal cut through an assembly. The green spots represent fuel rods, while the bigger, yellow circles represent the guide tubes. For details of the model see e.g. [15]. On the right hand side a ¾ vertical cut through the element shows the 18 different color coded axial zones.

The fuel elements are assumed to be uniform and typical PWR UO_2 fuel elements with an initial enrichment of 4.4% ^{235}U.
The cask is further assumed to be loaded with elements of two different burnups. The outer elements have a burnup of 60 GW/d, while the inner 16 elements should have a burnup of 27 GW/d.

For the SUnCSITT calculation, identical manufacturing tolerances were considered in both calculation steps, the burnup and the criticality calculations. The assumptions about the characteristics of the varied input parameters are shown in Table 2.

Components	**Expectation value**	**Dimension**	**Distribution function (P1,P2)**	**P1**	**P2**
Fuel Pellet Diameter	0.7844	[cm]	Normal distribution (μ,σ)	0.7844	0.00176
Inner Diameter Cladding	0.8	[cm]	Uniform distribution (min,max)	0.79	0.8
Outer Diameter Cladding	0.9144	[cm]	Uniform distribution (min,max)	0.8544	0.9744
Inner Dimension Fuel Element Shaft	22	[cm]	Uniform distribution (min,max)	21.95	22.05
Wall Thickness Fuel Element Shaft	0.75	[cm]	Uniform distribution (min,max)	0.7	0.8
Width Neutron Absorber	0.20574	[cm]	2,4-Beta function (min,max)	0.18074	0.23074
Wall Thickness Neutron Absorber Shaft	19.05	[cm]	2,4-Beta function (min,max)	19.04	19.06
Fuel Density	10.198	[g/cm^3]	Normal Distribution (μ,σ)	10.198	0.0435
Boron Concentration	524.568	[ppm]	Normal Distribution (μ,σ)	524.568	26.0776
Enrichment	4.4	[wt-% ^{235}U]	Uniform distribution (min,max)	4.35	4.45

Table 2: Input parameters and their characteristics varied in in the SUnCISTT analyses.

At first, SUnCISTT calculated for each of the 18 axial zones of the two different fuel elements 100 samples with varying boron concentration in the moderator, enrichment, and fuel density. To consider the axial varying burnup, SUnCISTT uses profiles provided from the NEA program ZZ-PWR-AXBUPRO-SNL [CAC 97]. The databank consists of axail burnup distributions of commercial PWRs for varying setups, reactor types, enrichments and more. A preselection of the 3169 profiles has been performed outside of SUnCISTT to ensure the use of only the best fit profiles. The preselection was based on the following parameters: geometry, enrichment, and burnup.

With use of the axial burnup profiles, the bu-orest application in SUnCISTT calculated a total of 3600 inventories. Each of the inventories was then transferred to its corresponding position in the SCALE model for the criticality calculations. A graphical sketch of the bu-orest-c-scale application is shown in Figure 8.
Thus, 100 samples of the loaded cask were created with SUnCISTT, respecting manufacturing tolerances in the complete analysis chain. Although 100 samples might not be sufficient for a profound analysis, they can be used to present the complexity of this kind of analysis and to demonstrate the successful application of the bu-orest-c-scale implementation.

The 100 input files, describing the variations of the loaded cask, were then analysed with the SCALE 6.1.2 version and its 3 dimensional Eigenwert Monte Carlo transport code KENO-V.a using the ENDF/B-VII continuous energy cross section library. 50,000 generations of Neutrons with 100,000 neutrons per generation were calculated, skipping the first 500 generations and using a convergence criterium of 0.0001.

The results for the neutron multiplication factor k_{eff} are shown in Figure 11.

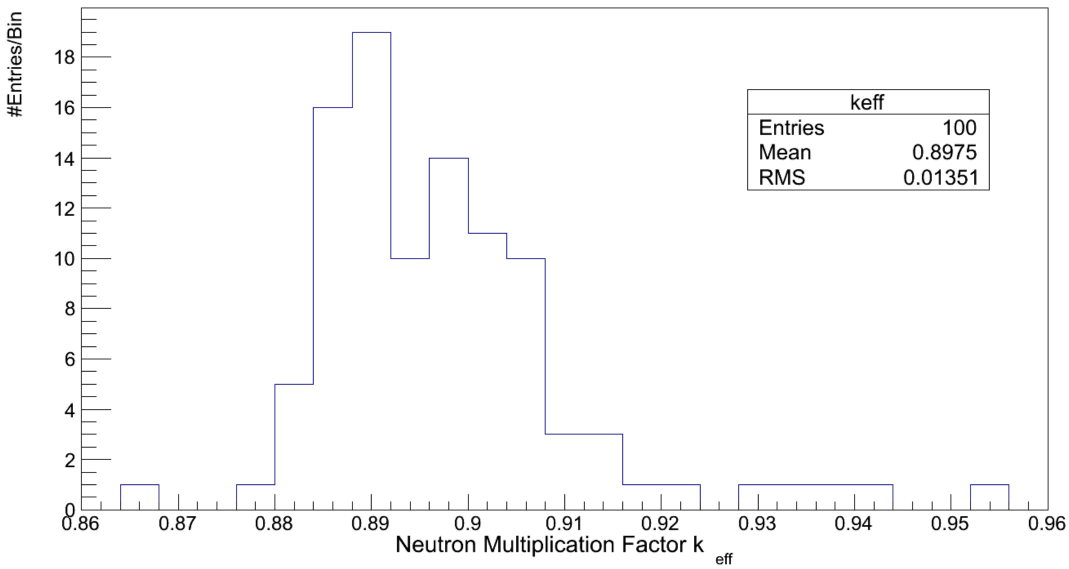

Figure 11: Frequency of the calculated neutron multiplication factor k_{eff} of the 100 sampled transport casks. The plot is also an example of one of the numerous automatically generated ROOT analysis files.

The results for k_{eff} were then transferred back to SUSA for the sensitivity analyses. The sensitivity analysis shows the impact of the uncertainty of the input parameters on the uncertainty of the resulting k_{eff} values. A correct and rigorous propagation of the uncertainties through the calculation chain as done by SUnCISTT is mandatory for an error free sensitivity analysis.
The result of our example indicate that reducing the uncertainty in the production process for the cladding of the fuel rods would have the biggest impact on decreasing the uncertainty of k_{eff}.

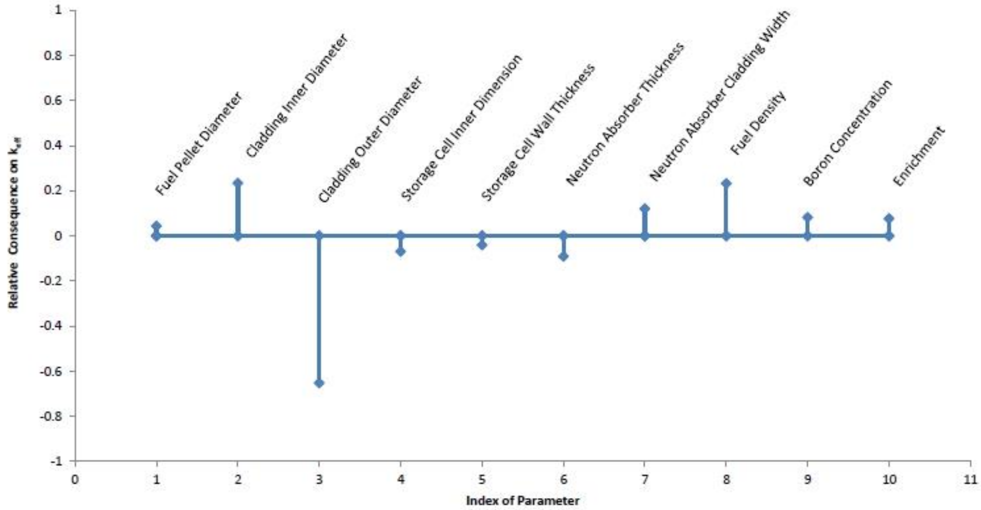

Figure 12: Sensitivity coefficients of the GBC-32 cask analysis. Plotted is the index of the model parameter on the x-axis versus the relative consequence on k_{eff} on the y-axis. The largest impact stems from the cladding diameters.

4. SUMMARY

Uncertainty analyses based on Monte Carlo sampling methods are state of the art, even in computational challenging applications. With SUnCISTT, GRS has developed an abstract interface tool that is capable to connect statistic software with recognized best-estimate codes. In this article the adoption with the well-established GRS tool SUSA was presented, that offers all statistical ingredients needed for uncertainty and sensitivity analyses. Successful couplings in so called SUnCISTT applications were shown in examples with best-estimate criticality codes from ORNL's SCALE package and GRS' burnup code OREST.

The object oriented approach taken in the development of SUnCISTT with the choice of Python as programming language is the basis for several of its features: the user can interact with the tool during runtime, new applications can be implemented easily by inheritance and it is thus easy to adapt to codes of other fields then the nuclear fuel cycle. With add-ons, taking advantage of the features of the underlying SUnCISTT applications, new analysis opportunities can easily be developed.

We have shown the powerful capabilities of SUnCISTT in individual uncertainty assessments as well as for complex and extensive analyses by presenting selected results from current investigations. With these analyses GRS contributed successfully in several international benchmarks on various topics [8,14,15].

Future developments will concentrate on extending the capabilities of SUnCISTT to a wider range of fields of research, the improvement of the users' experience, and the continuous use of the SUnCISTT applications in challenging analyses.

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