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### ***D13.11 Code Inventory in Europe***

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**ARCHER project** – Contract Number: 269892

Advanced High-Temperature Reactors for Cogeneration of Heat and Electricity R&amp;D

EC Scientific Officer: Dr. Panagiotis Manolatos

|                     |                                                             |
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**Summary**

This document contains the survey of system code as submitted by the different ARCHER project partners. As the partners were asked to submit descriptions of their codes with relevance to high temperature reactors the presented code inventory comprises code descriptions as submitted by the partners. In the second part, an evaluation table is presented to show which of certain capabilities do exist and where development needs are.

**Approval**

| Rev. | Short description | First author                               | WP Leader | SP leader                         | Coordinator                            |
|------|-------------------|--------------------------------------------|-----------|-----------------------------------|----------------------------------------|
| 0    | First issue       | Janis Lapins<br>(USTUTT-IKE)<br>24/08/2012 |           | F. Roelofs<br>(NRG)<br>12/10/2012 | Sander de Groot<br>(NRG)<br>12/10/2012 |

**Distribution list**

| Name                       | Organisation | Comments |
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# 1 Introduction

The gas-cooled reactor system codes available in Europe will be listed, and details will be provided considering:

- Features
- Applicability
- Limitations
- Code development needs, required improvements
- Qualification and validation needs
- Appropriateness and main purpose of the codes: evaluation, design, licensing
- Integration potential (possibility to include (information from) other codes
- Source code knowledge maintenance
- ...

The inventory will take into account the expected code needs for demonstration design and licensing, and prioritise the codes available. Preferably this also leads to selection.

The list, specifications and prioritisation/selection will be reported in deliverable D131.

Not all partners that have system codes are involved in this work package, to reduce the effort involved. It is however the responsibility of the task leader, to ensure that all codes are taken into account, specifications are retrieved, and an objective assessment is carried out.

**System codes** are able to simulate the primary loop and the secondary loop of a nuclear power plant with simplified usually one-dimensional models for the components. They leave out detailed simulation of specific components but can simulate whole circuits and their interdependence. System codes are abundant; however, most of the system codes are tailored for light water reactors.

The focus of development here is put on HTR-specific components (Helium-Blower, Helium-Steam-Generator, possibly helium-helium-heat exchangers) and possible coupling to neutronics and thermal hydraulics.

For that purpose a template for a questionnaire was sent to various institutions in Europe to specify following code details:

- System Code Name
- Initial Purpose (LWR, FBR, HTR)
- General Features
- Limitations
- Code development needs (for HTR applicability)
- Contact person/key information holder (for further question)
- Couplings (neutronics, thermal hydraulics, containment codes,...)
- State of validation, References (title of latest publications)
- Lines of code
- Under development since
- Programming language (F77, F90,...) and compiler
- Supported systems (Windows, Linux, MacOS,...)
- Input/Output structure (ASCII, XML, Binary,...)

## 2 Result of Survey of System Codes

### 2.1 ACCORD

|                                                                   |                                                                                                                                                                                                                |
|-------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                                   | LWR ,BWR                                                                                                                                                                                                       |
| General Features                                                  | reactivity control, heat transfer calculation, He-loop calculation, safety protection                                                                                                                          |
| Limitations                                                       |                                                                                                                                                                                                                |
| Code development needs (for HTR applicability)                    |                                                                                                                                                                                                                |
| Contact person/key information holder (for further question)      | JAEA                                                                                                                                                                                                           |
| Couplings (neutronics, thermal hydraulics, containment codes,...) |                                                                                                                                                                                                                |
| State of validation, References (title of latest publications)    | Core Dynamics Analysis for Reactivity Insertion and Loss of Coolant Flow Tests Using the High Temperature Engineering Test Reactor Kuniyoshi TAKAMATSU1), Shigeaki NAKAGAWA1) and Tetsuaki TAKEDA August, 2007 |
| Lines of code                                                     |                                                                                                                                                                                                                |
| Under development since                                           |                                                                                                                                                                                                                |
| Programming language (F77, F90,...) and compiler                  |                                                                                                                                                                                                                |
| Supported systems (Windows, Linux, MacOS,...)                     |                                                                                                                                                                                                                |
| Input/Output structure (ASCII, XML, Binary,...)                   |                                                                                                                                                                                                                |

Information provided by: Xu Cheng, KIT, [xu.cheng3@kit.edu](mailto:xu.cheng3@kit.edu)

### 2.2 ASTEC-V2

|                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose  | <ul style="list-style-type: none"> <li>- simulation of all phenomena occurring during a severe accident</li> <li>-initially only for water-cooled systems (BWR,PWR,CANDU)</li> <li>- safety analyses, source term evaluation, development of severe accident management guidelines</li> </ul>                                                                                                                                                                                                                                                                  |
| General Features | <ul style="list-style-type: none"> <li>- two-phase flow of coolant in primary and secondary system (CESAR)</li> <li>- core degradation (geometry, chem. reactions, melting, corium formation) (ICARE)</li> <li>- release of fission products (ELSA)</li> <li>- thermal-hydraulics and transport of aerosols and FP vapours (SOPHEROS)</li> <li>- simulation of direct containment heating (e.g. after lower head failure) (RUPUICUV)</li> <li>- simulation of the behaviour of corium droplets transported into the containment atmosphere (CORIUM)</li> </ul> |

|                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                   | <ul style="list-style-type: none"> <li>- simulation of thermalhydraulics and aerosol behaviour in containment (CPA)</li> <li>- H2 combustion (PROCO)</li> <li>- iodine behaviour in the containment (IODE)</li> <li>- corium-concrete interaction (MEDICIS)</li> <li>- core reflooding (DIVA)</li> <li>- evaluation of dose rate in the containment gaseous phase (DOSE)</li> <li>- simulation of decay of fission products and actinide isotopes (ISODOP)</li> <li>- simulation of the management of engineered safety features (SYSINT)</li> <li>- material data library including all recent research on nuclear material properties (MDB)</li> <li>- sensitivity analysis (SUNSET)</li> </ul> |
| Limitations                                                       | <ul style="list-style-type: none"> <li>- no module for steam explosion</li> <li>- no module for mechanical integrity of the containment</li> <li>- extensions needed for other reactor types (e.g. for sodium-cooled fast reactor → Na treatment)</li> <li>- missing physical model for mechanical behaviour of the reactor cooling system ( e.g. pipes, structures)</li> <li>- improvement of the solid debris modeling necessary</li> </ul>                                                                                                                                                                                                                                                     |
| Code development needs (for HTR applicability)                    | <ul style="list-style-type: none"> <li>- treatment of HTR aerosols comprising graphite particles generated by friction (different properties of constituent particles)</li> <li>- absence of water or steam in most HTR accident scenarios may affect various transport phenomena</li> <li>- fouling of heat transfer surfaces (effect of dust)</li> <li>- reactivity feedback necessary in case of water ingress accident</li> </ul>                                                                                                                                                                                                                                                             |
| Contact person/key information holder (for further question)      | JAEA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Couplings (neutronics, thermal hydraulics, containment codes,...) | <ul style="list-style-type: none"> <li>- CESAR/ICARE coupling</li> <li>- CESAR/DIVA coupling</li> <li>- CPA/MEDICIS coupling</li> <li>- ELSA/ICARE coupling</li> <li>- CPA/IODE coupling</li> <li>- coupling between MEDICIS and CPA possible</li> <li>- PROCO can be used with feedback to CPA</li> <li>- CESAR, ICARE, RUPUICUV and CPA do not use implemented MDB</li> </ul>                                                                                                                                                                                                                                                                                                                   |

|                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-----------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                       | <p>→ coupling of the modules via dynamic memory (except ELSA: coupled directly to ICARE)</p> <ul style="list-style-type: none"> <li>- no reactivity feedback (neutronic coupling)</li> <li>- no feedback of element masses computed by ISODOP (other modules work with initial isotopic composition)</li> <li>- no coupling of the ICARE air oxidation model to the current CESAR</li> </ul> <p>thermalhydraulics</p> <ul style="list-style-type: none"> <li>- Coupling to the IRSN JADE tool for pre-processing and on-line visualisation</li> <li>- Coupling to the GRS ATLAS tool for post-processing,</li> <li>- Coupling to the IRSN SUNSET tool for uncertainty and sensitivity analyses</li> </ul>                                                                                                                                                                                                                                               |
| <p>State of validation, References (title of latest publications)</p> | <ul style="list-style-type: none"> <li>- for ASTEC V1.3rev2 : 65 different experiments covering all physical phenomena involved in SA</li> <li>- benchmarks on plant applications have concerned diverse reactor types (PWR, VVER and BWR) and SA scenarios in operation states</li> <li>- references <ul style="list-style-type: none"> <li>• “ASTEC application to in-vessel corium retention”, D.Tarabelli, G.Ratel, R.Pélisson, M.Barnak, P.Matejovic, <i>Conference ERMSAR-2007</i>, Karlsruhe, June 12-14, 2007</li> <li>• “Recent activities on validation of modeling of thermal-hydraulic and aerosol phenomena in ASTEC CPA”, I. Kljenak, M. Dapper, J. Dienstbier, L.E. Herranz, M. Bendiab, M.K. Koch, J.Fontanet, <i>Conference ERMSAR-2007</i>, Karlsruhe, June 12-14, 2007</li> <li>• “Assessment of ICARE/CATHARE V1 severe accident code”, P.Chatelard, J.Fleurot, O.Marchand, P.Drai, <i>Conference ICONE-</i></li> </ul> </li> </ul> |

|                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|--------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                  | <p>14, Miami (Florida), USA, July 17-20, 2006</p> <ul style="list-style-type: none"> <li>• “Validation of CESAR thermal-hydraulic module of ASTEC V1.2 Code on BETHSY Experiments” (N. Trégourès, G. Bandini, L. Foucher, J. Fleurot, P. Meloni) Journal of Powers and Energy Systems, 2 (No. 1) (2008) ICONE-15 special issue</li> <li>• “Application of the ASTEC V1 Code to the LIVE-L1 Experiment”, Miassoedov, A., et al.,(2008) In: Proc. Int. Congress on Advances in Nuclear Power Plants (ICAPP'08), Anaheim(USA)</li> <li>• “Recent advances in ASTEC validation on circuit thermal-hydraulic and core degradation”G. Bandini et al. / Progress in Nuclear Energy 52 (2010) 148–157</li> </ul> |
| Lines of code                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Under development since                          | 1998 ASTEC V1 series<br>Since 2007 ASTEC V2 series (version V2.0 released in June 2009)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Programming language (F77, F90,...) and compiler | <p>- Fortran 77/90 (SIGAL, managing the “dynamic” memory for the different modules)</p> <p>- Fortran 90 (ODESSA)</p> <p>- while ASTEC V1.3 and ASTEC V2.0 developments were carried out using the Lahey If95 compiler as reference</p> <p>compiler, both the V2.0-rev1 and V2.0-rev2 assuming the Intel ifort compiler to be the new reference one</p> <p>- not possible to generate a 64-bits executable file using a 64-bits Linux computer (possible to generate a 32-bits executable on a 64-bits Linux computer)</p>                                                                                                                                                                                |
| Supported systems (Windows, Linux, MacOS,...)    | - code runs on both PC-Linux and PC-Windows (NT or XP operating systems for the latter) and requires 1Gb RAM to operate correctly                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Input/Output structure (ASCII, XML, Binary,...)  | <p>Input : fortran 90, 450 000 instructions</p> <p>Output : TIC software (standard fortran77 code,</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

|  |                                                                                                                                                      |
|--|------------------------------------------------------------------------------------------------------------------------------------------------------|
|  | interactive curve plotter, post processing of a fortran<br>Code, JAVATIC is a Graphic User Interface to the software TIC)<br>ASTEC-to-ATLAS coupling |
|--|------------------------------------------------------------------------------------------------------------------------------------------------------|

Information provided by: Nicole Guillard, IKE, [nicole.guillard@ike.uni-stuttgart.de](mailto:nicole.guillard@ike.uni-stuttgart.de)

## 2.3 ATHLET MOD 2.2. Cycle A

|                                                                   |                                                                                                                                             |
|-------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                                   | LWR (PWR, BWR, VVER, and RBMK), for core damage ATHLET-CD                                                                                   |
| General Features                                                  | highly modular best estimate 1D program, extended to supercritical coolant including the transition from super- to subcritical fluid states |
| Limitations                                                       | Project accidents, 22,5 MPa                                                                                                                 |
| Code development needs (for HTR applicability)                    | -                                                                                                                                           |
| Contact person/key information holder (for further question)      | H. Deitenbeck<br>H. Austregesilo                                                                                                            |
| Couplings (neutronics, thermal hydraulics, containment codes,...) | External coupling with DYN3D, COCOSYS, FLUENT                                                                                               |
| State of validation, References (title of latest publications)    | Sept. 2009, Program Manula                                                                                                                  |
| Lines of code                                                     | -                                                                                                                                           |
| Under development since                                           | Internal Coupling with DYN3D                                                                                                                |
| Programming language (F77, F90,...) and compiler                  | F77, 90, 95                                                                                                                                 |
| Supported systems (Windows, Linux, MacOS,...)                     | Windows, Linux                                                                                                                              |
| Input/Output structure (ASCII, XML, Binary,...)                   | ASCII                                                                                                                                       |

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 Xu Cheng, KIT, [xu.cheng3@kit.edu](mailto:xu.cheng3@kit.edu)

## 2.4 CATHARE 2 (v2.5 1 mod 3.1)

|                                                              |                                                                                                                                                                  |
|--------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                              | LWR                                                                                                                                                              |
| General Features                                             | 1D reference safety code developed for French pressurized water reactors                                                                                         |
| Limitations                                                  |                                                                                                                                                                  |
| Code development needs (for HTR applicability)               | development of a comprehensive turbo-machinery module, special treatments for gas mixtures, specific features for modelling of core neutronics and heat transfer |
| Contact person/key information holder (for further question) | <a href="http://www-cathare.cea.fr">http://www-cathare.cea.fr</a>                                                                                                |

|                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|-------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Couplings (neutronics, thermal hydraulics, containment codes,...) | FLICA - 3D thermal-hydraulic core component code;<br>ICARE - severe accident code modeling core degradation and fission product release                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| State of validation, References (title of latest publications)    | Validation of CATHARE Code for Gas-Cooled Reactors: Comparison with E.V.O Experimental Data on Oberhausen II Facility<br>Bentivoglio, Fabrice; Tauveron, Nicolas<br>2006 Jul 01 ;<br><b>Separate Effect Tests</b> (more than 1000 SET from 45 test facilities);<br><b>Integral Effect Tests</b> (about 30 IET);<br>G. Geffraye, O.Antoni, M.Farvacque, D.Kadri, G.Lavialle, B.Rameau, A. Ruby:<br>CATHARE 2 V2.5_2 : a Single Version for Various Applications<br>The 13th International Topical Meeting on Nuclear Reactor Thermalhydraulics (NURETH-13) N13P1095<br>Kanazawa City, Ishikawa Prefecture, Japan, September 27-October 2, 2009 |
| Lines of code                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Under development since                                           | More than 30 years of development                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| Programming language (F77, F90,...) and compiler                  | Compiler supporting the FORTRAN ANSI-77                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Supported systems (Windows, Linux, MacOS,...)                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Input/Output structure (ASCII, XML, Binary,...)                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

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## 2.5 CONTAIN

|                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose | The CONTAIN code is an analysis tool for predicting the physical, chemical, and radiological conditions inside the containment and connected buildings of a nuclear reactor in the event of an accident. CONTAIN was developed at Sandia National Laboratories under the sponsorship of the US Nuclear Regulatory Commission (USNRC) for analysing containment phenomena under severe accident and design basis accident conditions. It is designed to predict the thermal-hydraulic response inside containments and the release of radionuclides to the environment in the event of containment failure. The modelling capabilities of CONTAIN are also sufficiently flexible that it can be applied to the analysis of non-reactor problems, such as the migration of radioisotopes in waste repositories, and the thermal-hydraulic response of non-nuclear facilities under accident conditions. The |
|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

|                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                | <p>CONTAIN code usage in reactor safety application is its primary targeted application. Such analyses are an integral part of the USNRC's Severe Accident Research Program (SARP), where reactor safety issues are addressed through an appropriate mix of experimental and analytical research.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| General Features                               | <p>The CONTAIN 2.0 computer code is an integrated analysis tool used for predicting the physical conditions, chemical compositions, and distributions of radiological materials inside a containment building following the release of material from the primary system in a light-water reactor accident. It can also predict the source term to the environment. CONTAIN 2.0 is intended to replace the earlier CONTAIN 1.12, which was released in 1991. The purpose of this Code Manual is to provide full documentation of the features and models in CONTAIN 2.0. Besides complete descriptions of the models, this Code Manual provides a complete description of the input and output from the code. CONTAIN 2.0 is a highly flexible and modular code that can run problems that are either quite simple or highly complex. An important aspect of CONTAIN is that the interactions among thermalhydraulic phenomena, aerosol behavior, and fission product behavior are taken into account. The code includes atmospheric models for steam/air thermodynamics, intercell flows, condensation/evaporation on structures and aerosols, aerosol behavior, and gas combustion. It also includes models for reactor cavity phenomena such as core-concrete interactions and coolant pool boiling. Heat conduction in structures, fission product decay and transport, radioactive decay heating, and the thermal-hydraulic and fission product decontamination effects of engineered safety features are also modeled. To the extent possible, the best available models for severe accident phenomena have been incorporated into CONTAIN, but it is intrinsic to the nature of accident analysis that significant uncertainty exists regarding numerous phenomena. In those cases, sensitivity studies can be performed with CONTAIN by means of user-specified input parameters. Thus, the code can be viewed as a tool designed to assist the knowledgeable reactor safety analyst in evaluating the consequences of specific modeling assumptions.</p> |
| Limitations                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Code development needs (for HTR applicability) |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |

|                                                                   |                                            |
|-------------------------------------------------------------------|--------------------------------------------|
| Contact person/key information holder                             | Ignacio Cañadas, icm@empre.es              |
| Couplings (neutronics, thermal hydraulics, containment codes,...) | See previous info (columns 2,3, and 4)     |
| State of validation, References (title of latest publications)    | Appendix C of NUREG/CR-6533<br>SAND97-1735 |
| Lines of code                                                     | UNKNOWN                                    |
| Under development since                                           | FORTRAN                                    |
| Programming language (F77, F90,...) and compiler                  |                                            |
| Supported systems (Windows, Linux, MacOS,...)                     | WINDOWS, LINUX, UNIX                       |
| Input/Output structure (ASCII, XML, Binary,...)                   | ASCII, BINARY                              |

Information provided by: Ignacio Cañadas, Empresarios Agrupados A.I.E., icm@empre.es

## 2.6 CRYSTAL

|                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                |
|-------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                                   | HTR fuel                                                                                                                                                                                                                                                                                                                                                                                       |
| General Features                                                  | CRYSTAL calculates coated particles failure probability.<br>It is a one-dimensional multi-layer model that takes into account the visco-elastic behavior of the coating layers and the surrounding graphite during irradiation. The main source of stress in all layers is due to the pressure build-up from the gaseous fission products in the buffer layer. Moreover, the Pyrocarbon layers |
| Limitations                                                       | No flexible input/output data exist.<br><br>Cannot be used for accidents conditions, since the model equations are formulated as functions of neutron fluence rather than time.                                                                                                                                                                                                                |
| Code development needs (for HTR applicability)                    | input/output structure                                                                                                                                                                                                                                                                                                                                                                         |
| Contact person/key information holder                             | Eric A.R. de Geus<br><br>degeus@nrg.eu<br><br>Marek M. Stempniewicz<br><br>stempniewicz@nrg.eu                                                                                                                                                                                                                                                                                                 |
| Couplings (neutronics, thermal hydraulics, containment codes,...) | No interactive coupling with other codes is currently possible.                                                                                                                                                                                                                                                                                                                                |
| State of validation, References (title of latest publications)    | No validation exists against measured data. Benchmark calculations with the code TIMCOAT.                                                                                                                                                                                                                                                                                                      |
| Lines of code                                                     | ~5000<br>(including comments) in 35 subroutines.                                                                                                                                                                                                                                                                                                                                               |

|                                                  |       |
|--------------------------------------------------|-------|
| Under development since                          | 2007  |
| Programming language (F77, F90,...) and compiler | F90   |
| Supported systems (Windows, Linux, MacOS,...)    | Linux |
| Input/Output structure (ASCII, XML, Binary,...)  | ASCII |

Information provided by: Marek M. Stempniewicz, NRG, [stempniewicz@nrg.eu](mailto:stempniewicz@nrg.eu)

## 2.7 DYN3D

|                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                                   | <ul style="list-style-type: none"> <li>- LWR, VVER</li> <li>- extended to HTR</li> </ul>                                                                                                                                                                                                                                                                                                                                             |
| General Features                                                  | <ul style="list-style-type: none"> <li>- coupled neutron-kinetics/thermal-hydraulics code</li> <li>- neutron kinetics based on multigroup nodal trigonal or hexagonal diffusion or SP3.</li> <li>- 3D heat conduction based on finite volume method; further heat conduction model for compacts and TRISOs</li> <li>- He as coolant gas, but other coolant gases easily feasible</li> <li>- 1D coolant channel flow model</li> </ul> |
| Limitations                                                       | <ul style="list-style-type: none"> <li>- square or hexagonal fuel element geometry</li> <li>- unparallelized code</li> <li>- long calculation time for big problems</li> <li>- cross sections have to be preprocessed</li> <li>- 1D coolant channel flow model</li> </ul>                                                                                                                                                            |
| Code development needs (for HTR applicability)                    | - implementation of Pebble (bed) features (but coupling with CFX already done)                                                                                                                                                                                                                                                                                                                                                       |
| Contact person/key information holder (for further question)      | <p>-Silvio Baier, HZDR,<br/><a href="mailto:s.baier@hzdr.de">s.baier@hzdr.de</a></p> <p>-Susan Duerigen, HZDR,<br/><a href="mailto:s.duerigen@hzdr.de">s.duerigen@hzdr.de</a></p> <p>(-Sören Kliem, HZDR,<br/><a href="mailto:s.kliem@hzdr.de">s.kliem@hzdr.de</a>)</p> <p>(-Ulrich Rohde, HZDR,<br/><a href="mailto:u.rohde@hzdr.de">u.rohde@hzdr.de</a>)</p>                                                                       |
| Couplings (neutronics, thermal hydraulics, containment codes,...) | <ul style="list-style-type: none"> <li>- ATHLET 2.2A</li> <li>- FLICA-4</li> <li>- RELAP-5</li> <li>- CFX</li> <li>- TRANSURANUS (under development)</li> <li>- SERPENT-1.1.15, HELIOS-1.10 / HELIOS-2 for XS-generation</li> </ul>                                                                                                                                                                                                  |
| State of validation, References (title of latest publications)    | <p>Rohde, U., Baier, S., Duerigen, S., Fridman, E., Kliem, S., Merk, B.: <b>Development and verification of the coupled 3D neutron kinetics/thermal-hydraulics code DYN3D-HTR for the simulation of transients in</b></p>                                                                                                                                                                                                            |

|                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|--------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                  | <p><b>block-type HTGR.</b> Nuclear Engineering and Design, on press</p> <p>Baier, S., Kliem, S., Rohde, U.: <b>A 3D heat conduction model for block-type High Temperature Reactors and its implementation into the code DYN3D.</b> In: Proceedings of the Annual Meeting on Nuclear Technology (Jahrestagung Kerntechnik). Berlin, Germany, May 17-19 2011</p> <p>Duerigen, S.; Grundmann, U.; Mittag, S.; Merk, B.; Fridman, E.; Kliem, S.: <b>A Trigonal Nodal Solution Approach to the Multi-Group Simplified P3 Equations in the Reactor Code DYN3D.</b> In: Proceedings of the International Conference on Mathematics and Computational Methods Applied to Nuclear Science and Engineering (M&amp;C 2011). Rio de Janeiro, Brazil, May 8-12 2011</p> <p>Duerigen, S.; Bilodid, Y ; Fridman, E.; Mittag, S.: <b>A Trigonal Nodal SP3 Method with Mesh Refinement Capabilities – Development and Verification.</b> Submitted to PHYSOR 2012 Advances in Reactor Physics. Knoxville, Tennessee, USA, April 15-20 2012</p> <p>Rohde, U., Mittag, S., Grundmann, U., Petkov, P., Hadek, J.: Application of a Stepp-wise verification and validation procedure of the 3D neutron kinetics code DYN3D within the European NURESIM project. ICONE17, Bruxelles, Belgium, July 12-16, CD-ROM, paper 75446.</p> |
| Lines of code                                    | ~230000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Under development since                          | <ul style="list-style-type: none"> <li>- DYN3D-LWR since 1986</li> <li>- DYN3D-HTR since 2008</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Programming language (F77, F90,...) and compiler | <ul style="list-style-type: none"> <li>- F77, F90, F95</li> <li>- Intel Fortran</li> <li>- gfortran</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Supported systems (Windows, Linux, MacOS,...)    | <ul style="list-style-type: none"> <li>- Windows</li> <li>- Linux</li> <li>- Unix</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Input/Output structure (ASCII, XML, Binary,...)  | <ul style="list-style-type: none"> <li>- ASCII</li> <li>- Binary (extractable via numerical and graphical postprocessor)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

Information provided by: S. Baier, HZDR, [s.baier@hzdr.de](mailto:s.baier@hzdr.de)

## 2.8 GAMMA

|                 |      |
|-----------------|------|
| Initial Purpose | VHTR |
|-----------------|------|

|                                                                   |                                                                                                                                                                                                                                                                                                                                                 |
|-------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| General Features                                                  | thermo-fluid and chemical reaction behaviors in a multi-component mixture system as well as heat transfer within the solid components, free and forced convection between a solid and a fluid, and radiative heat transfer between the solid surfaces                                                                                           |
| Limitations                                                       |                                                                                                                                                                                                                                                                                                                                                 |
| Code development needs (for HTR applicability)                    | Plan to implement the turbo machinery models and the hydrogen production model of the high temperature steam electrolysis into GAMMA code                                                                                                                                                                                                       |
| Contact person/key information holder (for further question)      | C. Oh<br>P.O. Box 1625<br>Idaho National Laboratory, Idaho Falls, ID.<br>83415-3885, USA<br>Email: chang.oh@inl.gov                                                                                                                                                                                                                             |
| Couplings (neutronics, thermal hydraulics, containment codes,...) |                                                                                                                                                                                                                                                                                                                                                 |
| State of validation, References (title of latest publications)    | Development of Safety Analysis Codes and Experimental Validation for a Very High Temperature Gas-Cooled Reactor<br>Chang Oh, INEEL<br>Cliff Davis, INEEL<br>Richard Moore, INEEL<br>Hee C. NO, KAIST<br>Jong Kim, KAIST<br>Goon C. Park, SNU<br>John Lee, U. Michigan<br>W. Martin, U. Michigan<br>James Holloway, U. Michigan<br>November 2004 |
| Lines of code                                                     |                                                                                                                                                                                                                                                                                                                                                 |
| Under development since                                           |                                                                                                                                                                                                                                                                                                                                                 |
| Programming language (F77, F90,...) and compiler                  |                                                                                                                                                                                                                                                                                                                                                 |
| Supported systems (Windows, Linux, MacOS,...)                     |                                                                                                                                                                                                                                                                                                                                                 |
| Input/Output structure (ASCII, XML, Binary,...)                   |                                                                                                                                                                                                                                                                                                                                                 |

Information provided by: Xu Cheng, KIT, [xu.cheng3@kit.edu](mailto:xu.cheng3@kit.edu)

## 2.9 GOTHIC

|                 |                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose | GOTHIC (Generation of Thermal-Hydraulic Information for Containments) is a general purpose thermal-hydraulics software package for design, licensing, safety and operating analysis of nuclear power plant containments and other confinement buildings. Applications of GOTHIC include evaluation of containment and containment sub-compartment response to the full spectrum of high energy line breaks within the design basis envelope |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

|                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                   | as described in FSAR Chapter 6, Section 2. Applications may include, but is by no means limited to, pressure and temperature determination, equipment qualification profiles and inadvertent system initiation, and degradation or failure of engineered safety features                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| General Features                                                  | <p>GOTHIC (Generation Of Thermal-Hydraulic Information for Containments) is a general purpose thermal-hydraulics computer code for design, licensing, safety and operation analysis of nuclear power plant containments and other confinement buildings. Applications of GOTHIC include evaluation of containment and containment sub-compartment response to the full spectrum of high energy line breaks within the design basis envelope as described in the Safety Assessment Report (SAR).</p> <p>GOTHIC includes a pre- and post-processing interface, for easy preparation of input decks and graphycal display of results in the form of line, vector and contour plot. The solver (GOTHIC_S) is a state-of-the-art program that solves the conservation equations for mass, momentum, and energy for multi-component, multi-phase flows. The phase balance equations are coupled with closure laws for interface mass, energy, and momentum transfer that cover the entire flow regime from bubbly flow to film/drop flow, as well as single phase flows. Thermal non-equilibrium and phase velocity differences are also allowed. GOTHIC includes full treatment of the momentum transport terms in multi-dimensional models, with optional models (mixing length and K-epsilon) for turbulent shear and turbulent mass and energy diffusion. Conservation equations are solved for three fields: steam/gas mixture, continuous liquid and liquid droplets. The vapor phase is comprised of steam and a mixture of noncondensable gases (up to 8 species to select from a library including 50 different gases). Mass balances are solved for each component, thereby providing the volume fraction of each type of gas in the mixture. Separate volumes, including three-dimensional components, are connected by one-dimensional flow paths (junctions). Solid structures and several other components (valves, pumps, heat exchangers, burners, etc.) can also be modelled.</p> |
| Limitations                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Code development needs (for HTR applicability)                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Contact person/key information holder                             | Ignacio Cañadas, icm@empre.es                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Couplings (neutronics, thermal hydraulics, containment codes,...) | See previous info (columns 2,3, and 4)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

|                                                                |                                                          |
|----------------------------------------------------------------|----------------------------------------------------------|
| State of validation, References (title of latest publications) | At least three volumes of docs, included in the package. |
| Lines of code                                                  | UNKNOWN                                                  |
| Under development since                                        | FORTTRAN                                                 |
| Programming language (F77, F90,...) and compiler               |                                                          |
| Supported systems (Windows, Linux, MacOS,...)                  | WINDOWS, LINUX, UNIX                                     |
| Input/Output structure (ASCII, XML, Binary,...)                | ASCII, BINARY                                            |

Information provided by: Ignacio Cañadas, Empresarios Agrupados A.I.E., [icm@empre.es](mailto:icm@empre.es)

## 2.10 FLOWNET

|                                                                   |                                                                                                                                                                                           |
|-------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                                   | Thermal-fluid networks                                                                                                                                                                    |
| General Features                                                  | dynamic simulation of mass, momentum and energy transfer in thermal-fluid networks                                                                                                        |
| Limitations                                                       |                                                                                                                                                                                           |
| Code development needs (for HTR applicability)                    | extended to include a model for the High Temperature engineering Test Reactor (HTTR)                                                                                                      |
| Contact person/key information holder (for further question)      | P.G. ROUSSEAU and G.P. GREYVENSTEIN<br>School of Mechanical & Materials Engineering,<br>Faculty of Engineering<br>Potchefstroom University for CHE,<br>Potchefstroom, 2520 – South Africa |
| Couplings (neutronics, thermal hydraulics, containment codes,...) |                                                                                                                                                                                           |
| State of validation, References (title of latest publications)    | MODELLING OF THE HTTR IN FLOWNET<br>P.G. ROUSSEAU and G.P. GREYVENSTEIN<br>2002                                                                                                           |
| Lines of code                                                     |                                                                                                                                                                                           |
| Under development since                                           |                                                                                                                                                                                           |
| Programming language (F77, F90,...) and compiler                  |                                                                                                                                                                                           |
| Supported systems (Windows, Linux, MacOS,...)                     |                                                                                                                                                                                           |
| Input/Output structure (ASCII, XML, Binary,...)                   |                                                                                                                                                                                           |

Information provided by: Xu Cheng, KIT, [xu.cheng3@kit.edu](mailto:xu.cheng3@kit.edu)

## 2.11 MANTA

|                                                |                                                                                   |
|------------------------------------------------|-----------------------------------------------------------------------------------|
| Initial Purpose                                | PWR plants in all non-LOCA situations                                             |
| General Features                               | Neutronic and Thermo-hydraulic Analysis                                           |
| Limitations                                    |                                                                                   |
| Code development needs (for HTR applicability) | Compressible formulation of the balance equations, new gas turbine and compressor |

|                                                                   |                                                                                                                                                                                                                               |
|-------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                   | models, a specific HTR neutronic model, the calculation of physical properties of perfect gases and gas mixtures                                                                                                              |
| Contact person/key information holder (for further question)      |                                                                                                                                                                                                                               |
| Couplings (neutronics, thermal hydraulics, containment codes,...) |                                                                                                                                                                                                                               |
| State of validation, References (title of latest publications)    | A GFR benchmark: Comparison of transient analysis codes based on the ETDR concept<br>E. Bubelis, D. Castelliti, P. Coddington, I. Dor, C. Fouillet, E. de Geus, T.D. Marshall, W. van Rooijen, M. Schikorr, R. Stainsby, 2008 |
| Lines of code                                                     |                                                                                                                                                                                                                               |
| Under development since                                           |                                                                                                                                                                                                                               |
| Programming language (F77, F90,...) and compiler                  |                                                                                                                                                                                                                               |
| Supported systems (Windows, Linux, MacOS,...)                     |                                                                                                                                                                                                                               |
| Input/Output structure (ASCII, XML, Binary,...)                   |                                                                                                                                                                                                                               |

Information provided by: Xu Cheng, KIT, [xu.cheng3@kit.edu](mailto:xu.cheng3@kit.edu)

## 2.12 MELCOR

|                                                                   |                                                                                                                                                   |
|-------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                                   | LWR                                                                                                                                               |
| General Features                                                  | Parametric tool that could execute quickly;<br>Parameters called sensitivity coefficients can be used to adjust models                            |
| Limitations                                                       |                                                                                                                                                   |
| Code development needs (for HTR applicability)                    | Model for air ingress; chemical diffusion equation and chemical equilibrium model were implemented                                                |
| Contact person/key information holder (for further question)      | <a href="http://melcor.sandia.gov/">http://melcor.sandia.gov/</a>                                                                                 |
| Couplings (neutronics, thermal hydraulics, containment codes,...) |                                                                                                                                                   |
| State of validation, References (title of latest publications)    | DEVELOPMENT OF MELCOR INPUT TECHNIQUES FOR HIGH TEMPERATURE GAS-COOLED REACTOR ANALYSIS<br>A Thesis<br>by<br>JAMES ROBERT CORSON, JR.<br>May 2010 |
| Lines of code                                                     |                                                                                                                                                   |
| Under development since                                           |                                                                                                                                                   |
| Programming language (F77, F90,...) and compiler                  |                                                                                                                                                   |
| Supported systems (Windows, Linux, MacOS,...)                     |                                                                                                                                                   |
| Input/Output structure (ASCII, XML,                               |                                                                                                                                                   |

|             |  |
|-------------|--|
| Binary,...) |  |
|-------------|--|

Information provided by: Xu Cheng, KIT, [xu.cheng3@kit.edu](mailto:xu.cheng3@kit.edu)

## 2.13 MGT

|                                                                   |                                                                                                                                                                           |
|-------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                                   | HTR                                                                                                                                                                       |
| General Features                                                  | coupled neutronic-thermal hydraulic code for short time transients, explicit handling of the neutron capture resonances for U and Th, 3 dimensional diffusion calculation |
| Limitations                                                       | burn-up, equilibrium condition, running in phase, no handling of Pu or MA neutron capture resonances                                                                      |
| Code development needs (for HTR applicability)                    | consistency with TINTE and VSOP                                                                                                                                           |
| Contact person/key information holder                             | Dr. Kay Nünighoff (GRS)<br>Dr. Stefan Kassermann<br>(FZ Jülich)                                                                                                           |
| Couplings (neutronics, thermal hydraulics, containment codes,...) | coupled calculation of neutron spectrum, flux distribution, thermal dynamic behavior, corrosion effects                                                                   |
| State of validation, References (title of latest publications)    | partly validated                                                                                                                                                          |
| Lines of code                                                     |                                                                                                                                                                           |
| Under development since                                           |                                                                                                                                                                           |
| Programming language (F77, F90,...) and compiler                  | F77+F90                                                                                                                                                                   |
| Supported systems (Windows, Linux, MacOS,...)                     | Windows, Linux                                                                                                                                                            |
| Input/Output structure (ASCII, XML, Binary,...)                   | ASCII                                                                                                                                                                     |

Information provided by: N. Kohtz, TÜV Rheinland, [Norbert.Kohtz@de.tuv.com](mailto:Norbert.Kohtz@de.tuv.com)  
C. Pohl, TÜV Rheinland, [Christoph.Pohl@de.tuv.com](mailto:Christoph.Pohl@de.tuv.com)

## 2.14 MGT-3D

|                                                |                                                                                                                                                                                                                                        |
|------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                | HTR                                                                                                                                                                                                                                    |
| General Features                               | <ul style="list-style-type: none"> <li>- 3D Neutronics</li> <li>- I/Xe dynamics</li> <li>- 3D Fluid dynamics</li> <li>- time dependency</li> <li>- graphite corrosion</li> <li>- decay heat (DIN)</li> <li>- non local heat</li> </ul> |
| Limitations                                    | <ul style="list-style-type: none"> <li>- gas as heat sink</li> <li>- 0D spectrum code</li> <li>- no burnup</li> <li>- no fuel shuffling</li> </ul>                                                                                     |
| Code development needs (for HTR applicability) | none                                                                                                                                                                                                                                   |
| Contact person/key information holder          | Stefan Kassermann,<br><a href="mailto:s.kassermann@fz-juelich.de">s.kassermann@fz-juelich.de</a>                                                                                                                                       |

|                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Couplings (neutronics, thermal hydraulics, containment codes,...) | neutronics and fluid dynamics are coupled                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| State of validation, References (title of latest publications)    | <p><b>[1] H. Gerwin, W. Scherer</b><br/> Zur Validierung des Reaktordynamik-Programmsystems TINTE<br/> Graphit-Korrosion mit Luft,<br/> Vergleichsrechnungen zum Experiment<br/> VELUNA<br/> KFA-ISR-IB 8/92</p> <p><b>[2] B. Lee, H.Gerwin, H.F. Nießen, W. Scherer, B. Stöcker</b><br/> On the Validation of the Reactor-Dynamics Code-System TINTE<br/> Post-Calculations of the SANA-1 Experiments with a Radial Reflector<br/> KFA-ISR-IB-2/95, 1995</p> <p><b>[3] H.Gerwin, W. Scherer, E. Teuchert</b><br/> The TINTE Modular Code System for Computational Simulation of Transient Processes in the Primary Circuit of a Pebble-Bed-High-Temperature Gas-Cooled Reactor<br/> <i>Nuclear Science and Engineering</i>: 103, 302-312, 1989</p> |
| Lines of code                                                     | 40,400                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Under development since                                           | 2007, successor of TINTE (1985)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Programming language (F77, F90,...) and compiler                  | 2/3 F77<br>1/3 F90                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Supported systems (Windows, Linux, MacOS,...)                     | Windows XP, Linux                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Input/Output structure (ASCII, XML, Binary,...)                   | Input:<br>free format ASCII file<br><br>Output:<br>Formatted ASCII log file and binary data files                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |

Information provided by: Stefan Kassermann, FZJ, [s.kassermann@fz-juelich.de](mailto:s.kassermann@fz-juelich.de)

## 2.15 REPLAP5-3D

|                                                              |                                                                                                                                                                                                                       |
|--------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                              | LWR                                                                                                                                                                                                                   |
| General Features                                             | nonhomogeneous and nonequilibrium six-equation two-fluid model; noncondensable gases; 3D neutron kinetics; 3D thermalhydraulics;<br>Wide range of working fluids: H2O, D2O, He, K, H2, Li, Na, CO2, NaK, MS1, LiPb... |
| Limitations                                                  | No turbulence and viscous terms in 3D components – model should not be used to model large open tanks                                                                                                                 |
| Code development needs (for HTR applicability)               |                                                                                                                                                                                                                       |
| Contact person/key information holder (for further question) | ben@ujv.cz;<br><a href="http://www.inel.gov/relap5/relap5-3.htm">http://www.inel.gov/relap5/relap5-3.htm</a>                                                                                                          |
| Couplings (neutronics, thermal hydraulics,                   | CFD codes (Fluent);                                                                                                                                                                                                   |

|                                                                |                                                                                                                            |
|----------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|
| containment codes,...)                                         | Containment code (MELCOR)                                                                                                  |
| State of validation, References (title of latest publications) | RELAP5-3D© CODE MANUAL<br>VOLUME IV: MODELS AND CORRELATIONS,<br>INEEL-EXT-98-00834, Volume IV, Revision<br>2.4, June 2005 |
| Lines of code                                                  | ?                                                                                                                          |
| Under development since                                        | Version 1.0 released in 1997, version 2.4<br>released in 2005.                                                             |
| Programming language (F77, F90,...) and<br>compiler            | F77                                                                                                                        |
| Supported systems (Windows, Linux,<br>MacOS,...)               | Windows, Linux, Unix                                                                                                       |
| Input/Output structure (ASCII, XML,<br>Binary,...)             | ASCI/Binary                                                                                                                |

Information provided by: Xu Cheng, KIT, [xu.cheng3@kit.edu](mailto:xu.cheng3@kit.edu)

## 2.16 REPLAP5/MOD 3.2

|                                                                      |                                                                                                                                                                                                                                                |
|----------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                                      | LWR                                                                                                                                                                                                                                            |
| General Features                                                     | Multi-dimensional thermal-hydraulics<br>Multi-dimensional kinetics                                                                                                                                                                             |
| Limitations                                                          |                                                                                                                                                                                                                                                |
| Code development needs (for HTR<br>applicability)                    |                                                                                                                                                                                                                                                |
| Contact person/key information holder (for<br>further question)      | R. Stainsby<br>AMEC NNC Limited, UK                                                                                                                                                                                                            |
| Couplings (neutronics, thermal hydraulics,<br>containment codes,...) |                                                                                                                                                                                                                                                |
| State of validation, References (title of latest<br>publications)    | A GFR benchmark: Comparison of transient<br>analysis codes based<br>on the ETDR concept<br>E. Bubelis, D. Castelliti, P. Coddington, I. Dor,<br>C. Fouillet, E. de Geus,<br>T.D. Marshall, W. van Rooijen, M. Schikorr, R.<br>Stainsby<br>2008 |
| Lines of code                                                        |                                                                                                                                                                                                                                                |
| Under development since                                              |                                                                                                                                                                                                                                                |
| Programming language (F77, F90,...) and<br>compiler                  |                                                                                                                                                                                                                                                |
| Supported systems (Windows, Linux,<br>MacOS,...)                     |                                                                                                                                                                                                                                                |
| Input/Output structure (ASCII, XML,<br>Binary,...)                   |                                                                                                                                                                                                                                                |

Information provided by: Xu Cheng, KIT, [xu.cheng3@kit.edu](mailto:xu.cheng3@kit.edu)

## 2.17 REPLAP5-MOD 3.3

|                  |                                                                                    |
|------------------|------------------------------------------------------------------------------------|
| Initial Purpose  | LWR                                                                                |
| General Features | nonhomogeneous and nonequilibrium six-<br>equation two-fluid model, noncondensable |

|                                                                   |                                                                                                                               |
|-------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|
|                                                                   | gases,<br>point kinetics                                                                                                      |
| Limitations                                                       | Working fluid H <sub>2</sub> O, D <sub>2</sub> O;<br>one dimensional hydrodynamics;                                           |
| Code development needs (for HTR applicability)                    | Helium as working fluid?                                                                                                      |
| Contact person/key information holder (for further question)      | kra@ujv.cz                                                                                                                    |
| Couplings (neutronics, thermal hydraulics, containment codes,...) | CFD codes (Fluent);<br>3D neutron kinetics code (PARCS);<br>Containment code (MELCOR)                                         |
| State of validation, References (title of latest publications)    | RELAP5/MOD3.3 Code Manual Volume III: Developmental ASSESSMENT PROBLEMS, NUREG/CR-5535/Rev P3-Vol III, March 2006             |
| Lines of code                                                     | ?                                                                                                                             |
| Under development since                                           | RELAP5 released in 1982, version 3.3 released in 2003.<br>Currently development is finished, code is in maintenance mode only |
| Programming language (F77, F90,...) and compiler                  | F77                                                                                                                           |
| Supported systems (Windows, Linux, MacOS,...)                     | Windows, Linux, Unix                                                                                                          |
| Input/Output structure (ASCII, XML, Binary,...)                   | ASCII/Binary                                                                                                                  |

Information provided by: J. Berka, Centrum Vyzkumu Rez S.R.O., [bei@ujv.cz](mailto:bei@ujv.cz)

## 2.18 SCDAP/RELAP5/ATHENA

|                                                                   |                                                                                                                        |
|-------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                                   | LWR                                                                                                                    |
| General Features                                                  | Multi-dimensional thermal-hydraulics<br>Multi-dimensional kinetics                                                     |
| Limitations                                                       |                                                                                                                        |
| Code development needs (for HTR applicability)                    | Models to calculate transfer of decay heat,<br>oxidation of graphite,<br>ingress of air into the reactor               |
| Contact person/key information holder (for further question)      | <a href="http://www.inl.gov/relap5/scdap/scdap.htm">http://www.inl.gov/relap5/scdap/scdap.htm</a>                      |
| Couplings (neutronics, thermal hydraulics, containment codes,...) |                                                                                                                        |
| State of validation, References (title of latest publications)    | Extensions To SCDAP/RELAP5/ATHENA For Analysis Of HTGRS<br>Edwin A. Harvego<br>Larry J. Siefken<br>April 25 – 29, 2004 |
| Lines of code                                                     |                                                                                                                        |
| Under development since                                           |                                                                                                                        |
| Programming language (F77, F90,...) and compiler                  |                                                                                                                        |
| Supported systems (Windows, Linux, MacOS,...)                     |                                                                                                                        |
| Input/Output structure (ASCII, XML,                               |                                                                                                                        |

|             |  |
|-------------|--|
| Binary,...) |  |
|-------------|--|

Information provided by: Xu Cheng, KIT, [xu.cheng3@kit.edu](mailto:xu.cheng3@kit.edu)

## 2.19 SIM-ADS

|                                                                   |                                                                                                                                                                     |
|-------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                                   | sub-critical reactor systems (ADS)                                                                                                                                  |
| General Features                                                  | PC-based, multi-node point kinetic model that describes the nuclear and thermalehydraulic characteristics of critical and sub-critical reactor cores                |
| Limitations                                                       |                                                                                                                                                                     |
| Code development needs (for HTR applicability)                    |                                                                                                                                                                     |
| Contact person/key information holder (for further question)      | M. Schikorr<br>Forschungszentrum Karlsruhe, 76021<br>Karlsruhe, Germany                                                                                             |
| Couplings (neutronics, thermal hydraulics, containment codes,...) |                                                                                                                                                                     |
| State of validation, References (title of latest publications)    | Assessments of the kinetic and dynamic transient behavior of sub-critical systems (ADS) in comparison to critical reactor systems<br>W.M. Schikorr<br>November 2001 |
| Lines of code                                                     |                                                                                                                                                                     |
| Under development since                                           |                                                                                                                                                                     |
| Programming language (F77, F90,...) and compiler                  |                                                                                                                                                                     |
| Supported systems (Windows, Linux, MacOS,...)                     |                                                                                                                                                                     |
| Input/Output structure (ASCII, XML, Binary,...)                   |                                                                                                                                                                     |

Information provided by: Xu Cheng, KIT, [xu.cheng3@kit.edu](mailto:xu.cheng3@kit.edu)

## 2.20 SPECTRA

|                  |                                                                                                                                                                                                                                                                                                                                                                                                     |
|------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose  | <b>Initial:</b> LWR<br><b>Current:</b> LWR, HTR, GCFR, LMFR, Conventional plants                                                                                                                                                                                                                                                                                                                    |
| General Features | System code,<br>Main parts:<br><b>Thermal-hydraulics</b><br>2-phase, multiple gases, 1-D flow, Euler equation, no turbulence model.<br>Heat and mass transfer including natural, forced convection, full boiling curve, condensation, conduction in 1-D and 2-D, thermal radiation: net enclosure with participating gas.<br><b>Reactor kinetics</b><br>Point kinetics with delayed neutrons, decay |

|                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                   | <p>chains, including poisons, Xe, Sm, etc.</p> <p><b>Radioactive Particles</b></p> <p>Aerosol (including dust from graphite abrasion) transport, deposition, and resuspension.</p> <p>Fission product release (applicable to LWR), transport, sorption on structures and dust.</p> <p><b>Oxidation model</b></p> <p>Reactions of Zr, steel, carbon.</p> <p>General equation with user-defined coefficient can accommodate any other reaction.</p> <p><b>Mathematical Utilities</b></p> <p>Tabular functions, control functions, external data files.</p> <p><b>Input/Output</b></p> <p>Input procedures write echo of input, full interpretation of input, including model settings, default values etc., check all input and write diagnostics on input errors and warnings.</p> <p>Output procedures write output files (main, plot, restart, etc.) and run time diagnostics including warnings and errors.</p> |
| Limitations                                                       | <p>No 3-D flow</p> <p>No 3-D kinetics</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Code development needs (for HTR applicability)                    | <p>Fission product chemistry</p> <p>Dust production model</p> <p>Fission product release model applicable for HTR fuel</p> <p>V&amp;V for water ingress</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Contact person/key information holder (for further question)      | <p>Marek M. Stempniewicz: stempniewicz@nrg.eu</p> <p>Eric A.R. de Geus: degeus@nrg.eu</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Couplings (neutronics, thermal hydraulics, containment codes,...) | <p>Coupling to 3-D flow or 3-D reactor kinetics possible within a general utility package:</p> <p>External Data Files, which can run in a synchronized manner, exchanging data with other programs with user-defined frequency.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| State of validation, References (title of latest publications)    | <p>V&amp;V manual of about 800 pages includes results of test runs, verification and validation runs.</p> <p>Some validation results are published in open literature:</p> <p>“Analysis of PANDA Passive Containment Cooling Steady-State Tests with the Spectra Code”, <i>Nuclear Technology</i>, Vol. <b>131</b>, No. 1, pp. 82-101, July 2000.</p> <p>“Analyses of ISP-42, PANDA tests, with the SPECTRA code”. <i>Proceedings of ICONE-9</i>, Nice, France, 8 April 2001.</p> <p>“Application of SPECTRA on PBMR V704 Design”, <i>Proceedings HTR-2006: 3rd International Topical Meeting on High Temperature Reactor Technology</i>, Johannesburg, South Africa, 1-4 October 2006.</p>                                                                                                                                                                                                                       |

|                                                  |                                                                                                                                                                                                                                                                                                               |
|--------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                  | <p>“Coefficients for I-131 Sorption on Different Surfaces”, Proceedings of the 18th International Conference Nuclear Engineering, ICONE18, Xi'an, China, May 17-21, 2010.</p> <p>“Comparison of Several Resuspension Models Against Measured Data”, Nuclear Engineering and Design, 240 (2010) 1657–1670.</p> |
| Lines of code                                    | About 500,000<br>(including comments)<br>in about<br>900 subroutines.                                                                                                                                                                                                                                         |
| Under development since                          | 1996                                                                                                                                                                                                                                                                                                          |
| Programming language (F77, F90,...) and compiler | F90<br>Compaq<br>Lahey-Fujitsu<br>GNU                                                                                                                                                                                                                                                                         |
| Supported systems (Windows, Linux, MacOS,...)    | Windows<br>UNIX<br>LINUX                                                                                                                                                                                                                                                                                      |
| Input/Output structure (ASCII, XML, Binary,...)  | Main output, ASCII<br>Plot, ASCII<br>Restart, Binary<br>Diagnostics, ASCII<br>Initial Conditions, ASCII<br>External Data Files, ASCII                                                                                                                                                                         |

Information provided by: Marek M. Stempniewicz, NRG, stempniewicz@nrg.eu

## 2.21 TAC-NC

|                                                                   |                                                                                                                                                                                                                                             |
|-------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                                   | HTTR                                                                                                                                                                                                                                        |
| General Features                                                  | Two-dimensional thermal analysis                                                                                                                                                                                                            |
| Limitations                                                       |                                                                                                                                                                                                                                             |
| Code development needs (for HTR applicability)                    | TAC-NC is modified from the analytical code TAC-2D in order to calculate temperature transients in the case of loss of forced cooling accidents of the HTTR (High Temperature engineering Test Reactor) such as a depressurization accident |
| Contact person/key information holder (for further question)      | K. Kunitomi, I. Nishiguchi,<br>Department of HTTR Project. Japan Atomic Energy Research Institute, Oarai-machi, Ibaraki-ken, 319-11, Japan                                                                                                  |
| Couplings (neutronics, thermal hydraulics, containment codes,...) |                                                                                                                                                                                                                                             |
| State of validation, References (title of latest publications)    | Depressorization accident analysis for the FTTR by the TAC-NC<br>K. Kunitomi, I. Nishiguchi, H. Wada, T. Takeda, M. Hishida, Y. Sudo, T. Tanaka, S. Saito<br>August 2003                                                                    |
| Lines of code                                                     |                                                                                                                                                                                                                                             |
| Under development since                                           |                                                                                                                                                                                                                                             |
| Programming language (F77, F90,...) and                           |                                                                                                                                                                                                                                             |

|                                                 |  |
|-------------------------------------------------|--|
| compiler                                        |  |
| Supported systems (Windows, Linux, MacOS,...)   |  |
| Input/Output structure (ASCII, XML, Binary,...) |  |

Information provided by: Xu Cheng, KIT, [xu.cheng3@kit.edu](mailto:xu.cheng3@kit.edu)

## 2.22 THYDEHTGR

|                                                                   |                                                                                                                                                                                                                               |
|-------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                                   | Gas-Cooled Reactor                                                                                                                                                                                                            |
| General Features                                                  | Transient Thermal-Hydraulics of High-Temperature Gas-Cooled Reactor                                                                                                                                                           |
| Limitations                                                       |                                                                                                                                                                                                                               |
| Code development needs (for HTR applicability)                    |                                                                                                                                                                                                                               |
| Contact person/key information holder (for further question)      | Hirano, M., Hada, K. , JAEA                                                                                                                                                                                                   |
| Couplings (neutronics, thermal hydraulics, containment codes,...) |                                                                                                                                                                                                                               |
| State of validation, References (title of latest publications)    | A GFR benchmark: Comparison of transient analysis codes based on the ETDR concept<br>E. Bubelis, D. Castelliti, P. Coddington, I. Dor, C. Fouillet, E. de Geus, T.D. Marshall, W. van Rooijen, M. Schikorr, R. Stainsby, 2008 |
| Lines of code                                                     |                                                                                                                                                                                                                               |
| Under development since                                           |                                                                                                                                                                                                                               |
| Programming language (F77, F90,...) and compiler                  |                                                                                                                                                                                                                               |
| Supported systems (Windows, Linux, MacOS,...)                     |                                                                                                                                                                                                                               |
| Input/Output structure (ASCII, XML, Binary,...)                   |                                                                                                                                                                                                                               |

Information provided by: Xu Cheng, KIT, [xu.cheng3@kit.edu](mailto:xu.cheng3@kit.edu)

## 2.23 TINTE

|                                                |                                                                                                                                                             |
|------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                | HTR                                                                                                                                                         |
| General Features                               | coupled neutronic-thermal hydraulic code for short time transients, explicit handling of the neutron capture resonances for U and Th (?), corrosion effects |
| Limitations                                    | burn-up, equilibrium condition, running in phase, handling of Pu or MA neutron capture resonances, few group spectral calculation                           |
| Code development needs (for HTR applicability) | consistency with VSOP, (TINTE is updated and modified to the code MGT)                                                                                      |
| Contact person/key information holder          | Dr. Kay Nünighoff (GRS)                                                                                                                                     |

|                                                                   |                                                                                                         |
|-------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
|                                                                   | Dr. Stefan Kassermann<br>(FZ Jülich)                                                                    |
| Couplings (neutronics, thermal hydraulics, containment codes,...) | coupled calculation of neutron spectrum, flux distribution, thermal dynamic behavior, corrosion effects |
| State of validation, References (title of latest publications)    | well validated                                                                                          |
| Lines of code                                                     |                                                                                                         |
| Under development since                                           |                                                                                                         |
| Programming language (F77, F90,...) and compiler                  | F77+F90                                                                                                 |
| Supported systems (Windows, Linux, MacOS,...)                     | Windows, Linux                                                                                          |
| Input/Output structure (ASCII, XML, Binary,...)                   | ASCII                                                                                                   |

Information provided by: N. Kohtz, TÜV Rheinland, [Norbert.Kohtz@de.tuv.com](mailto:Norbert.Kohtz@de.tuv.com)  
C. Pohl, TÜV Rheinland, [Christoph.Pohl@de.tuv.com](mailto:Christoph.Pohl@de.tuv.com)

## 2.24 TRAC/AAA

|                                                                   |                                                                                                                                                                                                                                                                          |
|-------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                                   | Transient behaviour of fast-spectrum reactor systems cooled by liquid metal and gas                                                                                                                                                                                      |
| General Features                                                  |                                                                                                                                                                                                                                                                          |
| Limitations                                                       |                                                                                                                                                                                                                                                                          |
| Code development needs (for HTR applicability)                    | Developed based upon a special version of the TRAC-M code, and has inbuilt physical properties of He, LBE, Na, super-critical CO <sub>2</sub> fluids                                                                                                                     |
| Contact person/key information holder (for further question)      | Bubelis, Evaldas; Coddington, Paul [Laboratory for Reactor Physics and Systems Behaviour, Paul Scherrer Institute, CH-5232 Villigen PSI (Switzerland)]; Leung, Waihung [Spallation Neutron Source Division, Paul Scherrer Institute, CH-5232 Villigen PSI (Switzerland)] |
| Couplings (neutronics, thermal hydraulics, containment codes,...) |                                                                                                                                                                                                                                                                          |
| State of validation, References (title of latest publications)    | A GFR benchmark: Comparison of transient analysis codes based on the ETDR concept<br>E. Bubelis, D. Castelliti, P. Coddington, I. Dor, C. Fouillet, E. de Geus, T.D. Marshall, W. van Rooijen, M. Schikorr, R. Stainsby, 2008                                            |
| Lines of code                                                     |                                                                                                                                                                                                                                                                          |
| Under development since                                           |                                                                                                                                                                                                                                                                          |
| Programming language (F77, F90,...) and compiler                  |                                                                                                                                                                                                                                                                          |
| Supported systems (Windows, Linux, MacOS,...)                     |                                                                                                                                                                                                                                                                          |
| Input/Output structure (ASCII, XML, Binary,...)                   |                                                                                                                                                                                                                                                                          |

Information provided by: Xu Cheng, KIT, [xu.cheng3@kit.edu](mailto:xu.cheng3@kit.edu)

## 2.25 TRAC-M

|                                                                   |                                                                                                                                                          |
|-------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose                                                   | LWR                                                                                                                                                      |
| General Features                                                  | Can simulate transient, systemwide, multiphase, thermalhydraulic, and neutronic processes during accident and transient conditions.                      |
| Limitations                                                       |                                                                                                                                                          |
| Code development needs (for HTR applicability)                    | Fuel Element Performance; Dust & Transport & Deposition & Liftoff Code Module in addition to upgrades to the TRAC-M code                                 |
| Contact person/key information holder (for further question)      | Dr. Frank Odar,<br>SMSAB,<br>Division of Systems<br>Analysis and Regulatory Effectiveness, Office<br>of Nuclear Regulatory Research, Washington,<br>D.C. |
| Couplings (neutronics, thermal hydraulics, containment codes,...) |                                                                                                                                                          |
| State of validation, References (title of latest publications)    | PEBBLE BED MODULAR REACTOR<br>Summary of ISL's TRAC-M Code Model<br>Rex Shumway, and Birol Aktas<br>August 2001                                          |
| Lines of code                                                     |                                                                                                                                                          |
| Under development since                                           |                                                                                                                                                          |
| Programming language (F77, F90,...) and compiler                  |                                                                                                                                                          |
| Supported systems (Windows, Linux, MacOS,...)                     |                                                                                                                                                          |
| Input/Output structure (ASCII, XML, Binary,...)                   |                                                                                                                                                          |

Information provided by: Xu Cheng, KIT, [xu.cheng3@kit.edu](mailto:xu.cheng3@kit.edu)

## 2.26 VSOP

|                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Initial Purpose  | HTR (partly also for LWR, FBR)                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| General Features | coupled neutronic-thermal dynamic code for running in phase, steady state conditions and medium to long time transients, explicit handling of the neutron capture resonances beyond the typical resonance absorber materials (MA), 2/3 (partly) dimensional diffusion code with addons for specific problems (control rods, void areas), fuel shuffling, fuel cost calculation, 1dimensional thermal spectral code, calculation of double heterogeneity in thermal energy region |
| Limitations      | short time transients, limited groups for the neutron spectral code ( $\leq 30$ groups), two individual codes one for the thermal/near epithermal spectrum (30                                                                                                                                                                                                                                                                                                                   |

|                                                                   |                                                                                                                                                                                                |
|-------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                   | groups) and one for the epithermal/fast spectrum (68 groups), only limited 3 dimensional geometries                                                                                            |
| Code development needs (for HTR applicability)                    | implementation of a 1 dimensional spectral code for the whole neutron energy range (TOTMOS, under development)                                                                                 |
| Contact person/key information holder                             | Dr. Jochem Rütten (FZ Jülich)                                                                                                                                                                  |
| Couplings (neutronics, thermal hydraulics, containment codes,...) | coupled calculation of neutron spectrum, flux distribution, thermal dynamic behavior, burn-up, artificial transient conditions ( i.e. temperature effects, water ingress, change of fuel type) |
| State of validation, References (title of latest publications)    | well validated                                                                                                                                                                                 |
| Lines of code                                                     |                                                                                                                                                                                                |
| Under development since                                           |                                                                                                                                                                                                |
| Programming language (F77, F90,...) and compiler                  | F77+F90                                                                                                                                                                                        |
| Supported systems (Windows, Linux, MacOS,...)                     | Windows, Linux                                                                                                                                                                                 |
| Input/Output structure (ASCII, XML, Binary,...)                   | ASCII                                                                                                                                                                                          |

Information provided by: N. Kohtz, TÜV Rheinland, [Norbert.Kohtz@de.tuv.com](mailto:Norbert.Kohtz@de.tuv.com)  
C. Pohl, TÜV Rheinland, [Christoph.Pohl@de.tuv.com](mailto:Christoph.Pohl@de.tuv.com)

## 2.1 Additional codes

*These additional code information was provided by N. Kohtz:*

### WIMS (UK)

Coupled 3 dimensional lattice (spectral code, 172 groups) - burn up code, for general nuclear reactor application, developed since 1964

An HTR version comprising also a bespoke thermal hydraulic module WIMSTER has been produced by AMEC (UK) for the National Nuclear Regulator (NNR) of South Africa under the PBMR project.

### PEBBED (INL, USA, Abderrafi M. Ougouag, Hans D. Gougar)

"PEBBED Analysis of Hot Spots in Pebble-Bed Reactors", 2005, INL/CON-05-00575 PREPRINT

comprehensive (spectrum, flux, TH, burn-up, fuel management a.o.) code system for pebble and block type

### DORT/TORT (USA)

neutron transport code, upgrades available for time dependent calculations (TDTORT: Time-Dependent, 3-D, Discrete Ordinates, Neutron Transport Code System with Delayed Neutrons; DORT/TORT-TD (GRS): Time-Dependent, 3-D, Discrete Ordinates, A. Seubert (GRS)), applicable but not focused for HTR

### PANTHERMIX (Holland, NRG, Dr. Kuijper)

based on THERMX-DIREKT (FZJ, D) thermal dynamic code and PANTHER (UK) neutronic code

### SCALE (USA)

ORNL, coupled Monte-Carlo neutronics with thermal dynamic, comprehensive code system, applicable but not focused for HTR

ZIRKUS (IKE Stuttgart, D)

Coupled neutronic (diffusion, partly transport) – thermal dynamic – burn-up code, further developed by IKE for the National Nuclear Regulator (NNR) of South Africa under the PBMR project

RZKIND (IKE Stuttgart, D)

2 dimensional diffusion code for transient HTR application, similar to TINTE, further developed by IKE for the National Nuclear Regulator (NNR) of South Africa under the PBMR project

TRIPOLI (CEA, F)

Monte Carlo neutronic code, time dependent, coupleable to burn up codes, applicable but not focused for HTR

HCP (FZJ, D, Dr. Kassermann)

a combined code system of the VSOP and MGT codes, under development

DYN-3D (FZD /Rossendorf, D, Dr. U. Rohde)

LWR code extended to HTR application, focused on block type, comprise time dependent neutron two-group diffusion code and HELIOS spectrum code, 3 D thermal dynamic calculation, originally focused on LWR with hexagonal block type

COSTANZA-Dragon (F/Italy)

2 dimensional dynamics analysis on a notional prismatic HTR design: COSTANZA-Dragon, 2009, developed since 1973

MCNP/X (USA)

well established neutronic Monte-Carlo-code for a wide range of application, applicable but not focused for HTR

CASMO/SIMULATE (Studsvik)

coupled neutronic diffusion with thermal dynamic , focused on LWR

PSG2 / SERPENT (NEA, VTT)

coupled Monte-Carlo neutronic and burn-up calculations, applicable but not focused on HTR

ORIGEN

burn up code, also used as a module in ZIRKUS

CINDER90 (LANL, USA)

burn up code

VESTA (IRSN, F)

generic coupling of neutronic and burn-up, applicable but not focused on HTR

GAMMA+ (KAERI, SK)

coupled neutronic-thermal dynamic, restricted use

THERMIX-DIREKT (FZ Jülich, D, S. Struth)

thermal dynamic code, 2-D, steady state and time dependent, optimised to analyse HTR specific accidents as LOCA, DLOCA, local leakage a.o., specific module to handle the coolant flow in pebble beds

FRESCO / PANAMA (FZ Jülich, D, K. Verfondern)

release and transport of fission products out of the fuel (typically fuel kernels of coated particles)  
through coating and graphite to the coolant

PEBDYM (AMEC, UK)

The Pebble Bed Modular Reactor Whole Plant Model (PEBDYM) was developed to predict the overall transient performance of the PBMR reactor and power conversion system (PCS) at the macroscopic level. The model thus comprises a simplified thermal hydraulic representation of the PBMR reactor with 1-D neutron kinetics and models of all components of the PBMR power conversion system (turbine, compressors, recuperators, water coolers and connecting piping). The PEBDYM Model has been coded in modular form using the Advanced Continuous Simulation Language (ACSL) and is designed for use with acslXtreme version 2.4.2.1 using FORTRAN compiler Compag Visual Fortran Standard Edition 6.6. All FORTRAN code uses only FORTRAN 90 standard features. PEBDYM has

been developed by AMEC for the National Nuclear Regulator (NNR) of South Africa under the PBMR project. Owing to the modular structure of the code, an adaptation to other power conversion systems than the PBMR direct cycle is feasible for experienced users.

**FPRC (TÜV Rheinland, D. N. Kohtz)**

FPRC is a 1-D finite difference code solving the Diffusion equation for calculating fission product releases from coated particles and fuel spheres. It has been developed by TÜV Rheinland and a sub-supplier for the National Nuclear Regulator (NNR) of South Africa under the PBMR project. The code development was interrupted with the end of the PBMR project. In its current status the code is usable for spot check calculations of releases of metallic fission products at operational and accident temperatures. The code is written in C++ and runs in and was run under Windows.

**Codes developed or enhanced under the PBMR project in South Africa:**

For this project, code development has been performed both on the side of the Regulator (NNR) and on the side of the Designer (PBMR), respectively the License Applicant (Eskom).

Codes developed for the NNR by IKE Stuttgart, by AMEC UK and by TÜV Rheinland are already mentioned in the compilation above (ZIRKUS, RZKIND, FPRC, WIMS/WIMSTER, PEBDYM). With the end of the PBMR project, the ownership of these codes passed over to the License Applicant, Eskom, though some of the codes are physically also in Europe. Eskom's agreement must therefore be sought for use of these codes for new projects.

The PBMR designer, PBMR Pty Ltd, had performed significant and valuable code development and V&V during the PBMR project. HTR-specific codes out of the entire set of codes used in the PBMR licensing process are addressed below. Use of the codes for new projects would need the acceptance of PBMR Pty Ltd and/or Eskom. Key code developers are among the South African organisations which are applying for collaboration with ARCHER.

**VSOP99:**

The code was originally acquired from/licensed by FZJ, Germany. In collaboration with FZJ, Germany, PBMR Pty Ltd has performed significant work on the code, especially regarding formal V&V. Differences between the versions currently established in South Africa and in Germany (see above) should be investigated for advantages of one version to the other.

**TINTE:**

Same situation as with VSOP. PBMR Pty Ltd has spent significant efforts on code and V&V. German (see above) and South African versions should be compared.

**NobleG:**

The code calculates operational releases of gaseous fission products from fuel spheres and the whole core under the assumption that no gaseous fission products are released from intact coated particles. It was originally developed by HRB, Germany (now Westinghouse Germany). PBMR Pty Ltd has performed significant work on the code, especially regarding formal V&V.

**GETTER, FIPREX-GETTER:**

The codes calculate operational and accidental (at elevated temperatures) releases of metallic fission products from fuel spheres and the whole core. They were originally developed by HRB, Germany (now Westinghouse Germany). PBMR Pty Ltd has performed significant work on the codes, especially regarding formal V&V.

**RADAX5:**

The code calculates plate-out and remobilisation of fission products on/from surfaces of the primary circuit. It also comprises a dust distribution model. The code was originally developed by HRB, Germany (now Westinghouse Germany). PBMR Pty Ltd has performed significant work on the code, especially regarding formal V&V.

**Flownex:**

The code is a whole plant code with modular structure. It allows predicting the coupled overall steady state and transient behaviour of the reactor together with its power conversion unit. The calculation model that we know is tailored to the PBMR 400 DPP, but owing to the modular structure of the code, any other power conversion system should be describable. The code has been developed and is distributed by M-tech Company at North-West University, South Africa.

DAMD:

The code has been developed by Eskom/PBMR in the later stages of the PBMR Project. Its purpose is to calculate the fission product source term in the primary circuit of the PBMR. In a top-down integrated system methodology the code calculates the activation of graphite impurities, the migration of graphite and metallic dust, the transport of atomic species with the coolant and their plate-out, and the activation of nuclides in dust and coolant. The code has also been applied to the AVR and the results were presented at the HTR2008 Conference in Washington, DC (HTR2008-58338).

*These additional code information was provided by M. Fütterer, JRC*

Reactor physics

NJOY99, TRANSX, MCNP/MCNPX/CINDER90, SERPENT, MCB, EASY2005, PARCS, PARTSN4, NESTLE5.2.1, DIF3D/VARIANT, SCALE5.1, SUS3D

Thermal-hydraulics, Computational Fluid Dynamics, System Codes

TRACE, RELAP5, COBRA-IV, ANSYS CFX

Thermal-mechanics

FRETA-B, ANSYS, ABAQUS

Coupled code systems

MCNP/FISPACT, MCNPX-COBRA-IV-FRETA-B

Severe Accident Analysis

SAS4A, ASTEC

Hydrogen explosion modelling

REACFLOW

Tritium Transport Modelling

He2SG

### 3 Evaluation of Code Inventory

The data collected from the survey, including references, was thoroughly checked and categorised. In the ARCHER meeting in January 2012 in Amsterdam, it was decided not only to collect data for the 'system codes' that are capable of predicting parameters for the whole primary and secondary circuit but also to include the respective couplings to neutron physics codes and/or containment codes. Since at that time the survey was already sent to all participants possibly involved within this field of research, a new survey was not sent. But with the code information gathered, it was possible to do an internet research to check the capabilities of the provided codes and their couplings.

In order to evaluate the capabilities of the various system codes, different categories were introduced into an evaluation table comprising neutronics capabilities, thermal fluid dynamics within the reactor pressure vessel, thermal fluid dynamics for the primary and secondary circuit and also for processes of within the containment. This categorisation should help to identify the capabilities of the different code systems and display possible code improvement needs in order to establish a full primary and secondary circuit simulation (optionally also for containment) for high temperature gas-cooled reactors.

| Explanation for tables |                        |
|------------------------|------------------------|
| +                      | yes                    |
| +(name of code)        | yes, but over coupling |
| -                      | no                     |

| Name of code<br>* Fast reactor codes<br>** Containment codes | Fuel<br>(pebble,<br>block) | Neutronics (1)             |                                     |           |                |           |                |                    |
|--------------------------------------------------------------|----------------------------|----------------------------|-------------------------------------|-----------|----------------|-----------|----------------|--------------------|
|                                                              |                            | XS-Generation              | Method                              | Dimension | Neutron groups | Transient | Fuel shuffling | Burn-up            |
| ACCORD                                                       | block                      | -                          | point kinetics                      | 0d        | -              | +         | -              | -                  |
| ASTEC-V2                                                     | -                          | -                          | (point kinetics)                    | 0d        | -              | +         | -              | -                  |
| ATHLET MOD2.2b                                               | pebble                     | + (HELIOS, SCALE6, DRAGON) | diffusion and transport (TORT-TD)   | 3d        | few group      | +         | -              | -                  |
| ATHLET MOD 2.2 Cycle A w. DYN3D                              | pebble /block(DYN3D)       | -                          | diffusion and SP3 transport (DYN3D) | 3d        | 2              | +         | -              | -                  |
| CATHARE 2(v2.5_1mod3.1)                                      | -                          | -                          | -                                   | -         | -              | -         | -              | -                  |
| CONTAIN                                                      | -                          | -                          | -                                   | -         | -              | -         | -              | -                  |
| DYN3D                                                        | block                      | + (HELIOS, SERPENT)        | diffusion and SP3 transport         | 3d        | multigroup     | +         | ?              | + (SERPENT-1.1.15) |
| GAMMA+                                                       | block /pebble              | -                          | point kinetics                      | 0d        | -              | -         | -              | -                  |

| Name of code<br>* Fast reactor codes<br>** Containment codes | Fuel<br>(pebble,<br>block) | Neutronics (1)             |                                                                                                                          |                                                                                     |                                                    |           |                |                   |
|--------------------------------------------------------------|----------------------------|----------------------------|--------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|----------------------------------------------------|-----------|----------------|-------------------|
|                                                              |                            | XS-Generation              | Method                                                                                                                   | Dimension                                                                           | Neutron groups                                     | Transient | Fuel shuffling | Burn-up           |
| GOTHIC**                                                     | -                          | -                          | -                                                                                                                        | -                                                                                   | -                                                  | -         | -              | -                 |
| FLOWNET                                                      | block/<br>pebble           | -                          | point kinetics                                                                                                           | -                                                                                   | -                                                  | -         | -              | -                 |
| FLOWNEX                                                      | pebble                     | -                          | point kinetics/<br>diffusion (Z-KIND)                                                                                    | 0d, 1d                                                                              | 0, 4                                               | +         | -              | -                 |
| MANTA*                                                       | -                          | -                          | point kinetics                                                                                                           | -                                                                                   | -                                                  | +         | -              | -                 |
| MELCOR                                                       | -                          | -                          | -                                                                                                                        | -                                                                                   | -                                                  | -         | -              | -                 |
| MGT                                                          | pebble<br>block            | +(VSOP)                    | diffusion                                                                                                                | 3d                                                                                  | up to 43                                           | +         | -              | -                 |
| MGT-3D                                                       | pebble<br>block            | +                          | diffusion                                                                                                                | 3d                                                                                  | up to 43                                           | +         | -              | -                 |
| PANTHERMIX                                                   | pebble                     | + (WIMS7)                  | diffusion                                                                                                                | 3d                                                                                  | few groups                                         | +         | +              | +                 |
| RELAP5-3D                                                    | -                          | + (RAMONA,<br>HWR, GEN)    | diffusion                                                                                                                | 3d (NESTLE)                                                                         | 2-4                                                | +         | -              | -                 |
| RELAP5-MOD3.2                                                | -                          | -                          | point kinetics                                                                                                           | multidimension<br>al?                                                               |                                                    | +         | -              | -                 |
| RELAP5-MOD3.3                                                | -                          | -                          | point kinetics,<br>diffusion (PARCS),<br>SP3 transport<br>(PARCS)                                                        | 0d, 1d, 3d, 3d                                                                      | 0, 2                                               | +         | -              | -                 |
| SCDAP/RELAP5/ATH<br>ENA                                      | block                      | -                          | point kinetics                                                                                                           | 0d                                                                                  | -                                                  | +         | -              | -                 |
| SIM-ADS                                                      | -                          | -                          | point kinetics                                                                                                           | 2node model                                                                         | -                                                  | +         | -              | -                 |
| SPECTRA                                                      | block/<br>pebble           | -                          | point kinetics                                                                                                           | 0d                                                                                  | -                                                  | +         | -              | -                 |
| TAC-NC                                                       | -                          | -                          | -                                                                                                                        | -                                                                                   | -                                                  | -         | -              | -                 |
| THYDE-HTGR                                                   | block                      | -                          | point kinetics                                                                                                           | 0d                                                                                  | -                                                  | +         | -              |                   |
| TINTE                                                        | pebble<br>block?           | +(VSOP)                    | diffusion                                                                                                                | 2d                                                                                  | up to 43                                           | +         | -              | -                 |
| TRAC/AAA*                                                    | -                          | + (ERANOS)<br>+ (GENPMAXS) | diffusion, Sn<br>transport, nodal<br>variational transport<br>(ECCO/ERANOS2.<br>0)<br>diffusion, Sn<br>transport (PARCS) | 1d,2d,3d<br>(ECCO/ERAN<br>OS)<br>2d,3d<br>cartesian and<br>non-cartesian<br>(PARCS) | 175<br>(ECCO/ERAN<br>OS),<br>few groups<br>(PARCS) | +         | -              | +<br>(ERANOS<br>) |
| TRAC-M                                                       | pebble                     | -                          | -                                                                                                                        | -                                                                                   | -                                                  | +         | -              | -                 |

| Name of code<br>* Fast reactor codes<br>** Containment codes | Fuel<br>(pebble,<br>block) | Neutronics (1)         |                                               |                              |                                                                        |                         |                |         |
|--------------------------------------------------------------|----------------------------|------------------------|-----------------------------------------------|------------------------------|------------------------------------------------------------------------|-------------------------|----------------|---------|
|                                                              |                            | XS-Generation          | Method                                        | Dimension                    | Neutron groups                                                         | Transient               | Fuel shuffling | Burn-up |
|                                                              | /block                     |                        |                                               |                              |                                                                        |                         |                |         |
| VSOP                                                         | pebble/<br>block?          | + (with coupling)      | diffusion, transport<br>correction            | 2d diffusion,<br>1d spectrum | 30 spectral or<br>less, 30<br>epithermal, 68<br>for<br>fast/epithermal | long term<br>transients | +              | +       |
| WIMS                                                         | pebble                     | +                      | diffusion                                     | 3d                           | 172                                                                    | -                       | +              | +       |
| ZIRKUS                                                       | pebble                     | + (MICROX,<br>MICROX2) | diffusion, transport<br>correction for cavity | 2d diffusion,<br>1d spectrum | 193                                                                    | long term<br>transients | +              | +       |
|                                                              |                            |                        |                                               |                              |                                                                        |                         |                |         |

| Name of code<br>* Fast reactor codes<br>** Containment codes | Thermal fluid dynamics                |            |         |                     |                             |                          | Plant control system (5) | Containment phenomena (6) | Other special features (7)                                               |
|--------------------------------------------------------------|---------------------------------------|------------|---------|---------------------|-----------------------------|--------------------------|--------------------------|---------------------------|--------------------------------------------------------------------------|
|                                                              | Dimensions                            | Transi ent | RPV (2) | Primary circuit (3) | Secondar y circuit/ PCU (4) | Coupled to 1/2/3/4/5/6/7 |                          |                           |                                                                          |
| ACCORD                                                       | 2d                                    | +          | +       | -                   | -                           | 1/2/7                    | -                        | -                         | Loss of forced cooling                                                   |
| ASTEC-V2                                                     | 1d                                    | +          | -       | +                   | +                           | 1/3/4/5/6                | +                        | +                         |                                                                          |
| ATHLET Mod 2.2b                                              | 1d<br>3d (ANSYS)                      | +          | +       | +                   | +                           | 1/2/3/4/5/6/             | +                        | +                         | (COCOSYS)                                                                |
| ATHLET MOD2.2 Cycle A                                        | 1d                                    | +          | +       | +                   | +                           | 1(DYN3D)<br>/2/3/4/5     | +                        | +                         | (COCOSYS)                                                                |
| CATHARE 2(v2.5_1mod3.1)                                      | 1d, 3d                                | +          | +       | +                   | +                           | 2 (FLICA3D)<br>/3/4/5/6  | +                        | +                         | (ICARE)                                                                  |
| CONTAIN**                                                    | 1d                                    | +          | +       | +                   | +                           | 2/3/4/6/7                | -                        | +                         | fission product release, radiologic consequences, aerosol behavior (LWR) |
| DYN3D                                                        | 3d heat conduction<br>1d coolant flow | +          | +       | +                   | +                           | 1/2/3/4/5                | +                        | -                         | heat conduction models for compacts and TRISO                            |
| GAMMA+                                                       | 3d                                    | +          | +       | -                   | -                           | -                        | -                        | -                         | chemical reactions with air and water                                    |
| GOTHIC                                                       | 1d, 2d, 3d                            | +          | -       | -                   | -                           | 6                        | -                        | +                         |                                                                          |

| Name of code<br>* Fast reactor codes<br>** Containment codes | Thermal fluid dynamics                          |            |         |                     |                             |                                                  | Plant control system (5) | Containment phenomena (6) | Other special features (7)                                                      |
|--------------------------------------------------------------|-------------------------------------------------|------------|---------|---------------------|-----------------------------|--------------------------------------------------|--------------------------|---------------------------|---------------------------------------------------------------------------------|
|                                                              | Dimensions                                      | Transi ent | RPV (2) | Primary circuit (3) | Secondar y circuit/ PCU (4) | Coupled to 1/2/3/4/5/6/7                         |                          |                           |                                                                                 |
| FLOWNET                                                      | 1d, 2d                                          | +          | +       | +                   | +                           | 1/2/3/4/5/7                                      | +                        | -                         | contains models for helium heat exchanger, helium turbine                       |
| FLOWNEX                                                      | 1d, 2d                                          | +          | +       | +                   | +                           | 1/2/3/4/5/7                                      | +                        | -                         | contains models for helium heat exchanger, helium turbine                       |
| MANTA*                                                       | 1d                                              | +          | +       | +                   | +                           | 2/3/4/5/7                                        | +                        | -                         | gas-cooled fast reactors                                                        |
| MELCOR                                                       | 1d                                              | +          | +       | +                   | +                           |                                                  | +                        | +                         | chemical reactions for air ingress                                              |
| MGT                                                          | 3d                                              | +          | +       | +                   | -                           | 1/2/3/7                                          | -                        | -                         | chemical reactions for air and water ingress                                    |
| MGT-3D                                                       | 3d                                              | +          | +       | +                   | -                           | 1/2/3/7                                          | -                        | -                         | chemical reactions for air and water ingress                                    |
| PANTHERMIX                                                   | 2d                                              | +          | +       | -                   | -                           | 1/2/                                             | -                        | -                         |                                                                                 |
| RELAP5-3D                                                    | 3d                                              | +          | +       | +                   | +                           | 1/2/3/4/5/6/7                                    | +                        | +                         | (MELCOR)                                                                        |
| RELAP5-MOD3.2                                                | 1d                                              | +          | +       | +                   | +                           | 1/2/3/4/5/                                       | +                        | +                         | (MELCOR)                                                                        |
| RELAP5-MOD3.3                                                | 1d<br>3d (FLUENT)                               | +          | +       | +                   | +                           | 1/2/3/4/5/                                       | +                        | +                         | (MELCOR)                                                                        |
| SCDAP/RELAP5/ATHENA                                          | 2d conduction, 1d flow                          | +          | +       | +                   | +                           | 1/2/3/4/5/                                       | +                        | +                         | air ingress simulation, chemical reaction for air ingress                       |
| SIM-ADS*                                                     | 1d                                              | +          | +       | -                   | -                           | 1/2                                              | -                        | -                         | sub-critical accelerator driven systems                                         |
| SPECTRA                                                      | 1d, 2d conduction, 1d flow, radiation multi-gas | +          | +       | +                   | +                           | 1/2/3/4/7 can be coupled to 3-d reactor kinetics | -                        | -                         | chemical reaction for air ingress, water ingress (development), fission product |

| Name of code<br>* Fast reactor codes<br>** Containment codes | Thermal fluid dynamics |           |         |                     |                                                  |                          | Plant control system (5) | Containment phenomena (6) | Other special features (7)                                                                      |
|--------------------------------------------------------------|------------------------|-----------|---------|---------------------|--------------------------------------------------|--------------------------|--------------------------|---------------------------|-------------------------------------------------------------------------------------------------|
|                                                              | Dimensions             | Transient | RPV (2) | Primary circuit (3) | Secondary circuit/PCU (4)                        | Coupled to 1/2/3/4/5/6/7 |                          |                           |                                                                                                 |
|                                                              | components             |           |         |                     |                                                  |                          |                          |                           | release, aerosol (includes) transport deposition and resuspension                               |
| TAC-NC                                                       | 2d                     | +         | +       | +                   | -                                                | 2                        | -                        | -                         | HTTR tailored from TAC-2D                                                                       |
| THYDE-HTGR                                                   | 1d                     | +         | +       | +                   | +                                                | 1/2/3/4/5                | +                        | -                         |                                                                                                 |
| TINTE                                                        | 2d                     | +         | +       | +                   | -                                                | 1/2/3                    | -                        | -                         |                                                                                                 |
| TRAC/AAA*                                                    | 1d, 3d                 | +         | +       | +                   | +                                                | 1/2/3/4/5?/7             | -                        | -                         | Special version of TRAC-M, has helium properties<br>Coupled to FRED (fuel rod performance code) |
| TRAC-M*                                                      | 1d, 3d                 | +         | +       | +                   | +(RELAP5-SHAFT)<br>need for new he-turbine model | 1/2/3/~4/5               | -                        | -                         |                                                                                                 |
| VSOP                                                         | 2d                     | +         | +       | -                   | -                                                | 1/2                      | -                        | -                         |                                                                                                 |
| WIMS                                                         | 2d (WIMSTER)           | +         | +       | -                   | -                                                | 1/2                      | -                        | -                         |                                                                                                 |
| ZIRKUS                                                       | 2d (THERMIX/KO NVEK)   | +         | +       | -                   | -                                                | 1/2                      | -                        | -                         |                                                                                                 |
|                                                              |                        |           |         |                     |                                                  |                          |                          |                           |                                                                                                 |



## 4 Annex

### 4.1 Document approval by beneficiaries' internal QA

Fill involved beneficiaries as appropriate (mandatory for Milestones and Deliverables, but optional for other document type)

| #  | Name of beneficiary | Approved by | Function | Date |
|----|---------------------|-------------|----------|------|
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