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M. Kunick, R. A. Berry, R. C. Martineau, H.-J. Kretzschmar and *U. Gampe*

Application of the new IAPWS Guideline on the fast and accurate calculation of steam and water properties with the Spline-Based Table Look-Up Method (SBTL) in RELAP-7

The numerical simulation of thermalhydraulic processes in nuclear power plants requires very accurate and extremely fast algorithms for calculating the thermophysical properties of water and steam. In order to provide such algorithms, the International Association for the Properties of Water and Steam (IAPWS) has adopted the new "IAPWS Guideline on the Fast Calculation of Steam and Water Properties with the Spline-Based Table Look-Up Method (SBTL)". In this article, the SBTL method is applied to property functions of specific volume and specific internal energy (v,e) based on the scientific formulation IAPWS-95 and the latest IAPWS formulations for transport properties. From the newly generated SBTL functions, thermodynamic and transport properties as well as their derivatives and inverse functions are calculable in the fluid range of state for pressures up to 100 MPa and for temperatures up to 1273 K, including the metastable liquid and the metastable vapor regions. The SBTL functions reproduce the underlying formulations with an accuracy of 10–100 ppm and significantly reduced computing times. The SBTL method has been implemented into the nuclear reactor system safety analysis code RELAP-7 [2] to consider the real fluid behavior of water and steam in a novel 7-equation two-phase flow model.

Anwendung der neuen IAPWS-Richtlinie zur schnellen und genauen Berechnung der Eigenschaften von Wasser und Wasserdampf mit dem Spline-Basierten Table-Look-up-Verfahren (SBTL) in RELAP-7. *Die numerische Simulation thermohydraulischer Prozesse in Kernkraftwerksanlagen erfordert sehr genaue und extrem schnelle Stoffwert-Berechnungsalgorithmen für Wasser und Wasserdampf. Zu diesem Zweck hat die International Association for the Properties of Water and Steam (IAPWS) die neue „IAPWS Guideline on the Fast Calculation of Steam and Water Properties with the Spline-Based Table Look-Up Method (SBTL)" [1] verabschiedet. In diesem Beitrag wird das SBTL Verfahren auf Stoffwertfunktionen von spezifischem Volumen und spezifischer innerer Energie (v,e) basierend auf der wissenschaftlichen Formulierung IAPWS95 und den neuesten IAPWS Standards für Transporteigenschaften angewendet. Mit den neuen SBTL Funktionen lassen sich die thermodynamischen Zustandsgrößen und Transporteigenschaften sowie deren Ableitungen und Umkehrfunktionen im fluiden Zustandsgebiet bei Drücken bis zu 100 MPa und Temperaturen bis zu 1273 K, inklusive der metastabilen Gebiete für überhitzte Flüssigkeit und unterkühltes Gas, berechnen. Die SBTL Funktionen geben die zugrundeliegenden Formulierungen mit einer Genauigkeit von 10–100 ppm und erheblich reduzierten Rechenzeiten wieder. Das SBTL Verfahren wurde in den zur Sicherheitsanalyse von Kernreaktorsystemen entwickelten Code RELAP-7 [2] implementiert um das reale Zustandsverhalten von Wasser und Wasserdampf in einem neuen 7-Gleichungsmodell für die Zweiphasenströmung zu berücksichtigen.*

1 Introduction

The analysis of thermalhydraulic processes in nuclear power plants with numerical simulations is of particular importance for safety assessment and the development of advanced technologies. For these simulations, system codes and Computational Fluid Dynamics (CFD) are widely in use. In particular, the detailed analysis of transient processes is computationally intensive and requires long computing times. A large portion of the computing time is demanded for the calculation of fluid properties. In the thermalhydraulic system code RELAP-7 [2] as well as in density based CFD solvers, fluid properties are most frequently calculated from specific volume and specific internal energy (v,e). Furthermore, numerically consistent inverse functions of pressure and temperature (p,T), pressure and specific volume (p,v), pressure and specific enthalpy (p,h), pressure and specific entropy (p,s), and specific enthalpy and specific entropy (h,s) are required. The calculation of these property functions from accurate fundamental equations of state, such as the IAPWS Formulation 1995 for General and Scientific Use (IAPWS-95) [3, 4] for water and steam, requires iterative algorithms leading to inacceptable computing times. For faster property calculations, the IAPWS Industrial Formulation 1997 (IAPWS-IF97) [5, 6] and its supplementary releases on backward equations [7–10] enable computations of functions in dependence of (p,T), (p,h), (p,s), and (h,s) without iterative procedures. Due to the imperfect numerical consistency with the basic equations of IAPWS-IF97, the application of backward equations for simulating processes with small spatial and time discretization can lead to convergence problems. In these situations, inverse functions must be calculated by iteration from the basic equations with starting values determined from the available backward equations. Backward equations do not exist for functions of (v,e) and (p,v) or for fluids other than water and steam. Therefore, property calculations are often simplified,