

謝辞

本研究を遂行するにあたり、日頃より適切な御教授、御鞭撻を賜りました本研究室の指導教官である筑波大学 機能工学系 阿部 豊助教授ならびに同大学成合 英樹名誉教授に心から感謝の意を表します。また、日頃より有益な御助言、御協力を頂きました九州大学 化学工学部門 松隈 洋介助教授に心から感謝の意を表します。

また、本研究を遂行するにあたり有益な御助言、御協力を頂くとともに、貴重なデータを提供してくださいました日本原子力研究所丸山 結氏、森山 清史氏、渡辺 正氏、海老原 健一氏に心から感謝の意を表します。

文中に記載した蒸気膜崩壊実験およびPIV解析は日本原子力研究所 八木理公氏、三菱化工機 小林朋能氏、曙ブレーキ 出口幹氏、富士通フロンテック（株）柳田洋志氏ならびに三機工業（株） 小河秀行氏の甚大なる賜物であり、ここに感謝の意を表します。また、実験装置製作にあたり多大なる御協力を頂いた米沢放電工業株式会社に心から感謝の意を表します。

参考文献

- [1] Long, G., "Explosions of Molten Metals in Water - Cause and Prevention", Metals Prog., Vol. 71, pp.107-112 (1957).
- [2] Epstein, L. F., GEAP-3335 (1980).
- [3] Lipsett, S. G., Fire Tech. 2-118 (1966)
- [4] Sallac, J. A., Pulp and Paper Magazine of Canada, Vol. 56, pp.114 (1955).
- [5] Enger, T. and Hartman, D., Proc. of the 3rd Conf. on Liquified Natural Gas, Washington D.C. (1972).
- [6] Katz, D. L. and Sliepcevich, C. M., Hydrocarbon Processing, November, pp.240 (1971).
- [7] Thompson T. J. and Beckerly, J. G, The Technology of Nuclear Safety (MIT Press), Vol. 1, pp.672 (1964).
- [8] Hatfield, G. W., Mech. Eng., Vol. 77 (1955).
- [9] Zinn, W. H., Nucleonics, Vol. 14 (1955).
- [10] Fauske, H. K., "On the Mechanism of Uranium Dioxide-Sodium Explosive Interactions", Nucl. Sci. Eng., Vol. 51, pp.95-101 (1973).
- [11] Board, S. J. et al., "Detonation of Fuel Coolant Explosions", Nature, Vol. 254, pp.319-321 (1975).
- [12] Board, S. J. and Hall R. W., Proc. of the 3rd Specialist Meeting on Na/Fuel Interactions in Fast Reactors, Tokyo, Japan, pp.249 (1976).
- [13] Hall. W. B., OECD/CSNI Meeting Argonne, I11, (1977)
- [14] Anderson, R. P. and Armstrong D. R., Annual ASME Winter Meeting, Nucl. Reactor Safety Heat Transfer Section, Atlanta, Georgia, pp.31 (1977).
- [15] Bankoff, S. G. and Jo, J. H., NU2512-8 (1976).
- [16] Simpkins, P. G. and Bales, E.L., "Water-Drop Response to Sudden Accelerations", J. Fluid Mech., Vol. 55(4), pp.629-639 (1972).
- [17] Newman, R. N. et al., Proc. of Liquid Alkali Metals, Nottingham, pp.85 (1973)
- [18] Ciccarelli, G. and Frost, D. L., "Fragmentation Mechanisms Based on Single Drop Experiments Using Flash X-Ray Photography", Proc. 5th Int. Top. Mtg. on Nucl. Reactor Thermal Hydraulics, pp.615-626 (1995).
- [19] Ciccarelli, G. and Frost, D. L., "Fragmentation Mechanisms Based on Single Drop Steam Explosion Experiments Using Flash X-Ray Radiography", Nucl. Eng. Design, Vol. 146, pp.109-132 (1994).
- [20] Dullforce, T. A. et al., "Self-triggering of scale fuel-coolant interactions: Experiment", J. Phys. D, Vol. 9, pp.1295 (1976).
- [21] Epstein, L. F., Nucl. Sci. Eng., Vol.55, pp.462 (1974)
- [22] Ivins, R. O. et al., ANL-7399 (1967).
- [23] Nelson, L. S. and Duda, P. M., "Steam Explosion Experiments with Single Drops of Iron Oxide Melted with a CO₂ Laser", High Temp. - High Pres., Vol. 14, pp.259-281 (1982).
- [24] Nelson, L. S. et al., "Photographic Evidence for the Mechanism of Fragmentation of a Single Drop of Melt in Triggered Steam Explosion Experiments", J. Non-Equilib. Thermodyn., Vol. 13, pp.27-55 (1988).
- [25] Swift, D. L. and Pavlik , J., ANL-7125, pp.187 (1966)
- [26] Witte, L. C., et al., "Heat transfer fragmentation during molten-metal/water interactions", J. Heat Transfer,

- Vol. 95, pp.521 (1973).
- [27] Wright, R. W. and Humberstone G. H., Trans. ANS, Vol. 9, pp.305 (1966).
- [28] Darby, K. et al., Int. Conf. on Eng. of Fast Reactor for Safe and Reliable Operation, Karlsruhe, pp.898 (1972).
- [29] Inoue, A. and Bankoff, S. G., "Destabilization of Film Boiling due to Arrival of Pressure Shock (Part I: Experimental)", J. Heat Transfer, Vol. 103, pp.459-464 (1981).
- [30] 飯田ら、「高温液小滴と低沸点液による蒸気爆発の機構に関する研究(第1報、単一液による実験)」, 日本機械学会論文集B編, Vol. 52(476), pp.1777-1783 (1986).
- [31] 庄司ら,「静止溶融すず～流水系で生じる小規模水蒸気爆発に関する実験的研究」, 日本機械学会論文集B編, Vol. 49(476), pp.2190-2199 (1983).
- [32] Tsuruta, T. et al. Nucl. Sci. Tech., Vol. 22, pp.742 (1985).
- [33] 飛田ら, 第22回伝熱シンポジウム講演論文集, A212 (1985).
- [34] Matsumura, K. and Nariai, H., "Self Triggering Mechanism of Vapor Explosions for the Molten Tin and Water System", Nucl. Sci. Tech., Vol. 33(4), pp.298-306 (1996).
- [35] Yamano, N. et al., "Study of Premixing Phase of Steam Explosion in ALPHA Program", Proc. CSNI Specialist Mtg. on Fuel-Coolant Interactions, NUREG/CP-0127, pp.1-17 (1995).
- [36] Moriyama, K. et al., "ALPHA Visual Data Collection STX005-025: Melt Drop Steam Explosion Experiments", JAERI-DATA/CODE 99-017 (1999).
- [37] Sugimoto, J. et al., "Fuel-Coolant Interaction Experiments in ALPHA Program", Proc. 5th Int. Top. Mtg. on Nucl. Reactor Thermal Hydraulics, pp.890-897 (1992).
- [38] Nagasaka, H. et al., "COTELS Project (1): Overview of Project to Study FCI and MCCI during Severe Accident", OECD Workshop on Ex-Vessel Debris Coolability, November 1999 (to be published).
- [39] Nagasaka, H. et al., "COTELS Project (3): Ex-vessel Debris Cooling Tests", OECD Workshop on Ex-Vessel Debris Coolability, November 1999 (to be published).
- [40] Huhtiniemi, I. et al., "Results of Recent KROTOS FCI Tests: Alumina vs. Corium Melts", Proc. OECD/CSNI Specialists Mtg. on Fuel-Coolant Interactions, Tokai-mura, Japan, pp.275-286 (1997).
- [41] Huhtiniemi, I. et al., "Results of Recent KROTOS FCI tests: Alumina versus Corium Melts", Nucl. Eng. Design, Vol. 189, pp.379-389 (1999).
- [42] Annunziato, A. et al., "FARO and KROTOS Code Simulations and Analysis at JRC Ispra", Nucl. Eng. Design, Vol. 189, pp.359-378 (1999).
- [43] Annunziato, A. et al., "FARO and KROTOS Code Simulation and Analysis at JRC Ispra", Proc. OECD / CSNI Specialists Mtg. on Fuel-Coolant Interactions, Tokai-mura, Japan, Vol. 2, pp.751-768 (1997).
- [44] Magallon, D. and Hohmann, H., "Energetic Event in Fuel-Coolant Interaction Test FARO L-33", 9th Int. Conf. on Nucl. Eng. (ICON-E-9), pp.1-8 (2001).
- [45] Marshall, B. W. et al., "Recent Intermediate-Scale Experiments on Fuel-Coolant Interactions in an Open Geometry (EXO-FITS)", SAND85-1615C (Proc. Int. ANS/ENS Top. Mtg. on Thermal Reactor Safety), Vol. 1, pp.2-5-1-2-5-8 (1986).
- [46] Mitchell, D. E. and Evans, N. A., "Steam Explosion Experiments at Intermediate Scale: FITSB Series", NUREG/CR-3983 (1986).
- [47] Kim, B. and Corradini, M. L., "Modeling of Small-Scale Single Droplet Fuel/Coolant Interactions", Nucl.

Sci. Eng., Vol. 98, pp.16-28 (1988).

- [48] Annunziato, A. and Addabbo, C., "COMETA (core melt thermal-hydraulic analysis) a computer code for melt quenching analysis", Proc. CSNI Specialists Meeting on FCI, Santa Barbara, U. S. (NUREG / CP-0127), pp.233-250 (1993).
- [49] Thyagaraja, A. and Fletcher, D.F., "Buoyancy driven, transient, two-dimensional thermal-hydrodynamics of a melt-water-steam mixture", Computers and Fluids, Vol. 16, pp.59-80 (1988).
- [50] Fletcher, D. F., "Propagation Investigations Using CULDESAC Model", Proc. CSNI Specialists Mtg. on Fuel-Coolant Interactions, Santa Barbara, pp.180-192 (1993).
- [51] Davis, F. J. and Young, M. F., "Integrated fuel-coolant interaction (IFCI 6.0) code, user's manual", Technical Report NUREG / CR-6211, SAND94-0406, U. S. Nuclear Regulatory Commission (1994).
- [52] von Berg, E. et al., "Modeling of the Breakup of Melt Jets in Liquids for LWR Safety Analysis", Nucl. Eng. Design, Vol. 149, pp.419-429 (1994).
- [53] Burger, M. et al., "Breakup of Melt Jets as Pre-Condition for Premixing: Modeling and Experimental Verification", Nucl. Eng. Design, Vol. 155, pp.215-251 (1995).
- [54] Addabbo, C. et al., "Synopsis of the Results of ISP-39 on FARO Test L-14", Proc. OECD / CSNI Specialists Mtg. on Fuel-Coolant Interactions, Tokai-mura, Japan, Vol. 2, pp.493-566 (1997).
- [55] Kolev, N. I., "The code IVA3 for modeling of transient three-phase flows in complicated 3D geometry", Kerntechnik, Vol. 58(3), pp. 147-156 (1993).
- [56] Kolev, N. I., "Verification of the IVA4 Film Boiling Model with the Data Base of Liu and Theofanous", Proc. OECD / CSNI Specialists Mtg. on Fuel-Coolant Interactions, Tokai-mura, Japan, Vol. 2, pp.699-721 (1997).
- [57] Jacobs, H. et al., "Constitutive Relations for Multiphase Flow Modeling", Proc. OECD / CSNI Specialists Mtg. on Fuel-Coolant Interactions, Tokai-mura, Japan, Vol. 1, pp.205-218 (1997).
- [58] Moriyama, K. et al., "Study of premixing phase of steam explosion with jasmine code in ALPHA program", Proc. of 4th Int. Conf. on Nucl. Eng., New Orleans, Vol. 1B, pp.903-915 (1996).
- [59] Moriyama, K. et al., "Three-Component Melt Jet Breakup Model for FCI Analysis", Proc. Workshop on Severe Accident Research, Japan (SARJ-99) (1999).
- [60] Yang, Y. et al., "JASMINE-PRO a Code for the Propagation Phase on Steam Explosion", 1st Korea-Japan Symposium on Nucl. Thermal Hydraulics and Safety, pp.511-518 (1998).
- [61] Brayer, C. and Berthoud, G., "First Vapor Explosion Calculations Performed with MC3D Thermal-Hydraulic Code", Proc. OECD / CSNI Specialists Mtg. on Fuel-Coolant Interactions, Tokai-mura, Japan, Vol. 1, pp.391-409 (1997).
- [62] Picchi, S. and Berthoud, G., "MC3D Modeling of Stratified Explosion", Proc. Workshop on Severe Accident Reseach held in Japan (SARJ-98), pp.370-375 (1998).
- [63] Theofanous, T. G. et al., "The Verification Basis of the PM-ALPHA Code", Nucl. Eng. Design, Vol. 189, pp.59-102 (1999).
- [64] Theofanous, T. G. et al., "The Verification Basis of the ESPROSE.m Code", Nucl. Eng. Design, Vol. 189, pp.103-138 (1999).
- [65] 内藤ら,「軽水炉発電プラントの事故シミュレーションシステム IMPACT の開発」, 日本原子力学
会誌, Vol. 41(3), pp.174-201 (1999).

- [66] Vierow, K. et al. "Development of the VESUVIUS module: molten jet breakup modeling and model verification", Proc. OECD/CSNI Specialists Meeting on Fuel-Coolant Interactions, Tokai-mura, Japan, 1997, JAERI-Conf 97-011, NEA/CSNI/R(97)26, pp541-565 (1997).
- [67] Morita, K. et al., "SIMMER-III: Applications to Fuel-Coolant Interactions", Proc. OECD / CSNI Specialists Mtg. on Fuel-Coolant Interactions, Tokai-mura, Japan, Vol. 2, pp.785-803 (1997)
- [68] Chu, C.-C. et al., "A code manual for TEXAS-V: One dimensional transient fluid model fuel-coolant interaction analysis", <http://silver.ncep.wisc.edu/~NSRC/texas>.
- [69] Hong, S. W. et al., "Overview of KAERI Fuel-Coolant Interaction Test", Proc. Workshop on Severe Accident Research, Japan (SARJ-99) (1999).
- [70] Sienicki, K. K. et al., "Analysis of Melt Arrival Conditions on the Lower Head in US LWR Configurations", Proc. 5th Int. Top. Mtg. on Nucl. Reactor Thermal Hydraulics (NURETH-5), Vol. 2, pp.450-460 (1992).
- [71] Bang, K. H. et al., "TRACER-II: A Complete Computational Model for Mixing and Propagation of Vapor Explosions", Proc. OECD / CSNI Specialists Mtg. on Fuel-Coolant Interactions, Tokai-mura, Japan, Vol. 2, pp.804-817 (1997).
- [72] Rothman, D. H. and Zaleski, S., "Lattice Gas Cellular Automata", Cambridge Univ.Press (1997)
- [73] Rothman, D. H., "Cellular-Automaton Fluids: A Model for Flow in Porous Media", Geophys., Vol. 53(4), pp.509-518 (1988).
- [74] Rothman, D. H., "Macroscopic Laws for Immiscible Two-Phase Flow in Porous Media: Results from Numerical Experiments", J. Geophys.Res., Vol. 95(B6), pp.8663-8674 (1990).
- [75] Rothmann, D. H. and Zaleski, S., "Lattice gas models of phase separation: interfaces, phase transitions and multiphase flow", Rev. Modern Phys., Vol. 66(4), pp.1417-1479 (1994).
- [76] Wolf-Gladrow, D. A. et al., "Numerical Simulations of Hydrodynamics with a Pair Interaction Automaton in Two Dimensions", Comp. Sys., Vol. 4, pp.139-150 (1990).
- [77] Nadiga, B. T. and Sturtevant, B., "Shock Structure in a Nine-Velocity Gas", Physica D, Vol. 73, pp.205-216 (1994).
- [78] Frisch, U. et al., "Lattice-Gas Automata for the Navier-Stokes Equation", Phys. Rev. Lett., Vol. 56(14), pp.1505-1508 (1986).
- [79] Rothman, D. H. et al., "Immiscible Cellular Automaton Fluids", J. Statistical Physics, Vol. 52, pp.1119-1127 (1988).
- [80] Rothman, D. H. et al., "Immiscible Cellular Automaton Fluids", Lattice Gas Methods for Partial Differential Equations, pp.275-281 (1990).
- [81] Lifshitz, I. M. and Slyozov V. V., "The Kinetics of Precipitation from Supersaturated Solid Solutions", J. Phys. Chem. Solids, Vol. 19(1), pp.35-50 (1961).
- [82] 松隈ら, 「格子ガスオートマトン法による二成分流体の凝集・分離の数値計算」, 日本機械学会論文集B編, Vol. 66(652), pp.3049-3055 (2000).
- [83] 松隈洋介、高橋亮一, 「流入・流出部の境界条件に対するセルラオートマトン表現」, 日本機械学会論文集B編, Vol. 61(588), pp.2826-2832 (1995).
- [84] 松隈ら, 「格子ガスオートマトン法を用いた複雑形状流路内の流動解析」, 日本混相流学会誌, Vol. 13(2), pp.126-137 (1999).