公務出國報告（出國類別：研討會）

參加第十一屆國際核能熱水流運轉及安全專題會議

服務機關：行政院原子能委員會

姓名職稱：江庚晏副研究員

出國地區：韓國

出國期間：105 年 10 月 8 日至 105 年 10 月 14 日

報告日期：105 年 11 月 28 日

摘要

核能熱水流運轉及安全專題會議 (International Topical Meeting on Nuclear Thermal-Hydraulics, Operation and Safety, NUTHOS) 之目的為提供各國核能產業與學術機構交流研發技術成果與工程實務經驗之平台，第一屆會議自 1984 年在台北舉行，之後每二到四年舉辦一次，本次第十一屆會議於 105 年 10 月 9 日至 105 年 10 月 13 日假韓國慶州舉行。本次會議由韓國核能協會 (Korean Nuclear Society, KNS) 及美國核能協會 (American Nuclear Society, ANS) 共同贊助，以及協同各國際組織如中國核能協會 (Chinese Nuclear Society, CNS) 和加拿大核能協會 (Canadian Nuclear Society, CNS) 等共同辦理。與會人員來自歐亞美洲，共有 351 篇論文發表。本會核能安全管制研究中心試運組發表研究論文獲接受並派員前往參加會議與各方專家進行意見交流，前往了解國際熱水流最新研究成果、應用、及未來發展方向，俾於我國核能管制技術發展。

目錄

壹、 目的

　　行政院原子能委員會 (以下簡稱本會) 未來將成立派出單位「核能安全管制研究中心」，該中心將承接研發重任。為加速經驗傳承，及早培育高素質核安管制專業人才，精進管制技術能量，故派遣人員參加國際會議「第十一屆核能熱水流運轉及安全專題會議」(11th International Topical Meeting on Nuclear Thermal-Hydraulics, Operation and Safety, NUTHOS-11)，以因應本會針對核電廠事故分析之需求及提昇我國核能安全管制技術之能力。本會核能安全管制研究中心試運組本屆會議投稿研究論文獲接受，主要作者為江庚晏副研究員，在廖俐毅博士及王士珍博士的共同指導下完成此論文。核能安全管制研究中心試運組派江員赴韓國慶州發表研究成果並接受專家檢視，同時進行意見交流，前往了解國際熱水流最新研究成果、應用、及未來發展方向，以利我國核能管制技術發展。

貳、 行程

　　本次公差行程係參加第 11 屆核能熱水流及運轉安全專題會議，並簡報研究成果。行程自民國 105 年 10 月 8 日起至 105 年 10 月 14 日止，共計 7日，概要如表一，會議研究專題領域表如表二。會議相關照片詳圖一至圖四。

表一、出國行程

日期	行程	摘要
10 月 8 日	桃園國際機場-韓國釜山機場-慶州	去程
10 月 9 日 | 10 月 13 日	慶州	參加第 11 屆國際核能熱水流運轉及安全專題會議 (NUTHOS-11)，簡報研究成果。
10 月 14 日	慶州-韓國釜山機場-桃園國際機場	回程

1. Fundamental Thermal-Hydraulics

1.1 Single- and Two-Phase Flow Fundamentals

1.2 Sub-channel Flow Dynamics and Analysis

1.3 CHF and post-CHF Heat Transfer

1.4 Boiling and Condensation Heat Transfer

1.5 Nano-Fluid Thermal-Hydraulics

2. Computational Thermal-Hydraulics

2.1 Advances in Numerical Methods and Modeling

2.2 Code Development and V&V

2.3 CFD Application to Nuclear Reactor System Design and Safety Analysis

2.4 Multi-Scale and Multi-Physics Calculations

2.5 Accuracy and Uncertainty Analysis including CFD Codes

3. Experimental Thermal-Hydraulics

3.1 Experiments for Code Verification and Validation

3.2 Containment Tests and Analysis

3.3 Steam Generator Thermal-Hydraulic Experiment and Analysis

3.4 Passive System Performance Test and Analysis

4. Multi-disciplinary Thermal-Hydraulics

4.1 Thermal-Hydraulic Loads and Flow-Induced Vibration

4.2 Thermal-Hydraulics Related to Nuclear Fuel Safety

4.3 Thermal-Hydraulics with Materials and Water Chemistry

4.4 Multi-Physics Experiments and Analysis

5. Severe Accidents

5.1 Severe Accident Analysis and Accident Management

5.2 Degraded Core Thermal-Hydraulics

5.3 Fuel-Coolant Interaction and Steam Explosion

5.4 Hydrogen and Fission Product Behavior

5.5 Advanced Design Features for Severe Accident Mitigation

6. Plant Operation and Maintenance

6.1 Plant Transients and Accidents Analysis and Testing

6.2 Plant Licensing Renewal and Life Extension

6.3 Plant Reliability Improvement and Safety Culture

6.4 Risk-Informed and Performance-Based Regulation

6.5 Application of Big Data for Plant Diagnosis

7. Plant Diagnostics and Monitoring

7.1 Steam Generator Operation and Maintenance

7.2 Plant Simulators, Analyzers, Operator Training

7.3 PRA Applications to Design, Operation and Maintenance

7.4 Waste Management and Spent Fuel Pool Thermal Hydraulics

7.5 Environmental Nuclear Safety

8. Advances in Measurements and Instrumentations

8.1 Advanced Flow Visualization Techniques

8.2 Advanced Radiation Measurement Techniques

8.3 Advanced Measurement Techniques for Non-Aqueous and Extreme Environment

8.4 Application of Innovative Measurement Technology

9. Thermal-Hydraulics and Safety of Advanced Reactors

9.1 SFR Thermal-Hydraulics, Design and Safety Analysis

9.2 Gas Cooled Reactor Thermal-Hydraulics, Design and Safety Analysis

9.3 MSR Thermal-Hydraulics, Design and Safety Analysis

9.4 Supercritical Reactor Thermal-Hydraulics

9.5 Research Reactor Operation and Thermal-Hydraulics

9.6 SCO_2-Based Technology

10. Special Session

10.1 Containment Thermal-Hydraulics

10.2 Hydrogen Management

10.3 SMR

10.4 Safety Analysis of Design Extension Conditions

10.5 Coolability of Damaged Fuels

10.6 Scaling Issues

10.7 CANDU Thermal-hydraulics and Safety

10.8 Filtered Containment Venting System (FCVS)

10.9 OECD/NEA International Programs

圖一、NUTHOS-11會議會場照片（一）

圖二、NUTHOS-11會議會場照片（二）

圖三、NUTHOS-11會議會場照片 (三)

圖四、NUTHOS-11會議會場照片 (四)

參、 會議摘要

(一) 會議背景介紹

　　核能熱水流運轉及安全專題會議 (International Topical Meeting on Nuclear Thermal-Hydraulics, Operation and Safety, NUTHOS) 之目的在於提供一平台俾於各國核能產業與學術機構進行交流研發技術成果與工程實務經驗。第一屆會議於 1984 年在臺灣臺北舉行，爾後每隔二至四年舉辦一次，依序於日本東京 (1986)、韓國首爾 (1988)、臺灣臺北 (1994)、中國北京 (1997)、日本奈良 (2004)、韓國首爾 (2008)、中國上海 (2010)、臺灣高雄 (2012) 及日本沖繩 (2014)舉行。本次第 11 屆會議於 105 年 10 月 9 日至 105 年 10 月 13 日假韓國慶州舉行。會議由本次會議由韓國核能協會 (Korean Nuclear Society, KNS) 及美國核能協會 (American Nuclear Society, ANS) 共同贊助，以及協同各國際組織如中國核能協會 (Chinese Nuclear Society, CNS) 和加拿大核能協會 (Canadian Nuclear Society, CNS) 等共同辦理。

　　本次第 11 屆核能熱水流運轉及安全專題會議，會議主要內容分為專家座談以及技術專題報告。技術專題報告內容涵蓋熱水流分析、嚴重事故、電廠運轉及核能安全、實驗技術發展、先進型核子反應器以及特別專題等 10 大項領域，各領域內容再細分數小項，共計細分 52 小項，詳見表二。每日會議議程詳見附件一。與會人員來自歐亞美洲共計 351 篇論文發表。

(二) 我方人員論文內容簡介

　　本會核安管制研究中心試運組江員簡報論文一篇「Investigating the Effects of System Availability, Mitigation Strategy, and Operating Conditions on Core Uncovery and

Core Damage During Station Blackout Event for Maanshan Nuclear Power Station」，簡報詳附件二。論文內容簡要介紹如下。

發生於 2011 年 3 月 11 日的日本福島核災屬超越設計基準事故，伴隨當日強震而來的 15 公尺高海嘯對福島核電廠址造成巨大的衝擊，電源喪失使得核電廠進入了電廠事故全黑狀態 (Station Blackout, SBO)。為了順利移除爐心衰變熱所研擬的各種救援策略，以及在移除爐心衰變熱過程中因應各種突發狀況的應對措施成了世界各國紛紛著手進行研究的主題。本論文以嚴重事故軟體 MELCOR 1.8.5 版本模擬我國馬鞍山核電廠於遭遇如日本福島電廠核災情境時，於移除爐心衰變熱過程中發生各種不同情況下的結果。

爐心未被水覆蓋 (Core Uncovery) 及爐心損毀 (Core Damage) 可視為事故發展嚴重程度的指標。本研究以任一爐心部分失去其完整性訂為爐心損毀之定義。能夠使爐心未被水覆蓋以及爐心損毀發生的時間點延後或提前的因素非常多，然而限於篇幅，本論文選取其中六個因素進行分析，分別為：反應器冷卻水泵軸封洩漏率大小 (Reactor Coolant Pump Seal Leakage Rate)、調壓槽動力釋壓閥卡開 (Pressurizer Power Operated Relief Valve Stuck Open)、蒸汽驅動輔助飼水可用性 (Turbine Driven Auxiliary Feedwater Availability)、蒸汽產生器手動降壓 (Steam Generator Manual Depressurization)、氮氣隨著蓄壓槽冷卻水注入一次側管路 (Nitrogen Entering Primary Side Following Accumulator Injection)、非對稱式蒸汽產生器冷卻 (Asymmetric Steam Generator Cooldown)。

本論文將上述六個因素交叉組合共進行了 12 個案例的模擬，詳見附件二。此 12 個案例可略分為保守度偏高 (Bounding Cases) 及較趨近真實情況的兩個群組。保守度偏高的案例群組係指未執行蒸汽產生器手動降壓的案例，較趨近真實情況的案例則是指有執行蒸汽產生器手動降壓的案例。於此論文中，所模擬進行的蒸汽產生器手動降壓均係採用斷然處置措施 (Ultimate Response Guideline)中的兩段式降壓，於稍後段落中詳述。

本論文分析所假設的反應器冷卻水泵軸封洩漏率值係參考美國核管會(針對Surry核電廠) 之 SOARCA (State-of-the-Art Reactor Consequence Analyses Project, Volume 2: Surry Integrated Analysis, 2013) 報告。所假設之反應器冷卻水泵軸封洩漏率值係對應核電廠一次側正常運轉壓力值而言，爾後，隨著事故演進一次側壓力發生變化，洩漏率值亦隨之變化。另外，根據西屋公司的反應器冷卻水泵軸封洩漏模型分析報告 (WOG 2000 Reactor Coolant Pump Seal Leakage Model for Westinghouse PWRs, 2000)，冷卻水泵軸封洩漏率值與其故障模式有關，就單一冷卻水泵而言，最可能發生的冷卻水泵軸封洩漏率值為每分鐘 21 加侖，因此，除了探討洩漏率大小造成影響之案例外，此洩漏率值為論文中其餘案例分析所採用。案例分析結果顯示，冷卻水泵軸封洩漏率越大，發生爐心未被水覆蓋以及爐心損毀的時間點越早，符合預期。冷卻水泵軸封故障模式與是否安裝耐高溫O型環有關，亦與一次側水溫有關，在稍後的案例分析結果顯示，不同的情境下一次側水溫會在不同的時間點超過耐高溫O型環的設計溫度 600°F，造成耐高溫O型環的損毀進而使洩漏率增加，使發生爐心未被水覆蓋以及爐心損毀的時間點更為提早。

調壓槽動力釋壓閥卡開亦可能影響發生爐心未被水覆蓋以及爐心損毀的時間點。透過動力釋壓閥的反覆開關，調壓槽壓力方得以維持在一定範圍內。於本論文的模擬中，假設動力釋壓閥反覆開關次數達特定次數時，動力釋壓閥將發生卡開事件。此特定次數和動力釋壓閥本身每次開關發生卡開情形的機率 (Failure Probability Per Demand) 有關。經諮詢馬鞍山安全度評估小組成員及參照 Surry 電廠 SOARCA 報告將失效累積分佈函數 (Cumulative Distribution Function) 值訂為 0.5 後，可計算出相應動力釋壓閥發生卡開情形的開關次數。調壓槽動力釋壓閥卡開使得爐心水位提早下降，亦使得一次側壓力下降而使蓄壓槽啟動注入一次側冷端管路。就未執行蒸汽產生器手動降壓的案例而言，其一次側壓

力相對較高，調壓槽動力釋放閥開關次數也較多，發生卡開情形的機率也因此較大。

蒸汽驅動輔助飼水可用與否對事故發展的影響甚鉅，在可利用蒸汽產生器最為熱沉 (Heat Sink) 移除反應器衰變熱的情況下，爐心液態水位因吸收衰變熱而急遽下降的情形可獲紓緩，也給相關團隊更多時間餘裕準備後續救援事宜。於本論文中，將蒸汽驅動輔助飼水啟動的時間點訂定為發生電廠全黑事故的 12 分鐘後，此假設係參考馬鞍山電廠於 2001 年發生的電廠全黑事故時序。蒸汽驅動輔助飼水的啟動延後了蒸汽產生器乾涸 (Steam Generator Dry Out) 的時間點，也因此延後發生爐心未被水覆蓋的時間點。馬鞍山核電廠的蒸汽驅動輔助飼水泵在喪失直流電源 (DC Power) 時可以手動方式開啟。另外，馬鞍山核電廠設有柴油引擎驅動的輔助飼水泵，可在蒸汽驅動輔助飼水泵失效時接替之，將水注入蒸汽產生器。

蒸汽產生器手動降壓輔以輔助飼水或替代注水可延緩爐心未被水覆蓋發生的時間點。於此論文中，在確認蒸汽驅動輔助飼水可用後才開始執行蒸汽產生器手動降壓程序。如前所述，本論文中的蒸氣產生器手動降壓方式為斷然處置措施中的二階段降壓，即在確認蒸汽驅動輔助飼水可用的前提下手動將蒸汽產生器壓力降至 15 kg/m^2，隨後，在蒸汽驅動輔助飼水失效後將蒸汽產生器壓力降至接近大氣壓力使替代注水設備如消防車得以將水注入蒸汽產生器。在蒸汽驅動輔助飼水的聯合作動下，於手動降壓期間，蒸汽產生器水位並未掉落至蒸汽產生器底部且於稍後回升，因此並未發生熱傳大幅惡化的情形。執行手動降壓帶走大量衰變熱的同時，一次側水位亦因溫度下降而有下降情形，然僅有反應器壓力槽頂部 (Reactor Pressure Vessel Dome) 水位下降，爐心始終完全為水所覆蓋，而相較之下，未執行蒸汽產生器手動降壓的案例之爐心水位則有逐漸下降情形，也因此執行蒸汽產生器手動降壓的案例其燃料護套尖峰溫度 (Peak Cladding Temperature) 較未執行蒸汽產生器手動降壓的案例為低。

氮氣隨著蓄壓槽冷卻水注入一次側管路亦為影響爐心未被水覆蓋發生時間點的因素之一。在 MELCOR 的流體接點 (Flow Path) 相關設定中，可調整僅允許液體通過或允許氣體及液體通過。利用此特性，可模擬位於蓄壓槽頂部的氮氣進入一次側的影響。於事故發生時，移除衰變熱係仰賴一次側的自然對流循環，然而氮氣注入一次側冷端 (Cold Leg) 後會積累在蒸汽產生器一次側 U 型管路的頂端，阻礙自然對流循環移除衰變熱的過程，使得燃料護套溫度呈現上昇趨勢。案例分析結果顯示，氮氣的注入使得自然對流循環熱傳下降，此結果與眾多實驗及模擬的結論相符。透過提前在蓄壓槽頂端執行排氣動作或關閉底端的閥可阻止氮氣注入，然而執行此動作的困難度在於執行的時間點難以確切估算，且蓄壓槽位於圍阻體 (Containment) 內，若事故演進嚴重程度高，人員難以進入圍阻體執行此動作。另外，分析結果顯示，就本論文有執行蒸汽產生器手動降壓的案例而言，自蓄壓槽開始注入一次側冷端管路的時間點到氮氣開始注入的時間點相隔在約八小時以上，因此就阻絕氮氣的應變時間而言是足夠的。

　　非對稱式蒸汽產生器冷卻指的是，由於資源的限制或其他考量，僅其中一個蒸汽產生器進入執行第二階段的蒸汽產生器降壓以及替代注水冷卻動作，其餘兩個蒸汽產生器則停留在第一階段的壓力值，並未將其壓力進一步降至接近大氣壓力輔以替代注水。於本論文中替代注水係以馬鞍山核電廠之消防車相關參數進行模擬。非對稱式蒸汽產生器冷卻可能導致的後果是，未進行降壓的兩個迴路溫度會較有進行降壓冷卻的迴路溫度為高，使得此二迴路的反應器冷卻泵軸封封環損壞的可能性增加，進而使反應器冷卻泵軸封洩漏率增加。然而分析案例分析結果顯示，在兩天的模擬時間內無須考慮此顧慮，在約兩天後未被冷卻的迴路其溫度方增加至可能危及反應器冷卻泵軸封封環的程度。

　　江副研究員於進行本論文簡報發表的會議期程主持人為來自西班牙加泰羅尼亞理工大學 (Universitat Politècnica de Catalunya) 的 Reventos 教授及來自韓國

電力公社 (Korea Electric Power Corporation) 的 Chul Jin Choi 博士。兩位主持人首先表示簡報具有一定水準，除了讚賞外，接著對一些模擬細節做詢問，例如模擬氮氣進入一次側以及非對稱式蒸汽產生器冷卻等。另外 Reventos 教授建議，可針對某些案例分析結果做進一步的結論或建議會更完整，例如非對稱式蒸汽產生器冷卻在多久時間後對反應器冷卻泵軸封封環完整性造成威脅。該建議已納入並於上段論文簡要介紹內容中補齊。

(三) 與會人員演講及論文重點摘錄及討論

　　此次會議論文數量甚多，本段落摘錄部分與會人員演講及論文重點及心得討論，以下分別介紹：開幕演講中提供的韓國相關核能資訊 (Opening Address)、「International Development, Safety Issues, and Modelling Gaps of SMRs」、「Heat Transfer of Stratified Melt Pool in LWR Lower Head Under External Cooling und Different Upper Boundary Conditions」、「Orientation Effect on Pool Boiling Heat Transfer in Water Using Sintered Copper Microporous Coating」及「Thermal-Hydraulic Modeling of In-core Blockage by Debris Post-LOCA Long Term Core Cooling Phase」等論文。

(i)「Opening Address」；講者：韓國浦項工科大學 (Pohang University of Science and Technology, POSTECH) 的 Moo-Hwan Kim 教授。

　　Moo-Hwan Kim 教授首先介紹韓國的核電發展情況。韓國現在共有 25 部運轉中的機組，包含 21 座 PWR 及 4 座 CANDU-PHWR，另有 5 座 PWR (APR 1400) 建造中。另外計畫在 2029 年前再建造 6 座 APR 1400 或 APR+。目前的核能裝置總輸出電功率為 23.1 GW，所佔電力輸出為 30~35 %。負責核

能相關研發的韓國原子能研究院 (Korea Atomic Energy Research Institute, KAERI) 目前共有約 1,450 名永久雇員及約 1,000 名約聘雇員,研究領域涵蓋基礎研究、核子反應器技術研發、核燃料循環前端及後端之技術研發、核反應器安全研究、輻射及放射性同位素應用及政策研究等。在韓國,就持續發展核電所面臨到的挑戰包含福島核災的後續效應、反核團體及政治人物的施壓、國家本身經濟和電力需求成長緩慢、老舊電廠數量的持續成長、用過核燃料處理的議題、核能電廠廠址選擇議題以及再生能源的興起。

韓國原子能研究院於核子反應器安全方面進行的熱流實驗相關研究包含其先進型反應器 APR 1400、APR+、SMART (System-integrated Modular Advanced ReacTor) 的試驗、核燃料的臨界熱通量 (Critical Heat Flux) 和再泛水階段熱傳 (Reflood Heat Transfer) 試驗以及進階實驗量測技術的發展。於核電廠系統層級安全分析程式的研發包含 MARS 和 SPACE,電廠元件層級的程式則為 CUPID。韓國原子能研究院亦涉獵第四代反應器的研究,包含高溫氣冷式反應器 (High Temperature Gas-Cooled Reactor)、鈉冷式快中子反應器 (Sodium Fast Reactor) 和 超臨界水冷式反應器 (Supercritical Water Reactor)。韓國原子能研究院於嚴重事故研究方面與世界多個著名機構合作,本身亦擁有相關研究設備如 VESTA (Verification of Ex-vessel corium STAbilization) 和 TROI (Test for Real cOrium Interaction with water),前者能進行熔融物 (Corium) 與反應器結構物相互作用之相關試驗如反應器壓力槽底部熔穿試驗,後者能進行熔融物與水相互作用之相關試驗如蒸汽爆炸 (Steam Explosion)。相關設備資訊詳見圖五和圖六。

最終講者指出,之後的研究方向大致為超越設計基準事故、嚴重事故相關現象試驗及分析、三階安全度分析 (Level-III Probability Safety Analysis)、多機組事故分析、火災安全分析、電廠元件材料劣化現象、被動式安全系統 (Passive Safety System) 研究、以及輻射防護安全。

圖五、韓國原子能研究所 VESTA 設備相關資訊

(參考來源: Corium Research Platform at KAERI, Jin Ho Song, Presentation at PLINUS-

2 International Seminar Marseille, France May 16th, 2014)

圖六、韓國原子能研究所 TROI 設備相關資訊

(參考來源: Corium Research Platform at KAERI, Jin Ho Song, Presentation at PLINUS-

2 International Seminar Marseille, France May 16th, 2014)

(ii) 「International Development, Safety Issues, and Modelling Gaps of SMRs」；講者: 德國反應器安全協會 (Gesellschaft für Anlagen- und Reaktorsicherheit, GRS) 的 Andreas Schaffrath 博士

過往 SMR 有兩個定義，國際原子能總署 (International Atomic Energy Agency, IAEA) 將之定義為 Small and Medium Sized Reactors，指的是功率分別小於 300 MW 和 700 MW 的核子反應器。然而在美國，SMR 指的是 Small Modular Reactors。於 GRS 的研究中 SMR 一詞涵蓋上述兩者定義。SMR 的概念並非於近代才興起，事實上於 1950 即開始有 SMR 的建造。SMR 可應用於偏遠地區如南北極執行供熱和海水淡化的任務，亦可做為破冰船或是核子潛艇的動力來源。

另外，小型可移動式核子反應器可做為偏遠地區的能源供給來源，蘇聯所研發的 Pamir-630D 即為此例，詳圖七。GRS 對多種類型的 SMR 進行過研究，包含以輕水、重水、液態金屬、氣體、熔鹽做為冷卻劑的 SMR。若以申請執照的角度來看，以輕水做為冷卻劑的 SMR 是最好的選擇，因為現今許多已商轉的反應器亦使用輕水做為冷卻劑，相關技術經驗較為充足，阿根廷的 CAREM (Central Argentina de Elementos Modulares) 和韓國的 SMART (System-integrated Modular Advanced ReacTor) 即屬此類。
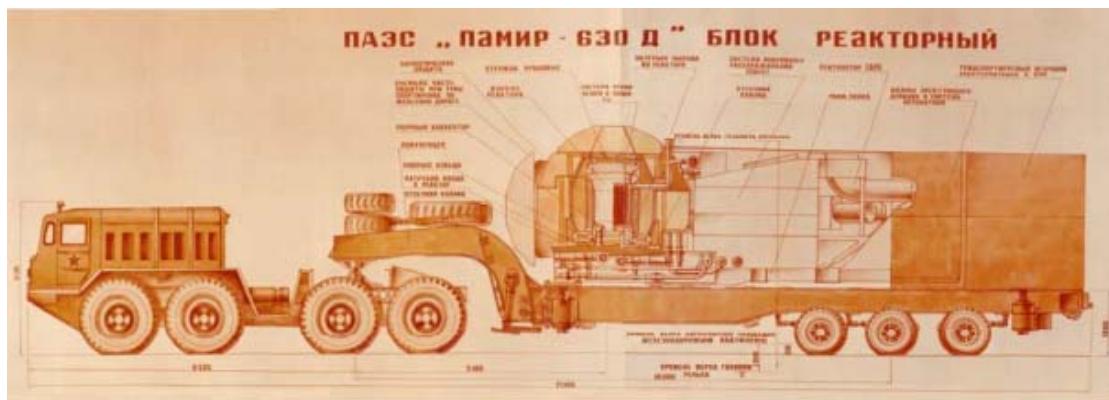
圖七、置於卡車上的移動式反應器 Pamir-630D

(參考來源: Shipment of HEU Fuel from Pamir Reactor in Belarus to the Russia and Conversion to High Density LEU Fuel, S. N. Sikorin, et al, RERTR 2011)

就安全的角度而言，SMR 較現行商轉的輕水式反應器為優。SMR 因為具備爐心功率密度較低、衰變熱較小、爐心座落於反應器壓力槽位置較低、爐心較靠近反應器壓力槽槽壁等特性，使得爐心冷卻較容易。另外，可利用無限供應的空氣或水在不需倚靠外力 (例如:自然對流循環) 的情況下做為圍阻體的最終熱沉。就經濟的角度而言，單一 SMR 的電力輸出獲益不及功率相對較大之輕水式反應器，然而 SMR 有建造成本較低、模塊化建造可加速建造過程、模塊化建造過程可加速除役、維修需求較少等優勢。

根據 Andreas Schaffrath 博士的簡報，目前 GRS 傾向將研究重心放在以輕

水做為冷卻劑的 SMR，簡報中以阿根廷的 CAREM 為例，該款 SMR 多個設計特點均以防範意外為目的，例如：利用自然對流循環可免於失去電力時可能失去冷卻劑供應來源的顧慮、在爐心中不用硼可免於發生因硼濃度稀釋而引發的相關意外之可能性、內裝式控制棒設計使得控制棒射棒意外不會發生…。此外，一般情況而言，SMR 在設計上可將連接反應器壓力槽的管路數目降至最低，達成此目標的效果較傳統 PWR 為佳的原因為，SMR 可將一次側迴路元件及蒸汽產生器置入反應器壓力槽中，例如 CAREM 將整合式蒸汽產生器 (Integrated Steam Generator) 安置於反應器壓力槽降流區 (Downcomer) 部位的整合式設計，詳見圖八。另外，傳統 PWR 發生一次側主冷卻劑管路斷頭式破口的話，其破口面積約為 1 平方公尺，然而於 CAREM 的設計中，即便連接反應器壓力槽尺寸最大的管路發生斷頭式破口的話，其破口面積僅為傳統 PWR 的 1/700，也因此當 CAREM 發生冷卻水流失事故時相對較易控制，也對反應器壓力槽內部組件以及圍阻體的衝擊較小。另外其反應器壓力槽所連接的管路高度均高於爐心，且爐心座落於反應器壓力槽中相對較低的位置，這些設計特性均使得發生爐心未被水覆蓋的可能性變得更小。
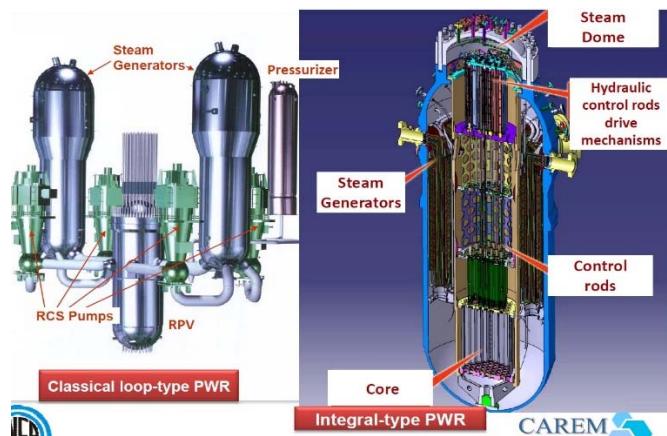
圖八、CAREM 的整合式設計與傳統 PWR 設計比較示意圖

(參考來源: http://www.atominfo.ru/newsh/o0146_2.jpg)

關於 SMR 相關模擬，目前有待進一步努力的領域包含中子、熱流和材料方面。在 GRS 的研究中，用以模擬中子動力學的程式為 QUABOX-CUBBOX，用以模擬熱水流的程式為 ATHLET (Analysis of THermal-hydraulics of LEaks and Transients)，用以模擬圍阻體的程式則為 COCOSYS (Containment Code System)。就中子模擬方面，有待進一步努力之優先研究方向包含快中子能譜 (Fast Neutron Spectra) 於程式中的驗證、SMR 元件材料的中子相關資料庫 (Nuclear Data Libraries) 具有一定程度不準度改善、改良式爐心核燃料裝填方式 (Advanced Loading Pattern) 分析、可燃式中子吸收劑 (Burnable Absorber) 於燃料週期初期的分析以及用以平衡長期過剩反應度的可移動式中子反射器 (Movable Reflector for Long-Term Compensation of Excess Reactivity) 相關分析。就熱流及圍阻體模擬方面，有待進一步努力的優先研究方向包含建構各種工作流體如氦氣、熔鹽、重水、液態金屬的流體特性參數於程式資料庫中、更新各種熱流關係式的應用範圍尤其是低壓力區、整合式蒸汽產生器的相關熱流模組、更新或驗證於大型水平圓柱狀物體的自然對流相關關係式以及工作流體之流動誘發振動現象 (Flow Induced Vibration)。

(iii) 「Heat Transfer of Stratified Melt Pool in LWR Lower Head Under External Cooling und Different Upper Boundary Conditions」；主要作者：德國卡爾斯魯厄理工學院 (Karlsruhe Institute of Technology, KIT) 的 Xiaoyang Gaus-Liu 先生。

此篇論文以 1,000 MWe 的 PWR 相關參數為基礎，計算於發生爐心熔毀反應器壓力槽內的熱傳聚焦效應 (Focusing Effect) 情境下，在金屬熔融層 (Metallic Layer) 厚度不同的案例中，對應熱傳聚焦效應的反應器壓力槽側壁能否得以被冷卻。核子事故若發展到爐心熔毀階段的話，高溫熔融物會聚積在反應器壓力槽底部，熔融物在不同情況下可能均勻地混合也可能分成數層。研究顯示，氧

化物熔融層 (Oxide Layer) 和金屬熔融層的分層現象甚為複雜，幾個決定分層結果的因子包含鈾和鋯的比例、熔融物的氧化程度以及鋼的質量等。依據重量的不同，氧化物熔融層位於下層，金屬熔融層位於上層。

位於下層的氧化物熔融層其周圍會生成氧化物硬殼層 (Oxidic Crust)，詳見圖九。氧化物硬殼層可視為熱絕緣層 (Thermal Insulation Layer) 使得下層的氧化物熔融層其熱量大多向上傳至金屬熔融層。就上層的金屬熔融物層而言，因其不具有如氧化物熔融層般形成硬殼層的現象，在承接來自下方大量熱量且僅能向上以輻射形式傳出少量熱量之情況下，其散發熱量主要途徑為反應器壓力槽側壁，使得反應器壓力槽側壁的熱通量甚高，此即為熱傳聚焦現象。熱傳聚焦現象增加了反應器壓力槽於側面被熔穿的機率。於該論文中所設定的臨界熱通量為 1.5 MW/m^2。

金屬熔融層和氧化物層中的熱傳均屬於自然對流循環，其計算過程較強制對流 (Forced Convection) 熱傳而言為繁雜，因為於強制對流熱傳的計算中熱傳係數 (Heat Transfer Coefficient) 和熱通量以及邊界溫度差均無關，然而於自然對流循環熱傳的計算中，熱傳係數和邊界溫度差有關，是以從 Nu-Ra 關係式中解出溫度差值需以迭代 (Iteration) 方式進行。此論文提及，論文最終結果的最大計算誤差來源為 Nu-Ra 關係式的選擇，另一主要誤差來源則是關於金屬熔融層和氧化物熔融層材料成分組成的假設。其假設會影響該熔融層的材料特性參數如黏滯度、熱膨脹係數、密度、比熱等，進而影響無因次參數如 Ra 的計算，再進而可能影響金屬熔融層內的流場分佈 (Flow Regime) 預測結果以及可能的 Nu-Ra 關係式選擇，如圖十所示。

計算結果顯示，當上層的金屬熔融層厚度較厚時，其輻射熱傳量非常有限，當其厚度縮減時，輻射熱傳現象較為明顯，但其所佔比重仍低。另外，當上層的金屬熔融層厚度小於 0.2 公尺時，其最可能出現的流場分佈情形為層流 (Laminar Flow)，當金屬熔融層厚度介於 0.2～0.4 公尺時，其流場分佈情形可能

視其熔點溫度而定而有轉變成紊流 (Turbulent Flow) 的可能性。若其發出熱通量小於臨界冷卻熱通量限制的話，金屬熔融層整體溫度會維持在一相對低值，且硬殼層可因此生成。此論文估算，若以 1,000 MWe 的 PWR 有 100 公噸氧化熔融物且假設其能量密度為 1 MW/m^3 的條件去估算，若要使反應器壓力槽外部冷卻策略成功的話，則金屬熔融層厚度需大於 0.6 公尺，約相當於 80 公噸的鋼。
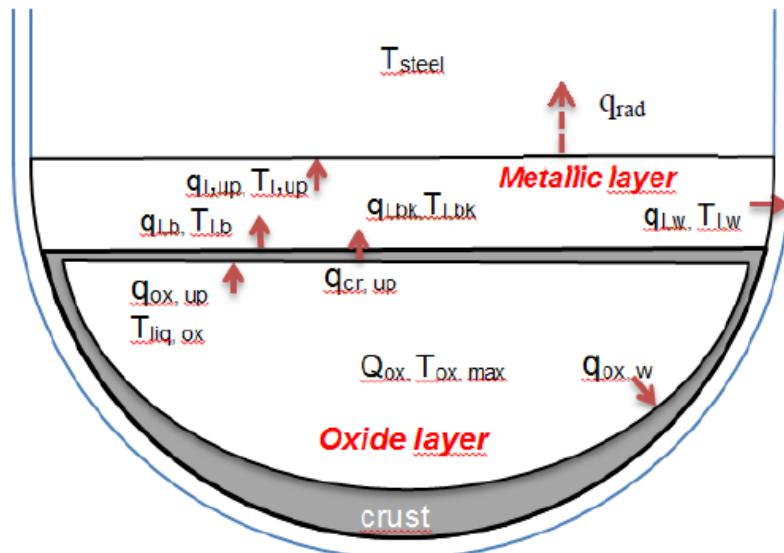
圖九、爐心熔毀時的熔融物分層以及熱傳聚焦現象示意圖

(參考來源："Heat Transfer of Stratified Melt Pool in LWR Lower Head Under External Cooling und Different Upper Boundary Conditions"，Xiaoyang Gaus-Liu, Alexei Miassoedov, 2016, NUTHOS-11)
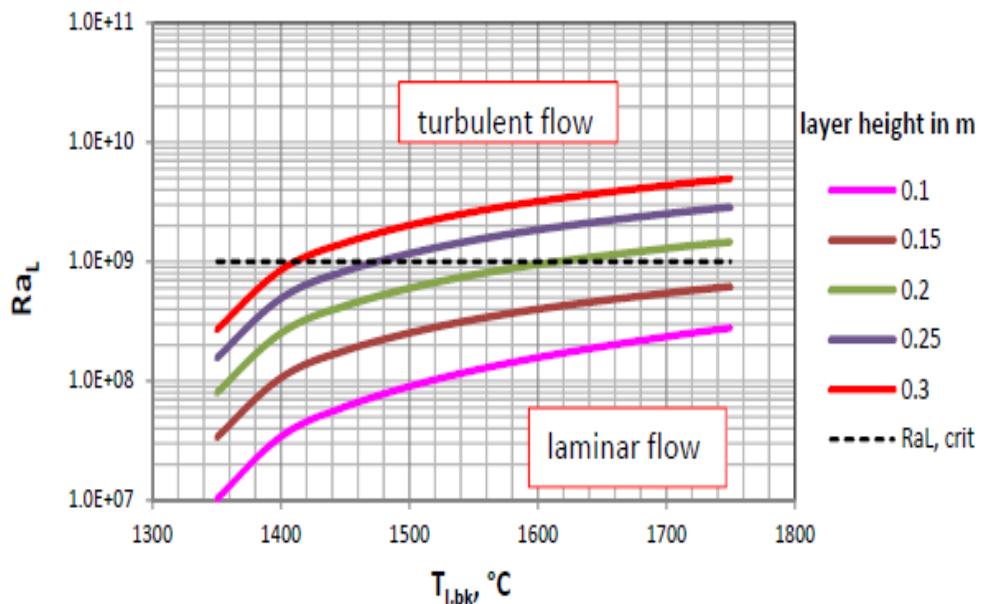
圖十、金屬熔融層的厚度和溫度會影響其近邊側之流場分佈情形
(參考來源:"Heat Transfer of Stratified Melt Pool in LWR Lower Head Under External Cooling und Different Upper Boundary Conditions", Xiaoyang Gaus-Liu, Alexei Miassoedov, 2016, NUTHOS-11)

(iv) 「Orientation Effect on Pool Boiling Heat Transfer in Water Using Sintered Copper Microporous Coating」；主要作者：德州大學達拉斯分校 (The University of Texas at Dallas) 的 Seung M. You 先生。

　　此篇論文探討於銅金屬表面加覆一微粒子薄層 (Microporous Coating) 以及變更加熱面傾斜角度 (Inclination Angle) 對於該平面臨界熱通量 (Critical Heat Flux, CHF) 之影響。此薄層具耐高溫、導熱佳且透水性好之特性，成份為熱燒結 (Sintered) 之銅粉。該薄層平均孔隙率為 0.66，而其粒子平均大小為 67 μm，係根據實驗結果而挑選出的最佳尺寸。探討加熱面傾斜角度對臨界熱通量有其重要性。於嚴重事故階段，進行反應器壓力槽外部冷卻為減緩事故的手段之一。一般而言，反應器壓力槽底部為一半球狀，是以執行外部冷卻時水會以

不同的角度與壓力槽下半部接觸，因此探討臨界熱通量於加熱面處於不同傾斜角度的變化情形可做為執行外部冷卻時之參考。

單就加覆一層微粒子薄層 (High Temperature Thermally Conductive Microporous Coating, HTCMC) 的效應而言，無論將該加熱面調整成任何角度，其臨界熱通量均有增加數倍的情形發生。另一方面，若單就調整加熱面傾斜角度的效應而言，和其他角度相比，若加熱平面傾斜角度介於 90°～180° 時其臨界熱通量值較低，無論是否有加覆微粒層的平面皆為如此。然而，如前所述，即便處於臨界熱通量相對較低的 180°，有加覆微粒子薄層的平面 (以下簡稱 HTCMC 平面) 其臨界熱通量為未加覆微粒薄層的平面 (以下簡稱對照組平面) 之 4.3 倍。此發現對於強化反應器壓力槽於嚴重事故時的完整性有正面效益。HTCMC 平面以及對照組平面的臨界熱通量於不同傾斜角的比較情形以及沸騰曲線比較情形詳見圖十一和圖十二。

當較冷的液態水被氣泡團阻擋無法接觸到加熱面，最終發生乾涸情形 (Dryout) 時，臨界熱通量是焉發生。當加熱平面傾斜角為 0° 時，氣泡生成因浮力之助可順利向上離開加熱表面，隨後氣泡周圍的液態水得以補充流向氣泡成核址所在位置。然而，當加熱面傾斜角為 180° 時，因浮力之故使得氣泡相對而言較不易離開加熱面，停留在加熱面的時間變長也間接使得周遭液態水不易接觸到加熱面，是以當傾斜角為 180° 時其臨界熱通量較低。

就 HTCMC 平面而言，當其貼近金屬表面側的氣泡生成向上通過其加覆層結構時會被拆解成許多尺寸較小的氣泡向上離開，此情形會延遲乾涸情形的發生。加覆層的存在使得氣泡成核址數量增加，另加覆層的氣泡成核空腔 (Cavity) 形狀多屬可再入型 (Reentrant)，使得其氣泡成核半徑較大，根據 Clasius-Clapeyron 公式，其所需過熱度 (Superheat) 較小，此特性使得 HTCMC 平面產生核沸騰熱傳 (Nucleate Boiling Heat Transfer) 的熱通量值僅需對照組平面的 1/8。
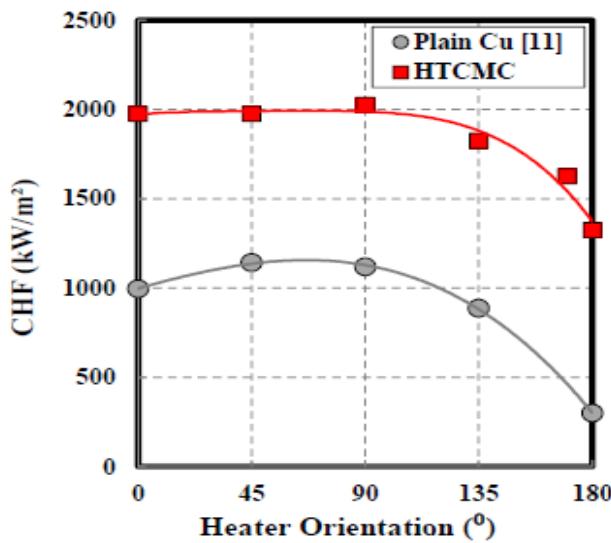
圖十一、HTCMC平面與對照組平面的臨界熱通量比較情形

(參考來源：“Orientation Effect on Pool Boiling Heat Transfer in Water Using

Sintered Copper Microporous Coating”，Seongchul Jun et al., NUTHOS-11, 2016)
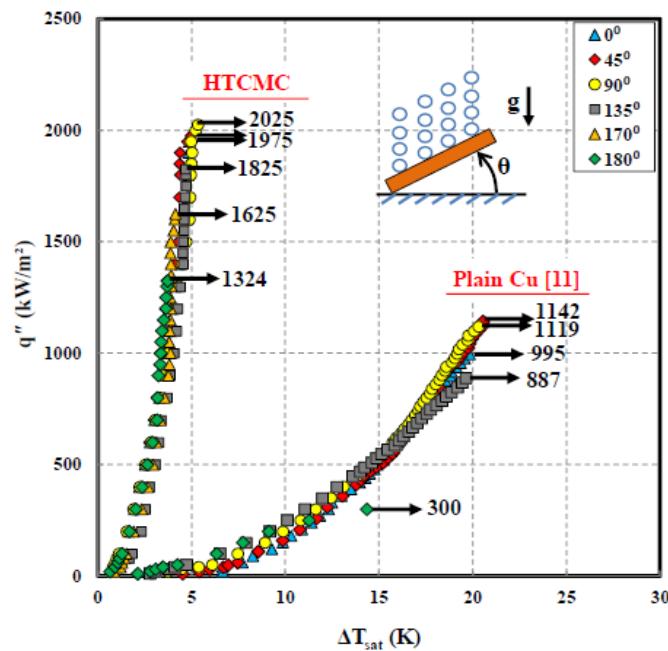
圖十二、HTCMC平面與對照組平面的沸騰曲線比較情形

(參考來源：“Orientation Effect on Pool Boiling Heat Transfer in Water Using

Sintered Copper Microporous Coating”，Seongchul Jun et al., NUTHOS-11, 2016)

(v) 「Thermal-Hydraulic Modeling of In-core Blockage by Debris Post-LOCA Long Term Core Cooling Phase」；主要作者：韓國核能管制協會 (Korea Institute of Nuclear Safety, KINS) 的 Young Seok Bang 先生。

　　此篇論文以韓國自行發展的程式 MARS-KS 模擬爐心於發生喪失冷卻水意外後之長期爐心冷卻階段 (Post-LOCA Long Term Core Cooling) 發生碎屑堵塞 (Debris In-core Blockage) 的熱流現象。此論文不僅建置碎屑於爐心入口堵塞的模組，同時也建置碎屑附著於爐心燃料護套 (Cladding) 上的模組使其狀況更貼近真實情況，即 GSI - 191 (General Safety Issue – 191) 中所討論的因發生冷卻水流失事故所產生的纖維性碎屑 (Fibrous Debris) 通過水坑過濾器 (Sump Strainer) 堵塞於爐心影響冷卻效果的情形。

　　MARS-KS 係以 RELAP5 為基礎再併入數個先進模擬模組而來。此論文以一可關閉之閥設置於爐心入口用以模擬碎屑於爐心入口堵塞之情形，另於爐心燃料護套外側加置一層材料模擬碎屑附著於爐心燃料護套上之情形，詳圖十三。根據論文所述，第四層材料理論上而言應能毫無困難地加至原先的燃料棒模型，然而就 MARS-KS 而言，此動作需關閉燃料護套間隙熱傳導模組 (Gap Conductance Model)、護套型變模型 (Cladding Deformation Model) 以及鋯水反應模組 (Metal-Water Reaction) 方能成功執行。韓方寄望，於現今發展中的另一程式 SPACE 能改進此一情形。

　　關於燃料護套外層所加置的碎屑層，其厚度為 16.7 mil，係根據 APR1400 下游效應的相關計算結果報告 (In-vessel Downstream Effect Evaluation of the APR1400) 而來，而關於爐心入口碎屑堵塞後所所允許冷卻水通過的截面積值亦根據此份報告結果而訂。至於燃料護套外層所加置的碎屑層其熱傳導係數 (Thermal Conductivity) 則根據 WCAP-16793 報告而訂定。就所加置的碎屑層厚度以及熱傳導係數值而言，所使用的設定值均有一定的保守度。在進行加置燃

料護套外層碎屑層之參數設定時另需留意，此層應於預定碎屑附著於燃料護套表面之時方彰顯其作用，意即模擬相關參數設定需分為碎屑附著前 (Pre-debris Layer Phase) 以及碎屑附著後 (Post-debris Deposition) 兩階段。程式可使用類似 RELAP5 的重啟 (Restart) 功能於預定時間內執行碎屑層相關熱傳參數的變化。例如於碎屑附著前階段，將碎屑的熱傳導係數設定為一較大值，避免造成過多的額外熱阻 (Thermal Resistance)，而於預定碎屑附著時間點後方將碎屑之熱傳導參數調整為 WCAP 報告中所載之值。另外，考慮到燃料護套間隙熱傳導模組不可用以及加置碎屑層的綜合效應，本論文將護套間隙縮小，將其縮小使之熱流效應和未加置碎屑層案例於再泛水階段 (Reflood) 之熱流效應接近，且可預期於長期冷卻階段所預測的燃料護套溫度具有一定的保守度。

為了估算安全餘裕，此論文另行模擬爐心全堵塞案例 (Complete Blockage) 將之與碎屑堵塞之案例作比較，兩案例關鍵參數比較詳圖十四，參數比較結果均符合預期。圖十五為碎屑附著於燃料護套後燃料護套溫度增加情形之示意圖，圖十五右側為碎屑以附著於護套外層後與未有碎屑附著案例之溫度比較情形，如圖所示，碎屑層的附著使得燃料護套溫度上升 30~40 K，仍離 WCAP 報告中訂定的接受準則 800 K 有相當程度的差距。圖十五左側為兩案例的溫度預測隨時間變化情形，其於碎屑附著前階段之溫度差異源自 MARS-KS 程式的燃料護套間隙熱傳導模型，承前所述，該模型於加置碎屑層案例中無法啟用。最後，論文指出，雖然於碎屑附著前階段該程式能力有限無法啟用護套間隙熱傳導模型，但於碎屑附著後階段所預測的燃料護套溫度有相當程度的可信度，原因有二，其一為於碎屑層厚度此階段為影響燃料護套溫度的主要因子，其二為於現實狀況燃料護套間隙厚度應較此計算中所使用之值為小。
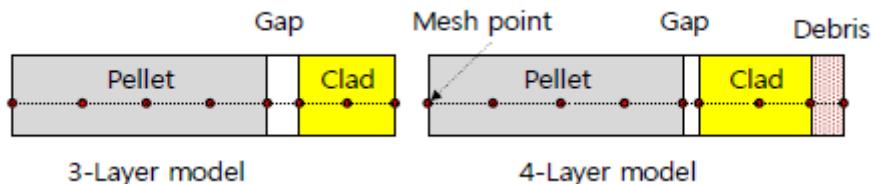
圖十三、於原先的燃料棒模型加上一層碎屑於最外側之示意圖

(參考來源：“Thermal-Hydraulic Modeling of In-core Blockage by Debris Post-LOCA Long Term Core Cooling Phase”, Young Seok Bang et al., NUTHOS-11, 2016)

(a) Cladding temperatures

(b) Core flow rates

(c) Available driving head

(d) Core heat transfer coefficient
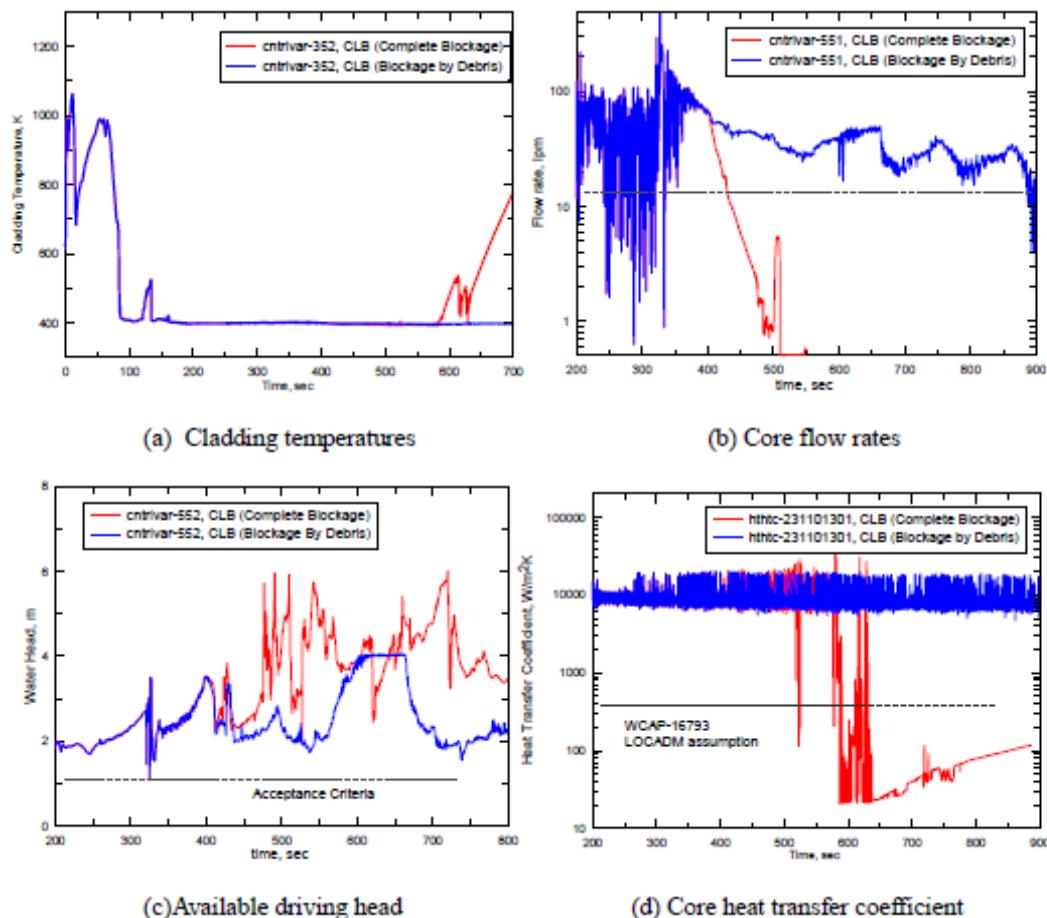
圖十四、碎屑堵塞案例以及爐心完全堵塞案例之各種參數比較情形

(參考來源：“Thermal-Hydraulic Modeling of In-core Blockage by Debris Post-LOCA Long Term Core Cooling Phase”, Young Seok Bang et al., NUTHOS-11, 2016)

(a) Thermal response　　　(b) Temperature distribution
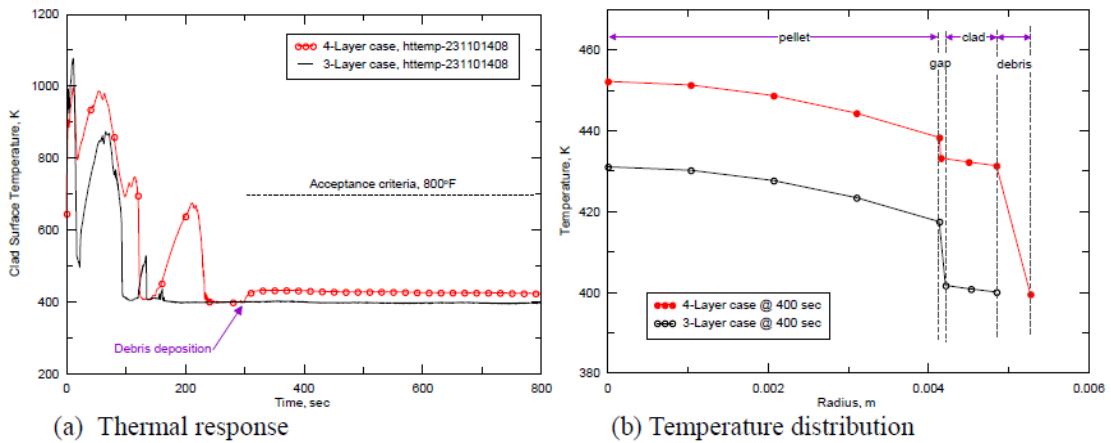
圖十五、碎屑附著於燃料護套後燃料護套溫度增加情形 (右圖為時間為
400 秒時之溫度比較情形)

(參考來源: "Thermal-Hydraulic Modeling of In-core Blockage by Debris Post-
LOCA Long Term Core Cooling Phase", Young Seok Bang et al., NUTHOS-11, 2016)

　　除了上述論文外，其餘論文如利用虛擬實境科技模擬電廠於發生電廠全黑
時的狀態 ("3D Immersive Display Application for Public Illustration of a Station
Blackout for CPR1000", Shangzhen Xie, NUTHOS-11, 2016)、探討利用震波-氣泡物
理機制減緩蒸汽爆炸帶來的衝擊 ("Shock energy absorption during shock-bubble
interaction in microbubble clouds for shock mitigation", Chanwoo KIM, NUTHOS-11,
2016) 以及探討爐心參數量測儀器安裝位置對於反應器外部冷卻影響 ("The
Effect of ICI Mounting Location on External Reactor Vessel Cooling", Jungsoo Suh,
NUTHOS-11, 2016) 也都是值得探討的研究主題。

肆、 心得與建議

1. 參加國際會議發表論文除接受國際同儕審議外，亦可掌握國際研究最新趨勢，並與知名學者專家進行寶貴資訊交流，也可就雙方有共同興趣的議題進行深入討論或是探討未來學術合作之可能性，此舉對於提升我國學術水準有甚大助益。例如本次韓國行在香港城市大學錢景常教授促成下，得以與國際重量級嚴重事故領域 Nam Dinh 教授共進午餐商討未來合作相關事宜，是相當難得的機會，目前也持續以電子郵件商討未來合作事宜。建議未來若經費許可，應持續派員參與此類國際會議。

2. 近年中日韓核能發展極為迅速，無論於先進型電廠設計、物理模型研究、程式發展、安全救援策略等均有大幅進展，能獨立進行研究亦能與歐美知名機構合作互動，反觀我國因政策以及經費資源上的嚴重不足，所進行之研究方向及深度極為受限，甚至已有脫離國際研究趨勢，殊為可惜，建議投注適當資源，持續追蹤先進核能議題、培養相關人才與國際接軌，並適時參與國際合作進行相關的研究。

3. 此次會議主辦方為韓國，其會議行政流程、場地安排、英文表達能力、文宣設計表現均出色，值得我國參考。

附件一、 會議日程表

	Oct. 9th (Sun)	Oct. 10th (Mon)	Oct. 11th (Tue)	Oct. 12th (Wed)	Oct. 13th (Thu)	Oct. 14th (Fri)
07:30-08:00		Speaker's Breakfast				
08:00-08:30						
08:30-09:00		Opening Ceremony 08:30-09:00	Keynote Lecture 1 08:30-09:20	Keynote Lecture 2 08:30-09:20	Keynote Lecture 3 08:30-09:20	CANSAS 2016 (Oct. 12th-14th)
09:00-09:30		Break				
09:30-10:00		Plenary Speech 1 09:10-10:30		Break		
			Session 3 09:40-10:40	Session 7 09:40-10:40	Session 9 09:40-10:40	
10:00-10:30						
10:30-11:00		Coffee Break		Coffee Break		
11:00-11:30		Plenary Speech 2 10:50-12:50	Session 4 11:00-13:00	Session 8 11:00-13:00	Session 10 11:00-12:20	
11:30-12:00						
12:00-12:30			Panel Session 2 11:00-12:30		Closing Ceremony 12:20-12:50	
12:30-13:00	Registration					
13:00-13:30		Lunch 12:50-14:00	Lunch 13:00-14:00			4th IET Workshop 09:00-18:00
13:30-14:00						
14:00-14:30		Session 1 14:00-16:00	Session 5 14:00-16:00			
14:30-15:00						
15:00-15:30		Panel Session 1 14:00-15:30	Panel Session 3 14:00-15:30	NUSSA 2016	Technical Tour	
15:30-16:00				Cultural Tour		
16:00-16:30		Coffee Break				
16:30-17:00		Session 2 16:20-18:40	Session 6 16:20-18:20			
17:00-17:30						
17:30-18:00						
18:00-18:30	Welcome Reception 18:10-20:00					
18:30-19:00			Banquet 19:00-21:30			

10 October (Mon)		
Opening Ceremony		
Time	08:30 - 09:00	
Venue	Room 300A (3F)	
Chairpersons	Chul-Hwa Song (KAERI, Korea), Xu Cheng (Shanghai Jiaotong Univ., China & KIT, Germany)	
Plenary Speech (1)		
Time	09:10 - 10:30	
Venue	Room 300A (3F)	
Chairpersons	Jong H. KIM (KAIST, Korea), Michio MURASE (INSS, Japan)	
09:10 - 09:50	Prospects of nuclear energy technology and nuclear safety R&D in Korea	**Won-Pil Baek** (KAERI, Korea)
09:50 - 10:30	Achieving wider global acceptance of nuclear power in climate change mitigation	**Peter B. LYONS** (DOE, USA)
Plenary Speech (2)		
Time	10:50 - 12:50	
Venue	Room 300A (3F)	
Chairpersons	Goon-Cherl PARK (Seoul National Univ., Korea), Hisashi NINOKATA (POLIMI, Italy)	
10:50 - 11:30	NEA activities in nuclear safety	**Ho NIEH** (NEA, France)
11:30 - 12:10	Prevention of severe accident - lessons learned from Fukushima-Daiichi-accident	**Haruki MADARAME** (Univ. of Tokyo, Japan)
12:10 - 12:50	Technology innovation: SNPTC's practice and prospect	**Zhongtang WANG** (SNPTC, China)
Single- and Two-Phase Flow Fundamentals (1)		
Time	14:00 - 16:00	
Venue	Room 201 (2F)	
Chairpersons	Michio MURASE (INSS, Japan), Dongjin EUH (KAERI, Korea)	
14:00 - 14:20	The effect of vertical seismic acceleration on the nonlinear dynamics of a nuclear-coupled natural circulation boiling system	**Jin-Der LEE**, Shao-Wen CHEN, Chin PAN (National Tsing Hua Univ., Taiwan)

14:20 - 14:40	An experimental study of the ONB incipient for subcooled flow water in narrow rectangular channel	Omar Sharief AL-YAHIA, Daeseong JO (Kyungpook National Univ., Korea)
14:40 - 15:00	Durability of dropwise condensation on graphene coated surfaces	Kyung Won HWANG, Seong Kyu LEE, Joo Won KANG, Hyun Sun PARK, Kiyofumi MORIYAMA (POSTECH, Korea), Moo Hwan KIM (KINS, Korea)
15:00 - 15:20	Countercurrent flow limitation in vertical pipes with the sharp-edged upper end	Michio MURASE, Takayoshi KUSUNOKI, Yasunori YAMAMOTO (INSS, Japan), Katsuya MORI, Akio TOMIYAMA (Kobe Univ., Japan)
15:20 - 15:40	Computational study of heat transfer from inner surface of a circular tube to forced flow of liquid metal in the laminar and transition regions	Koichi HATA, Katsuya FUKUDA (Kobe Univ., Japan), Suguru MASUZAKI (NIFS, Japan)
15:40 - 16:00	Experimental study of single vapor bubble rising in subcooled water	Hongrae JO, Daeseong JO (Kyungpook National Univ., Korea)

Sub-channel Flow and CHF Heat Transfer (1)

Time	14:00 - 15:40	
Venue	Room 202 (2F)	
Chairpersons	Yoichi UTANOHARA (INSS, Japan), Dae-Hyun HWANG (KAERI, Korea)	
14:00 - 14:20	Development and study of thermal-hydraulic code for spiral-spacer rods assembly	Dan ZHANG, Bi SHUMAO, Zhang HANG, Zhang SHU (NPIC, China)
14:20 - 14:40	Two-phase flow measurement in an upward pipe flow using wire-mesh sensor technology	Lifang JIAO, Wei LIU, Taku NAGATAKE, Shinichiro UESAWA, Mitsuhiko SHIBATA, Hiroyuki YOSHIDA (JAEA, Japan), Kazuyuki TAKASE (Nagaoka Univ. of Tech., Japan)
14:40 - 15:00	Similarity principle and single effect experiments to simulate and analyze the accident scenarios in the spent fuel storage pool	Hassan CHAHI, Wolfgang KAESTNER, Sören ALT (Univ. of Appl. Sci. Zittau/Görlitz, Germany)
15:00 - 15:20	Assessment of critical heat flux correlations in narrow rectangular channels	Alberto GHIONE, Brigitte NOEL (CEA, France), Paolo VINAI, Christophe DEMAZIÈRE (Chalmers Univ. of Technology, Sweden)
15:20 - 15:40	Experimental study of CHF in a R134a cooled vertical tube at high pressures	Florian FEUERSTEIN, Patrick SCHINDLER, Denis KLINGEL, Xu CHENG (KIT, Germany)

Advances in Numerical Methods and Modeling (1)

Time	14:00 - 16:00	
Venue	Room 203 (2F)	
Chairpersons	Xiaoxing LIU (Kyushu Univ., Japan), Young Seok BANG (KINS, Korea)	

14:00 - 14:20	Numerical simulation of droplet breakup using a mesh-particel hybrid method	**Xiaoxing LIU**, Koji MORITA (Kyushu Univ., Japan), Shuai ZHANG (Zhejiang Univ., China)
14:20 - 14:40	Numerical simulation of single bubble growth in saturated nucleate boiling	**Ning CHENG**, Yun GUO, Changhong PENG (Univ. of Science and Technology of China, China)
14:40 - 15:00	Three-dimensional flooding analysis in the turbine building of Fukushima Dai-ichi nuclear power plant by the tsunami of great east Japan earthquake using particle method	**Seiichi KOSHIZUKA**, Kohei MUROTANI, Yasutoshi NANNICHI (Univ. of Tokyo, Japan), Eiichi NAGAI, Toshimitsu FUJISAWA (Prometech Software, Inc., Japan), Akira ANJU (Kozo Keikaku Engineering, Inc., Japan)
15:00 - 15:20	Direct numerical simulation and large eddy simulation of a flow at low Reynolds number over backward-facing step using CFD code GASFLOW-MPI	**Han ZHANG**, Jianjun XIAO (KIT, Germany), John R. TRAVIS (Engineering Scientific Software Inc., USA)
15:20 - 15:40	A numerical simulation on melt jet breakup with a coupled multiphase flow model	Mingjun ZHONG, **Yueshan ZHOU**, Jinbiao XIONG, Meng LIN, Yanhua YANG (Shanghai Jiao Tong Univ., China)
15:40 - 16:00	Thermal-hydraulic modeling of in-core blockage by debris for post-LOCA long term core cooling phase	**Young Seok BANG**, Joo-Seok LEE (KINS, Korea)

Passive System Performance Test and Analysis (1)

Time	14:00 - 15:40	
Venue	Room 204 (2F)	
Chairpersons	Andreas SCHAFFRATH (GRS, Germany), Hyun-Sik PARK (KAERI, Korea)	
14:00 - 14:20	An experiment on the passive cooling system of the fission blanket of the hybrid reactor	**Donghua LU**, Xi YAO, Qinglong WEN, Jingyu LIU (CNPRI, China)
14:20 - 14:40	An experimental investigation on the steam condensation in passive safety injection tank during the pressure balance period of an SBLOCA test	**Hwang BAE**, Sung Uk RYU, Byong-Guk JEON, Sung-Jae YI, Hyun-Sik PARK (KAERI, Korea)
14:40 - 15:00	Visualization of cross-sectional two-phase flow structure during condensation of steam inside inclined tubes	Hyung Dae KIM, **Andree PUSEY** (Kyunghee Univ., Korea), Hyun Sik PARK, Tae Soon KWON (KAERI, Korea)
15:00 - 15:20	Experimental investigation of steam condensation in a rod bundle for the passive containment cooling system	**Jinhoon KANG**, Jaejun JEONG, Byongjo YUN (Pusan National Univ., Korea), Dongwook JERNG (Chung-Ang Univ., Korea),

| 15:20 -
15:40 | Experimental study on steam-water counter current flow in scale-down model of the AP1000 surge line | Wenxi TIAN, **Jiangtao YU**, Wenxi TIAN, Leitai SHI, Zhiwei WANG, Guanghui SU (Xi'an Jiaotong Univ., China), Yapei ZHANG,　Suizheng QIU (Shaanxi Normal Univ., China) |
| | | |

Research Reactor Operation and Thermal-Hydraulics (1)

Time	14:00 - 15:40	
Venue	Room 205 (2F)	
Chairpersons	Iztok TISELJ (JSI, Slovenia), Kwon-Yeong LEE (Handong Global Univ., Korea)	
14:00 - 14:20	The preliminary study on optimization of core flow distribution in natural circulation	Feng GE, **Yan WANG** (Tsinghua Univ., China)
14:20 - 14:40	Development and application of siphon breaker simulation program for research reactor	**Kwon-Yeong LEE**, Wan-Soo KIM (Handong Global Univ., Korea)
14:40 - 15:00	Coolant temperature measurements in TRIGA research reactor	Romain HENRY, **Iztok TISELJ**, Marko MATKOVIČ (JSI, Slovenia)
15:00 - 15:20	Assessment of thermal-hydraulic validation capability of China LEAd-based non-nuclear integrated test facility	**Yunqing BAI**, Guangzhan XU, Ming JIN, Tao ZHOU, Sheng GAO (INEST, China)
15:20 - 15:40	HX tube rupture accident process study for china LEAd-based reactor	**Rongyuan SA**, Danna ZHOU, Hualei JIANG, Wangli HUANG, Chaodong ZHANG, Chunjing LI (INEST, China)

Panel Session 1 (Perspectives on Nuclear Thermal-Hydraulic R&D)

Time	14:00 - 15:30	
Venue	Room 206 (2F)	
Chairpersons	H. NINOKATA (POLIMI, Italy), Hee Cheon NO (KAIST, Korea)	
Panelists		Han Gon KIM (KHNP-CRI, Korea)
		Koji OKAMOTO (Univ. of Tokyo, Japan)
		Kenichiro NOZAKI (TEPCO, Japan)
		Xu CHENG (KIT, Germany)
		Xiaodong SUN (Ohio State Univ., USA)

Hydrogen Management

Time	14:00 - 16:00	
Venue	Room 101 (1F)	
Chairpersons	Sanjeev GUPTA (Becker Technologies GmbH, Germany), Seong Wan HONG (KAERI, Korea)	

14:00 - 14:20	The effect of PAR self-ignition on Hydrogen risk assessment : an example	**Ahmed BENTAIB**, Nicolas MEYNET, Alexandre BLEYER, Stephanie PHOUDIAH (IRSN, France)
14:20 - 14:40	MITHYGENE Hydrogen deflagration Benchmark main outcomes and conclusions	**Ahmed BENTAIB**, Nicolas MEYNET, Alexandre BLEYER, Romain GROSSEUVRES, Laura GASTALDO (IRSN, France), Nabiha CHAUMEIX (CNRS-ICARE, France), Etienne STUDER, Sergey KUDRIAKOV (CEA, France), Simon JALLAIS, Elena VYAZMINA (AIR LIQUIDE, France)
14:40 - 15:00	Validation of the LP code MELCOR for containment analyses using results from the OECD/NEA experimental program THAI and THAI2	Jiri DUSPIVA, **Miroslav KOTOUC** (UJV Rez, a.s., Czech Republic)
15:00 - 15:20	Application of the MELCOR 1.8.6 for VVER-1000 containment analyses using results from the OECD/NEA THAI program	Jiri DUSPIVA, **Miroslav KOTOUC**, Tomas JANDA (UJV Rez, a.s., Czech Republic)
15:20 - 15:40	Overview of analyses and experiments for hydrogen control at KAERI	**Seong-Wan HONG**, Sang-Baik KIM, Jongtae KIM, Hyung-Seok KANG, Young-Su NA (KAERI, Korea)
15:40 - 16:00	Qualification and operational study for NIS-PAR	**Sanjeev GUPTA** (Becker Technologies GmbH, Germany), Hans-Joachim SCHOLTKA (Siempelkamp NIS Ingenieurgesellschaft mbH, Alzenau), Andras NÉMETH (Paks Nuclear Power Plant, Hungary), Michael EIGENBAUER (Gundremmingen Nuclear Power Plant, Germany)

CFD Application to Nuclear Reactor System Design and Safety Analysis (1)

Time	14:00 - 16:00	
Venue	Room 102 (1F)	
Chairpersons	Elia MERZARI (ANL, USA), Wang Kee IN (KAERI, Korea)	
14:00 - 14:20	The effect of ICI mounting location on external reactor vessel cooling	**Jungsoo SUH**, Huiun HA (KHNP-CRI, Korea)
14:20 - 14:40	CFD study on critical heat flux in curved surface	**Guanghuai WANG**, Changhong PENG, Yun GUO (Univ. of Science and Technology of China, China)
14:40 - 15:00	Numerical investigation on the liquid film behavior of the passive containment cooling for a nuclear power plant	**Yunke ZHONG**, Deqi CHEN, Zile YANG, Yi XIAO, Lian HU (Chongqing Univ., China)

15:00 - 15:20	CFD simulation of passive residual heat removal heat exchanger based on porous media model	**Wenxi TIAN**, Jian GE, G.H. SU, Siuzheng QIU (Xi'an Jiaotong Univ., China)
15:20 - 15:40	Evaluation of pressure drop in lower reflector of fuel assembly for sodium-cooled fast reactor	**Wang Kee IN**, Kwan Geun LEE, Kyoung Ho YOON, Jin Sik CHEON (KAERI, Korea), Young Shin JEONG (UNIST, Korea)
15:40 - 16:00	Validation of liquid-film transport model in a CFD code for passive containment cooling system using exact numerical solutions	**Jianjun XIAO** (KIT, Germany), John R. TRAVIS (Engineering and Scientific Software Inc., USA), Maurizio BOTTONI (MEEO, Italy)

Single- and Two-Phase Flow Fundamentals (2)

Time	16:20 - 18:20	
Venue	Room 201 (2F)	
Chairpersons	Sung Joong KIM (Hanyang Univ., Korea), Thai Van Nguyen (Hanoi Univ. of Science and Technology, Vietnam)	
16:20 - 16:40	Numerical simulation of the mechanism of bubble dynamics	**Shan-fang HUANG**, Xiao-yu GUO, Da-xin GONG (Tsinghua Univ., China), Jin-yu WANG (NPIC, China)
16:40 - 17:00	Film thickness characteristic of churn-annular flow transition	**Feng-Jiun KUO**, Ming-Lun CHAI, Hsiao-Jou LIN, Min-Song LIN, Shao-Wen CHEN, Bau-Shih PEI (National Tsing Hua Univ., Taiwan)
17:00 - 17:20	Bubble and liquid velocities in the horizontal nozzle and diffuser	**Tram Thanh TRAN**, Huyn Sik PARK (UST, Korea), Byoung Jae KIM (KAERI, Korea)
17:20 - 17:40	Experimental study of two-phase flow in a rectangular pipe under various vibration condition	Min-Lun CHAI, Feng-Jiun KUO, Shao-Wen CHEN, Jong-Rong WANG, Jin-Der LEE, Chunkuan SHIH (National Tsing Hua Univ., Taiwan)
17:40 - 18:00	Experimental research on forced convective heat transfer of molten salts in circular tubes	**Yushuang CHEN**, Naxiu WANG, Yuan FU, Zhongfeng TANG, Haihua ZHU (CAS, China)
18:00 - 18:20	Influence of the natural convection heat transfer inside a vertical pipe varying with length, diameter and Prandtl number	**Seung-Min OHK**, Bum-Jin CHUNG (Kyunghee Univ., Korea)

Sub-channel Flow and CHF Heat Transfer (2)

Time	16:20 - 18:40	
Venue	Room 202 (2F)	
Chairpersons	Bao-Wen YANG (Xi'an Jiaotong Univ., China), Tae-Hyun CHUN (KAERI, Korea)	
16:20 -	An experimental study of droplet-wall collision heat transfer regime map on a hot	**Junseok PARK**, Hyungdae KIM (Kyunghee Univ., Korea)

16:40	surface	
16:40 - 17:00	Validation of ACE(Advanced Continuous-fluid, Eulerian) method of MATRA-S for low flow conditions	**Kyong-Won SEO**, Hyuk KWON, Seong-Jin KIM, Dae-Hyun HWANG (KAERI, Korea)
17:00 - 17:20	Study on critical heat flux for subcooled boiling with non-uniform axial heat flux distribution	**Xirui LIU**, Bao-Wen YANG (Xi'an Jiaotong Univ., China)
17:20 - 17:40	LES analysis of jets in cross flow	Paolo ERRANTE, **Ulrich BIEDER** (CEA, France)
17:40 - 18:00	CHF measurement for flat plates considering dimensional effects (length & width) under atmospheric and pool boiling conditions	**Dong Hoon KAM**, Young Jae CHOI, Yong Hoon JEONG (KAIST, Korea), Hae Min PARK(CEA, France)
18:00 - 18:20	Role of surface roughness in film boiling via saturated distilled water quenching	**Jun-young KANG**, Hyun Sun PARK, Gi Cheol LEE (POSTECH, Korea), Moo Hwan KIM (KINS, Korea), Kumar SRIDHARAN (Univ. of Wisconsin-Madison, USA)
18:20 - 18:40	Mechanistic predictions of the effect of spacer grids with mixing vanes on local void fraction distribution in PWR reactor rod bundles	B. M. WAITE, **M. Z. PODOWSKI** (RPI, USA)

Advances in Numerical Methods and Modeling (2)

Time	16:20 - 18:40	
Venue	Room 203 (2F)	
Chairpersons	Seiichi KOSHIZUKA (Univ. of Tokyo, Japan), Tae-Soon KWON (KAERI, Korea)	
16:20 - 16:40	Transient thermal stress and thermal fatigue analysis at a T-junction with a coupled CFD-FEM method	Yue ZHANG, **Tao LU** (Beijing Univ. of chemical technology, China)
16:40 - 17:00	Modeling of a molten metal droplet penetrating into sodium pool using incompressible SPH	**Fang WANG**, Zhigang ZHANG, Zhi YANG, Jin-ke LI (Harbin Engineering Univ., China)
17:00 - 17:20	Sensitivity analysis of nuclear power plant specific activity in limiting condition of operating	**Seung Chan LEE** (KHNP-CRI, Korea)
17:20 - 17:40	Thermohydraulic assessment of isotopes irradiated in SAFARI-1 research reactor	**Franck M SENDA** (NECSA, South Africa), Stephen M MOSINKI (NECSA, South Africa)
17:40 - 18:00	Evalutaion of turbulent structure over a curved heating surface with LES method	**Xiang CHAI** (Shanghai Jiaotong Univ., China), Bin CHEN (NPIC, China), Jinbiao XIONG, Xu CHENG (Shanghai Jiaotong Univ., China)

18:00 - 18:20	Temperature and pressure analysis of LOCA for Kuosheng MARK III containment usiung TRACE/CONTAN	**Wen-Hsiung WU**, Lih-Yih LIAO (Atomic Energy Council, Taiwan), Jong-Rong WANG, Chunkuan SHIH, Shao-Wen CHEN (National Tsing Hua Univ., Taiwan)
18:20 - 18:40	Validation of macroscopic turbulence model for the subchannel analysis	**Seung-Jun LEE**, Han Young YOON (KAERI, Korea), Seok Joun YOON, Hyoung Kyu CHO (Seoul National Univ., Korea)

Passive System Performance Test and Analysis (2)

Time	16:20 - 18:00	
Venue	Room 204 (1F)	
Chairpersons	Andreas SCHAFFRATH (GRS, Germany), Hyun-Sik PARK (KAERI, Korea)	
16:20 - 16:40	An experimental investigation on the external condensation for a vertical finned tube	**Yeong-Jun JANG**, Dong-Jae CHOI, Yeon-Gun LEE (Jeju National Univ., Korea), Sin KIM (Chung-Ang Univ., Korea)
16:40 - 17:00	Analysis on thermal performance of hybrid heat pipe for passive in-core cooling system in SMR	**Kyung Mo KIM**, In Cheol BANG (UNIST, Korea)
17:00 - 17:20	Experimental investigation on small break loss of coolant accident of surge line	**Chuanxin PENG**, Xiaodong LU, Yuanfeng ZAN, Wenbin ZHUO, Xiao YAN (NPIC, China)
17:20 - 17:40	Full scale experimental study of entrainment at ADS4 branch of CAP14000	**Peng ZHANG**, Lei ZHANG, Wei LI, Di ZHI, Xiao HU, Huajian CHANG (SNPTRD, China), Peipei CHEN (State Power Investment Overseas Co. LTD. of China, China)
17:40 - 18:00	Experimental study on CMT thermal hydraulic behaviors in ACME integral test facility	**LI YUQUAN**, Zhong JIA, Hao Bao TAO (SNPTRD, China), Ye Zi SHEN, Chang Hua JIAN (Tsinghua Univ., China)

Hydrogen and Fission Product Behavior (1)

Time	16:20 - 18:20	
Venue	Room 205 (2F)	
Chairpersons	Ahmed BENTAIB (IRSN, France), Jongtae KIM (KAERI, Korea)	
16:20 - 16:40	Hydrogen distribution behavior analysis in multi-compartment	**Hanchen LIU**, Lili TONG, Xuewu CAO (Shanghai Jiaotong Univ., China)
16:40 - 17:00	Industrial-scale hydrogen deflagration simulations using EUROPLEXUS code	**Sergey KUDRIAKOV**, Etienne STUDER, Alberto BECCANTINI (CEA, France), Alexey VELIKORODNY (AUSY, France)
17:00 - 17:20	Investigation and modification of aerosol deposition model of ART mod 2 using experimental data from NSSP-502 and Phébus FPT1	Wasin VECHGAMA, Somboon RASSAME (Chulalongkorn Univ., Thailand), **Kampanart SILVA** (TINT, Thailand)

17:20 - 17:40	Capturing local hydrogen risk in the OPR1000 containment using MELCOR simulation under SBO scenario	**Nam Kyung KIM**, Joongoo JEON, Wonjun CHOI, Gyoodong JEUN, Sung Joong KIM (Hanyang Univ., Korea)
17:40 - 18:00	Thermal-hydraulic analysis of PHWR containment using MELCOR code	Yongjae LEE, Wonjun CHOI, Sungjoong KIM (Hanyang Univ., Korea), **Sungchu SONG**, Seon Oh YU (KINS, Korea)
18:00 - 18:20	GOTHIC simulation of passive autocatalytic recombiner tests performed in the OECD/THAI project	**Zhe Rita LIANG** (CNL, CANADA)

Experiments for Code Verification and Validation (1)

Time	16:20 - 18:20	
Venue	Room 206 (2F)	
Chairpersons	Wang Guo DONG (SNERDI, China), Chang Hyun KIM (KHNP, Korea)	
16:20 - 16:40	A study of GOTHIC8.0 application to condensation and evaporation phenomenon in passive containment cooling system	**Guo Dong WANG,** Benxue HU (SNERDI, China)
16:40 - 17:00	Experimental study on paraffin melting in a cylindrical cavity	**Shuai WANG**, Changhong PENG, Yun GUO (Univ. of Science and Technology of China, China)
17:00 - 17:20	CCFL characteristics and droplets entrainment ratio in a 1/3.9 downscaled model of a PWR hot-leg pipe geometry	**Suleiman Al ISSA**, Rafael Macian-JUAN (Technical Univ. Munich, Germany)
17:20 - 17:40	Experimental investigation on isothermal stratified flow mixing in a horizontal T-junction	**Alexander ISAEV**, Rudi KULENOVIC, Eckart LAURIEN (Univ. of Stuttgart, Germany)
17:40 - 18:00	Design of flow characteristics test facility for intermediate heat exchanger of sodium cooled fast reactor	**Woo Shik KIM**, Heung June CHUNG, Dong-Jin EUH (KAERI, Korea)
18:00 - 18:20	Visualization and analysis of flow redistribution inside a 5x5 rod bundle containing 3x3 blockage	Sang-Ki MOON, **Ngoc Hung NGUYEN**, Chul-Hwa SONG, Seol Ha KIM, Jong Rok KIM (KAERI, Korea)

Thermal-Hydraulics, Design and Safety Analysis of SFR and GCR (1)

Time	16:20 - 18:20	
Venue	Room 101 (1F)	
Chairpersons	Yoshitaka FUKANO (JAEA, Japan), Hae-Yong JEONG (Sejong Univ., Korea)	
16:20 - 16:40	Analytical studies on fuel element failure propagation due to adventitious fuel pin failure in small to large size sodium-cooled fast reactors	**Yoshitaka FUKANO** (JAEA, Japan)

16:40 - 17:00	Unprotected control rod withdrawal event analyses using MARS-LMR to guide the design of control rod stop system in PGSFR	**Chiwoong CHOI**, Taekyeong JEONG, Jaeho JEONG, Kwilim LEE, Kwi-Seok HA (KAERI, Korea)
17:00 - 17:20	Study on heat transfer characteristics in decay heat exchanger of sodium-cooled fast reactor	**Jonggan HONG**, Jaehyuk EOH, Sujin YEOM, Ji-Young JEONG, Tae-Ho LEE (KAERI, Korea)
17:20 - 17:40	Experimental study on natural circulation characteristics in a closed loop sodium system	**Sujin YEOM**, Jae-Hyuk EOH, Jong-Man KIM, Youngil CHO, Yungjoo KO, Byeong-Yeon KIM, Min-Hwan JUNG, Da-Young GAM, Ji-Young JUNG (KAERI, Korea)
17:40 - 18:00	Study of the free surface flow in the MICAS mock-up in support of the ASTRID SFR program.	**David GUENADOU**, Philippe AUBERT, Valérie BISCAY, Manon BOTTIN, Jean-Philippe DESCAMPS (CEA, France)
18:00 - 18:20	Experiment for PGSFR sub-assembly flow characteristics using 37-rod bundle and preliminary analysis code validation	**Dongjin EUH** (KAERI, UST, Korea), S.K. CHANG, H.M. KIM, S. KIM, S.R. CHOI, H.S. CHOI, H.Y. LEE (KAERI, Korea)

11 October (Tue)	
Keynote Lecture (1)	
Time	08:30 - 09:20
Venue	Room 201+202 (2F)
Chairperson	Dominique BESTION (CEA, France)
08:30 - 09:20	Varieties of sensors based on wire-mesh sensor signal acquisition techniques
Keynote Lecture (2)	
Time	08:30 - 09:20
Venue	Room 203+204 (2F)
Chairperson	Tatjana JEVREMOVIC (IAEA, USA)
08:30 - 09:20	International developments, safety issues and modelling gaps of SMR
Keynote Lecture (3)	
Time	08:30 - 09:20
Venue	Room 205+206 (2F)
Chairperson	Hee Cheon NO (KAIST, Korea)
08:30 - 09:20	Post-Fukushima severe accident research initiatives

Keynote Lecture (1), 08:30-09:20: **Horst-Michael PRASSER** (PSI, Switzerland)

Keynote Lecture (2), 08:30-09:20: **Andreas SCHAFFRATH**, Anne Krüssenberg, Sebastian Buchholz (GRS, Germany)

Keynote Lecture (3), 08:30-09:20: **JinHo SONG** (KAERI, Korea)

CFD Application to Nuclear Reactor System Design and Safety Analysis (2)

Time	09:40 - 10:40	
Venue	Room 201 (2F)	
Chairpersons	Tao WAN (JAEA, Japan), Tae-Soon KWON (KAERI, Korea)	
09:40 - 10:00	CFD analysis of passive heat removal by various gases in the spent fuel dry storage system	**Doyoung SHIN**, Uiju JEONG, Gyoodong JEUN, Sung Joong KIM (Hanyang Univ., Korea)
10:00 - 10:20	Applilicability of a hydrocyclone for separation of impurities in the seawater cooling system	**Heung June CHUNG**, Dae Won CHO (KIMM, Korea)
10:20 - 10:40	Numerical study on LBE flow behavior of the TEF-T LBE spallation target at JAEA	**Tao WAN**, Haronari OBAYASHI, Toshinobu SASA (JAEA, Japan)

Code Development and V&V (1)

Time	09:40 - 10:40	
Venue	Room 202 (2F)	
Chairpersons	Tomasz SKOREK (GRS, Germany), Han Young YOON (KAERI, Korea)	
09:40 - 10:00	Further development of COUPLE code taking account of gas-liquid interfacial motion	**Liancheng GUO**, Xue-Nong CHEN, Andrei RINEISKI (KIT, Germany)
10:00 - 10:20	Validation of ATHLET system code - scalling effects by simulation of reflooding experiments	**Tomasz SKOREK**, Livia TIBORCZ (GRS, Germany)
10:20 - 10:40	Numerical simulation of countercurrent flow based on two-fluid model	**huandong CHEN**, xiaoying ZHANG (South China Univ. of technology, China)

Fuel-Coolant Interaction, Steam Explosion and Severe Accident Mitigation (1)

Time	09:40 - 10:40	
Venue	Room 203 (2F)	
Chairpersons	Armando M. GOMEZ TORRES (ININ, Mexico), Rae Joon PARK (KAERI, Korea)	
09:40 - 10:00	Adsorption characteristics of radioactive organic iodine on AgX	**Jifeng WANG**, Toshiki KOBAYASHI, Yuichiro UZUYAMA , Koji ENDO (Rasa Industries, Ltd., Japan)
10:00 - 10:20	3D immersive display application for public illustration of a station blackout for CPR1000	Shangzhen XIE, **Miu-Ling LAM**, Zichen ZHAO, Bing Lam LUK, Ting-Hsuan CHEN, John K.L. HO, Ching-Chang CHIENG (City Univ. of Hong Kong, China)

10:20 - 10:40	A parametric study using the CFD code GASFLOW on venting strategy for a hard venting containment system of a Mark II BWR reactor	**Armando M GOMEZ-TORRES**, Vicente XOLOCOSTLI-MUNGUIA, Eduardo SAINZ-MEJIA (INFN, Mexico)

Severe Accident Analysis and Accident Management (1)

Time	09:40 - 10:40	
Venue	Room 204 (2F)	
Chairpersons	Alexandre VIKTOROV (CNSC, Canada), Kiyofumi MORIYAMA (POSTECH, Japan)	
09:40 - 10:00	Heat transfer of stratified melt pool in LWR lower head under external cooling und different upper boundary conditions	**Xiaoyang GAUS-LIU**, Alexei MIASSOEDOV (KIT, Germany)
10:00 - 10:20	Impact of containment venting on source term for Fukushima-like BWR scenarios	**A. RYDL**, L. FERNANDEZ-MOGUEL, T. LIND (PSI, Switzerland)
10:20 - 10:40	Probabilistic analysis on ex-vessel melt jet breakup and cooling transient and suggestion for simplified modeling	**Kiyofumi MORIYAMA**, Hyun Sun PARK, Woo Hyun JUNG, Byoungcheol HWANG, Eunho KIM, Jin Ho PARK, Mooneon LEE, Tae Yang HAN, Seok Won WHANG (POSTECH, Korea)

Coolability of Damaged Fuels

Time	09:40 - 10:20	
Venue	Room 205 (2F)	
Chairpersons	Georges REPETTO (IRSN, France), Sang Ki MOON (KAERI, Korea)	
09:40 - 10:00	Thermal hydraulics behavior of a rod bundle with partially blocked area during the reflooding phase of the Loss Of Cooling Accident	**Georges REPETTO**, Benoit BRUYERE, Stéphane EYMERY, Tony GLANTZ (IRSN, France)
10:00 - 10:20	Experimental study on heat transfer inside a blocked region of a rod bundle during a LOCA	Juan David PENA CARRILLO, Tony GLANTZ, **Georges REPETTO** (IRSN, France), Michel GRADECK, Alexandre LABERGUE (LEMTA, France)

CANDU Thermal-Hydraulics and Safety

Time	09:40 - 10:40	
Venue	Room 206 (2F)	
Chairpersons	Bo Wook RHEE (KAERI, Korea)	
09:40 - 10:00	Cold leg break LOCA analysis for Canadian-SCWR	**Fei CHAO**, Yuan YUAN, Pan WU, Jianqiang SHAN, Junli GOU (Xi'an Jiaotong Univ., China)

10:00 - 10:20	Advanced evaluation of severe accident source terms for CANDU reactors	Y.M. SONG, J.Y. JUNG (KAERI, Korea), **S. NIJHAWAN** (Prolet Inc., Canada)
10:20 - 10:40	Analysis of fission products behavior during severe accident for CANDU6	**Shangren FENG**, Lili TONG, Xuewu CAO (Shanghai Jiao tong Univ., China)

Waste Management, Spent Fuel Pool and Environmental Nuclear Safety (1)

Time	09:40 - 10:40	
Venue	Room 101 (1F)	
Chairpersons	Si Young LEE (SRNL, USA), TaeWoon KIM (KAERI, Korea)	
09:40 - 10:00	Characterization of environmental source terms in SBO-induced SGTR sequence in a typical 1000MWth PWR and comparison with other source term studies	**Tae Woon KIM**, Seok Jung HAN, Kwang il AHN (KAERI, Korea)
10:00 - 10:20	Fabrication and characterization of glass for vitrification of rare earth waste from pyrogreen process	**Young Hwan HWANG**, Seok-Ju HWANG, Cheon-Woo KIM (KHNP, Korea)
10:20 - 10:40	A study on the treatment of waste electrolytes from the pyrochemical process of used nuclear fuel	**Hee Chul EUN**, Jung Hoon CHOI, Na-Young KIM, Seung-Yeop HAN, Ki-Rak LEE, Hwan-Seo PARK, Do-Hee AHN (KAERI, Korea)

Passive System Performance Test and Analysis (3)

Time	09:40 - 10:40	
Venue	Room 102 (1F)	
Chairpersons	Jean Luc VACHER (EDF, France), Kyoung-Ho KANG (KAERI, Korea)	
09:40 - 10:00	Effects of airborne volatile organic compounds on the performance of Pi/TiO2 coated ceramic honeycomb type passive autocatalytic recombiner	**Chang Hyun KIM**, Je Joong SUNG, Sang Jun HA (KHNP, Korea), Phil Won SEO (Ceracomb Co. Ltd., Korea)
10:00 - 10:20	The safety system and safety features of small reactor ACPR50S concept	Xiang-hui LU, Min RUI, Yong-gang SHEN, **Jiang YANG**, Zhi-kang LIN (China General Nuclear Power Corporation, China)
10:20 - 10:40	Neutronics safety-related investigations of a generic SMART core with state-of-the-art tools	**Yousef ALZABEN**, Victor Hugo SANCHEZ ESPINOZA, Robert STIEGLITZ (KIT, Germany)

Single- and Two-Phase Flow Fundamentals (3)

Time	11:00 - 13:00	
Venue	Room 201 (2F)	

Chairpersons	Xiaojing LIU (Shanghai Jiaotong Univ., China), Hyoung Kyu CHO (Seoul National Univ., Korea)	
11:00 - 11:20	Numerical simulation on bubble dynamics in swirl flow using VOF	**Zhongchun LI**, Hong ZHANG, Sijia DU, Shuhua DING, Xiaoming SONG (NPIC, China)
11:20 - 11:40	An experimental investigation of downward facing critical heat flux in a rectangular channel with the aligned flow obstacles	**Uiju JEONG**, Kyusang SONG, Hong Hyun SON, Gwang Hyeok SEO, Gyoodong JEUN, Sung Joong KIM (Hanyang Univ., Korea)
11:40 - 12:00	Estimation of interfacial area concentrations for two-group bubbles in gas-liquid two-phase flows	**Xiuzhong SHEN** (Kyoto Univ., Japan), Baoqing DENG (Univ. of Shanghai for Science and Technology, China)
12:00 - 12:20	Experemental study on flow and heat transfer of single-phase water in square channel	**Hui BAO** (CAS, China), Yun GUO, Changhong PENG (Univ. of Science and Technology of China, China)
12:20 - 12:40	Numerical simulation of subcooled flow boiling in vertical tube with non-uniform distribution of power	**Qiang WANG**, Puzhen GAO (Harbin Engineering Univ., China)
12:40 - 13:00	Modeling of liquid entrainment phenomena in AP1000 ADS-4 branch line	**Ducheng SUN**, Yan ZHANG, Wenxing LIU (NPIC, China), Yan XIANG, Suizheng QIU, Guanghui SU (Xi'an Jiaotong Univ., China)

Code Development and V&V (2)

Time	11:00 - 13:00	
Venue	Room 202 (2F)	
Chairpersons	Ulrich BIEDER (CEA, France), Chang Hyun KIM (KHNP, Korea)	
11:00 - 11:20	PANDA SETH-2 containment spray test CFD simulation: effect of turbulence modeling	**Nejdet ERKAN**, Koji OKAMOTO (Univ. of Tokyo, Japan)
11:20 - 11:40	Development of thermal-hydraulic transient analysis code for ACR-700	**Shiying WEI**, Wenxi TIAN, Meiyin ZHENG, Suizheng QIU, G.H. SU (Xi'an Jiaotong Univ., China)
11:40 - 12:00	Transient verification of cosFlow-SUBC	**Chaoli TANG**, Bin LUO (SNPSDC, China), Hao ZHANG (SNPSDC, Shanghai Jiaotong Univ., China)
12:00 - 12:20	Experimental Investigation and CFD validation on a 5X5 rod bundle flow with spacer grid and mixing vanes	**Hao SHEN**, Shilong CHEN, Jinbiao XIONG, Xu CHENG (Shanghai Jiao tong Univ., China)
12:20 - 12:40	RELAP-7 code assessment plan and requirement traceability matirix	**Junsoo YOO**, Yong-Joon CHOI, Curtis L. SMITH (INL, USA)
12:40 - 13:00	Development of sodium-water coupled thermal-hydraulics simulation code for sodium-heated straight tube steam generator of fast reactors	**Ryuji YOSHIKAWA**, Masaaki TANAKA, Hiroyuki OHSHIMA (JAEA, Japan), Yasutomo IMAI (NDD Corporation, Japan)

Multi-Scale / Multi-Physics Calculations and Uncertainty Analysis including CFD Codes		
Time	11:00 - 13:00	
Venue	Room 203 (2F)	
Chairpersons	Damar WICAKSONO (EPFL, Switzerland), Donna Post GUILLEN (INL, USA)	
11:00 - 11:20	A small modular lead cooled fast reactor design and related thermal hydraulic analysis approach development	Hongli CHEN, Jingchao FENG, **Shuzhou LI**, Pengcheng ZHAO , Feipeng Qi, Xilin ZHANG, Haoran ZHANG, Chi WANG, Kangli SHI, Qin ZENG, Minyou YE (Univ. of Science and Technology of China, China)
11:20 - 11:40	Heat transfer model of a small-scale waste glass melter with cold cap layer	Alexander ABBOUD, **Donna Post GUILLEN** (INL, USA), Richard POKORNY (Univ.of Chemistry and Technology Prague, Czech Republic)
11:40 - 12:00	Evaluation of deterministic sampling for uncertainty quantification in a probabilistic accident analysis model	**Saidur RAHMAN**, Durga Rao KARANKI, Damar WICAKSONO, Omar ZERKAK, Vinh DANG (PSI, Switzerland)
12:00 - 12:20	Application of artificial neural networks for scram reliability analyses	**Alexander KOZLACHKOV**, Michael BYKOV, Valery SIRYAPIN (OKB GIDROPRESS, Russia)
12:20 - 12:40	Bayesian calibration of thermal-hydraulics model with time-dependent output	**Damar WICAKSONO** (EPFL, Switzerland), Omar ZERKAK (PSI, Switzerland), Andreas PAUTZ (EPFL, PSI, Switzerland)
12:40 - 13:00	Surrogate models for uncertainty propagation in BEPU methodologies: a regulatory view	**Rafael MENDIZÁBAL** (CSN, Spain)
Severe Accident Analysis and Accident Management (2)		
Time	11:00 - 13:00	
Venue	Room 204 (2F)	
Chairpersons	Alexandre VIKTOROV (CNSC, Canada), Rae Joon PARK (KAERI, Korea)	
11:00 - 11:20	Study on impact of boron dilution to the safety for PWR plant under multiple steam generator tube rupture events	**Mingxi WEI**, Tatsuya KUNISHI, Ken MURAMATSU, Hitoshi MUTA (TCU, Japan)
11:20 - 11:40	Analysis of the vulcano VE-U7 corium spreading experiment using MPS method	**Yusan YASUMURA**, Akifumi YAMAJI (Waseda Univ., Japan)
11:40 - 12:00	Evaluation of plant-specific severe accident management guidance (SAMG)	Quanmin LEI, Samuel GYEPI-GARBRAH, Peter DEVITT, **Alexandre VIKTOROV** (CNSC, Canada)
12:00 - 12:20	Development, validation, and application of the containment code system COCOSYS	**Nils REINKE**, Walter KLEIN-HEBLING, Claus SPENGLER, Siegfried SCHWARZ, Sara BECK, Holger NOWACK, Martin SONNENKALB (GRS, Germany)

12:20 - 12:40	Development of suppression pool model based on MELCOR	**Maolin JING,** Bin ZHANG, Bo ZHANG, Jianqiang SHAN (Xi'an Jiaotong Univ., China)
12:40 - 13:00	One-dimensional analysis for long-term cooling of ex-vessel corium: sensitivity analysis	**Byoungcheol HWANG**, Kiyofumi MORIYAMA, Mooneon LEE , Eunho KIM, Hyun Sun PARK (POSTECH, Korea), Gisuk HWANG (Wichita State Univ., USA), Massoud KAVIANY (Univ. of Michigan, USA)

OECD/NEA International Programs (1)

Time	11:00 - 13:00	
Venue	Room 205 (2F)	
Chairpersons	Didier JACQUEMAIN (IRSN, France), Ki-Yong CHOI (KAERI, Korea)	
11:00 - 11:20	Review of uncertainty methods for CFD application to nuclear reactor thermalhydraulics	**Dominique BESTION**, Agnes de CRECY (CEA, France), Fabio MORETTI (NINE, France), Romain CAMY (EDF, France), Arnaud BARTHET, Sege BELLET, Jose Luis Munoz COBO (Polytechnic Univ. of Valencia, Spain), Arnoldo BADILLO, Bojan NICENO (PSI, Switzerland), Pater HEDBERG (Swedish Radiation Safety Authority, Sweden), Martina SCHEUERER (GRS, Germany), Anna NICKOLAEVA (OKB Gidropress, Russia)
11:20 - 11:40	Conclusion of the International OECD/NEA-NUGENIA Iodine workshop	**D. JACQUEMAIN**, T. ALBIOL (IRSN, France), S DICKINSON (NNL, UK), L.-E. HERRANZ (CIEMAT, Spain), F. FUNKE (AREVA GMBH, Germany), G. GLOWA (CNL, Canada), S. GUPTA (Becker Technologies, Germany), H. HOSHI, A. HOTTA (NRA, Japan), T. KÄRKELÄ (VTT, Finland), M. KISSANE (OECD, France), T. LIND (PSI, Switzerland), M. SALAY (US NRC, USA), J.-H. SONG (KAERI, Korea), J.-P. VAN DORSSELAERE (IRSN, France)
11:40 - 12:00	Benchmarking of fast-running software tools used to model radioactive releases during nuclear accidents	**A. VIKTOROV**, P. DEVITT (CNSC, Canada)
12:00 - 12:20	Simulation of the ATLAS benchmark test A5.1 with the code ATHLET	Livia TIBORCZ, **Henrique AUSTREGESILO** (GRS, Germany)

12:20 - 12:40	Integral effect test for steam generator tube rupture (SGTR) during a prolonged station blackout (SBO)	**Byoung-Uhn BAE,** Kyoung-Ho KANG, Yu-Sun PARK, Jong-Rok KIM, Nam-Hyun CHOI, Ki-Yong CHOI (KAERI, Korea)
12:40 - 13:00	Ananlysis on the experimental result of the OECD-ATLAS A5.1 test	**Yusun PARK,** Byoung-Uhn BAE, Kyoung-Ho KANG, Ki-Yong CHOI (KAERI, Korea)

Panel Session 2 (Perspectives on Severe Accidents R&Ds)		
Time	11:00 - 12:30	
Venue	Room 206 (2F)	
Chairpersons	Luis E. HERRANZ (CIEMAT, Spain), JinHo SONG (KAERI, Korea)	
Panelists		Terttaliisa LIND (PSI, Switzerland)
		Ahmed BENTAIB (IRSN, France)
		J.-M. Bonnet (IRSN, Frane)
		M. Naithoh (IAE, Japan)
		Randall O. GAUNTT (SNL, USA)

Waste Management, Spent Fuel Pool and Environmental Nuclear Safety (2)		
Time	11:00 - 12:40	
Venue	Room 101 (1F)	
Chairpersons	Si Young LEE (SRNL, USA), Kyung-Suk SUH (KAERI, Korea)	
11:00 - 11:20	Engineering scale layer-melt crystallization of LiCl molten salt for waste salt purification in the pyrochemical process	**Jung Hoon CHOI,** Tae Kyo LEE, Hee Chul EUN, Ki Rak LEE, Seung Youb HAN, Hwan Seo PARK, Do Hee AHN (KAERI, Korea)
11:20 - 11:40	Candidate wasteforms composing of phosphae and silicate for the immobilization of radioactive waste salt via dechlorination process	**Ki Rak LEE,** Hwan-Seo PARK, Ahreum HAN, In-Hak CHO, Jung-Hoon CHOI, Hee-Chul EUN, Seung Youb HAN, Do-Hee AHN (KAERI, Korea)
11:40 - 12:00	Evaluation for the transport pathway of radionuclide measured in the air sampling in Korea from the Fukushima accident	**Kyung-Suk SUH,** Byung-Il MIN, Kihyun PARK, Sora KIM, Byung-Mo YANG (KAERI, Korea)
12:00 - 12:20	Experimental study on heat transfer performance of a passive cooling system for spent fuel pool	**Zhenqin XIONG,** Hanyang GU, Minglu WANG (Shanghai Jiaotong Univ., China), Cheng YE (SNERDI, China)
12:20 - 12:40	Study on improvement of the cold crucible induction melter stability	**Seok-Ju HWANG,** Young-Hwan HWANG, Cheon-Woo KIM (KHNP, Korea)

Thermal-Hydraulics, Design and Safety Analysis of SFR and GCR (2)		
Time	11:00 - 13:00	
Venue	Room 102 (1F)	

Chairpersons	Ken-ichi MATSUBA (JAEA, Japan), Dong-wook JERNG (Chung-Ang Univ., Korea)	
11:00 - 11:20	Design of electric core simulator system for sodium integral effect test loop for safety simulation and assessment	**Jewhan LEE**, Jae-Hyuk EOH, Ji-Young JEONG (KAERI, Korea), Soon-Joon HONG, Yong-Hwy KIM (FNC Tech, Korea)
11:20 - 11:40	Multi-dimensional thermal-hydraulic analysis using large eddy simulation on thermal striping in the PGSFR	**Seung-Ho RYU**, Seok-Ki CHOI, Dehee KIM, Tae-Ho LEE (KAERI, Korea)
11:40 - 12:00	Experimental investigation on characteristics of mixed particle debris in sedimentation and bed formation behavior	**Md Abdur Rob SHEIKH**, Eikaku SON, Motoki KAMIYAMA , Tohru MORIOKA, Tatsuya MATSUMOTO, Koji MORITA (Kyushu Univ., Japan), Kenichi MATSUBA, Kenji KAMIYAMA, Tohru SUZUKI (JAEA, Japan)
12:00 - 12:20	Pressure transient analysis for sodium-water reaction event using SPIKE code	**Huee-Youl YE**, Sun-Rock CHOI, Ji-Woong HAN, Tae-Ho LEE (KAERI, Korea)
12:20 - 12:40	An empirical correlation to predict the distance for fragmentation of simulated molten-core materials discharged into a sodium pool	**Kenichi MATSUBA,** Mikio ISOZAKI, Kenji KAMIYAMA, Tohru SUZUKI, Yoshiharu TOBITA (JAEA, Japan)
12:40 - 13:00	Performance evaluation of new pattern of wire wrap spacer in 19-pin rods bundle of SFR fuel assembly for enhanced heat transfer	**Yeong Shin JEONG**, Han SEO,In Cheol BANG (UNIST, Korea), Seong Dae PARK (KAERI, Korea)

Single- and Two-Phase Flow Fundamentals (4)		
Time	14:00 - 16:00	
Venue	Room 201 (2F)	
Chairpersons	Seungjin KIM (Pennsylvania State Univ., USA), Bum-Jin CHUNG (Kyunghee Univ., Korea)	
14:00 - 14:20	Flow measurement in a 2-D slice for ERVC conditions by PIV	**Jongwoong YOON**, Yong Hoon JEONG (KAIST, Korea)
14:20 - 14:40	Correction factors associated with the local interfacial area concentration measurement using four point sensors	Vivek MUGUNDHAN, Hariom BHARGAVA, **Kannan IYER** (IIT Bombay, India)
14:40 - 15:00	Onset of nucleate boiling for downward flow in narrow rectangular channel under low pressure	**Jung Hyun SONG,** Juhyung LEE, Yong Hoon JEONG (KAIST, Korea), Soon Heung CHANG (HGU, Korea),
15:00 - 15:20	Scaling criteria for modeling high pressure condensation phenomena using reduced pressure system and simulant fluid	**Khalid KHASAWNEH,** Yong Hoon JEONG (KAIST, Korea)
15:20 - 15:40	Characterization of the effects of 90-degree vertical-upward and vertical-downward elbows in bubbly two-phase flow	Daniel MENA, Shouxu QIAO, **Seungjin KIM** (Pennsylvania State Univ., USA)

15:40 - 16:00	Experimental study of horizontal air-water plug-to-slug transition flow	Ran KONG, **Seungjin KIM** (Pennsylvania State Univ., USA), Stephen BAJOREK, Krik TIEN, Chris HOXIE (US NRC, USA)

Code Development and V&V (3)		
Time	14:00 - 16:00	
Venue	Room 202 (2F)	
Chairpersons	Tatjana JEVREMOVIC (IAEA, USA), Sang Jong Lee (KEPCO NF, Korea)	
14:00 - 14:20	Assessment of RELAP/SCDAPSIM MOD3.4 with severe fuel damage scoping test	**Noppawan RATTANADECHO**, Somboon RASSAME (Chulalongkorn Univ., Thailand), Kampanart SILVA (TINT, Thailand), Chris ALLISON (Innovation System Software, USA)
14:20 - 14:40	NIRK3D and 3DKIN: general description and current status of the new 3D kinetics capabilities of RELAP5/SCDAPSIM/MOD4.0	**Victor MARTINEZ-QUIROGA** (Innovation Systems Software, Spain), C. M. ALLISON, J.R. WAGNER (Innovation Systems Software, USA), Fatih AYDOGAN (Univ. of Idaho, USA), Akbas SABAHATTIN (Bozok Univ., Turkey)
14:40 - 15:00	CFD analysis of a steam generator separation test in the VVER1000 reactor Kozloduy-6	Q. FENG, **U. BIEDER** (CEA, France)
15:00 - 15:20	The development of RELAP/SCDAPSIM/MOD4.0 for advanced fluid systems design analysis	Chris M ALLISON, Richard J WAGNER, Judy K HOHORST (Innovation Systems Software, USA), Marina PEREZ-FERRAGUT, **Victor MARTINEZ-QUIROGA**, Jordi FREIXA, Elisabet Mas de les Valls (Universitat Politècnica de Catalunya, Spain), Zheng FU (Tsinghau Univ., China), Chacha LIN (Ohio State Univ., USA), Mengmeng LOU (McMaster Univ., Canada)
15:20 - 15:40	Research on improving the calculation speed for sparse linear system of the thermal-hydraulic system analysis code	**Li GE**, Jianqiang SHAN, Junli GOU, Bo ZHANG, Mengyao CAI (Xi'an Jiaotong Univ., China)
15:40 - 16:00	Preliminary safety analysis for a 300MWth lead-cooled fast reactor	**Tianyu LU**, Jianqiang SHAN, Junli Gou (Xi'an Jiaotong Univ., China)

Boiling / Condensation Heat Transfer and Nano-Fluid Thermal-Hydraulics (1)		
Time	14:00 - 16:00	
Venue	Room 203 (2F)	
Chairpersons	Tomoaki KUNUGI (Kyoto Univ., Japan), Hyungdae KIM (Kyunghee Univ., Korea)	

14:00 - 14:20	Experiment of ultrasonic effect on heat transfer in pool subcooled condition	Fang-Chin LIU, **Shao-Wen CHEN**, Feng-Jiun KUO, Min-Lun CHAI, Jong-Rong WANG, Wei-Keng Lin, Jin-Der Lee (National Tsing Hua Univ., Taiwan)
14:20 - 14:40	Development of a model for pure steam condensation in a vertical tube	**Baojing WANG**, Junli GOU, Jianqiang SHAN (Xi'an Jiaotong Univ., China)
14:40 - 15:00	Study on bubble behaviors of subcooled flow boiling at high subcooling degrees	Yang CAO, Zensaku KAWARA, Takehiko YOKOMINE, **Tomoaki KUNUGI** (Kyoto Univ., Japan)
15:00 - 15:20	Wall area of influence and growing wall heat transfer due to sliding bubbles in subcooled boiling flow	**JUNSOO YOO** (INL, USA), Carlos E. ESTRADA-PEREZ, Yassin A. HASSAN (TAMU, USA)
15:20 - 15:40	A mechanistic model of wall heat flux partitioning for nucleate boiling considering the nature of heat transfer at nucleation sites	**Nhan Hien HOANG**, In-cheol CHU, Dong-Jin EUH, Chul-Hwa SONG (KAERI, Korea)
15:40 - 16:00	Heat transfer coefficient measurement at top region of reactor vessel lower head under IVR-ERVC condition	**Jun Yeong JUNG**, Yong Hoon JEONG (KAIST, Korea)

Severe Accident Analysis and Accident Management (3)		
Time	14:00 - 16:00	
Venue	Room 204 (2F)	
Chairpersons	Masanori NAITOH (The Institute of Applied Energy, Japan), Sung Joong KIM (Hanyang Univ., Korea)	
14:00 - 14:20	RELAP/SCDAPSIM/MOD3.5 analysis of PHEBUS FPT-3 bundle heating and melting experiment with irradiated fuel and B4C control rod	Bảo Trân Lê (VNUHCM, Vietnam), **Chris M. ALLISON**, Judith K. Hohorst (Innovation Systems Software, USA)
14:20 - 14:40	Enhanced MELCOR models for standard PWR-Westinghouse design	Rafael BOCANEGRA, Marta RUIZ-ZAPATERO, Gonzalo JIMENEZ, **Cesar QUERAL** (UPM, Spain)
14:40 - 15:00	PIV visualization of bubble induced natural convective flow in 2-D rectangular pool for Ex-Vessel debris bed coolability	**Taeyang HAN**, Eunho KIM, Hyun Sun PARK, Kiyofumi MORIYAMA (POSTECH, Korea)
15:00 - 15:20	Design considerations for a core-catcher concept based on bottom-flooding through porous concrete	**Ö. YILMAZ**, G. POHLNER, M. BUCK, J STARFLINGER (Univ. of Stuttgart, Germany), C. JOURNEAU (CEA Cadarache, France)
15:20 - 15:40	Analysis for the TEPCO Fukushima Daiichi unit 2 by the SAMPSON code with core support plate model	**Chiaki KINO**, Hiroaki SUZUKI, Naotoshi TOMINAGA, Hidetoshi OKADA, Marco PELLEGRINI, Masanori NAITOH (IAE, Japan)

15:40 - 16:00	Numerical analysis of SURC-1 and SURC-3 MCCI experiments by MPS method	**Emiko KIBINO**, Xin LI, Akifumi YAMAJI (Waseda Univ., Japan)

Degraded Core Thermal-Hydraulics (1)

Time	14:00 - 15:40	
Venue	Room 205 (2F)	
Chairpersons	Randall O. GAUNTT (SNL, USA), Hyun Sun PARK (POSTECH, Korea)	
14:00 - 14:20	An experimental study on pressure drops and interfacial drag for two phase flow through packed beds	**Liangxing LI**, Xumao ZOU, Liubo KONG, Huixiong LI (Xi'an Jiaotong Univ., China)
14:20 - 14:40	Redefinition of Ra' for the 2D test facility for the oxide pool in a severe accident	**Su-Hyeon KIM**, Hae-Kyun PARK, Bum-Jin CHUNG (Kyunghee Univ., Korea)
14:40 - 15:00	Particle morphology and size distribution effect on pressure gradients of single- and two-phase flow of water/air in mixed beds for ex-vessel coolability	**Jin Ho PARK**, Mooneon LEE, Hyun Sun PARK, Eunho KIM, Kiyofumi MORIYAMA (POSTECH, Korea)
15:00 - 15:20	First experimental results on reflooding of debris beds at elevated pressure	**S. LEININGER**, T. KNOBELSPIES, R. KULENOVIC, E. LAURIEN (Univ. of Stuttgart, Germany)
15:20 - 15:40	Modeling of debris bed formation by particles deposition and relocation during severe accidents in light water reactors	**Wael HILALI**, Michael BUCK, Joerg STARFLINGER (Univ. of Stuttgart, Germany)

Panel Session 3 (Integrated Safety Analysis Approach for Post-Fukushima Era)

Time	14:00 - 15:30	
Venue	Room 206 (2F)	
Chairpersons	Akira YAMAGUCHI (Univ. of Tokyo, Japan), Joon-Eon YANG (KAERI, Korea)	
Panelists		Woody Epstein (Curtiss Wright, USA)
		Hyun-Gook KANG (RPI, USA)

CFD Application to Nuclear Reactor System Design and Safety Analysis (3)

Time	14:00 - 15:40	
Venue	Room 101 (1F)	
Chairpersons	Seiichi KOSHIZUKA (Univ. of Tokyo, Japan), Eung soo KIM (Seoul National Univ., Korea)	
14:00 - 14:20	Numerical investigation of the characteristics of two-phase flow in the rod bundle with spacer grid	**Zile YANG**, Deqi CHEN, Yunke ZHONG, Yi XIAO, Lian HU (Chongqing Univ., China), Dewen YUAN, Wenxing LIU (NPIC, China)

14:20 - 14:40	CFD analysis for the verification of test vessel for the flow simulation of PGSFR	**Seok-Kyu CHANG**, Woo Shik KIM, In-cheol CHU, Dong-Jin EUH (KAERI, Korea)
14:40 - 15:00	Validation of the CFD code FLUENT by SPIV data for mixing flows	Farkas ISTVÁN, Farkas TATIANA, Gottlasz VALÉR, **Iván TÓTH** (MTA EK, Hungary)
15:00 - 15:20	Validation of wall film condensation model in the presence of non-condensable gas for two-fluid model	**Jehee LEE**, Goon-Cherl PARK, Hyoung Kyu CHO (Seoul National Univ., Korea)
15:20 - 15:40	Optimized design of residual heat removal system with dry cooling technology for the APR1400 design	**Jangsik MOON**, Abdulla Salem ALKAABI, Yong Hoon JEONG (KAIST, Korea)

Thermal-Hydraulics, Design and Safety Analysis of SFR and GCR (3)

Time	14:00 - 16:00	
Venue	Room 102 (1F)	
Chairpersons	Xiaodong SUN (Ohio State Univ., USA), Yoon-Yeong BAE (KAERI, Korea)	
14:00 - 14:20	Analysis of main heat transfer system malfunction of the pebble-bed modular high temperature gas-cooled reactor	**Yanhua ZHENG**, Fubing CHEN, Zhipeng CHEN, Lei SHI (Tsinghua Univ.,China)
14:20 - 14:40	Effects of coolant subcooling on Ex-Pin phenomena for SFR with metal fuel under initiating phase of severe accidents using simulants	**Hyo HEO**, Min Ho LEE, In Cheol BANG (UNIST, Korea), Dong Wook JERNG (Chung-Ang Univ., Korea)
14:40 - 15:00	Pebble bed equivalent conductivity test facility for chinese modular high temperature gas cooled reactor	**Cheng Ren**, Xingtuan YANG (Tsinghua Univ.,China)
15:00 - 15:20	Gap size uncertainty quantification in advanced gas reactor TRISO fuel irradiation experiments	**Binh Thi PHAM**, Jeffrey J. EINERSON, Grant L. HAWKES, Nancy J. LYBECK, David A. PETTI (INL,USA)
15:20 - 15:40	Heat transfer characteristics of one side heated vertical rectangular channel applied as vessel cooling system	**Tetsuaki TAKEDA** (Univ. of Yamanshi,Japan)
15:40 - 16:00	Transient behavior of a scaled RCCS test facility under postulated fault and accident scenarios	**Darius D. LISOWSKI**, Rui Hu, Matthew D.BUCKNOR, Adam R.KRAUS, Craig D.GERARDI, Mitch T.FARMER (ANL,USA)

Experiments for Code Verification and Validation (2)

Time	16:20 - 18:20	
Venue	Room 201 (2F)	
Chairpersons	Lionel ROSSI (CEA, France), Byong-Jo YUN (Pusan National Univ., Korea)	

16:20 - 16:40	Heat transfer testing facility for the molten salt reactor heat exchanger	**Qiao Ling KONG**, Li Wen HUI, Huang Wei GUANG, Jin QIAN (CAS,China)
16:40 - 17:00	Experimental study of air-water pool entrainment with side exit	**Wei LI**, Peng ZHANG, Xiao HU, Lei ZHANG, Zhi DI, Daogui TIAN, Huajian CHANG (SNPTRD, China), Peipei CHEN (SPIC, China)
17:00 - 17:20	Simulations of level-swell experiments with TRACE	**Yacine AOUNALLAH** (PSI,Switzerland)
17:20 - 17:40	Vertical distribution of the void fraction, using x-ray attenuation measurements, for different flow regimes in a horizontal pipe	**lionel ROSSI**, Romain De FAYARD, Souha KASSAB (CEA,France)
17:40 - 18:00	Investigation on temperature fluctuations in thermal mixing pipe flows by micro-thermocouple measurements	**Mi ZHOU**, Rudi KULENOVIC, Eckart LAURIEN, Matthias KAMMERER, Xaver SCHULER (Univ. of Stuttgart,Germany)
18:00 - 18:20	RELAP5-3D analysis of EBR-II shutdown heat removal test SHRT-17	Domenico De LUCA, Alessandro PETRUZZI, **Marco CHERUBINI** (NINE, Italy)

Code Development and V&V (4)

Time	16:20 - 18:20	
Venue	Room 202 (2F)	
Chairpersons	Tatjana JEVREMOVIC (IAEA, USA), Sang Jong LEE (KEPCO NF, Korea)	
16:20 - 16:40	Development and validation of a thermal-hydraulic model of the SPES-2 facility with the French system code CATHARE	**Calogera LOMBARDO**, Paride MELONI, Massimiliano POLIDORI (ENEA,Italy)
16:40 - 17:00	Comparison of CATHARE code using a 3D Reactor Pressure Vessel modelling approach and experimental results on intermediate break LOCAs of ROSA 2 program	**Sofia CARNEVALI**, Pascal BAZIN (CEA,France)
17:00 - 17:20	Establishment of TRACE containment model and Maanshan ELAP analysis	**Jung Hua YANG**, Shao-Wen CHEN (National Tsing Hua Univ.,Taiwan), Jong-Rong WANG, Chunkuan SHIH (NUHU,Taiwan)
17:20 - 17:40	Numerical investigation on the effect of neutron dynamics on the characteristics of boiling two phase natural circulation instabilities	**Sapna SINGH** (HBNI,India), Arun Kumar NAYAK (BARC,India)
17:40 - 18:00	Modeling and analysis of selected OECD PKL3 station-blackout experiments using TRACE	**Roman MUKIN**, Omar ZERKAK, Andreas PAUTZ (PSI,Switzerland)

18:00 - 18:20	Thermal-hydraulic evaluation of the system code TRACE/PARCS using different sets of cross-sections	Petros PAPADOPOULOS (ETH Zürich,Switzerland), **Abdelkrim SEKHRI** (Kernkraftwerk Leibstadt AG,Switzerland), Patricio HIDALGA, Rafael MIRO, Gumersindo VERDU (Polytechnic Univ. of Valencia,Spain)

Boiling / Condensation Heat Transfer and Nano-Fluid Thermal-Hydraulics (2)

Time	16:20 - 18:00	
Venue	Room 203 (2F)	
Chairpersons	Guanghui SU (Xi'an Jiaotong Univ., China), In Cheol BANG (UNIST, Korea)	
16:20 - 16:40	Experimental observation of single vapor bubble behavior on a horizontal tube fabricated with flexible heater	**Jae Soon KIM**, Yu-Na KIM, Goon-Cherl PARK, Hyoung Kyu CHO (Seoul National Univ., Korea)
16:40 - 17:00	Numerical investigation on the heat transfer characteristic under flow instability	**Sipeng WANG**, Bao-wen YANG (Xi'an Jiaotong Univ., China)
17:00 - 17:20	A Dimensionless parameter for AlN/H2O nanofluid flow boiling heat transfer based on the experimental study	Yun WANG, Kuanghan KUANG, Bo LIU, Junmei WU, **Guanghui SU** (Xi'an Jiaotong Univ., China)
17:20 - 17:40	Analysis of CHF enhancement by magnetite nanoparticle coating in subcooled boiling regioin	**Young Jae CHOI**, Dong Hoon KAM, Yong Hoon JEONG (KAIST, Korea)
17:40 - 18:00	Scaling of the steady state behaviour of rectangular single-phase natural circulation for passive containment cooling	**Shengjun ZHANG**, Feng SHEN (SNPRI, China)

Severe Accident Analysis and Accident Management (4)

Time	16:20 - 18:00	
Venue	Room 204 (2F)	
Chairpersons	Alexandre VIKTOROV (CNSC, Canada), Sang-Baik KIM (KAERI, Korea)	
16:20 - 16:40	Conversations about challenges In multi-unit CANDU reactor severe accident mitigation strategies	**Sunil NIJHAWAN** (Prolet Inc.,Canada)
16:40 - 17:00	Evaluation of the in-vessel heat transfer characteristics for the Fukushima Daiichi nuclear power plant debris removal	**Hikaru MITSUDA**, Kai YAMADA, Shuichiro MIWA, Hiroto SAKASHITA, Michitsugu MORI (Hokkaido Univ.,Japan), Ryo KIKUCHI, Katsumasa MIYOSHI (NDF,Japan)
17:00 - 17:20	Estimation of water injection rate of Fukushima Daiichi unit 2 after forced depressurization	**Kenichiro NOZAKI**, Shinya MIZOKAMI, Takeshi HONDA, Daisuke YAMAUCHI (TEPCO,Japan), Shoichi SUEHIRO, Hiroshi SHIRAI (TEPSYS,Japan)

17:20 - 17:40	Numerical simulation of MCCI process with different types of concrete based on MPS method	Penghui CHAI, Koji OKAMOTO (Univ. of Tokyo,Japna)
17:40 - 18:00	MELCOR2.1/SNAP analysis of Fukushima-like accident for Chinshan BWR/4 NPP	Yu CHIANG, Ai-Ling HO, Jong-Rong WANG, Shao-Wen CHEN, Chunkuan SHIH, Wen-Sheng HSU (National Tsing Hua Univ.,Taiwan), Jyh-Tong TENG (Chung Yuan Christian Univ.,Taiwan)

Hydrogen and Fission Product Behavior (2)

Time	16:20 - 18:20	
Venue	Room 205 (2F)	
Chairpersons	Etienne STUDER (CEA, France), Yongmann SONG (KAERI, Korea)	
16:20 - 16:40	Hydrogen mobilization by passive autocatalytic recombiners	Etienne STUDER, D. ABDO, F. DABBENE (CEA Saclay,France), J. ALENGRY (Manpower Company,France) S. KELM, J. BAGGEMANN, E. REINECKE (IEK-6,Germany), H.-J. ALLELEIN (RWTH Aachen Univ.,Germany)
16:40 - 17:00	Source term behaviors in SBO sequence in a typical 1000MWth PWR and comparison with other source term results	Tae Woon KIM, Seok Jung HAN, Kwang Il AHN (KAERI,Korea)
17:00 - 17:20	Characteristics of radiological consequences of the Fukushima accident	JinHo SONG (KAERI,Korea)
17:20 - 17:40	Numerical analysis for H2 combustion in the APR1400 containment using a multi-dimensional H2 analysis system	Hyung Seok KANG, Jongtae KIM, Sang Baik KIM, Seong Wan HONG (KAERI,Korea)
17:40 - 18:00	Mitigation of local hydrogen combustion by inertion during pressurizer surgeline failure induced SBO accident	Joongoo JEON, Doyoung SHIN, Wonjun CHOI, Nam Kyung KIM, Gyoodong JEUN, Sung Joong KIM (Hanyang Univ.,Korea)
18:00 - 18:20	Evaluation of aerosol collection efficiency in pool according to bubble shape under severe accident condition	Hyun Joung JO, Sung Il KIM, Kwang Soon HA (KAERI,Korea)

FCVS Thermal-Hydraulics

Time	16:20 - 18:20	
Venue	Room 206 (2F)	
Chairpersons	Luis E. HERRANZ (CIEMAT, Spain), Kwang Soon HA (KAERI, Korea)	

16:20 - 16:40	Phenomena in filtered containment venting system and scaling analysis for separate effect testing	Shripad T REVANKAR (Purdue Univ.,USA, POSTECH,Korea), **Hyun Sun PARK** (POSTECH,Korea), Jin Ho SONG (KAERI,Korea)
16:40 - 17:00	The effect of thermal-hydraulic conditions on iodine retention in a wet scrubber of the FCVS	**Terttaliisa LIND**, Ignazio BEGHI, Lothar OPILIK, Detlef SUCKOW (PSI, Switzerland)
17:00 - 17:20	Study of new evaluation method for aerosol decontamination factor	**Taizo KANAI**, Masahiro FURUYA, Takahiro ARAI, Yoshihisa NISHI (CRIEPI,Korea)
17:20 - 17:40	Preliminary insights from the PASSAM project: investigation on enhancement of source term mitigation	Thierry ALBIOL (IRSN, France), **Luisen HERRANZ** (CIEMAT, Spain), E. RIERA (CSIC, Spain), C. DALIBART (EDF, France), T. LIND (PSI, France), A. Del CORNO (RSE, Italy), T. KÄRKELÄ (VTT, Finland), N. LOSCH (AREVA GmbH, Germany), B. AZAMBRE (Univ. de Lorraine, France)
17:40 - 18:00	Assessment of aerosol generation and injection devices for representative nuclear core melt aerosol species	**Jeffrey KOBALZ**, Christian Martin KUBELT, Björn Alexander KRUPA (RWTH Aachen Univ.,Germany), Benjamin Von LAUFENBERG, Martin FREITAG, Sanjeev GUPTA, Gerhard POSS (Becker Technologies GmbH,Germany), Kathrin TROLLMANN (Forschungszentrum Jülich GmbH,Germany), Hans-Josef ALLELEIN (Forschungszentrum Jülich GmbH, RWTH Aachen Univ.,Germany)
18:00 - 18:20	Overview of filtered containment venting in Asia NPPs	**Jun YANG** (Huazhong Univ. of Science and Technology, China), Doo Yoog LEE (FNC Tech, Korea), Shuichiro MIWA (Hokkaido Univ., Japan), Shao-wen CHEN (National Tsing Hua Univ., China)

Research Reactor Operation and Thermal-Hydraulics (2)

Time	16:20 - 18:20	
Venue	Room 101 (1F)	
Chairpersons	Francesc REVENTOS (Universitat Politècnica de Catalunya, Spain), Bub-Dong CHUNG (KAERI, Korea)	

16:20 - 16:40	Recent MYRRHA safety studies with the SIMMER code	**Xue-Nong CHEN** , Rui LI, Fabrizio GABRIELLI, Andrei RINEISKI, Lena ANDRIOLO, Liancheng GUO (KIT,Germany), Diego CASTELLITI (SCK-CEN,Belgium), Evaldas BUBELIS (KIT,Germany), Giacomino BANDINI, Massimo SAROTTO (ENEA,Italy)
16:40 - 17:00	Development and qualification of RELAP5-3D nodalization of the core of OPAL RR	**Domenico De LUCA**, Alessandro PETRUZZI (NINE, Italy), Matt EATON, Vittorio BADALASSI (Imperial College,UK), Jim SCOTT, Vaz MOTTL (ARPANSA,Australia)
17:00 - 17:20	Analysis on the roles of components in passive emergency core cooling system in pressurized water reactor	**Soon Il CHUNG**, Soon Joon HONG (FNC Technology Co.Ltd.,Korea), Han Gon KIM (KHNP Co.Ltd.,Korea)
17:20 - 17:40	Evaluation of CHF correlations for the narrow rectangular channel in the downward flow condition	**Huiyung KIM**, Jaejun JEONG, Byongjo YUN (Pusan National Univ.,Korea), Jonghark PARK, Cheol PARK (KAERI,Korea)
17:40 - 18:00	Development status of thermal hydraulic facilities for China lead-based reactor	**Yican WU**, FDS TEAM (INEST,China)
18:00 - 18:20	An engineering scaled thermal-hydraulics test facility for lead-cooled reactor	Yican WU, Qunying HUANG, Yunqing BAI, Sheng GAO, **Xiaomin ZHAO** (INEST,China)

Thermal-Hydraulics, Design and Safety Analysis of SFR and GCR (4)

Time	16:20 - 18:20	
Venue	Room 102 (1F)	
Chairpersons	Pavel KUDINOV (KTH, Sweden), Kwi-Lim LEE (KAERI, Korea)	
16:20 - 16:40	Flow transition caused by nonuniform wall heating in a vertical annular channel	**Toshiro KAMIDANI**, Tomoaki KUNUGI, Takehiko YOKOMINE (Kyoto Univ.,Japan)
16:40 - 17:00	Evaluation of thermal-hydraulic behavior in a large sodium pool of a scaled-down sodium integral effect test facility, STELLA-2	**Jung YOON**, Dong-Won LIM, Young-Chul JO, Jaehyuk EOH, Ji-Young JEONG (KAERI, Korea)
17:00 - 17:20	Suppression of sodium-water reaction by titanium nanoparticle concentration change	**Gunyeop PARK**, Soo Jae KIM, Hyun Soo KIM, Hyun Sun PARK, Moo Hwan KIM (POSTECH,Korea)
17:20 - 17:40	Safety analysis of one pump seizure accident for 2015 PGSFR	**Jae-Ho JEONG** , Kwi-Lim LEE , Chi-Woong CHOI, Tae-Kyung JEONG, Kwi-Seok HA (KAERI,Korea)
17:40 - 18:00	Flow distribution anlaysis for the core of VHTR using looped network analysis method	**Jeong-Hun LEE**, Hyoung-Kyu CHO, Goon-Cherl PARK (Seoul National Univ., Korea)

18:00 - 18:20	Improvement of GAMMA+ heat transfer model based on the air-cooled RCCS test results of KAERI	**Chan Soo KIM**, Byung Ha PARK, Yoon Yeong BAE, Jong Hwan KIM, Sung Nam LEE (KAERI, Korea)

12 October (Wed)	

Keynote Lecture (4)		
Time	08:30 - 09:20	
Venue	Room 201+202 (2F)	
Chairperson	Francesco D'AURIA (Univ. of Pisa, Italy)	
08:30 - 09:20	Multi-scale thermal-hydraulic analyses performed in the NURESIM-NURISP-NURESAFE European projects	**Dominique BESTION** (CEA, France)

Keynote Lecture (5)		
Time	08:30 - 09:20	
Venue	Room 203+204 (2F)	
Chairperson	Xu CHENG (Shanghai Jiaotong Univ., China)	
08:30 - 09:20	Challenges in the prediction of rod bundle CHF - from Subchannel analysis, CFD modeling, rod bundle measurement, to CHF prediction	**Bao-Wen YANG** (Xi'an Jiaotong Univ., China)

Keynote Lecture (6)		
Time	08:30 - 09:20	
Venue	Room 205+206 (2F)	
Chairperson	Michael Z. PODOWSKI (RPI, USA)	
08:30 - 09:20	Severe accident research five years after Fukushima	**Randall O. GAUNTT** (SNL, USA)

Code Development and V&V (5)		
Time	09:40 - 10:40	
Venue	Room 201 (2F)	
Chairpersons	Ivor David CLIFFORD (PSI, Switzerland), Byoung-Uhn BAE (KAERI, Korea)	
09:40 - 10:00	SPACE code evaluation with mechanistic models for the PAFS (Passive Auxiliary Feedwater System) condensation heat exchanger	**Byoung-Uhn BAE**, Seok KIM, Yu-Sun KANG, Kyoung-Ho KANG (KAERI, Korea), Tae-Hwan AHN, Byong-Jo YUN (Pusan National Univ., Korea)

10:00 - 10:20	Validation of sub-models in wall heat flux partitioning model using CUPID code under low and high pressure conditions	**Yun-Je CHO**, Han-Young YOON (KAERI, Korea)
10:20 - 10:40	System code validation series based on a consistent plant nodalization of the ROSA/LSTF integral test facility using TRACE v5.0 patch 4	**Ivor David CLIFFORD**, Omar ZERKAK, Andreas PAUTZ (PSI, Switzerland), Huaqin YAO (Univ. of Tokyo, Japan), Jordi FREIXA (Universitat Politècnica de Catalunya, Spain)

CFD Application to Nuclear Reactor System Design and Safety Analysis (4)

Time	09:40 - 10:40	
Venue	Room 202 (2F)	
Chairpersons	Ignacio GALLEGO-MARCOS (KTH, Sweden), Wang Kee IN (KAERI, Korea)	
09:40 - 10:00	Predictive capability of subcooled boiling flow in pressurized vertical annulus channel with advanced force-balance model and interfacial area transport equation	**Van Thai NGUYEN** (Hanoi Univ. of Science and Technology, Vietnam)
10:00 - 10:20	Numerical simulation of bubble growth and departure from a heated surface	**Ying HUANG**, Puzhen GAO, Qiang WANG, Xianbing CHEN (Harbin Engineering Univ., China)
10:20 - 10:40	Influence of URANS turbulence models on in-vessel flow mixing during cold leg accumulator injection	**Riccardo PURAGLIESI**, Omar ZERKAK, Andreas PAUTZ (PSI, Switzerland)

Containment Tests and Analysis

Time	09:40 - 10:40	
Venue	Room 203 (2F)	
Chairpersons	Paladino DOMENICO (PSI, Switzerland), Hyung Seok KANG (KAERI, Korea)	
09:40 - 10:00	Experimental studies on thermal-hydraulic features in tight lattice rod bundles	**Xuemei LANG**, Houjun GONG, Feng XIE, Lei ZHOU (NPIC, China)
10:00 - 10:20	Study on occurrence condition of thermal stratification in suppression chamber using model of steam condensation	**Daisuke YAMAUCHI**, Koji OKAMOTO, Byeongnam JO, Nejdet ERKAN (Univ. of Tokyo, Japan)
10:20 - 10:40	Erosion of a helium layer due to the flow resulting from the interaction of a steam jet with a flow obstruction in a large vessel	**Sidharth PARANJAPE**, Ralf KAPULLA, Guillaume MIGNOT, Domenico PALADINO (PSI, Switzerland)

Severe Accident Analysis and Accident Management (5)

Time	09:40 - 10:40
Venue	Room 204 (2F)

Chairpersons	Frank RAHN (Whitney Research, USA), Dong Ha KIM (KAERI, Korea)	
09:40 - 10:00	Severe accident management guidelines support calculations for feedwater injection to steam generators during a SBO in Atucha 2 nuclear power plant using RELAP5/SCDAPSIM mod3.6	**Analia BONELLI**, Pablo SERRANO, Oscar MAZZANTINI (Nucleoelé ctrica Argentina S.A., Argentina), Chris ALLISON (Innovative Systems Software, USA)
10:00 - 10:20	Validation of severe accident code SAMPSON debris cooling analysis module (DCA) against OLHF experiments and development of creep models	Filippo SCARPA, **Marco PELLEGRINI**, Masanori NAITOH (The Institute of Applied Energy, Japan)
10:20 - 10:40	Severe accident analysis and accident management for a natural circulation small modular reactor	Longze LI (Xi'an Jiaotong Univ., China), **Tae Woon KIM** (KAERI, Korea), Shripad T. REVANKAR (Purdue Univ., USA), G.H. SU (Xi'an Jiaotong Univ., China)

Scaling Issues

Time	09:40 - 10:20
Venue	Room 205 (2F)
Chairpersons	Cesar QUERAL (Technical Univ. of Madrid, Spain), Kyoung-Ho KANG (KAERI, Korea)

09:40 - 10:00	Scaling in complex thermal hydraulic phenomena	**Peter LIEN** (US NRC, USA), Upendra Singh ROHATGI (Brookhaven National Laboratory, USA)
10:00 - 10:20	Scaling analysis and test facility design for steam ingress accident in MHTGR	Chengqi WANG, Shanbin SHI, David J. ARCILESI, **Xiaodong SUN**, Richard N. CHRISTENSEN (Ohio State Univ., USA), Piyush SABHARWALL (INL, USA)

Fuel-Coolant Interaction, Steam Explosion and Severe Accident Mitigation (2)

Time	09:40 - 10:40
Venue	Room 206 (2F)
Chairpersons	Jiyun ZHAO (City Univ. of Hong Kong, China), Seung Mun YOU (Univ. of Texas at Dallas, Korea)

09:40 - 10:00	Orientation effects on pool boiling heat transfer in water using sintered copper microporous coating	Seongchul JUN, Jinsub KIM, **Seung M. YOU** (The Univ. of Texas at Dallas, USA), Hwan Yeol KIM (KAERI, Korea)
10:00 - 10:20	An experimental study on CHF with hypervapotron structure in external reactor vessel cooling	**Yufeng ZHAO** (SNPRI, China), Fangxin HOU, Ming ZHANG (Tsinghua Univ., China), Tianfang GAO, Peipei CHEN (State Nuclear Power Technology Corporation, China)

10:20 - 10:40	Experimental study on the effect of graphene oxide coated surface on critical heat flux enhancement in external reactor vessel cooling	**Min Ho LEE**, Hyo HEO, In Cheol BANG (UNIST, Korea)

Plant Transients and Accidents Analysis and Testing (1)

Time	09:40 - 10:40	
Venue	Room 101 (1F)	
Chairpersons	Henrique AUSTREGESILO (GRS, Germany)	
09:40 - 10:00	Radiation parameter calculation in reactor auxiliary building during LOCA for Kuosheng BWR-6 plant	Yng-Ruey YUANN (INER, Taiwan), Tai-Tieng HUANG (INER, National Tsing Hua Univ., Taiwan), **Chih-Ming TSAI** (INER, Taiwan)
10:00 - 10:20	Control room unfiltered in-leakage limit of design-basis LOCA for Kuosheng BWR6 plant	**Chih-Ming TSAI**, Yng-Ruei YUANN (INER, Taiwan), Tai-Tieng HUANG (INER, National Tsing Hua Univ., Taiwan), Chia-Yu WU (T-Stone Science and Technology, Taiwan)
10:20 - 10:40	Research on improving LOCA margin for CPR1000 NPP	**Ting WANG**, Jiang YANG, Xianghui LU, Siyuan FANG, Xi HUANG, Zhikang LIN (CNPRI, China)

Hydrogen and Fission Product Behavior (3)

Time	09:40 - 10:40	
Venue	Room 102 (1F)	
Chairpersons	Terttaliisa LIND (PSI, Switzerland), Kwang Soon HA (KAERI, Korea)	
09:40 - 10:00	Sensitivity of PARs performance to accident modeling in small break LOCAs in PWRs	Joan FONTANET, **Luis Enrique HERRANZ** (CIEMAT, Spain)
10:00 - 10:20	Effect of initial operating conditions on hydrogen issue in filtered containment venting system	**Young Su NA**, Song-Won CHO, Kwang Soon HA (KAERI, Korea)
10:20 - 10:40	Experimental effort to observe hydrogen's behavior	**Young Su NA**, Seong-Ho HONG, Seong-Wan HONG (KAERI, Korea)

Sub-channel Flow and CHF Heat Transfer (3)

Time	11:00 - 12:40	
Venue	Room 201 (2F)	
Chairpersons	Yohei SATO (PSI, Switzerland), Kyong-Won SEO (KAERI, Korea)	
11:00 - 11:20	Effect of CNT layer on pool boiling critical heat flux using layer-by-layer assembly technique	**Gwang Hyeok SEO**, Uiju JEONG, Hong Hyun SON, Gyoodong JEUN, Sung Joong KIM (Hanyang Univ., Korea)

11:20 - 11:40	Experimental assessment of critical heat flux for the real conditions of IVR-ERVC strategy	**Hae Min PARK**, Jun Yeong JUNG, Yong Hoon JEONG (KAIST, Korea)
11:40 - 12:00	Pool boiling simulation of water up to critical heat flux using an interface tracking method	**Yohei SATO**, Bojan NICENO (PSI, Switzerland)
12:00 - 12:20	Parametric trends analysis of the CHF based on vertical round tube and 5×5 rod bundle databases	**Wei LIU** (NPIC, China), Shumiao WANG, Jianqiang SHAN (Xi'an Jiaotong Univ., China)
12:20 - 12:40	CHF enhancement of cellulose nano fiber (CNF) fluid in wire-pool boiling experiment	Sub Lee SONG, **Won-Ki HWANG**, Yun-Seok LEE (Handong Global Univ., Korea), Dong Soo Hwang (POSTECH, Korea), Jae Young LEE, Kwon-Yeong LEE (Handong Global Univ., Korea)

CFD Application to Nuclear Reactor System Design and Safety Analysis (5)

Time	11:00 - 13:00	
Venue	Room 202 (2F)	
Chairpersons	Ignacio GALLEGO-MARCOS (KTH, Sweden), Jongtae Kim (KAERI, Korea)	
11:00 - 11:20	Modelling of heat transfer processes in the spent fuel pool using one and three dimensional computer codes	Algirdas KALIATKA, Audrius GRAZEVICIUS, **Eugenijus USPURAS** (Lithuanian Energy Institute, Lithuania)
11:20 - 11:40	Numerical investigation of recombiners efficiency in severe accidents	**Jan-patrice SIMONEAU**, Alexandre ZANCHETTI (EDF, France)
11:40 - 12:00	Numerical simulation of fluid and wall temperature fluctuation downstream from a mixing tee	**Yoichi UTANOHARA**, Akira NAKAMURA, Koji MIYOSHI (INSS, Japan)
12:00 - 12:20	CFD study of a multi-phase subcooled flow boiling model and the evaluation of the model's predictive capability for boiling characteristics	**Seung Jun KIM**, Brett OKHUYSEN (LANL, USA), Etienne DEMARLY, Emilio BAGLIETTO (MIT, USA)
12:20 - 12:40	Conceptual design of the primary loop of pool-type natural circulating nuclear reactor dedicated to seawater desalination	**Woonho JEONG**, Yong Hoon JEONG (KAIST, Korea)
12:40 - 13:00	Modeling of thermal stratification and mixing in a pressure suppression pool using GOTHIC	**Ignacio Gallego MARCOS**, Walter VILLANUEVA, Pavel KUDINOV (KTH, Sweden)

Experiments for Code Verification and Validation (3)

Time	11:00 - 13:20	
Venue	Room 203 (2F)	
Chairpersons	Wei LIU (JAEA, Japan)	
11:00 - 11:20	Analysis and comparison of experimental data generated using PIV and UVP in the mixing of parallel twin jets	**Saya LEE**, Arturo CABRAL, Huhu WANG, Sero YANG, Yassin A HASSAN (Texas A&M Uinv., USA)

11:20 - 11:40	Description of test facility of oxidation layer heat transfer experiment of molten pool	Lian CHEN, Kun HAN, Tao LI, Ying CHEN (SNPTRD, China), **Huajian CHANG** (SNPTRD, Tsinghua Univ., China)**,** Daogui TIAN (SNPTRD, China)
11:40 - 12:00	A methodology for evaluation of mass flow rates of two-phase flows in pipes	**Jun YANG**, Yuan LANQIN (CNL, Canada)
12:00 - 12:20	Outcomes of the third ATLAS domestic standard problem for code assessment of integral effect test simulating main steam line break accident of an advanced pressurized water reactor	**Kyoung-Ho KANG,** Yusun PARK, Byoung-Uhn BAE, Jong-Rok KIM, Ki-Yong CHOI (KAERI, Korea)
12:20 - 12:40	Characteristics of interfacial shape in the Nearly-horizontal tube under the air-water separated flow conditions	**Taehwan AHN,** Jeongmin MOON, Jaejun JEONG, Byongjo YUN (Pusan National Univ., Korea)
12:40 - 13:00	Measurement of void fraction distribution in air-water two-phase flow in a 4x4 rod bundle	**Wei LIU,** Lifang JIAO, Taku NAGATAKE, Mitsuhiko SHIBATA, Masao KOMATSU, Kazuyuki TAKASE, Hiroyuki YOSHIDA (JAEA, Japan)
13:00 - 13:20	Experimental study of the effect of LOCA-generated debris on the pressure drop of fuel assembly	**Zhangpeng GUO,** Weiqian ZHUO, Da WANG, Fenglei NIU (North China Electric Power Univ., China)

Severe Accident Analysis and Accident Management (6)

Time	11:00 - 12:40	
Venue	Room 204 (2F)	
Chairpersons	Nam DINH (North Carolina State Univ., USA), Kwang Il AHN (KAERI, Korea)	
11:00 - 11:20	Development of core relocation surrogate model for prediction of debris properties in lower plenum of a Nordic BWR	**Sergey GALUSHIN,** Walter VILLANUEVA, Dmitry GRISHCHENKO, Pavel KUDINOV (KTH, Sweden)
11:20 - 11:40	Filtered containment venting and monitoring of radioactive releases in severe accident situations	Axel HILL, **Norbert LOSCH,** Mathieu GAUDIOT, Fabian FUTH (AREVA, France)
11:40 - 12:00	Overall effectiveness of multiple actions of severe accident mitigation strategies of OPR1000 under SBLOCA, SBO, and TLOFW scenarios	**Wonjun CHOI,** Nam Kyung KIM, Joongoo JEON, Gyoodong JEUN, Sung Joong KIM (Hanyang Univ., Korea)
12:00 - 12:20	Effect of melt agglomeration on coolability of a debris bed	**Sergey YAKUSH** (IPMech RAS, Russia), Pavel KUDINOV (KTH, Sweden)
12:20 - 12:40	Analysis of the risk of formation of agglomerated debris in Nordic BWRs	**Pavel KUDINOV,** Sergey GALUSHIN (KTH, Sweden), Mikhail DAVYDOV (EREC, Russia)

OECD/NEA International Programs (2)

Time	11:00 - 13:00	
Venue	Room 205 (2F)	

Chairpersons	Luis E. HERRANZ (CIEMAT, Spain), Ki-Yong CHOI (KAERI, Korea)	
11:00 - 11:20	Analysis of OECD/NEA ATLAS A5.1 test with TRACE5. application to a standard PWR Westinghouse	Julio RIVAS-LEWICKY, **Cesar QUERAL,** Lidia CARO-MARTINEZ (Technical Univ. of Madrid, Spain), Julio PEREZ-SANZ(CSN, Spain)
11:20 - 11:40	Summary of WGAMA activities on CFD application to nuclear reactor safety	Dominique BESTION (CEA, France), **Fabio MORETTI** (NINE, Italy)
11:40 - 12:00	ATLAS A5.1 blind test calculation	Valeria PARRINELLO, **Marco CHERUBINI,** Alessandro PETRUZZI (NINE, Italy)
12:00 - 12:20	The OECD/NEA/CSNI SOAR on scaling (the S-SOAR)	**Francesco D'AURIA** (Univ. of Pisa, Italy), Dominique BESTION (CEA, France), Peter H. LIEN (US NRC, USA), Hideo NAKAMURA (JAEA, Japan)
12:20 - 12:40	Overview of the ongoing CSNI/WGAMA activities at the OECD nuclear energy agency	**Luis E. HERRANZ** (CIEMAT, Spain), Didier JACQUEMAIN (IRSN, France), Martin KISSANE (NEA, France)
12:40 - 13:00	Learnings from 30 years of R&D on molten core concrete interaction	Sudhamay BASU (US NRC,USA), **Jean-Michel BONNET,** Michel CRANGA, Didier VOLA (IRSN, France), Mitchell T. FARMER (ANL, USA), Fernando ROBLEDO (CSN, Spain), Claus SPENGLER (GRS, Germany)

Fuel-Coolant Interaction, Steam Explosion and　Severe Accident Mitigation (3)

Time	11:00 - 13:00	
Venue	Room 206 (2F)	
Chairpersons	Jiyun ZHAO (City Univ. of Hong Kong, China), Seong Wan HONG (KAERI, Korea)	
11:00 - 11:20	Experimental study on the effect of molten Tin temperature to vapor explosion	**Rong-jin ZHANG,** Wei BAI, Wei-Feng NI (SNPSDC, China), Meng LIN (Shanghai Jiaotong Univ., China)
11:20 - 11:40	Investigation on the molten fuel dynamics in the water medium after severe accidents	**Jiyun ZHAO,** Mehrdad Shahmohammadi BENI (City Univ. of Hong Kong, Hong Kong)
11:40 - 12:00	Experimental revisit of melt jet breakup length correlations for fuel-coolant interactions	**Woohyun JUNG,** Kiyofumi MORIYAMA, Hyun Sun PARK (POSTECH, Korea)
12:00 - 12:20	Shock energy absorption during shock-bubble interaction in microbubble clouds for shock mitigation	**Chanwoo KIM,** Hyun Sun PARK, Kiyofumi MORIYAMA (POSTECH, Korea)
12:20 - 12:40	Comparison of jet breakup in fully-flooded and partially-flooded reactor cavity	**Hyoung-Tak KIM,** Kwang-Hyon BANG (Korea Maritime and Ocean Univ., Korea)
12:40 - 13:00	Application of TEXAS-V surrogate model to assessment of the containment failure risk due to steam explosion in a Nordic type BWR.	**Grishchenko DMITRY,** Galushin SERGEY, Basso SIMONE, Kudinov PAVEL (KTH, Sweden)

SCO2-Based Technology		
Time	11:00 - 13:00	
Venue	Room 101 (1F)	
Chairpersons	Nicolas ALPY (CEA, France), Jeong Ik LEE (KAIST, Korea)	
11:00 - 11:20	Experimental and numerical studies of supercritical CO2 test loop with GAMMA code	**Seong Jun BAE**, Bongseong OH, Yoonhan AHN, Jeong Ik LEE (KAIST, Korea)
11:20 - 11:40	Performance test results of supercritical CO2 compressor near critical point	**Jae Eun CHA** (KAERI, Korea), Jekyoung LEE, Seong Kuk Cho, Jeong Ik Lee (KAIST, Korea), Tae Ho Kim, Hyun Sun Park (POSTECH, Korea)
11:40 - 12:00	Preliminary study of super critical carbon dioxide Brayton cycle for heat removal in nuclear power plants	Shuhong WEI, **Hua ZHENG** (China Nuclear Power Design Co.Ltd., China)
12:00 - 12:20	Transient analysis of S-CO2 cooled KAIST, Korea micro modular reactor with GAMMA+ code	**Bong Seong OH**, Jeong Ik LEE, Seong Gu KIM, Seong Kuk CHO, Hwanyeol YU (KAIST, Korea)
12:20 - 12:40	Transient analysis of supercritical carbon dioxide Brayton cycle loop for system operation and control	**Joo-Hyun PARK**, Hyun Sun PARK, Taeho KIM, Jin Gyu KWON (POSTECH, Korea), Sung Won BAE, Jae Eun CHA (KAERI, Korea)
12:40 - 13:00	Supercritical CO2 cycle coupling to sodium cooled fast reactors: recent R&D achievements at CEA	Hong Son PHAM, **Nicolas ALPY**, David HAUBENSACK, Thierry CADIOU, Manuel SAEZ, Olivier GASTALDI, Gilles RODRIGUEZ (CEA, France)
Thermal-Hydraulics, Design and Safety Analysis of MSR and Supercritical Reactors		
Time	11:00 - 13:00	
Venue	Room 102 (1F)	
Chairpersons	Shisheng WANG (KIT, Germany), Eung soo KIM (Seoul National Univ., Korea)	
11:00 - 11:20	Analytical investigation of the draining system for a molten salt fast reactor	**Shisheng WANG**, Mattia MASSONE, Andrei RINEISKI (KIT, Germany), E. MERLE-LUCOTTE (Universite Grenoble Alpes, France)
11:20 - 11:40	Feasibility test of similarity technique between high-Pr FLiBe and DOWTHERM RP for single-phase natural circulation	**Yukyung SHIN**, Seok Bin SEO, In Guk KIM, In Cheol BANG (UNIST, Korea)
11:40 - 12:00	Preliminary licensing analysis for a solid-fuel molten salt reactor	Dalin ZHANG, Limin LIU, Minghao LIU, Rongshuan XU, Cheng GONG, Chenglong WANG, Wenxi TIAN, Suizheng QIU, **G.H. SU** (Xi'an Jiaotong Univ., China)

12:00 - 12:20	Design and testing of helically-coiled fluted tube heat exchangers for FHR applications	Minghui CHEN, **Xiaodong SUN**, Richard N. CHRISTENSEN , Shanbin SHI (Ohio State Univ., USA), Isaac SKAVDAHL, Vivek UTGIKAR (Univ. of Idaho, USA), Piyush SABHARWALL (Idaho National Laboratory, USA)
12:20 - 12:40	Analysis of heat transfer characteristics of Canadian SCWR fuel assembly concept	**Armando NAVA DOMINGUEZ**, Yanfei RAO, Thomas BEUTHE (CNL, Canada)
12:40 - 13:00	Startup thermal analysis of a supercritical-pressure light water-cooled reactor CSR1000	**Yuan YUAN**, Jianqiang SHAN, Pan WU, Junli GOU (Xi'an Jiaotong Univ., China)

13 October (Thu)	

Keynote Lecture (7)		
Time	08:30 - 09:20	
Venue	Room 201+202 (2F)	
Chairperson	Bub-Dong CHUNG (KAERI, Korea)	
08:30 - 09:20	Development of V2UP procedure for verification and validation, uncertainty quantification and prediction applying to thermal fatigue issue in sodium-cooled fast reactor	**Masaaki TANAKA** (JAEA, Japan)

Keynote Lecture (8)		
Time	08:30 - 09:20	
Venue	Room 203+204 (2F)	
Chairperson	Guanghui SU (Xi'an Jiaotong Univ., China)	
08:30 - 09:20	Progress of COSINE development and assessment	**Yanhua YANG** (SNPSDC, China)

Keynote Lecture (9)		
Time	08:30 - 09:20	
Venue	Room 205+206 (2F)	
Chairperson	Nam DINH (North Carolina State Univ., USA)	
08:30 - 09:20	Advanced safety and regulation issues for current and future nuclear power plants after Fukushima accident	**Michitsugu MORI** (Hokkaido Univ., Japan)

Code Development and V&V (6)		
Time	09:40 - 10:40	

Venue	Room 201 (2F)	
Chairpersons	Yanhua YANG (SNPSDC, China), Han-Gon KIM (KHNP-CRI, Korea)	
09:40 - 10:00	Application of the component thermal-hydraulics analysis code CUPID for sub-channel scale analysis of rod bundle geometry under adiabatic conditions	**Seok-Jong YOON**, Goon-Cherl PARK, Hyoung-Kyu CHO (Seoul National Univ., Korea)
10:00 - 10:20	Development of Boron transport model based on subchannel approach	**Shengzhe LI**, X. J. LIU, X. CHENG (Shanghai Jiaotong Univ., China)
10:20 - 10:40	Analysis of the cold leg top slot break for ATLAS using the SPACE	**Bum-Soo YOUN**, Se-Yun KIM, Dong-Hyuk LEE (KHNP-CRI, Korea)

CFD Application to Nuclear Reactor System Design and Safety Analysis (6)

Time	09:40 - 10:40	
Venue	Room 202 (2F)	
Chairpersons	Koji MORITA (Kyushu Univ., Japan), Walter VILLANUEVA (KTH, Sweden)	
09:40 - 10:00	Scaling of the erosion of a thermally stratified layer in a large water pool during a steam injection through spargers	**Ignacio GALLEGO-MARCOS**, Walter VILLANUEVA, Pavel KUDINOV (KTH, Sweden)
10:00 - 10:20	Turbulence modeling studies for application to buoyancy-driven air flow simulations of the NSTF	**Adam KRAUS**, Hu RUI, Lisowski DARIUS, Bucknor MATTHEW (ANL, USA)
10:20 - 10:40	Pre-test simulations of SIMECO-2 experiments on stratified melt pool heat transfer	**Peng YU**, Andrei KOMLEV, Walter VILLANUEVA, Yichuan LI, Weimin MA, Sevostian BECHTA (KTH, Sweden)

Multi-Physics Experiments and Analysis

Time	09:40 - 10:40	
Venue	Room 203 (2F)	
Chairpersons	Iztok TISELJ (JSI, Slovenia), Ivor David CLIFFORD (PSI, Switzerland)	
09:40 - 10:00	TRACE/PARCS analysis of the sensitivity of select ATWS events for MELLLA+ BWR/3-4 plant designs to assumptions of sodium pentaborate mixing in the lower plenum	**Peter YARSKY** (US NRC, USA)
10:00 - 10:20	TRACE/PARCS analysis of the sensitivity of select ATWS events for MELLLA+ BWR/5-6 plant designs to assumptions of sodium pentaborate mixing in the upper plenum	**Peter YARSKY** (US NRC, USA)
10:20 - 10:40	Simulating the performance of HWR moderator as a backup heat sink during fuel overheating accidents	**Matthias KRAUSE** (IAEA, Austria), Thambiayah NITHEANANDAN (CNL, Canada)

Severe Accident Analysis and Accident Management (7)

Time	09:40 - 10:40	
Venue	Room 204 (2F)	
Chairpersons	Sergey YAKUSH (IPMech RAS, Russia), Kwang-Il AHN (KAERI, Korea)	
09:40 - 10:00	An analysis on the containment response during station blackout accident	**Vo Thi HUONG** (KAERI,UST, Korea), Jin Ho SONG, Tae Woon KIM, Dong Ha Kim (KAERI, Korea)
10:00 - 10:20	Development and validation of a computationally efficient model for prediction of debris agglomeration	**Pavel KUDINOV** (KTH, Sweden), Mikhail DAVYDOV (EREC, Russia)
10:20 - 10:40	In-vessel debris bed coolability and implications for vessel failure mode	**Sergey YAKUSH** (IPMech RAS, Russia), Pavel KUDINOV (KTH, Sweden)

Safety Analysis of Design Extension Conditions

Time	09:40 - 10:40	
Venue	Room 205 (2F)	
Chairpersons	Dominique BESTION (CEA, France), Kyung-Doo KIM (KAERI, Korea)	
09:40 - 10:00	Analytical basis for the use of a rapidly deployable mobile pump to recover from and extended loss of AC power with a failure of the turbine driven auxiliary feedwater pump	Michael POWELL (APS), Matt WILCOX, **Jeff TAYLOR** (Westinghouse, USA)
10:00 - 10:20	Determination method of complex sequences for new nuclear power plant design extension conditions	**Hua ZHENG**, Wei SHUHONG (CNPEC, China)
10:20 - 10:40	Evaluation of spent fuel pool design and simulator model in design extension condition	**Myeong-Soo LEE** (KHNP-CRI, Korea)

Degraded Core Thermal-Hydraulics (2)

Time	09:40 - 10:40	
Venue	Room 206 (2F)	
Chairpersons	Koji OKAMOTO (Univ. of Tokyo, Japan), Rae Joon PARK (KAERI, Korea)	
09:40 - 10:00	Time-resolved visualization of melt behavior of control rod materials in BWRs	**Shota UEDA**, Hiroshi MADOKORO, Byeongnam JO, Masahiro KONDO, Nejdet ERKAN, Koji OKAMOTO (Univ. of Tokyo, Japan)

10:00 - 10:20	Experimental investigation of spreading and deposition behaviors of molten core debris	**Matsumoto TATSUKI**, Ogura TAKAHITO, Nishigaki SORA, Miwa SHUICHIRO, Sakashita HIROTO, Mori MICHITSUGU (Hokkaido Univ., Japan), Ma ZAIYONG(Xi'an Jiaotong Univ., China)
10:20 - 10:40	Assessment and improvement of models on reflooding of a severely degraded core to be used in current severe accident system codes	**Christophe D'ALESSANDRO**, Michael BUCK, Joerg STARFLINGER (Univ. of Stuttgart, Germany)

Plant Simulators, Analyzers, Operator Training and PRA Applications to Design, Operation and Maintenance

Time	09:40 - 10:40	
Venue	Room 101 (1F)	
Chairpersons	Hidemasa YAMANO (JAEA, Japan), Sung Won BAE (KAERI, Korea)	
09:40 - 10:00	Development of simulation tools at EDF/SEPTEN	**David PIALLA**, Simon ROBERTS, Benjamin HENSSIEN (EDF, France)
10:00 - 10:20	Potential enhancements to PRA standard for internal flooding PRA	**James Chow LIN** (ABSG Consulting Inc., USA)
10:20 - 10:40	Development of risk assessment methodology against natural external hazards for sodium-cooled fast reactors: project overview and margin assessment methodology against volcanic eruption	**Hidemasa YAMANO**, Hiroyuki NISHINO , Kenichi KURISAKA, Yasushi OKANO, Takaaki SAKAI (JAEA, Japan), Takahiro YAMAMOTO, Yoshihiro ISHIZUKA, Nobuo GESHI, Ryuta FURUKAWA, Futoshi NANAYAMA (AIST, Japan), Takashi TAKATA, Emiko AZUMA (Osaka University, Japan)

Plant Transients and Accidents Analysis and Testing (2)

Time	09:40 - 10:40	
Venue	Room 102 (1F)	
Chairpersons	Sidharth PARANJAPE (PSI, Switzerland)	
09:40 - 10:00	Study on containment internal flooding analysis	Dong Soo SONG, **Seung Chan LEE** (KHNP, Korea)
10:00 - 10:20	An extended-BEPU approach for safety analysis on nuclear power plants	Francisco SÁNCHEZ-SÁEZ, Sofia CARLOS, Isabel MARTÓN, Pablo MARTORELL, **Jose Felipe VILLANUEVA**, Sebastián MARTORELL(Polytechnic Univ. of Valencia, Spain)
10:20 - 10:40	Pre- and post- test simulations of station black out experiments at the PKL test facility	Freixa JORDI, **MartÍnez-Quiroga VÍCTOR**, Renventós FRANCESC (Universitat Politècnica de Catalunya, Spain)

Containment and Pool Systems		
Time	11:00 - 12:00	
Venue	Room 201 (2F)	
Chairpersons	Didier JACQUEMAIN (IRSN, France), Kwang Soon HA (KAERI, Korea)	
11:00 - 11:20	Outcome of first containment cooling experiments using CIGMA	**Yasuteru SIBAMOTO**, Taisuke YONOMOTO, Masahiro ISHIGAKI, Satoshi ABE (JAEA, Japan)
11:20 - 11:40	LINX: a separator test facility for containment safety studies	Guillaume MIGNOT, Julien DUPONT, **Domenico PALADINO** (PSI, Switzerland), Horst-Michael PRASSER (ETHZ, Switzerland)
11:40 - 12:00	Scaling and CFD modelling of the pool experiments with spargers performed in the PANDA facility	**Ignacio GALLEGO-MARCOS**, Walter VILLANUEVA, Pavel KUDINOV (KTH, Sweden), Ralf KAPULLA, Sidharth PARANJAPE, Domenico PALADINO (PSI, Switzerland)
Steam Generator Thermal-Hydraulic Experiment and Analysis		
Time	11:00 - 12:20	
Venue	Room 202 (2F)	
Chairpersons	Jovica RIZNIC (CNSC, Canada), Han Young YOON (KAERI, Korea)	
11:00 - 11:20	Characteristics of countercurrent flow limitation in vertical pipes	**Yasunori YAMAMOTO**, Michio MURASE (INSS, Japan), Katsuya MORI, Akio TOMIYAMA (Kobe Univ., Japan)
11:20 - 11:40	A study on the prediction of the vapor mass flow rate and pressure loss for the steam generator	**Kenta FUJI**, Shinichi MOROOKA (Waseda Univ., Japan)
11:40 - 12:00	Effect of gas velocity on the penetration length during gas injecting into water	**Hualei JIANG**, Rongyuan SA, Chaodong ZHANG, Jian HE (INEST, China)
12:00 - 12:20	Analysis of the influence of steam generators during a loss of residual heat removal system under mid-loop conditions at PKL facility simulated by RELAP5	**Villanueva JOSE FELIPE**, Carlos SOFIA, Sánchez-Sáez FRANCISCO, Martorell SEBASTIÁN(Polytechnic Univ. of Valencia, Spain)
Thermal-Hydraulics Related to Nuclear Fuel Safety, Materials and Water Chemistry		
Time	11:00 - 12:20	
Venue	Room 203 (2F)	
Chairpersons	Hongbin ZHANG (INL, USA), Deok Hyun LEE (KAERI, Korea)	

11:00 - 11:20	Steady-state thermal-hydraulic analysis of bimodal space nuclear reactor with heat pipe	**Xiaoyan TIAN**, Huaqi LI, Xinbiao JIANG, Lixin CHEN, Ning YANG, Tengyue MA, Lei ZHU, Pan HU (NINT, China)
11:20 - 11:40	Comparisons of Wilks' and Monte Carlo methods in response to the 10CFR50.46(c) proposed rulemaking	**Hongbin ZHANG**, Ronaldo SZILARD, Ling ZOU, Haihua ZHAO (INL, USA)
11:40 - 12:00	Thermomechanical analysis of a LBLOCA sequence in a PWR-Westinghouse 3 loop with TRACE5 patch4	Julio RIVAS-LEWICKY, **Cesar QUERAL**, Eneko ZUGAZAGOITIA (Technical Univ. of Madrid, Spain)
12:00 - 12:20	Fuel Crud deposition under sub-cooled nucleate boiling in PWR primary coolant using acoustic emission monitoring	**Hee-Sang SHIM**, Seung Heon BAEK, Deok Hyun LEE, Do Haeng HUR (KAERI, Korea)

Fuel-Coolant Interaction, Steam Explosion and Severe Accident Mitigation (4)

Time	11:00 - 11:40	
Venue	Room 204 (2F)	
Chairpersons	Pascal PILUSO (CEA, France), Hwan Yeol KIM (KAERI, Korea)	
11:00 - 11:20	Validation of DECOSIM code against experiments on particle spreading by two-phase flows in water pool	**Sergey E. YAKUSH** (IPMech RAS, Russia), Alexander KONOVALENKO, Simone BASSO, Pavel KUDINOV (KTH, Sweden)
11:20 - 11:40	Noble gas control room accident filtration system for severe accident conditions CRAFT – full scale system test	Axel HILL (AREVA GmbH, Germany), Philipp MARX (AREVA GmbH, Germany)

Advances in Measurements and Instrumentations

| Time	11:00 - 12:20	
Venue	Room 205 (2F)	
Chairpersons	Sangkyu LEE (Univ. of Utah, Korea), In-Cheol CHU (KAERI, Korea)	
11:00 - 11:20	How does the integrated statistical filtering method improve cosmic muon tomography images of nuclear reactors?	**Sangkyu LEE** (Korea Military Academy, Korea), Tatjana JEVREMOVIC (Univ. of Utah, USA)
11:20 - 11:40	Development of plug-in type ultrasonic flowmeter for lead-bismuth spallation target system	**Hironari OBAYASHI**, Masaru HIRABAYASHI, Toshinobu SASA, Kuniaki ARA (JAEA, Japan)
11:40 - 12:00	Development of hybrid imaging method for multiphase flow using X-ray and neutrons	**Ito DAISUKE**, Saito YASUSHI (Kyoto Univ., Japan)
12:00 - 12:20	Recent improvements of ultrasound reflector recognition and tracking technique for bubbly flow measurement	**Povolny ANTONIN**, Kikura HIROSHIGE (Tokyo Institute of Technology, Japan)

Waste Management, Spent Fuel Pool and Environmental Nuclear Safety (3)		
Time	11:00 - 12:00	
Venue	Room 206 (2F)	
Chairpersons	Hanyang GU (Shanghai Jiaotong Univ., China), Kyung-Suk SUH (KAERI, Korea)	
11:00 - 11:20	Comparison of forward and reverse estimation of source terms in Fukushima Daiichi accident	**Tae Woon KIM**, Jin Ho SONG, Sung Il KIM, Kwang Soon HA (KAERI, Korea)
11:20 - 11:40	Development of mobile liquid radioactive waste treatment system(MOLRS) for severe accidents of NPPs	**Ji-Hoon LEE**, Hang-Rae CHO, Cheon-Woo KIM (KHNP-CRI, Korea)
11:40 - 12:00	Integrated analyzing and training simulator for spent fuel pool, CAREPOOL	**Yongdeog KIM**, Youngae KIM, Hocheol SHIN (KHNP-CRI, Korea)

Plant Operation and Maintenance - Generals		
Time	11:00 - 12:20	
Venue	Room 101 (1F)	
Chairpersons	Francesc REVENTOS (Universitat Politècnica de Catalunya, Spain), Chul Jin CHOI (KEPCO E&C, Korea)	
11:00 - 11:20	Investigating the effects of system availability, mitigation strategy, and operating conditions on core uncovery and core damage during station blackout event for Maanshan nuclear power station	**Keng-Yen CHIANG**, Lih-Yi LIAO (Atomic Energy Council, Taiwan), Shih-Jen WANG (INER, Taiwan)
11:20 - 11:40	The research of RPV stud holes inspection equipment based on array image acquisition	**Ren HE**, Tan HONGWEI, Songfeng Weng, SONGFENG (NPIC, China)
11:40 - 12:00	Uncertainties in predictions by system thermal-hydraulic codes: the CASUALIDAD method	**Petruzzi ALESSANDRO** (NINE, ITALY)
12:00 - 12:20	Significance of the input parameters selection and the nodalization qualification in the final results of an IBLOCA BEPU calculation	**Victor MARTÍNEZ-QUIROGA**, Jordi FREIXA, Marina PÉREZ-FERRAGUT, Francesc REVENTÓS (Universitat Politècnica de Catalunya, Spain)

Plant Transients and Accidents Analysis and Testing (3)		
Time	11:00 - 11:40	
Venue	Room 102 (1F)	
Chairpersons	Camille CHARIGNON (EDF, France), Jang Hwan NA (KHNP-CRI, Korea)	
11:00 - 11:20	A new IB-LOCA evaluation model based on the CATHARE System Code	**Camille CHARIGNON** (EDF-SEPTEN, France), Jean-Christophe LECOY(Area NP, France)

11:20 - 11:40	Consensual PSA models and data application to different types of NPPs	Jang Hwan NA (KHNP, Korea), **Seong Kyu PARK** (ACT, Korea)

Closing Session

Time	12:20 - 12:50	
Venue	Room 300A (3F)	
Chairpersons	Xiaodong SUN (Ohio State Univ., USA), Koji OKAMOTO (Univ. of Tokyo, Japan)	

行政院原子能委員會
Atomic Energy Council

Investigating the Effects of System Availability, Mitigation Strategy, and Operating Conditions on Core Uncovery and Core Damage During Station Blackout Event for Maanshan Nuclear Power Station

NUTHOS-11
Oct. 9~13, 2016
Gyeongju , Korea

Atomic Energy Council, Taiwan
Center of Nuclear Regulatory Research

Keng-Yen Chiang

1

Outline

✓ Purpose of This Study
✓ Introduction
✓ Cases Simulated & Results
✓ Discussions
✓ Conclusions

2

Purpose of This Study

Purpose of This Study

Fukushima Daiichi accident in Japan (BDBEE)	might not have been devastating as it was

improved mitigation strategy or system design

So, what if the Fukushima-like situation takes place in Taiwan? In the light of this, this study investigates the effects of system availability, mitigation strategy as well as operating conditions on core uncovery/damage for a NPP (PWR) in Taiwan under Fukushima-like situation.

Purpose of This Study (conti.)

SG manual depressurization

PZR PORV stuck open

N_2 entering primary side following ACC injection

RCP seal leakage rates

TDAFW availability

Asymmetric SG cooldown

The timing of core uncovery/damage
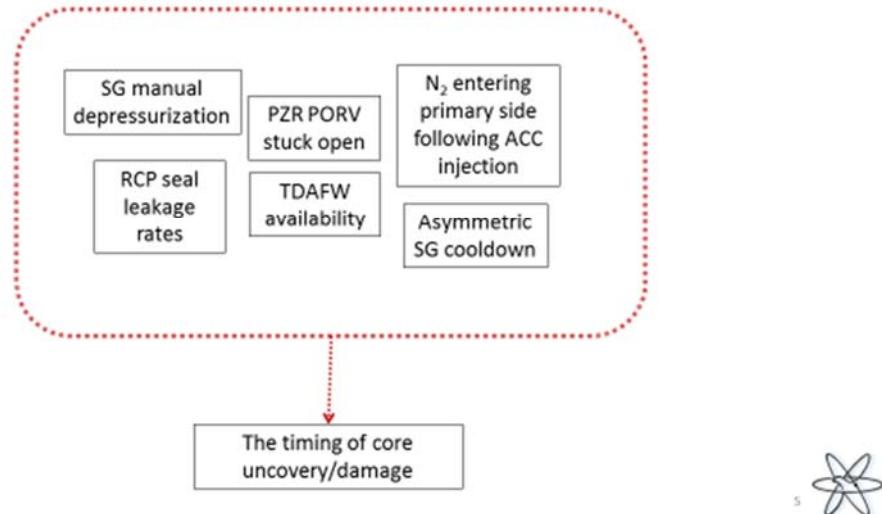
Introduction

Maanshan Nuclear Power Station (MNPS)

Maanshan		
Thermal Power	2822 MWt	
Electric Power	951 MWe	
Reactor Type	PWR	
Turbine Vendor	General Electric	
Containment Type	Large, Dry Post-Tensioned	
	Unit 1	Unit 2
Commercial Date	7/27/1984	5/18/1985
Expiration Date	7/26/2024	5/17/2025

Nodding Diagram for MNPS

* 3 Intact Loops

* Including Accumulators, Steam
  Generators, Pressurizer, Pressurizer
  Relief Tank, Refueling Water Storage
  Tank…
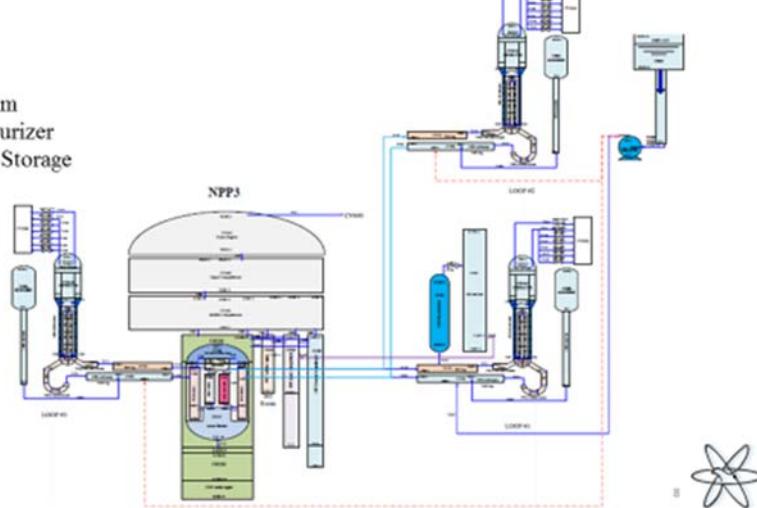
MELCOR

✓ A fully integrated, engineering-level computer code developed by Sandia National Lab for the USNRC to model the progression of severe accidents in NPPs (for both PWRs and BWRs).

✓ Estimation of severe accident source terms, and their sensitivities and uncertainties in a variety of applications.

✓ The version used in this study is MELCOR 1.8.5.

http://energy.sandia.gov/energy/nuclear-energy/nuclear-energy-safety-technologies/melcor/

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Cases Simulated & Results

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Table 1. Cases Description and Results Summary

	RCP Seal Leakage Per Pump (gpm)	TDAFW	PZR PORV Stuck Open	ACC N2 Injection	TAF (hr)	Start of Zr Oxidation (hr)	Core Melt (hr)	First Hydrogen Deflagration (hr)	ACC Injection (hr)
base case	x	x	x	x	2.19	2.49	2.64	2.79	3.65
case 1a	21	x	x	x	2.17	2.48	2.62	2.82	4.10
case 1b	182	x	x	x	1.34	1.94	2.06	5.86	3.92
case 1c	500	x	x	x	0.81	1.08	1.18	3.28	1.58
case 2	21	o	x	x	8.18	13.71	14.58	17.71	21.00
case 3	21	x	o	x	1.88	2.11	2.21	2.22	2.22
case 4	21	x	x	o	2.17	2.48	2.62	2.82	4.23
case 5	21	o	o	x	8.18	13.71	14.58	17.71	18.36
case 6	21	o	x	o	8.18	13.71	14.58	17.71	21.2
case 7	21	x	o	o	1.88	2.11	2.21	2.22	5.47
case 8	21	o	o	o	8.18	13.71	14.58	17.71	19.7

Bounding case analyses : w/o manual SG depressurization

Table 2. SG Depressurization Cases with Different Situations

Cases with manual SG depressurization

case 9	21 gpm Seal Leakage per RCP + SG Depressurization
case 10	21 gpm Seal Leakage per RCP + SG Depressurization with ACC N2 Injection
case 11	21 gpm Seal Leakage per RCP + SG Depressurization + Asymmetric SG Cooldown
case 12	21 gpm Seal Leakage per RCP + SG Depressurization with ACC N2 Injection + Asymmetric SG Cooldown

Comparing Case 1a, 1b, 1c : The effects of Different RCP Seal Leakage Rate

|	RCP Seal Leakage Per Pump (gpm)	TDAFW	PZR PORV Stuck Open	ACC N2 Injection	TAF (hr)	Start of Zr Oxidation (hr)	Core Melt (hr)
base case	x	x	x	x	2.19	2.49	2.64
case 1a	21	x	x	x	2.17	2.48	2.62
case 1b	182	x	x	x	1.34	1.94	2.06
case 1c	500	x	x	x	0.81	1.08	1.18

◆Note: These leakage rates were analyzed in the SOARCA report (Surry). In addition, according to the PRA analyses of WOG RCP seal leakage model, 21gpm is the most likely one to occur and is therefore used in the following analyses

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Comparison of Core Liquid Water Level for Different RCP Seal Leakage Rates

✓ RCP seal leakage ~ LOCA-like behavior

✓ Greater leakage rate -> Faster core uncovery

Core Liquid Water Level
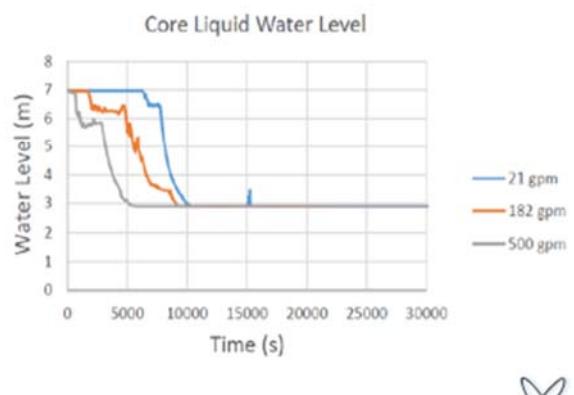
Comparing Case 1a and Case 2: The Effects of TDAFW Availability

	RCP Seal Leakage Per Pump (gpm)	TDAFW	PZR PORV Stuck Open	ACC N2 Injection		TAF (hr)	Start of Zr Oxidation (hr)	Core Melt (hr)
case 1a	21	x	x	x		2.17	2.48	2.62
case 2	21	o	x	x		8.18	13.71	14.58

Comparing Case 1a and Case 2: The Effects of TDAFW Availability
(w/o TDAFW)   (with TDAFW)

Core and SG Water Level
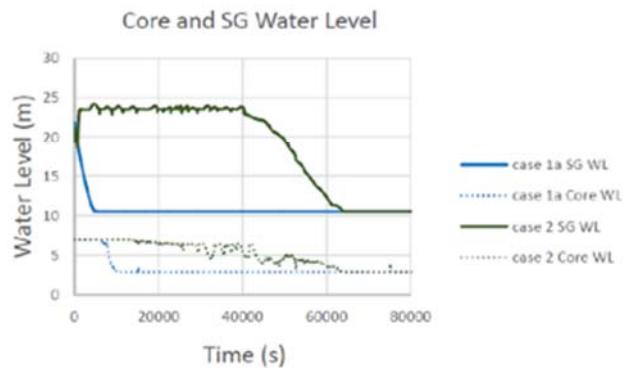
Comparing Case 1a and Case 3: The Effects of PZR PORV Stuck Open

	RCP Seal Leakage Per Pump (gpm)	TDAFW	PZR PORV Stuck Open	ACC N2 Injection			TAF (hr)	Start of Zr Oxidation (hr)	Core Melt (hr)
case 1a	21	x	x	x			2.17	2.48	2.62
case 3	21	x	o	x			1.88	2.11	2.21

RPV Dome Pressure

Core Water Level

Table 1. Cases Description and Results Summary

	RCP Seal Leakage Per Pump (gpm)	TDAFW	PZR PORV Stuck Open	ACC N2 Injection	TAF (hr)	Start of Zr Oxidation (hr)	Core Melt (hr)	First Hydrogen Deflagration (hr)	ACC Injection (hr)
base case	x	x	x	x	2.19	2.49	2.64	2.79	3.65
case 1a	21	x	x	x	2.17	2.48	2.62	2.82	4.10
case 1b	182	x	x	x	1.34	1.94	2.06	5.86	3.92
case 1c	500	x	x	x	0.81	1.08	1.18	3.28	1.58
case 2	21	o	x	x	8.18	13.71	14.58	17.71	21.00
case 3	21	x	o	x	1.88	2.11	2.21	2.22	2.22
case 4	21	x	x	o	2.17	2.48	2.62	2.82	4.23
case 5	21	o	o	x	8.18	13.71	14.58	17.71	18.36
case 6	21	o	x	o	8.18	13.71	14.58	17.71	21.2
case 7	21	x	o	o	1.88	2.11	2.21	2.22	5.47
case 8	21	o	o	o	8.18	13.71	14.58	17.71	19.7

Bounding case analyses : w/o manual SG depressurization

Table 2. SG Depressurization Cases with Different Situations

case 9	21 gpm Seal Leakage per RCP + SG Depressurization
case 10	21 gpm Seal Leakage per RCP + SG Depressurization with ACC N2 Injection
case 11	21 gpm Seal Leakage per RCP + SG Depressurization + Asymmetric SG Cooldown
case 12	21 gpm Seal Leakage per RCP + SG Depressurization with ACC N2 Injection + Asymmetric SG Cooldown

Cases with manual SG depressurization

SG Depressurization Cases with Different Situations

Case	Description
case 9	21 gpm Seal Leakage per RCP + SG Depressurization
case 10	21 gpm Seal Leakage per RCP + SG Depressurization with ACC N2 Injection
case 11	21 gpm Seal Leakage per RCP + SG Depressurization + Asymmetric SG Cooldown
case 12	21 gpm Seal Leakage per RCP + SG Depressurization with ACC N2 Injection + Asymmetric SG Cooldown

- SG Depressurization: URG (Ultimate Response Guideline) style depressurization which has two stages

- Asymmetric SG Cooldown: only one SG, instead of three, is cooldown by alternate SG injection such as fire truck due to resource limitation or other reasons.

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Investigating the Effects of Executing Manual SG Depressurization

✓ **It is assumed that two-step SG depressurization is executed after assuring auxiliary feedwater is available.**

Question#1: What is two-step SG depressurization?

This two-step SG depressurization manner is proposed in the URG* (Ultimate Response Guideline) and is illustrated in the next slide.

Question#2: When do we assure TDAFW is available and when to execute SG depressurization?

TDAFW is assumed to actuate roughly 12 minutes after the incipience of SBO, which is based on the scenario of SBO accident happened on 18th March, 2001 in Maanshan, and SG depressurization is assumed to start one minute after that.

*K.S. Liang, S.C. Chiang, Y.F. Hsu, H.J. Young, B.S. Pei, L.C. Wang, "The Ultimate Emergency Measures to Secure a NPP under an Accidental Condition with no Designed Power or Water Supply", *Nuclear Engineering and Design*, **253**, pp. 259-268 (2012).

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SG Pressure

Start of 1st Stage Depressurization: Depressurize the SGs to roughly 15 kg/cm² and maintain at this level until TDAFW becomes unavailable

Start of 2nd Stage Depressurization: Depressurize the SGs to atmospheric level so that alternate injection like fire truck can come into play

SG Pressure

— w/o SG Depress.
— with SG Depress.

For conservatism, this study assumes TDAFW becomes unavailable after operating for 1hr. SGs are depressurized to atmospheric pressure for fire truck injection since then.

TDAFW makes up water into SG while the execution of SG manual depressurization takes away inventory. The overall effect is, SG water level does not drop below SG bottom, and therefore SG heat transfer does not degrade greatly.

SG Water Level

— w/o SG Depress.
— with SG Depress.
········ Bottom of SG

Core Water Level

The case without executing manual SG depressurization has its core water level dropping below TAF but the one with SG depressurization does not. This is the effects of executing manual SG depressurization.

This conclusion is the same as NUREG/IA-0430* that uses TRACE as simulation tool.

*Jong-Rong Wang, Kai-Chun Huang, Hao-Tzu Lin, Chunkuan Shih, *TRACE Simulation of SBO Accident and Mitigation Strategy in Maanshan PWR*, NUREG/IA-0430, (2013)

Investigating the Effects of Asymmetric SG Cooling

Question#1: What is asymmetric SG cooling?

Asymmetric SG cooldown means only one SG, instead of three, is cooldown by alternate SG injection such as fire truck due to resource limitation or other reasons. Only one SG is depressurized to atmospheric pressure and is cooldown by fire truck, while the other two SGs have their pressure remaining at around 15kg/cm^2

Question#2: What are the possible concerns that asymmetric SG cooling that could have?

The concern is, the non-cooled loops having higher temperature are possibly having higher RCP seal failure probability.

Hot Leg Temperature
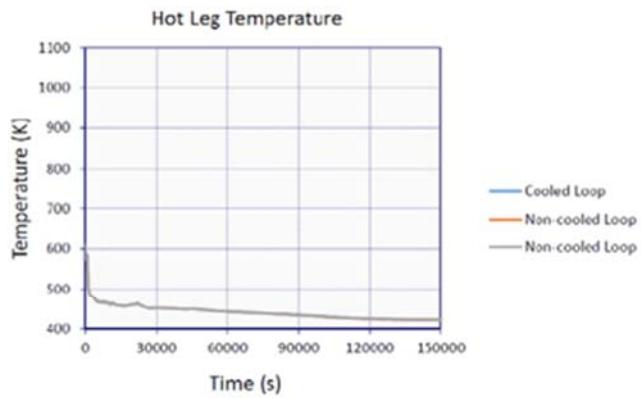
✓ It shows that the temperatures of the cooled loop and non-cooled loops are very close until the end of simulation time (~1.7days). This is because the water level does not drop below hot leg and neither does void occur. Therefore, the concern that the non-cooled loops having higher temperature are possibly having higher RCP seal failure probability is not an issue according to the results.

Investigating the Effects of Nitrogen Entering into Primary Side

Question#1: What could happen as the nitrogen in ACCs entering primary system?

Nitrogen that enters into primary system could accumulate on the SG U-Tube top and impede natural circulation. This degrades heat transfer and increases cladding temperature.

Question#2 : How to simulate whether the nitrogen in ACCs enter into primary system or not?

In MELCOR, the fluid that is allowed for passing through the flow path can be set to as "liquid only" or "the mixture of liquid and gas".

Investigating the Effects of Nitrogen Entering Primary Side via ACC Injection

✓ As ACC tank nearly reaches empty, nitrogen enters into primary side.
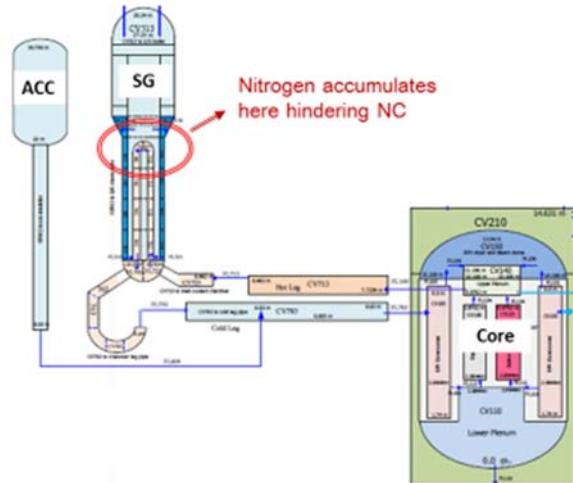
✓ Nitrogen enters into primary side, accumulates at SG U-tube top and Impedes natural circulation
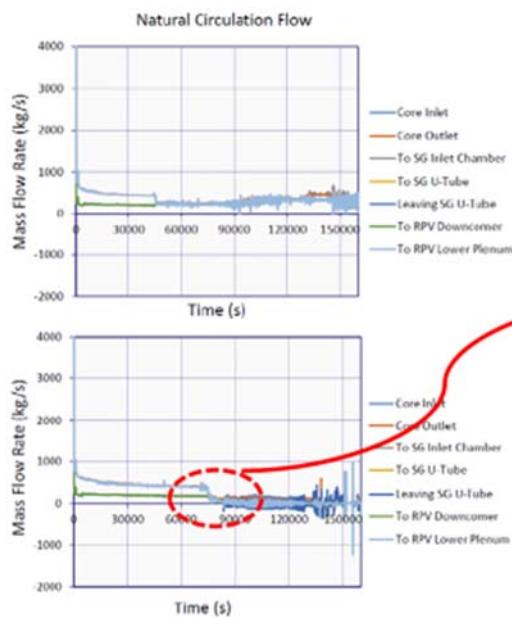
As nitrogen enters into the primary system, it accumulates on the SG U-tube top and impedes natural circulation: the mass flow rate decreases.

PCT

PCT increases since then
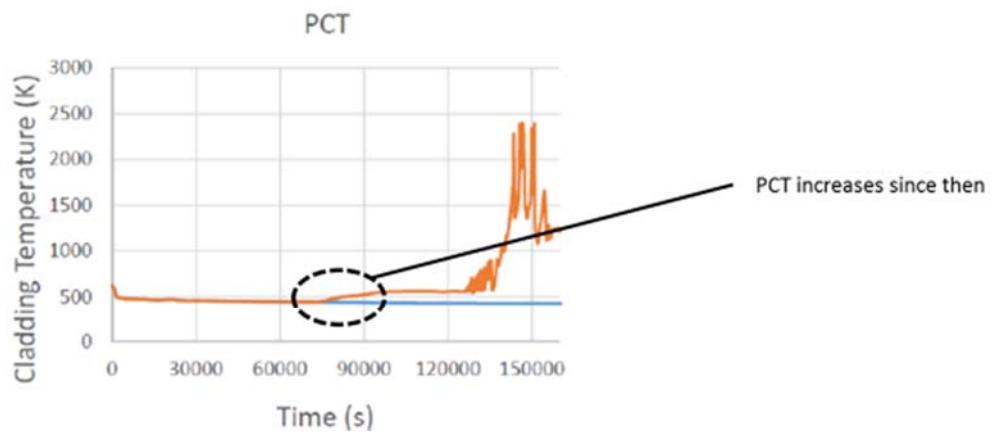
Nitrogen's impeding natural circulation in the primary side results in degraded heat transfer, and therefore results in higher PCT (Peak Cladding Temperature)

Discussions

SG Makeup

✓ TDAFW can delay core uncovery allowing staff to prepare other mitigation actions such as AC power restoration and portable equipment arrangement. Therefore, the availability of TDAFW is decisive since during such an event there are uncertainties in site conditions that limited staffing availability is expected.

✓ The TDAFWP of MNPS can be manually started when there is no DC power. Regarding DC power supply enhancement, the regulatory body requires MNPS to enhance emergency DC power supply to secure a storage capacity of at least 8 hrs without load shedding and at least 24 hrs after the unnecessary loads being isolated. These improve the availability of TDAFW.

✓ When TDAFW is unavailable, the diesel engine driven AFP in MNPS can be used to make up water into SG.

SG Makeup (conti.)

✓ TDAFW could increase inventory for secondary side, but it is not reliable for long-term core cooldown since steam supply is limited. Taiwan Stress Test National Report indicates that under tsunami-like situation, the vital element leads to successful core cooldown is SG standby makeup (diesel engine fire-fighting pumps).

✓ Besides, alternate SG water makeup possibly utilizes different water sources in later stage, and the effects such as water chemistry, corrosion or other reasons that might endanger the integrity of piping system or components are worthy of investigation.

Nitrogen Injection via ACCs

✓ In MNPS, the valves of ACCs can be closed to isolate nitrogen remotely from the control room. When the valves fail to isolate due to reasons such as mechanical failure, compressed air or power depletion, it can be closed manually. However, these valves are located inside the containment and the possibility of executing this depends on how accident progresses. The injection of nitrogen into primary system could be avoided by venting the accumulator tank prior to its occurrence, but the difficulty lies in the capability to finish this operation as well as the uncertainty in the timing to execute.

✓ The results in this study demonstrate that nitrogen hinders natural circulation degrading heat transfer, which is consistent with many other simulations and experiments. Natural circulation is not easy to model in that flow behaviors and thermal gradient are complex during such a situation. The effects of natural circulation deserves further efforts.

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RCP Seal Leakage

✓ RCP seal leakage takes away the inventory in primary side accelerating core uncovery as well as core damage. The RCPs in MNPS are equipped with high temperature o-rings, which degrade quickly as temperature approaches 600°F. For the cases analyzed with executing SG manual depressurization, all of their temperatures do not exceed 600°F during the one-day simulation time, including the cases with asymmetric SG cooldown.

✓ MNPS is planned to deploy Westinghouse shutdown seal, which will further decrease seal leakage rate to less than 1 gpm per pump from the current 21 gpm per pump. The replacement of new seals is helpful to extend the timing of seal material degradation, since decrement in leakage rate results in smaller temperature and pressure ascending rate in primary side.

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Future Work

✓ This study compares the results of SBO events under different situations using MELCOR 1.8.5. The upgrade of the MELCOR 1.8.5 input deck to the latest version 2.1 is planned.

✓ Creep rupture is likely to happen in hot leg and SG U-Tube and potentially affects how accident progresses. It is not modelled in this study and is also included as part of future work.

✓ As part of FLEX, MNPS is planned to deploy intermediate pressure injection system for the RCS. How the availability of this system affects accident progression deserves further efforts.

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Conclusions

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Conclusions

✓ The tsunami-like situation for the MNPS three-loop pressurized water reactor was analyzed, along with investigating different factors that affect the timing of core uncovery as well as core damage. The factors analyzed include the availability of TDAFW, stuck open PORV on PZR, SG depressurization, asymmetric SG cooldown, and the accidental injection of nitrogen into primary side from ACCs. Relevant discussions were also summed up. The code MELCOR 1.8.5 is used in this study for simulations.

✓ The upgrade from MELCOR 1.8.5 to the latest MELCOR 2.1 is planned as part of future work. With an attempt to preliminarily analyze factors affecting the timing of core uncovery and other indicators representing the severity of how accident progresses in this study, more could be explored regarding specific issues or phenomena in future work.

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Thank you for listening ☺

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