

**THE DEPOSITION OF NICKEL FERRITE ONTO HEATED ZIRCALLOY-4
SURFACES IN HIGH-TEMPERATURE BOILING WATER:
INTERACTIONS WITH DISSOLVED ZINC AND BORON**

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ปิติ ศรีสุขวัฒนานันท์: การสะสมของนิเกิลเฟอร์ไรต์บนผิวหน้าแลกเปลี่ยนความร้อน เซอร์โคเนียมในน้ำเดือดอุณหภูมิสูง: ปฏิกริยากับสารละลายสังกะสีและโบรอน (The Deposition of Nickel Ferrite onto Heated Zircaloy-4 Surfaces in High Temperature Boiling Water: Interactions with Dissolved Zinc and Boron) อ. ที่ปรึกษา : รศ.ดร. ชีรศักดิ์ ฤกษ์สมบูรณ์, ศ. ดีเรค เอช ลิสเตอร์ และ ศ. แฟรงค์ อาร์ สจ๊วต 86 หน้า ISBN 974-9651-77-4

ในเตาปฏิกรณ์นิวเคลียร์แบบน้ำความดันสูง มีการใช้สารละลายสังกะสีเพื่อลดการสะสมของกัมมันตภาพรังสี แต่การศึกษาเพิ่มเติมยังคงมีความต้องการในแง่ของผลกระทบของสังกะสีต่อการสะสมของอนุภาคบนผิวหน้าแลกเปลี่ยนความร้อนในแกนของเตาปฏิกรณ์นิวเคลียร์ ซึ่งสามารถนำไปสู่ความผิดปกติในการทำงานของแกนในเตาปฏิกรณ์เนื่องจากการสะสมของโบรอนร่วมกับอนุภาค การทดลองนี้ศึกษาการสะสมของอนุภาคบนผิวแลกเปลี่ยนความร้อน และผลกระทบจากฟิเอชและการใช้สารละลายสังกะสีต่อการสะสมของอนุภาคในการจำลองรูปของเตาปฏิกรณ์นิวเคลียร์แบบน้ำความดันสูง ภายใต้สภาวะการเดือดแบบเย็นยิ่งยวด นอกจากนี้ยังได้ศึกษาการเปลี่ยนแปลงของโบรอนที่เกี่ยวข้องกับการสะสมของอนุภาค อนุภาคที่ปรากฏในเตาปฏิกรณ์ทั่วไปได้ถูกสังเคราะห์และฉีดเข้าไปในระบบเพื่อให้ไปสะสมบนผิวแลกเปลี่ยนความร้อน การเปลี่ยนแปลงของโบรอนถูกศึกษาโดยใช้นิวตรอน ผลการศึกษาพบว่าอนุภาคจำนวนมากได้เกาะและสะสมอยู่บนผิวที่มีการเดือดเป็นรูปแบบปล่องไฟ และหนาประมาณ 10 ไมโครเมตร ในสภาวะฟิเอชต่ำ (ฟิเอช 6.8) การสะสมของอนุภาคมีปริมาณน้อยมากบนผิวแลกเปลี่ยนความร้อนที่ไม่มีการเดือด ฟิเอชเป็นปัจจัยสำคัญในการสะสมของอนุภาค ในขณะที่สารละลายสังกะสีเพิ่มปริมาณของอนุภาคที่เกาะ ขอสรุปที่ชัดเจนสำหรับการเปลี่ยนแปลงของโบรอนไม่สามารถทำได้ และความละเอียดของการวัดปริมาณ โบรอนโดยนิวตรอนยังไม่เพียงพอ

ABSTRACT

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Zinc addition has been implemented and shown to have a beneficial effect in Pressurized Water Reactors (PWRs) in terms of radiation field reduction in nuclear power plants. However, more studies are required to investigate the effect of zinc addition on in-core crud deposition, which is linked to the possibility of an unexpected shift of power, referred to as Axial Offset Anomaly (AOA). The neutron flux depression is caused by boron that may be sequestered in deposits of corrosion products that accumulate on the heated surfaces. In this work, the deposition of corrosion product, and the effect of pH and 10-ppb zinc addition on deposition were studied. In addition, the boron hideout phenomenon was investigated. The corrosion product, non-stoichiometric nickel ferrite, was synthesized and injected into a recirculating water loop operating under PWR subcooled boiling conditions, where it deposited on heated Zircaloy-4 surfaces in an autoclave. Boron sequestration was estimated by sampling the coolant from the autoclave, after it had been isolated from the main loop and allowed to cool. Attempts were also made to estimate sequestration by neutron-based techniques. The deposit morphology on the boiling surfaces indicated “chimneys”, typical of wick boiling, and the deposit thickness under low pH condition ($\text{pH}_{300^\circ\text{C}} 6.8$) was about 10 μm . Very small amounts of deposits were observed on non-boiling surfaces. The pH plays an important role in deposition, while zinc addition increases the amount of deposit. Concrete conclusions could not be made from the boron hideout-return results, while the sensitivity of boron measurement by neutron-based techniques was not sufficient.

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ABBREVIATIONS

AO	Axial Offset
AOA	Axial Offset Anomaly
BWR	Boiling Water Reactor
ICP-OES	Inductively-Couple Plasma-Optical Emission Spectroscopy
MCA	Multichannel Analyzer
PWR	Pressurized Water Reactor
PGAA	Prompt Gamma-ray Activation Analysis
SCA	Single Channel Analyzer

LIST OF SYMBOLS

a_0	Lattice parameter (Å)
d	d-spacing (Å)
h, k, l	Planar indices
\bar{C}_0	Mean count in the absence of boron
\bar{C}_b	Mean count in the presence of boron
$\bar{C}_{b,\text{min}}$	Minimum mean count in the presence of boron
σ	Standard deviation
$\bar{\sigma}_0$	Standard deviation in the absence of boron
$\bar{\sigma}_b$	Standard deviation in the presence of boron
n	Order of reflection
λ	An x-ray wavelength (Å)
θ	Angle beam incident x-ray beam and crystal plane (h, k, l)
σ^2	Variance
$\bar{\sigma}_0^2$	Variance of mean count in the absence of boron
$\bar{\sigma}_b^2$	Variance of mean count in the presence of boron
C	Count
R	Ratio of counts
Σ	Macroscopic cross section (m^{-1})
ϕ	Neutron flux
V	Volume of substance (cm^3)
N_i	Atomic density of isotope i
σ_i	Microscopic cross section of isotope i (barn)
w_i	Weight fraction of isotope i
ρ	Density of substance (kg/m^3)
A_i	Atomic weight of isotope i
u	Atomic mass unit, 1.66×10^{-27} kg

m Number of measurements