Fuel Development, Testing, and Schedule for the Traveling Wave Reactor

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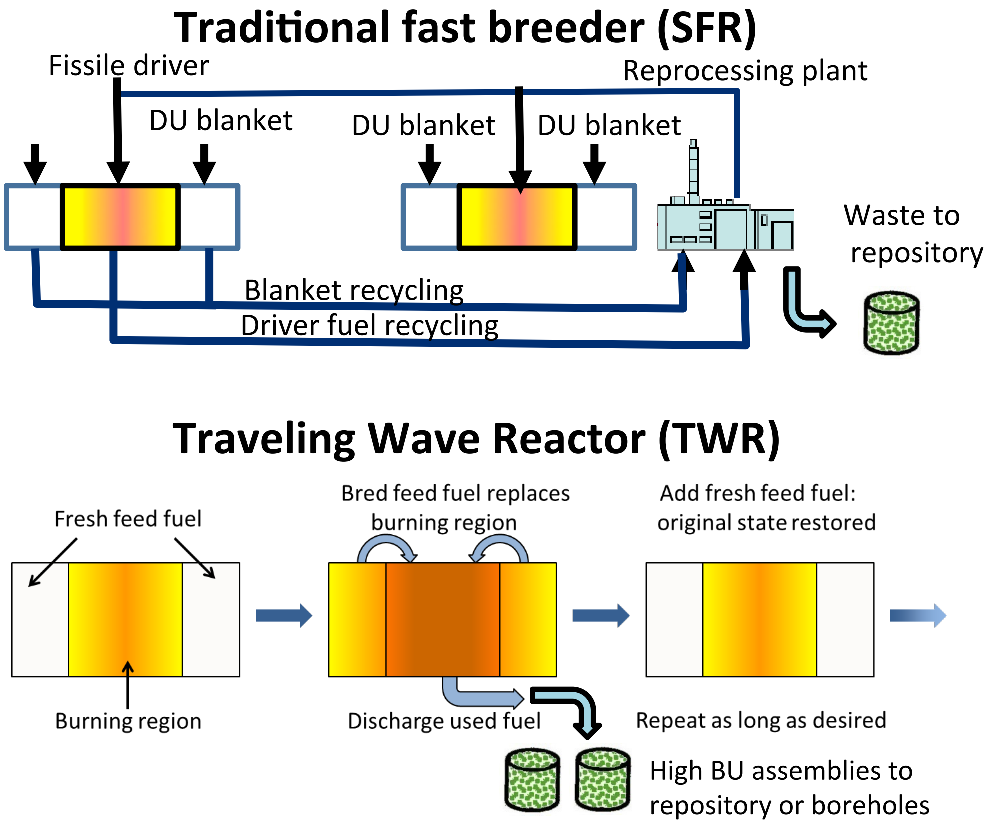
DOE-NRC Second Workshop on Advanced Non-LWR Reactors

North Bethesda Marriott, June 7-8, 2016

The Traveling Wave Reactor

- First breeds fissile Pu-239 in U-238 feed fuel
- Unlike in a traditional SFR, TWR fuel is directly used after breeding, without a reprocessing step
  - Once-through fuel cycle with 30x uranium utilization of LWRs
- Requires:
  - An excellent neutron economy – judicious use of structural materials
  - High burnup fuels and irradiation resistant materials



Main Focus Areas for Fuels and Materials

- Historic data and archived material
  - Forms basis for material choice
- Understand fuel/material behavior
  - Use information to optimize material, and benchmark predictive codes
- Fabrication
  - Supply chain development
- In-pile and out-of-pile testing
  - Heavy ion and neutron irradiations
- Post irradiation examination

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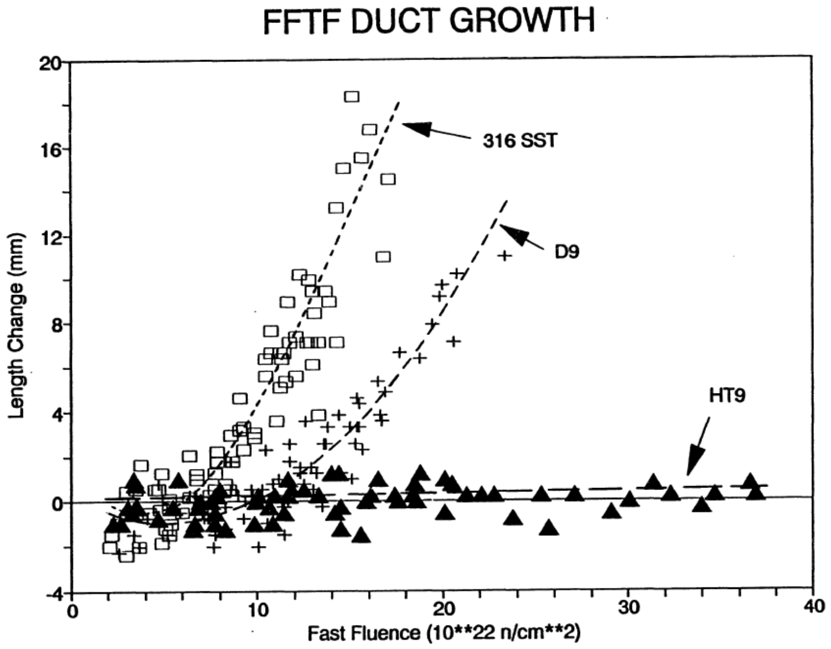
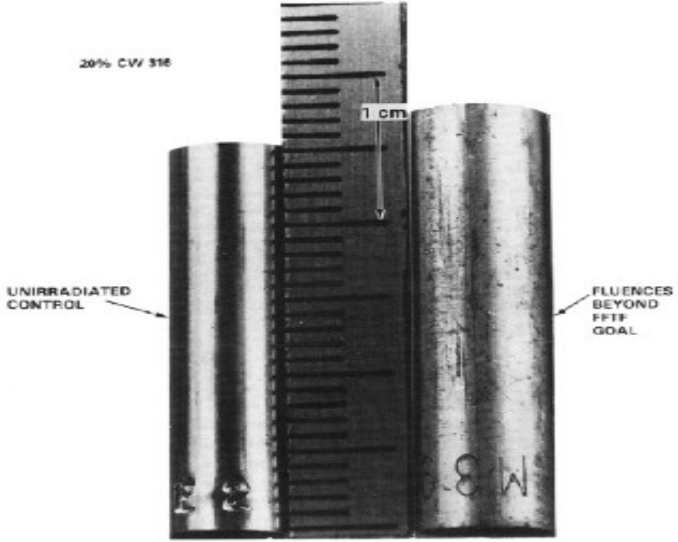
U.S. Fast Reactor Fuel Experience

- Clad and structural materials
  - Stainless steel (austentic, ferritic-martensitic)
- Ceramic fuel
  - Oxide (UO_2 and MOX)
    - High melting temperature, low conductivity
  - Carbide (UC)
    - High melting temperature, high conductivity
  - Nitride (UN)
    - High melting temperature, high conductivity
- Metal fuel
  - Uranium metal
    - Low melting temperature, high conductivity
  - Uranium metal alloys (U-Fs, U-Zr, U-Mo, etc.)
    - Moderate melting temperature, high conductivity

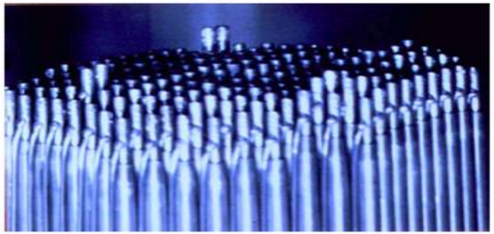
F/M Performance Advantages



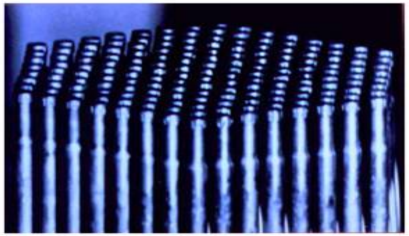
AL Pitner et al., Rpt. # WHC-SA-1967-FP, Oct. 1993



FFTF Fuel Pin Bundles



Stainless steel, swelling



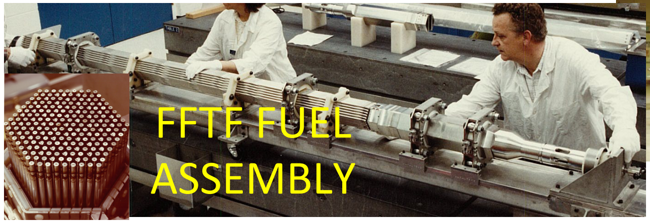
HT-9, no swelling

US DOE Metallic Fuel Pin Data and New PIE on FFTF Metallic Fuel Assemblies

- Fuel Pin – U-10Zr alloy sodium bonded in steel cladding

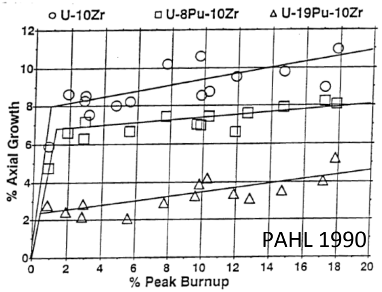
Schematic of fuel element

- EBR-II and FFTF fuel pin irradiation test data from INL and PNNL
- TerraPower sponsors new PIE at INL on FFTF metal fuel assemblies
  - Profilometry, fission gas release, neutron radiographs, gamma scan, metallography, etc…
- Data used to understand fuel performance and to benchmark models
- Data supports licensing case

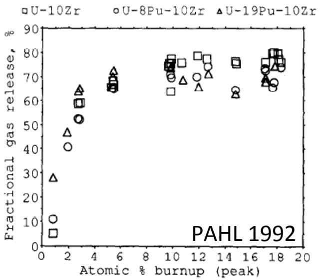


HOT CELLS AT INL

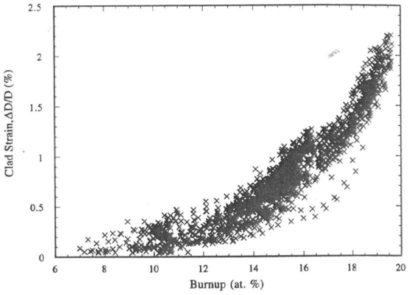
FUEL AXIAL GROWTH



GAS RELEASE

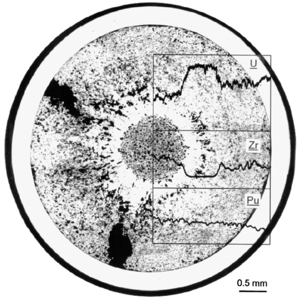


CLADDING STRAIN



YACOUT 1996

METALLOGRAPHY

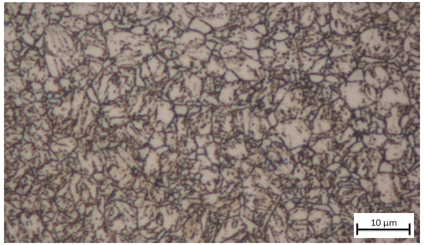


KIM 2006

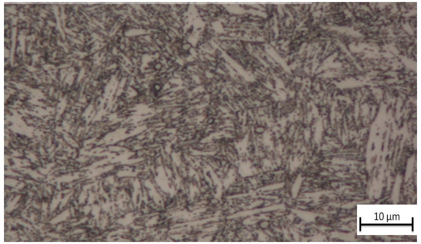
Advanced HT9 Development

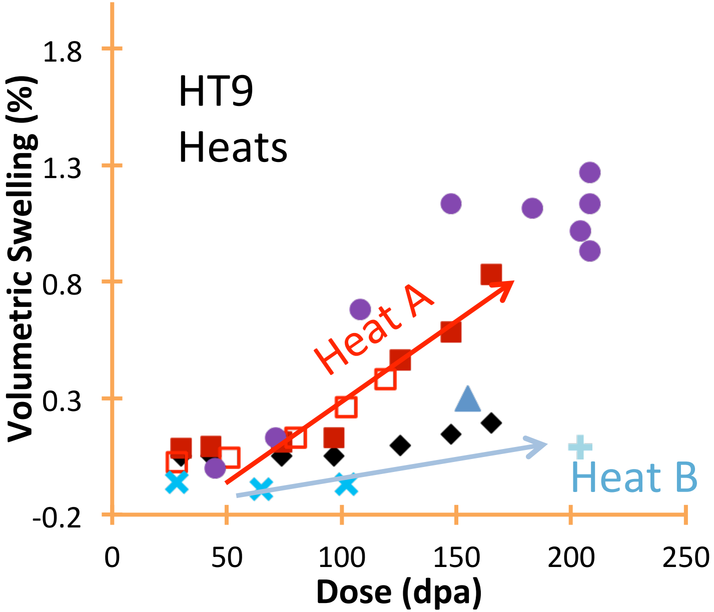
- Why did different HT9 heats result in different swelling behavior?
- Exhaustive review of archive (unirradiated) HT9 and performance data
- Identified optimal microstructure features and processing
- Commercial fabrication of advanced HT9 for irradiation testing

Poor structure (heat A)



Good structure (heat B)





HT9 Fabrication and Processing

Double melting process

Homogenization

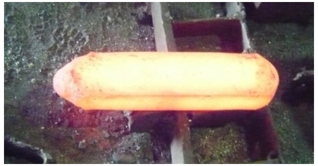
Forging

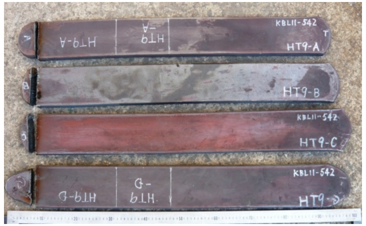
Hot rolling or extrusion

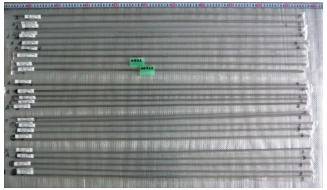
Cold rolling or drawing

Final heat treatment

KOBE STEEL







DUCT FABRICATION – VERIDIAM

PIN FABRICATION – KOBE STEEL

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Commercial Fabrication of HT9



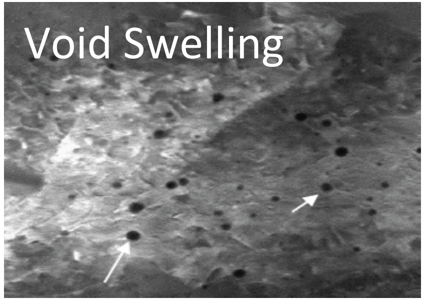

- Three orders for commercial-sized ingots
  - Kobe Steel (3 tons)
  - Carpenter Steel (5 tons each)
- Product to be used for:
  - Fabrication of fuel test pins
  - Fuel assembly mockups, thermal-hydraulic testing
  - Materials test programs

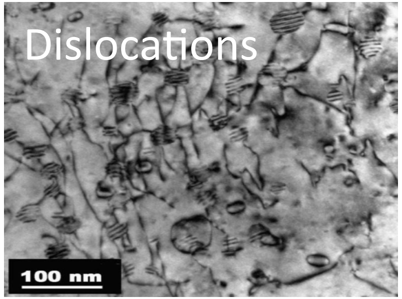
Proof of Fabrication

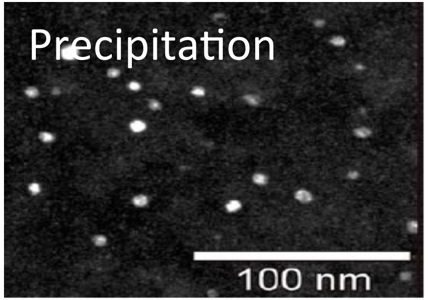
Heavy Ion Irradiation Program

- Program Objectives: Provide qualitative (head-to-head) information on radiation effects in short time frames; and establish a correlation between heavy ion and neutron irradiation

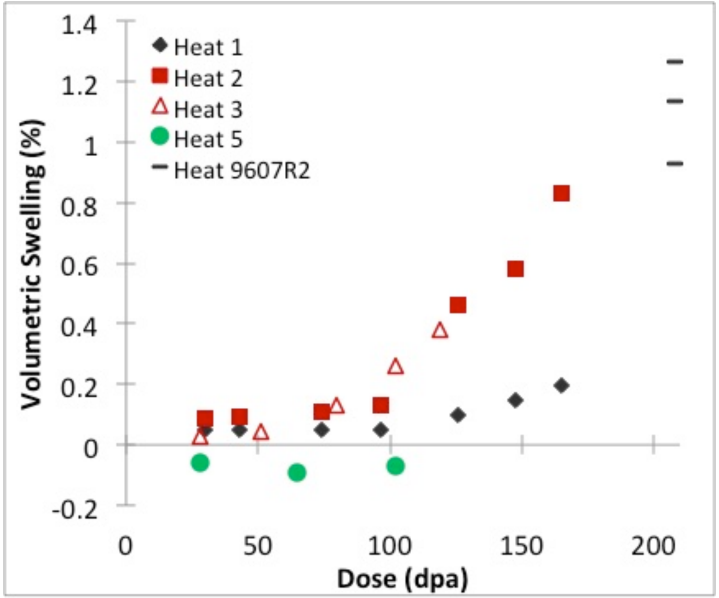
- Benchmark material : ACO-3 duct from FFTF, 155 dpa @ avg. 443°C
- Fe^{++} irradiation of archive ACO-3, 188 dpa @ 460°C
- Irradiation-induced microstructure features are similar, including dislocations, G-phase, α', voids



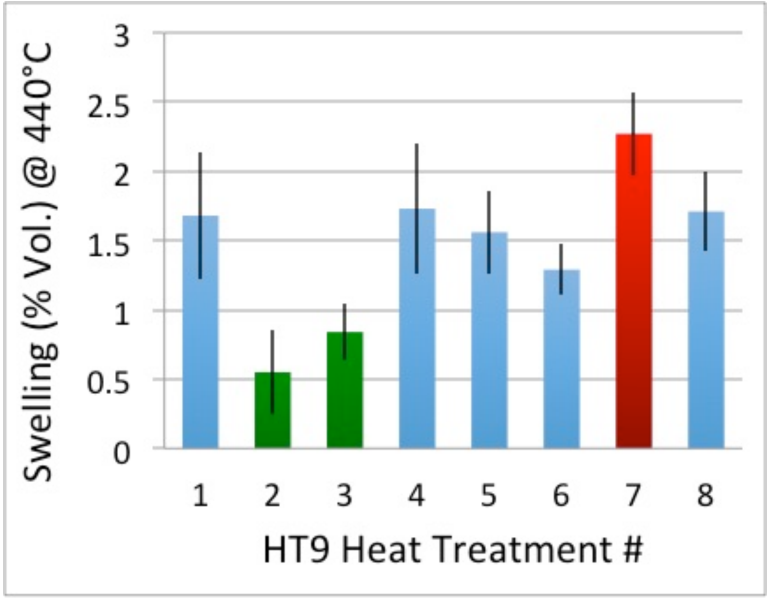




Both Neutron and Ion Irradiations Show Importance of Optimized Heat Treatment



Neutrons (previous irradiations)



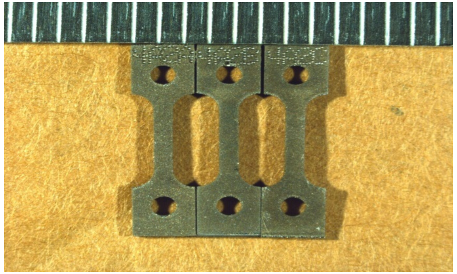
Ions

BOR-60 Materials Test, TP-1 and TP-2

Goals Include: Irradiate HT9 to 280 dpa by 2019, provide data on optimized production process HT9

- Rigs 1 and 2 inserted into BOR-60 Dec 24, 2013.
  - 360 and 400˚C
  - New TerraPower Optimized Material (>350 specimens).
  - DOE Pre-Irradiated (~150 specimens)
  - Temperature maintained by gamma heating

Pressurized Tube



ACO-3 Tensile

TEM Capsule

Assembled Suspension with 16 sample/monitor holders

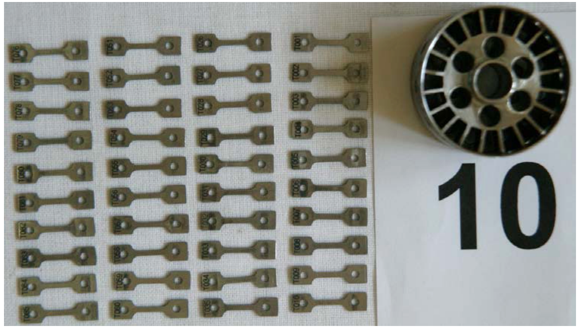
Container with Assembled Suspension Inside

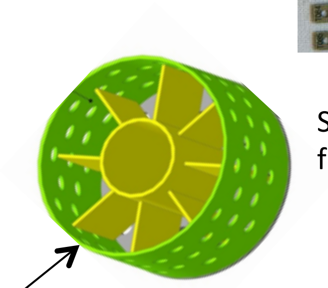
Lower Section interfaces with below core low pressure sodium plenum

BOR-60 Materials Test, TP-3, TP-4, TP-5 (High Temperature Rigs)

Goals Include: Irradiate HT9 to 280 dpa by 2019, provide data on optimized production process HT9

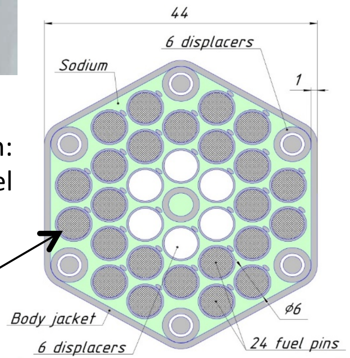
- Rigs 3,4,5 inserted in Mar & May 2014
- 450, 500, 625˚C
- New TerraPower Optimized Material (>750 specimens).
- DOE Pre-Irradiated (~100 specimens)
- Temperature maintained by pre-heater fuel.
- First irradiated samples (Rigs 1 and 2) to discharged in 2014 (10 dpa) and replacement samples inserted.





Sample Holder for TP-3, 4, 5

Cross-section: Pre-heater fuel



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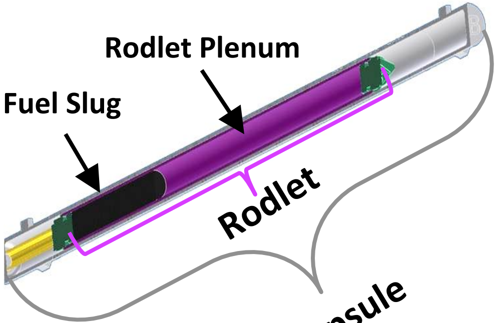
Fuel Fabrication at INL and Irradiation Testing in the ATR

- Purpose: Quickly examine a variety of advanced fuel concepts for commercial TWR design
- Fuel slugs fabricated at Idaho National Laboratory (INL)
- Five specimens, Five capsules
- Inserted into Advanced Test Reactor (ATR) Fall 2013
- 5at% burnup by year end 2014
- Follow on testing in progress



ATR Specimen Insertion

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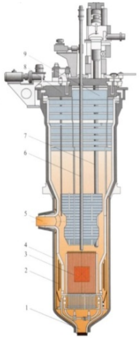
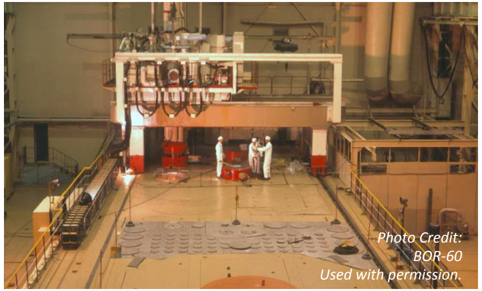
Fuel Pin Irradiation Testing in Russian BOR-60 Fast Reactor at RIAR

- BOR-60 Fuels Irradiation Program intended to provide qualification for TWR prototype and commercial fuel designs
- Three test rigs, ~60 fuel pins
- Testing will be parametric and prototypic by design
  - Benchmark fuel pin models
  - Connect with metallic fuel database
  - Demonstrate advanced fuel pin performance
- Lab-scale fuel pin factory at INL (EFF) using commercial processes
  - Construction, testing → now
  - Fuel pin fabrication begins → early 2017
- Test inserted into BOR-60 → Q4 2018

BOR-60 FAST REACTOR





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TWR FUEL QUALIFICATION

Global Integration Network