NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

The NWMO Copper Coated Container

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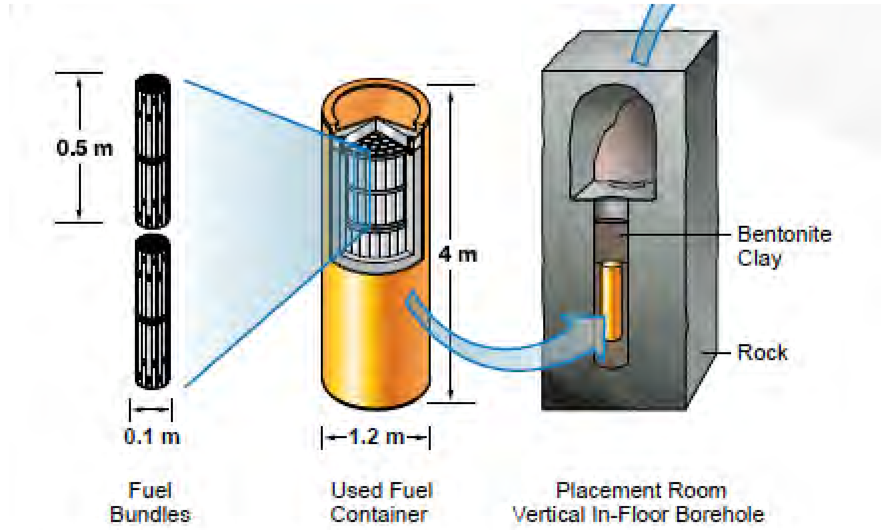
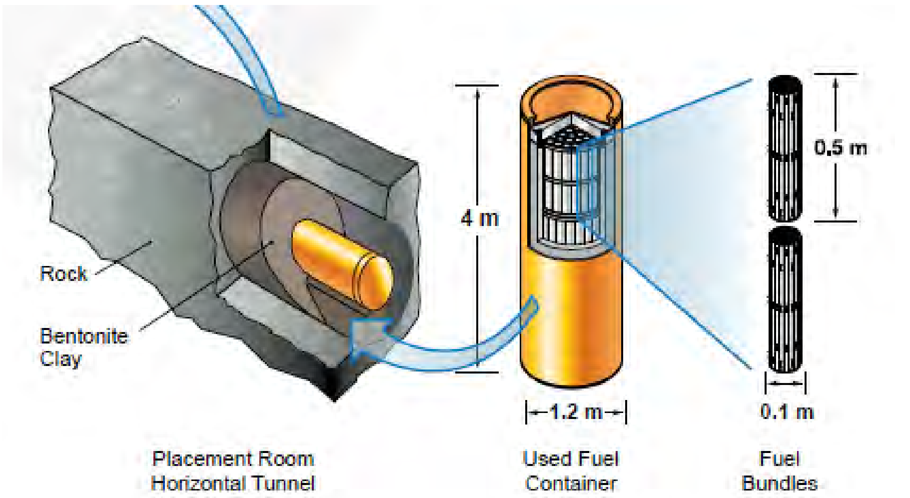
Reference Designs – Pre Mark Program

- Conceptual Reference design is based on SKB/NAGRA concepts
- SKB (Sweden) crystalline rock
  - In-floor bore hole
  - Dual vessel (steel/copper)
- NAGRA (Switzerland) sedimentary rock
  - Horizontal tunnel in-room
  - Steel and steel/copper vessels
- *Costing & Communication*
- *$16-24 Billion (CAD)*





Design Optimization: Keys

» Can we use copper coatings?

» Is technology ready?

- What are implications for cost? For size of container? For safety?
- Identified two container design and emplacement concepts for further development:

<u>Mark I</u>

- Leverages SKB/Posiva KBS-3 designs and emplacement concepts; all steel option being assessed for sedimentary

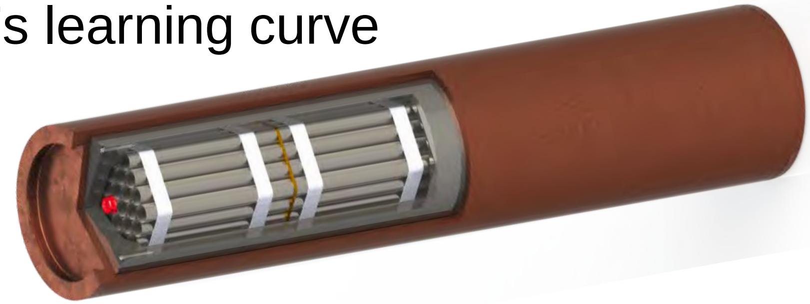
<u>Mark II</u>

- Customized for CANDU fuel, standard manufacturing and copper coated
- Standard ASME materials (pipe/plate), no custom forging
- Significant potential for life-cycle cost reduction ($2Billion CAD)

Two 2012 Design Concepts

Mark 1 – Dual-shell design

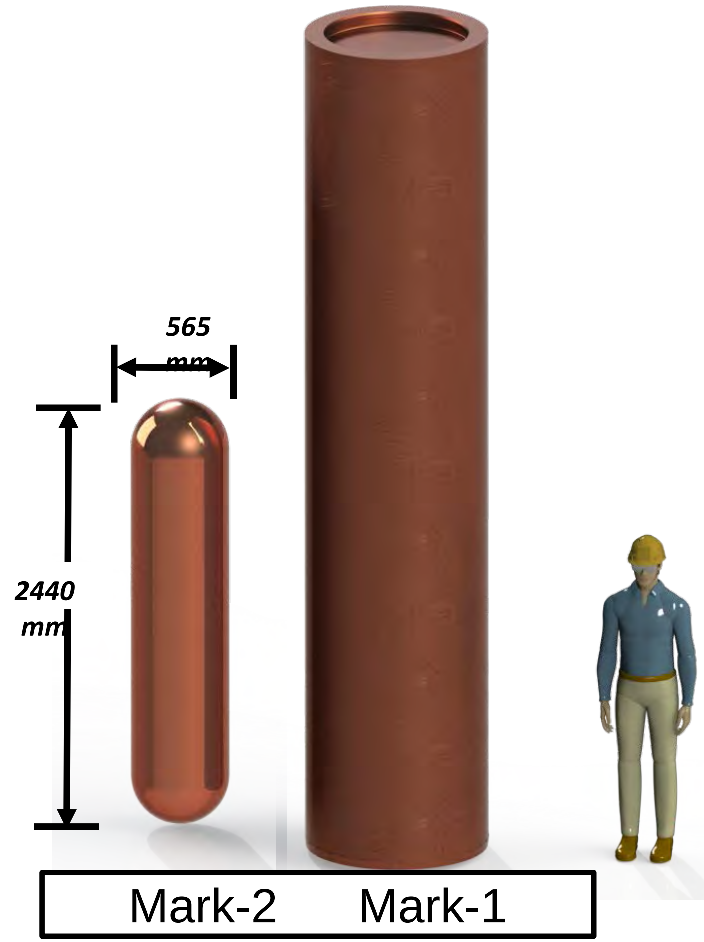
» Copy the KBS-3 concept as much as possible to be able to take advantage of SKB's learning curve



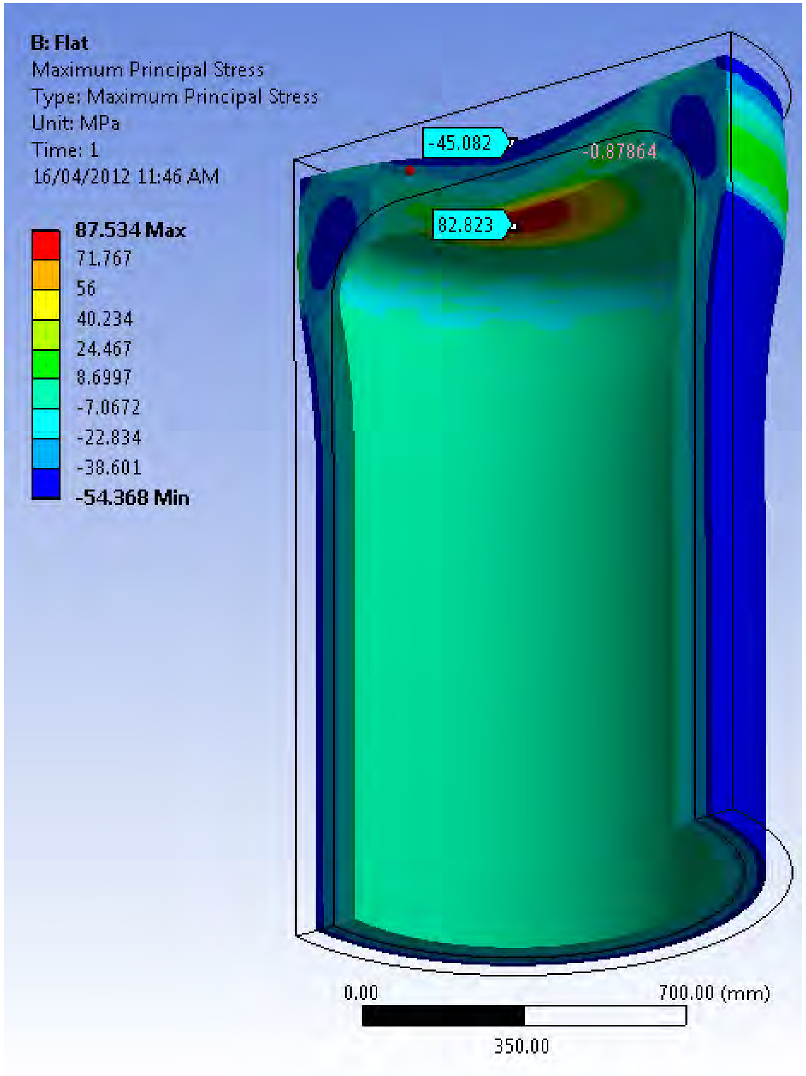
Mark 2- Optimized design for CANDU fuel

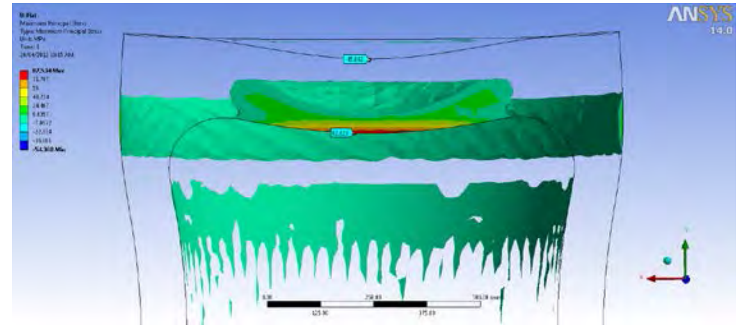
» Design alternatives related to size and geometry

» Apply advances in copper coating technology to apply required thickness of corrosion barrier

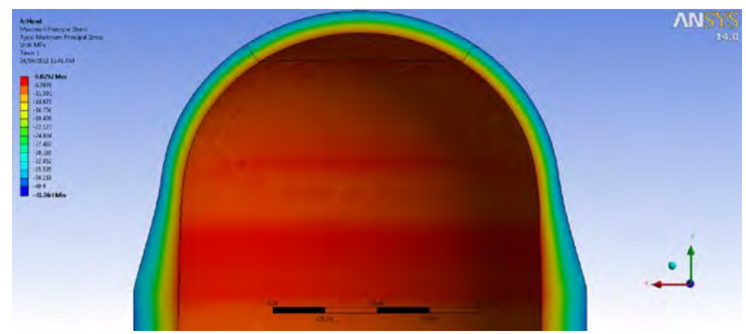


Analysis: Flat vs. Spherical Head





Tensile Only



Spherical Head

3 mm Copper Coating Corrosion Barrier

» Advanced techniques available for achieving fully bonded, metallurgical and corrosion compliant coatings
  - Cold spray
  - Electrodeposition

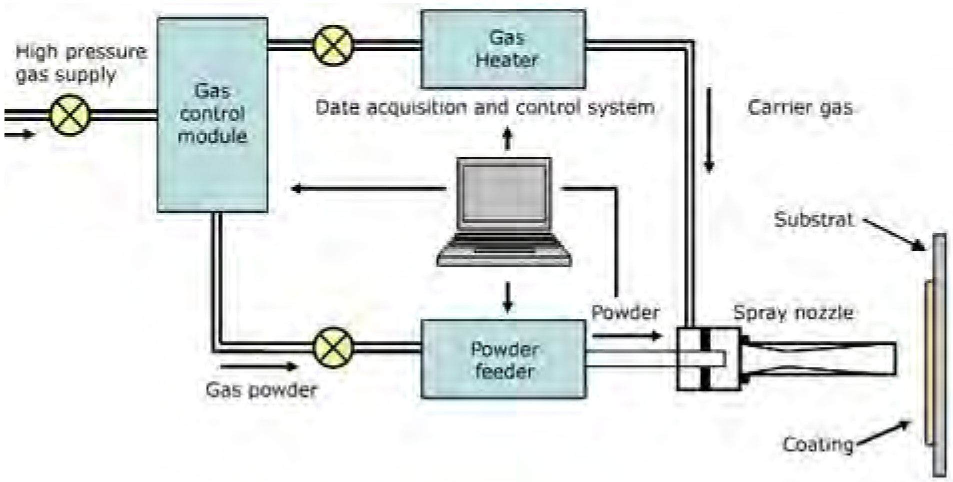
» Allows corrosion needs (not manufacturing) to define copper thickness

» 2011 Corrosion allowances
  - 100,000 year = 0.4 mm
  - 1,000,000 year = 1.3 mm

» 2 Coating needs
  - Container & lid
  - Weld zone (hot cell)

Copper Coating Development: Cold Spray

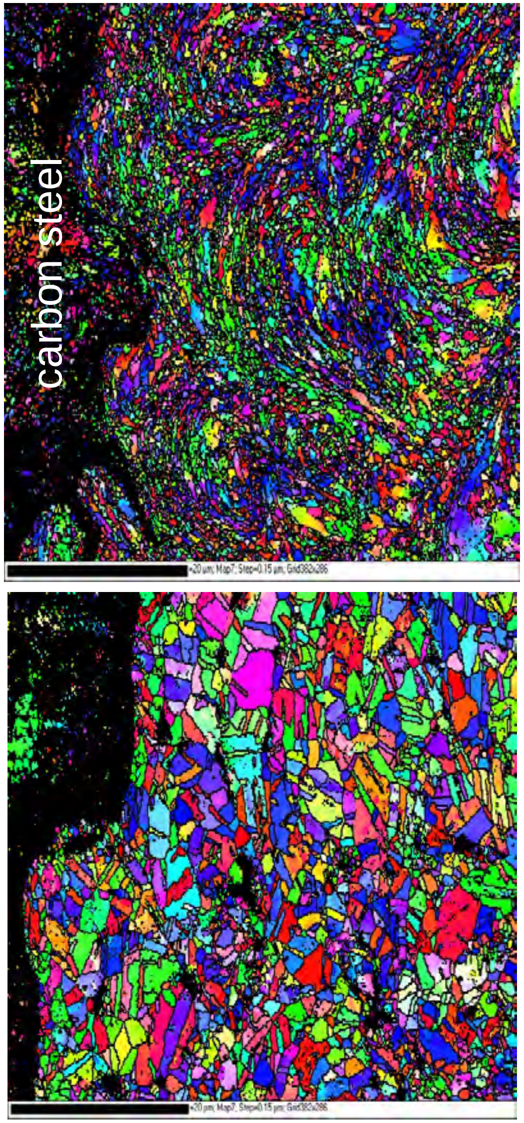
- High pressure gas propels powder toward surface to produce coating
  - Solid state process
  - Adhesion via mechanical bond
  - No melting of powder



- Optimized for Adhesion
  - Requires He carrier gas for 1st layer, adhesion > 60 MPa
- Brittle coating
  - Requires annealing to increase ductility

5 Years of Cold Spray Development

- Many variables:
  - Pressure
  - Temperature
  - Gas type (He vs. N_2)
  - Surface Preparation
  - Powder
- Reference parameters defined
  - 1 layer He carrier, N_2 after
  - Spherical powder, 30 μm average particle size
  - 5 MPa
  - 600 – 800 °C
- Annealing required (> 350°C)
  - EBSD shows grain growth



As Deposited

Annealed

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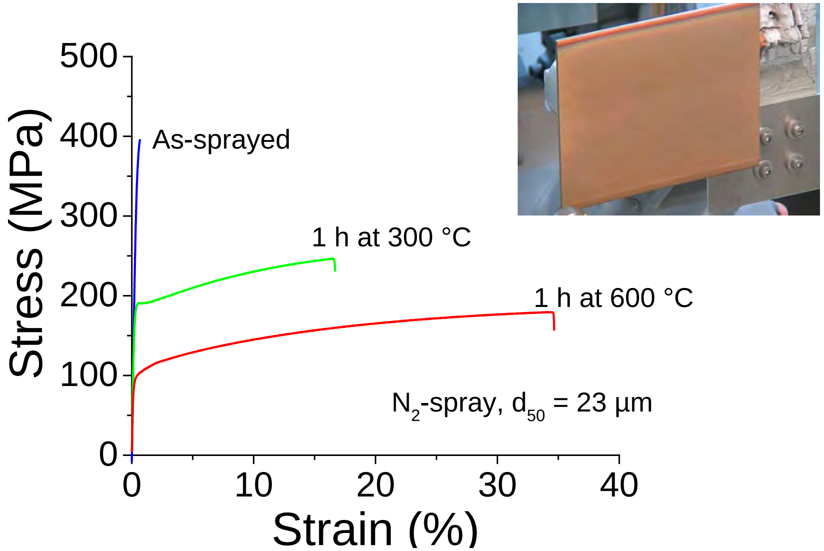
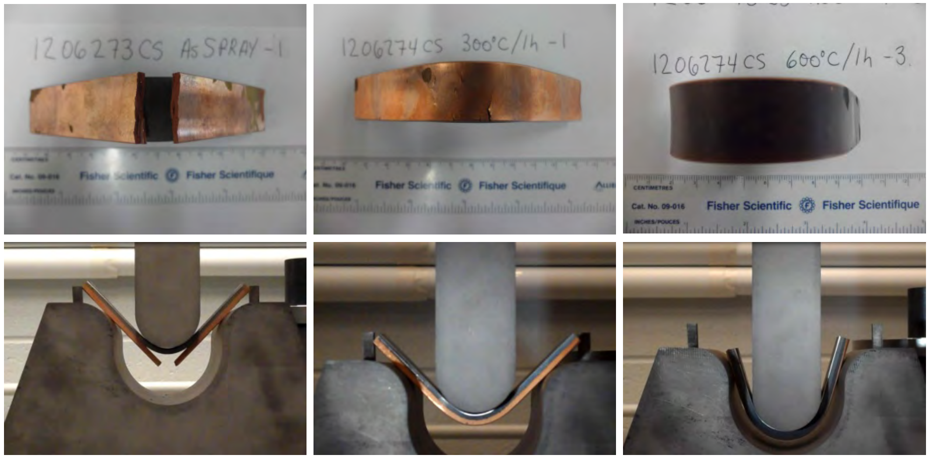
General Coating Development

Tensile Testing
ASTM E8

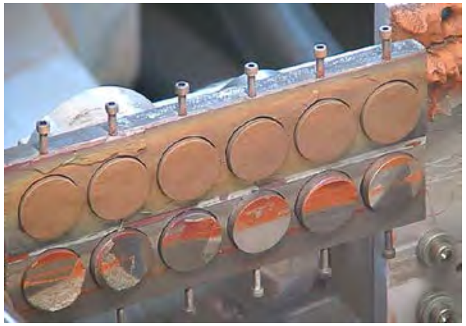


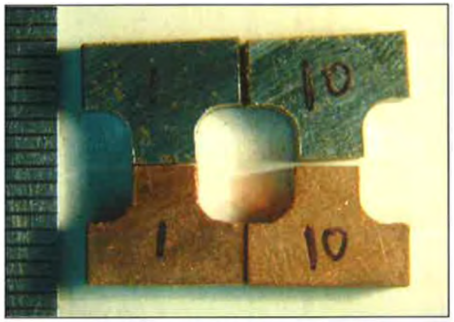
Bend Testing
ASTM E290 for Annealing

As-sprayed | 300 °C, 1 h | 600 °C, 1 h



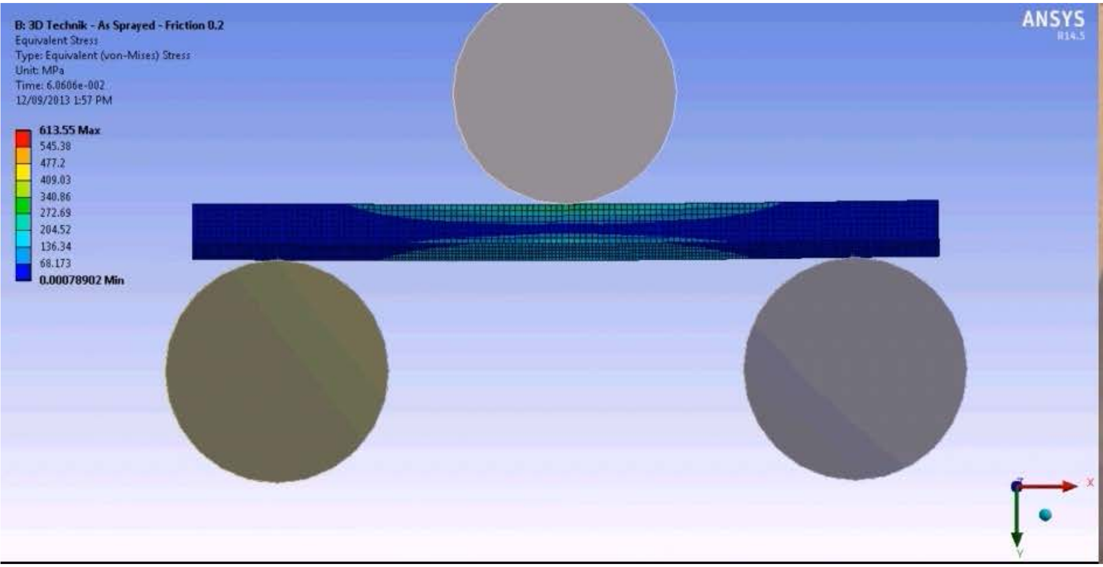
Bond Strength Testing
ASTM C633 & modified E8

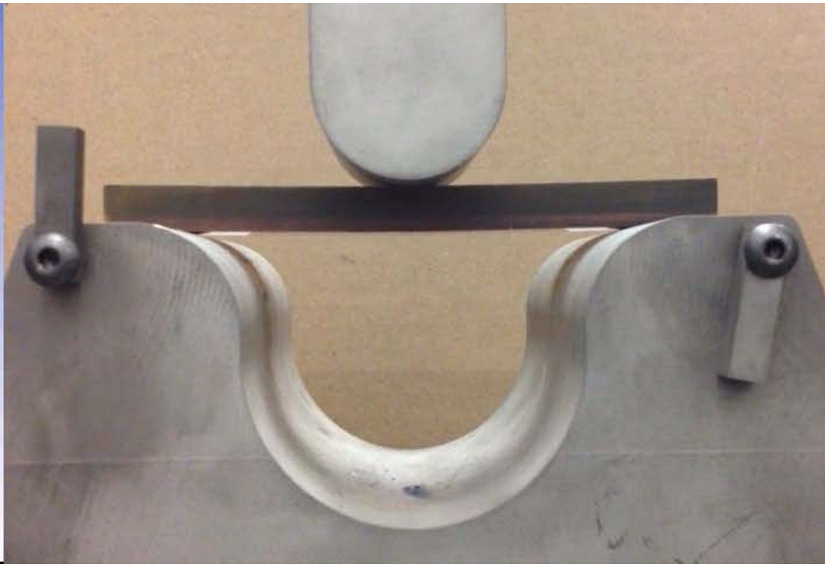




Results: Experiment vs. Modeling

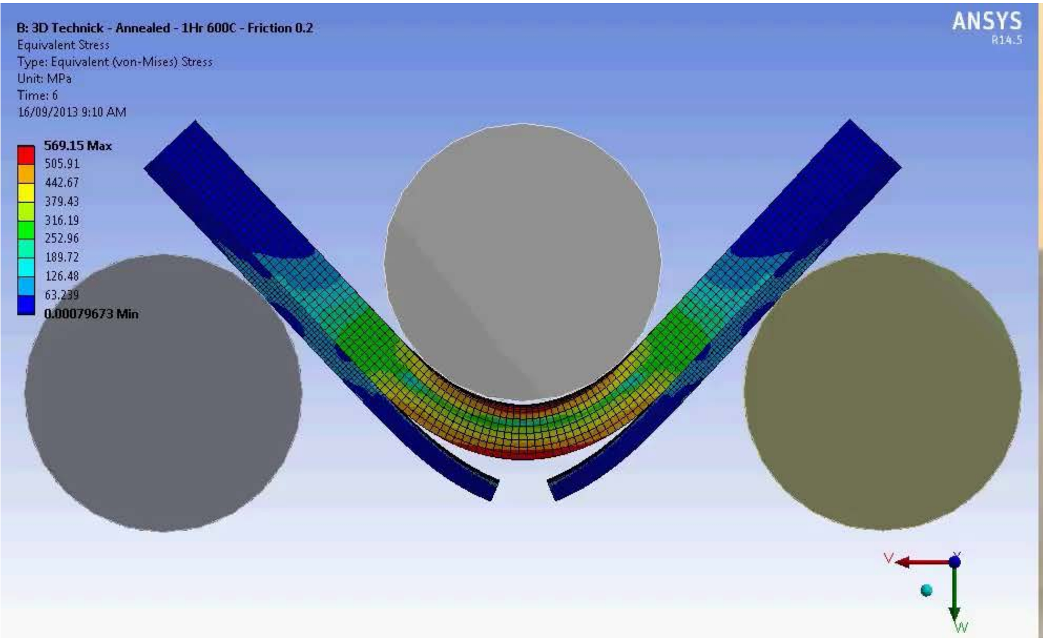
- Copper Coating – As Sprayed
  - Failure within 1 mm of deflection, <1% strain

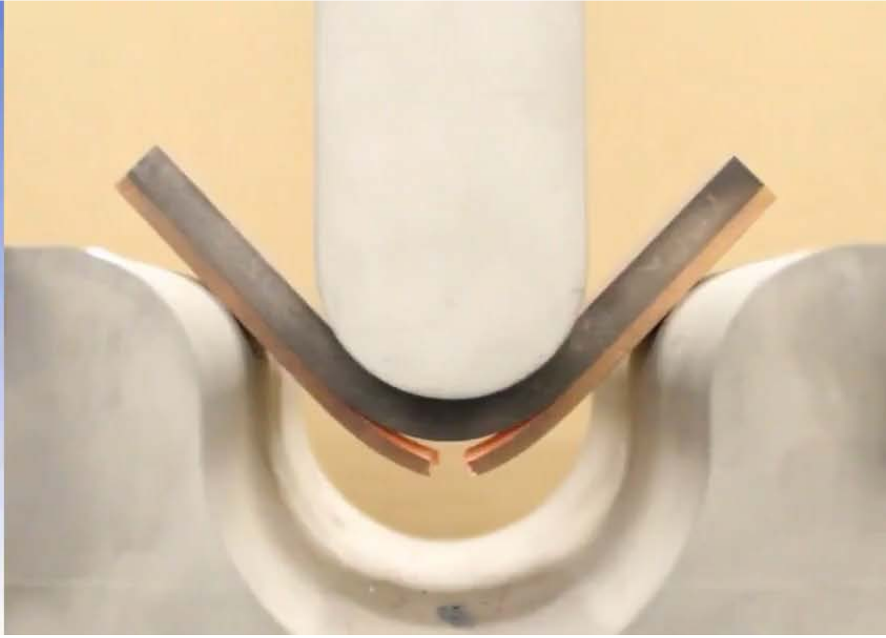




Results: Experiment vs. Modeling

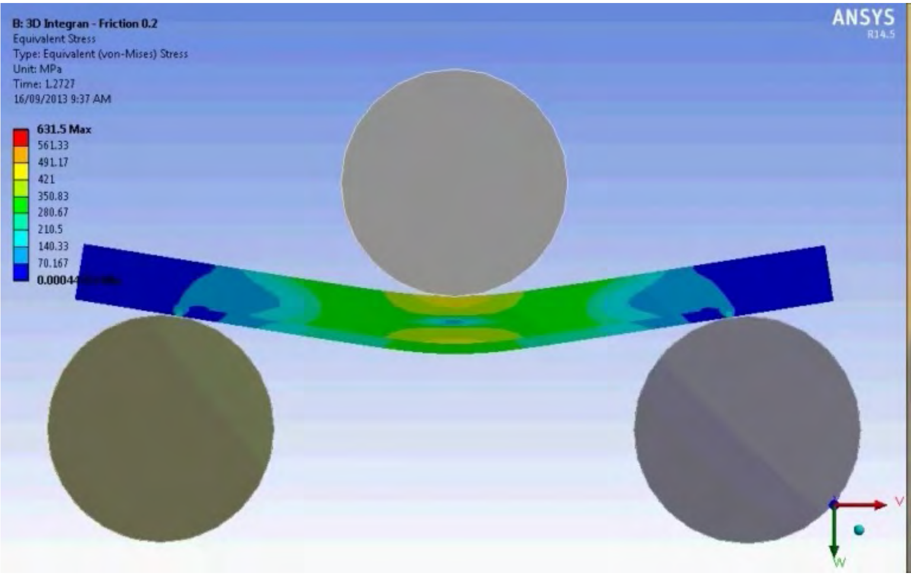
- Copper Coating – Coldspray (Partly Annealed)

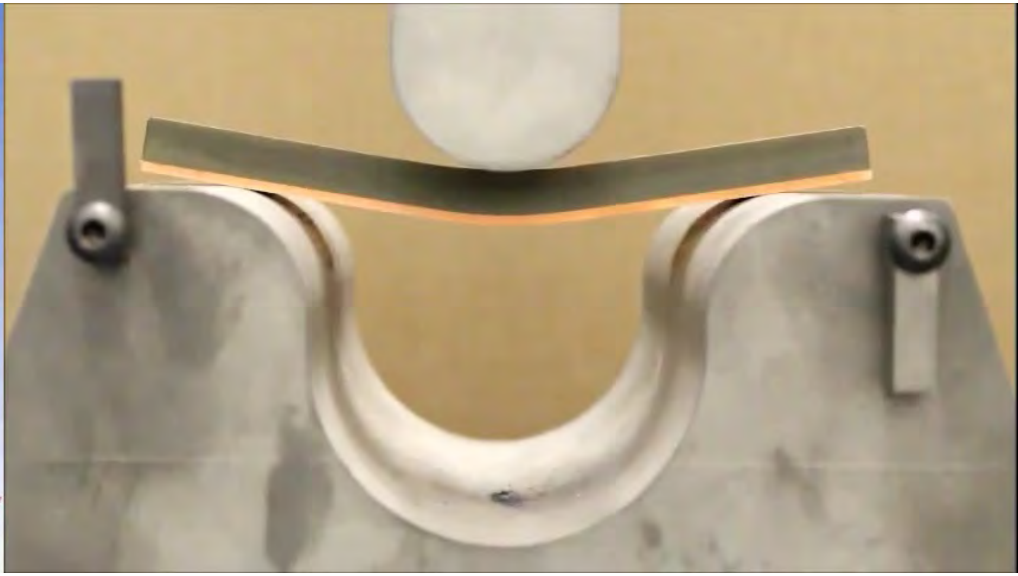




Results: Experiment vs. Modeling

- Copper Coating – Fully Ductile

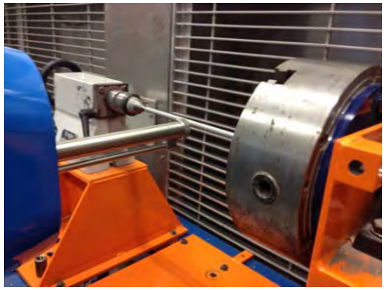


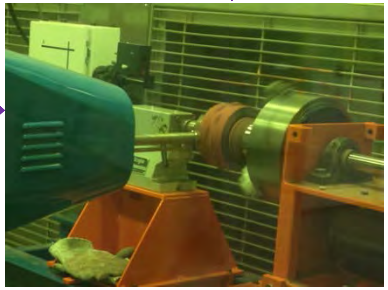


Other Cold Spray Samples

Rod Samples

Rod Ends, Discs

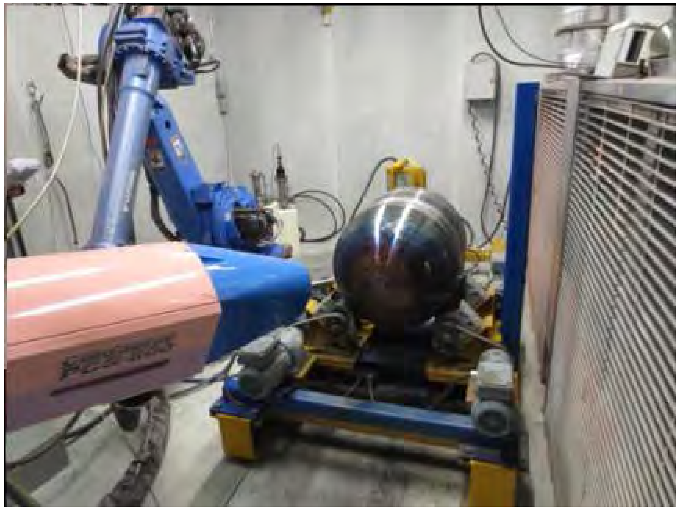


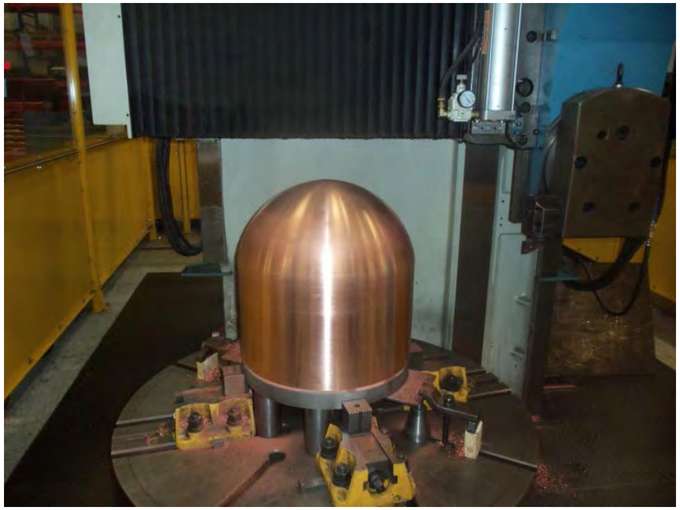


Plates

18" long 20" Diameter pipe Samples

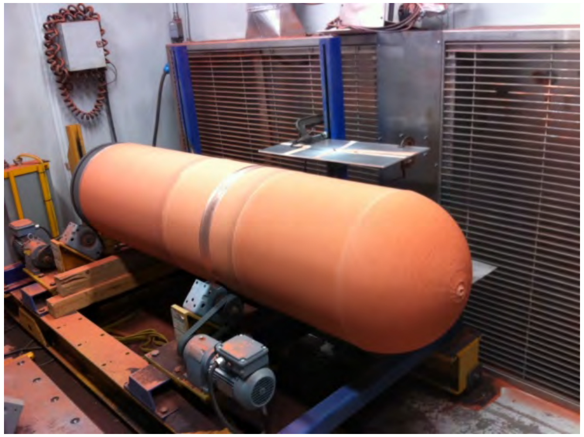
The “Stubby Assembly”





Cold Spray & Machining a Lower Assembly





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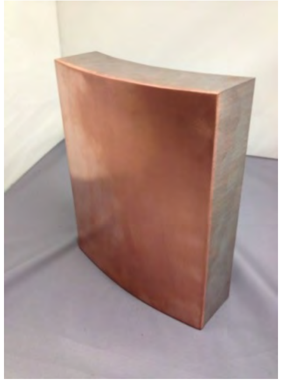
Coating Development: Electrodeposition

- 3 mm coating
- Standard ASME substrate steel
  - A516 Gr. 70 or equivalent



Electrodeposited Hemihead

Electrodeposited Hemihead

The First Hemihead Machined

The Stubby Assembly

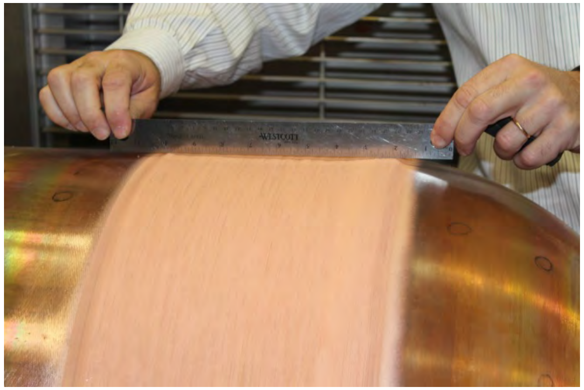
The Stubby Assembly

The Leading Vessel: 2013-15 Manufacturing







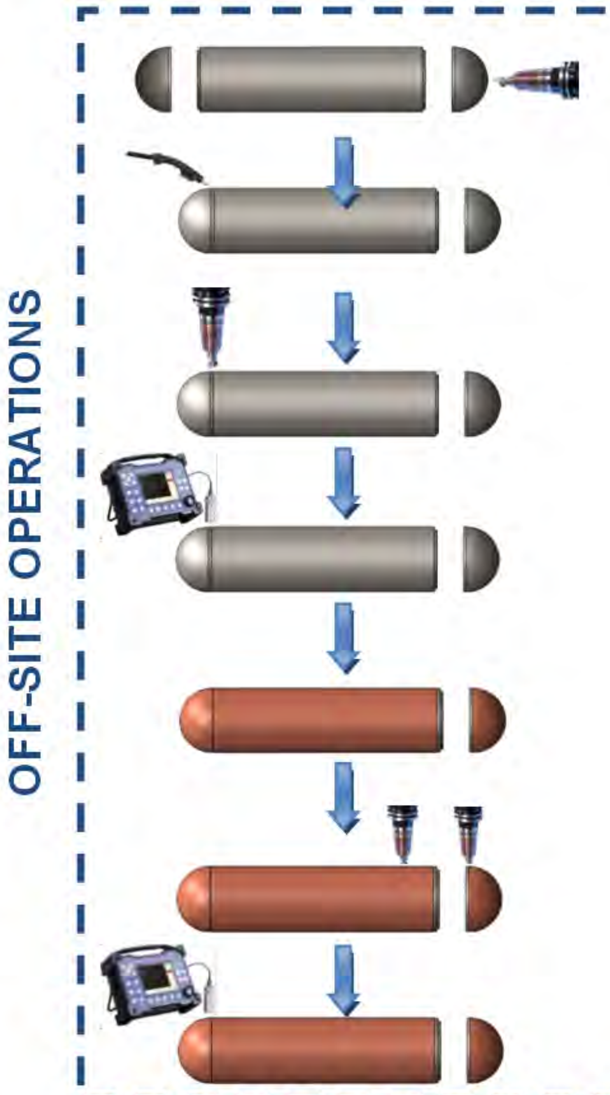





ALBERTA PLYWOOD
WATERPROOF BOND

The Finished Product

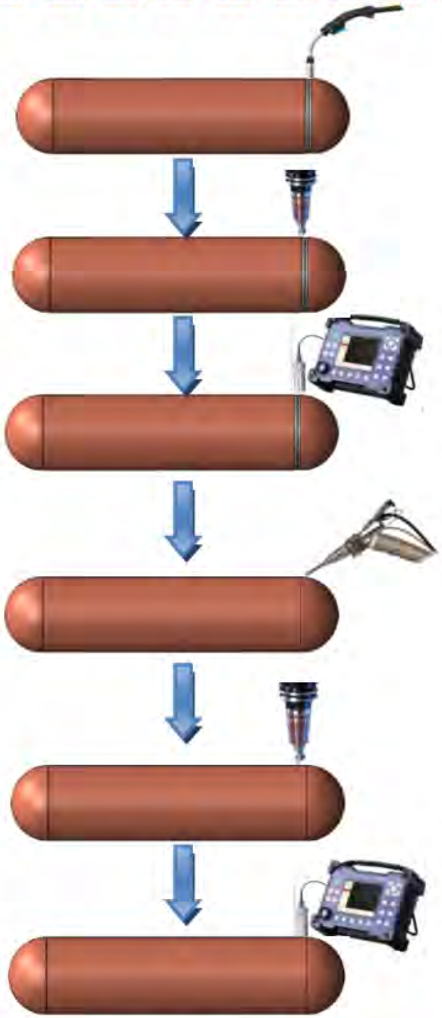
Serial Manufacturing: 2017-2019



1. Procurement of materials
2. Machining of shell / head components for assembly
3. Welding of Hemi-Head Assemblies (structural attachments)
4. Welding of Lower Assembly (HLAW or GMAW)
5. Machining of Lower Assembly Weld Cap
6. NDE (and repair) of Lower Assembly Weld Zone
7. Copper Coating of Lower Assembly and Upper Head via Electrodeposition
8. Machining of Copper Coated Surfaces
9. NDE (and repair) of Copper Coated Surfaces

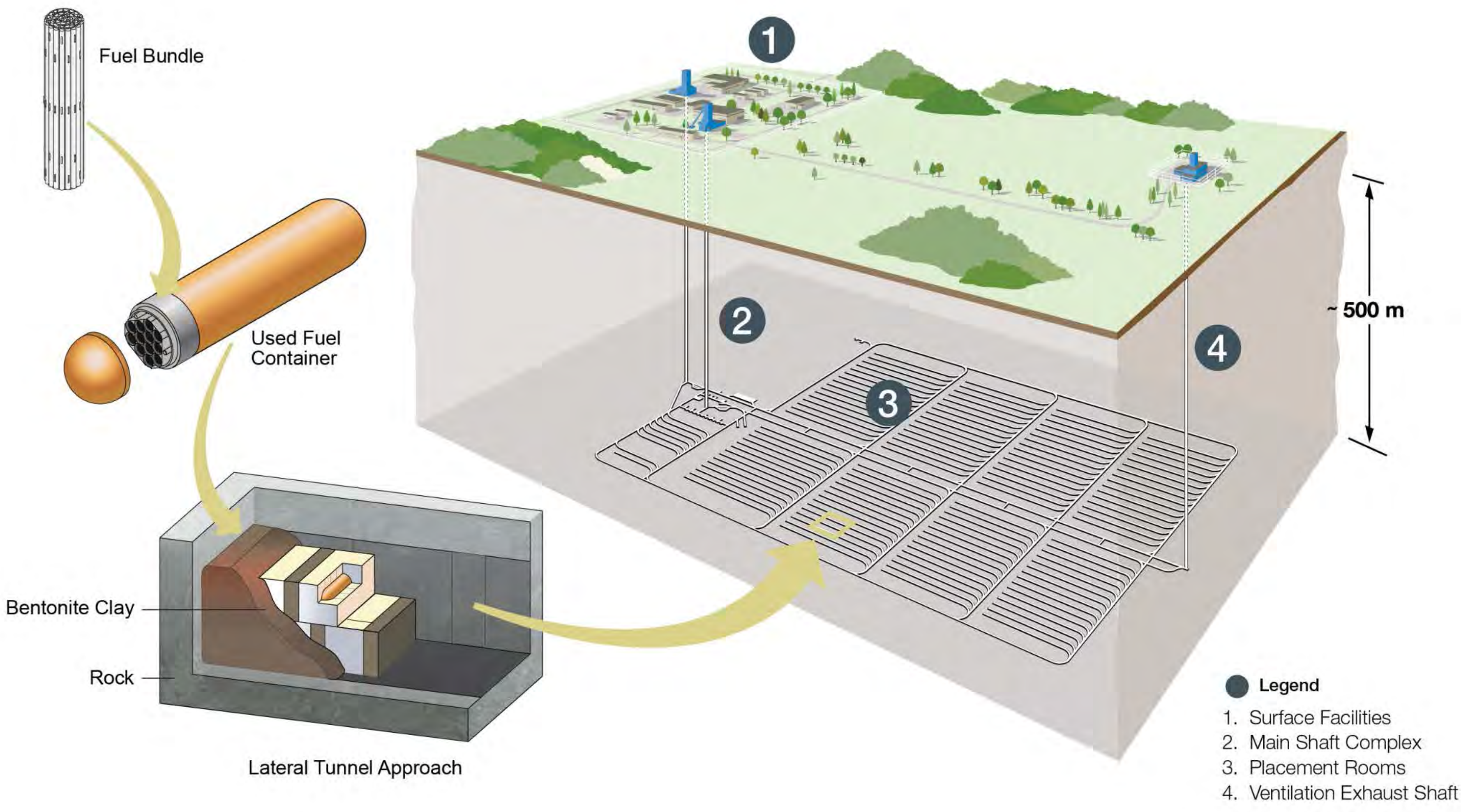
Conceptual Hot Cell Operations

Radiological (Hot Cell) Operations



10. Closure Welding after Fuel Loaded
11. Machining of Closure Weld Cap
12. NDE (and repair) of Closure Weld Zone
13. Copper Coating of Closure Weld Zone via Cold Spray
14. Annealing of Copper Coating at Weld Zone
15. Machining of Copper Coating at Weld Zone
16. NDE (and repair) of Copper Coating at Weld Zone

NWMO's vision for a Waste Facility



Challenges & Future R&D

- Application to other materials
  - Cast iron
  - Different steels
  - Welded materials
- Electrodeposition optimization
  - Pre-treatment of steel
  - Smooth coatings
- Interface between coatings
  - Characterize with advanced methods
  - Validate that adhesion is high & free of contaminants
- Handling Challenges

Vacuum Lift for Handling Bentonite & UFCs

Conclusions & Ongoing Work

- Copper coatings are viable for NWMO containers
  - Ongoing work to continue to develop concept
- Significant cost savings and flexibility in container size can be realized
- Participation with international community has proven beneficial
  - Nagra partnership on program since 2012
  - RWM co-funded work on electroplating
  - BEP of UK has initiated work on larger containers
  - Surao, NUMO in corrosion work at Grimsel
- NWMO is looking to collaborate on future work and would benefit from an international effort
  - Regulator
  - Public

Acknowledgements

- National Research Council of Boucherville (Montreal): Cold Spray
- Integran Technologies Inc. Toronto: Electrodeposition
- Surface Science Western / Western University & the David Shoesmith Research group: Characterization and Corrosion Testing
- Novika of Quebec: Laser Welding
- Nagra
- RWM

Questions?