Fabrication and Quality Control Of Fuel For Prototype Fast Breeder Reactor (PFBR)

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OUTLINE OF THE PAPER

- INTRODUCTION
- MOX FUELS FOR FAST REACTORS
- FABRICATION STEPS FOR PFBR
- QUALITY CONTROL
- CONCLUSION
- ACKNOWLEDGEMENT
Pu Bearing MOX Fuel Fabrication for Thermal & Fast Reactors

**Scope of work**

**First stage**
- (U~4%Pu) MOX for BWRs (TAPS)
- (U~0.4%Pu) MOX for PHWRs (KAPS)

**Second stage**
- (U-44%Pu) MOX for FBTR
- (U-28%Pu) MOX for PFBR

**Third stage**
- (Th-3%Pu) MOX for AHWR

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MOX FUELS FOR FAST FACTORS

MIXED CARBIDE FUEL PINS FOR FBTR

♣ (0.7 Pu – 0.3 U)C

MOX FUEL PINS FOR FBTR

♣ (0.44 Pu – 0.56 U)O$_2$

MOX FUEL PINS FOR PFBR

♣ (21% PuO$_2$ & 28% PuO$_2$)

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MOX Fuel for PFBR Technology Developed

a) Fabrication of annular pellets using rotary press
b) Sinter to size
c) Dry Centreless grinding of oversize pellets
d) Pellet inspection using digital imaging
e) Welding technology for D-9
FABRICATION OF MOX FUEL

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COMPACPTION PRESS AND COMPACTED PELLETS

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AUTOMATION IN PELLET FABRICATION SYSTEM

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PFBR PELLETS

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PFBR FUEL PIN

Spring Top Blanket Fuel Middle plug Bottom End Plug

Top End Plug Spring Support Bottom Blanket
Fit-up Of PFBR Tube With Plug (Before Welding)

Plug 6.6 mm

20 mm

Clad

40 mm 5.71 mm

0.45 mm

5 mm

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CLOSE VIEW OF LASER WELDING SETUP

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PFBR END PLUG WELDS

LASER WELD

TIG WELD

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PFBR FUEL PINS
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QUALITY CONTROL IN A TYPICAL FUEL FABRICATION PLANT

INITIAL INCOMING MATERIALS

: HARDWARE, FUEL FEED MATERIALS

DURING PRODUCTION

1. GREEN PELLETS : VISUAL, DENSITY, DIMENSIONS

2. SINTERED PELLETS : VISUAL, DENSITY AND OTHER CHARACTERISTICS

3. MONITORING VARIOUS PRODUCTION PARAMETERS AND COMPARE WITH MANUFACTURING ENGINEERING INDEX

4. FUEL RODS

5. FUEL BUNDLES

6. DOCUMENTATION
FLOWWORKSHEET OF PFBR MOX FUEL

**FUEL FABRICATION STEPS**
- PuO₂
- UO₂
- Attitor Milling
- Precompaction & Granulation
- Compaction
- Sintering
- Dry Centreless Grinding
- Vacuum Degassing
- Stack Making
- Pellet Loading
- Fuel Element Welding
- Decontamination
- Wire Wrapping
- Packing & Transport
- Decontamination

**SCRAP RECYCLE STEPS**
- Oxidized Scrap
- Microwave/Thermal Processing
- CRO
- Rejects
- Decladding
- Reject Elements

**PROCESS / Q.C. STEPS**
- Pu, Am, Isotopes, Impur.
- U, O/M, S.A, Impurities
- NWCC
- Granulometry
- Density, Inspection
- ρ, U/Pu, α-Autoradiography
- Pellet Inspection
- Stack Inspection, Visual
- Metallography
- Contamination check
- He leak test, X-Radiography, XGAR, γ-scanning, Metrology, Visual
- Final Inspection
Comparison of NWCC and Chemical Analysis Results of MOX Fuel for Fast Reactors

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ALPHA AUTO RADIOGRAPHY

- DISTRIBUTION OF Pu
- PuO2 AGGLOMERATES

- ALPHA PARTICLES FALL ON CELLULOSE NITRATE FILM
- PROCESSED FILM REVEALS TRACKS
- UNIFORMITY AND SIZE
- COLOUR IMAGE
PHOTOMICROGRAPHICS OF PFBR PELLET

Longitudinal section  Transverse section

ALPHA AUTORADIOGRAPH OF PFBR PELLET
Video Microscope For Micro structural Evaluation Of MOX Pellets

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PELLET SORTING SYSTEM

1- Laser Detector, 2- Laser Transmitter, 3- Solenoid, 4- Solenoid
5- Bowl Feeder, 6- Controller for Vibratory Bowl Feeder, 7- Main Control Unit

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VISUAL INSPECTION & PELLET SORTING SYSTEM

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CHEMICAL CHARACTERISATION OF MOX FUELS

1. PuO$_2$ % ENRICHMENT
2. HEAVY METAL CONTENT
3. DISSOLUTION TEST
4. O/M RATIO
5. NON METALLIC IMPURITIES
6. TRACE METALLIC IMPURITIES
7. COVER GAS ANALYSIS
8. TOTAL GAS ANALYSIS
END PLUG WELD

- TIG WELD
- FREEDOM FROM
- MODIFICATIONS
- ADVANCED TECHNIQUES

X-RADIOGRAPHY
LACK OF PENETRATION
LACK OF FUSION
POROSITY – INCLUSION-OTHER
SHAPE CORRECTION BLOCK
DEFECT STANDARD
MICRODENSITOMETRY
IMAGE PROCESSING
REAL TIME MOTION RADIOGRAPHY
LINEAR ARRAY DETECTORS
ULTRASONICS

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Radiography of End Cap Welds

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Shape Correction Block For PFBR
End Cap Welds
REAL TIME MOTION RADIOGRAPHY

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X-Ray Tube

Monitor

Pin carriage

Slit

Fluoroscopic arrangement
ULTRASONIC END CAP WELD INSPECTION

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Detection of a gross lack of penetration

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GAMMA AUTORADIOGRAPHY (GAR)

- PuO$_2$ AGGLOMERATE AND COMPOSITION BY NDE
- X RAY FILMS IN PVC CASSETTES KEPT IN CONTACT WITH WELDED RODS
- DARKENING OF THE PROCESSED FILM IS PROPORTIONAL TO PuO$_2$ ENRICHMENT
- DEFECTS:
  - PELLETS OF WRONG ENRICHMENT
  - PuO$_2$ AGGLOMERATES IN THE PERIPHERY
  - COMPOSITIONAL VARIATION
GAMMA AUTORADIOGRAPHY (GAR)

(Cont...)

- ANOTHER CHECK FOR PuO₂ ENRICHMENT
- ADDITIONAL QUALITY CONTROL STEP INTRODUCED
- MICRODENSITOMETRY
- COLOUR GAMMA AUTORADIOGRAPHY
- SIMPLE TEST
- X-GAR : (X-RADIOGRAPHY+GAMMA AUTORADIOGRAPHY)

RESULTANT IMAGE GIVES ADDITIONAL INFORMATION ABOUT INTERNAL COMPONENTS LIKE SPRING, SPRING SUPPORT etc.
X-RAY GAMMA AUTO-RADIOGRAPHY

X-ray source → [Diagram]

slit → TRAY

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X-RAY GAMMA AUTO-RADIOGRAPHY

X-ray source → slit → X-RAYS

FUEL ELEMENT

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X-RAY GAMMA AUTO-RADIOGRAPHY

X-ray source → slit → FUEL ELEMENT

X-RAYS → FUEL ELEMENT

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X-RAY GAMMA AUTO-RADIOGRAPHY

X-ray source → slit → X-RAYS

FUEL ELEMENT

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X-RAY GAMMA AUTO-RADIOGRAPHY

X-ray source → slit

TRAY

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X-RAY GAMMA AUTO-RADIOGRAPHY

X-ray source → TRAY → FUEL ELEMENT → slit

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X-RAY GAMMA AUTO-RADIOGRAPHY

X-ray source

slit

FUEL ELEMENT

X-RAY CASSETTE

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X-RAY GAMMA AUTO-RADIOGRAPHY

X-ray source → slit → X-RAYS

FUEL ELEMENT

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X-RAY GAMMA AUTO-RADIOGRAPHY

X-ray source → slit → X-RAYS

FUEL ELEMENT

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X-RAY GAMMA AUTO-RADIOGRAPHY

X-ray source → slit → X-RAYS

FUEL ELEMENT

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X-RAY GAMMA AUTO-RADIOGRAPHY

X-ray source

slit

X-RAYS

FUEL ELEMENT

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X-RAY GAMMA AUTO-RADIOGRAPHY

X-ray source

slit

X-RAYS

FUEL ELEMENT

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X-GAR OF PFBR FUEL PIN

Plenum Spring

DDUO₂    MOX

DDUO₂    Plenum Space

Spring support

Middle Plug

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Gamma Scanning of Fuel Elements
Gamma scan of PFBR MOX fuel pins with varying composition
SURFACE EXAMINATION AND METROLOGY

✓ COLOUR, SPARKING, DENTS,
✓ SCRATCHES
✓ PHYSICAL DAMAGE
✓ MANUAL : CCD-TV
✓ METROLOGY : MECHANICAL LVDT NONCONTACT (LASER)

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MORE NDE AND PROCESS CONTROL CHECKS INCREASE RELIABILITY AND CONFIDENCE AND HENCE REDUCE DESTRUCTIVE TESTS

• e.g. PuO2 ENRICHMENT MONITORED AT DIFFERENT STAGES BY NWCC, PGS, GAR.

REDUCTION OF DESTRUCTIVE CHEMICAL ANALYSIS

CHEMICAL ANALYSIS NEEDED FOR SAMPLES NEAR THE LIMITS

COMBINATION OF PROCESS AND QUALITY CONTROL CHECKS IMPROVE THE QUALITY OF THE FUEL

INTELLIGENT PROCESSING TECHNIQUES-FOR TQM
CONCLUSION

- PROCESS PARAMETERS FOR FABRICATION OF MOX FUEL FOR PFBR FINALISED.
- ADVANCED TECHNIQUES FOR FABRICATION AND QUALITY CONTROL DEVELOPED.
- AUTOMATION TO REDUCE MANREM
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