FINAL DESIGN REVIEW OF BORON CARBIDE SAFETY ROD (U)

by

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A Technical Report for publication

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WSRC-TR-91-512

RRTD

REACTOR RESTART
TECHNICAL DIRECTOR

Keywords: Safety Rods
Gamma Heating
Loss of Coolant Accident

Retention - Permanent

FINAL DESIGN REVIEW OF BORON CARBIDE SAFETY ROD (U)

Prepared by:

Rex N. Lutz, Reactor Programs Section, RRD

Issued: September 1991

SRS WESTINGHOUSE SAVANNAH RIVER COMPANY

Savannah River Site
Aiken, SC 29808

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DATE: September 1991

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Reactor Materials Production

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FINAL DESIGN REVIEW OF BORON CARBIDE SAFETY ROD

SUMMARY

The Final Design Review meeting was held August 30, 1991 to evaluate the status of the design program for the boron carbide safety rod. Meeting attendance is provided as Appendix A. The objectives of the meeting were:

1. Review the results of the boron carbide safety rod testing program.
2. Identify any reasons to extend the fabrication hold put in place following the delivery of the test rods.
3. Determine what additional work is necessary.
4. Make appropriate recommendations to WSRC management.

This report has been prepared to meet the intent of existing and draft Reactor Restart Division requirements. Following the review, a memorandum was issued (RRD-PSI-910073) to accomplish prompt notification of WSRC management.

The Committee reviewed information presented by representatives of Savannah River Laboratory (SRL) Equipment Engineering Section (EES), SRL Materials Technology Section (MTS) and Reactor Materials Engineering and Technology (RMET). The meeting agenda is provided as Appendix B.

This Design Review Committee concluded that the production hold established following the Interim Design Review should be released, allowing the full production run to begin September 3, 1991. There is no anticipated change to the design as a result of further confirmatory testing.

The Committee also made the following recommendations:

1. The thermal gradient across the boron carbide pellets in a rod left in core during power operations should be calculated. The potential for thermal stress induced cracking should be assessed.
2. The potential impacts of boron carbide relocation due to pellet damage should be evaluated, especially with respect to pellet height in the rod.
3. The interior surfaces of the vibration test rods should be examined, following completion of testing, for indications of abrasion or wear caused by the pellets.
4. It should be demonstrated that there are no significant effects on the safety rod resulting from the serial combination of vibration and insertion.
5. The production procedures should include provisions to 1) ensure that the axial loading spring is dimensionally correct prior to use and 2) specify the actions required if mishandling occurs during the production process.

Responsibilities for follow-up on these recommendations have been assigned. MTS will address recommendations 1 and 2, EES will address recommendations 3 and 4, and RMP will address recommendation 5. RP will issue requests for task scope modifications where required.

It has been the objective of the design process to meet or exceed these criteria, identifying and addressing any additional concerns, and design a replacement safety rod that functions as desired. A Preliminary Design Review was held May 16, 1991, and is documented in Reference 1. An Interim Design Review was held July 9, 1991, and is documented in Reference 2. The design was fixed following that review, and test units were fabricated and tested prior to the Final Design Review.

PRESENTATIONS

The speakers' presentations are summarized in the order of appearance at the review. Copies of presentation materials are provided in Appendix C.

MTS Testing Program

N. J. Iyer, Materials Technology Section (MTS), summarized the results of the MTS testing and analyses. The MTS program includes eight analyses and tests, described in References 3 and 4. An interim report (Reference 5) provides details of the work accomplished at the time of the design review.

The MTS analytical and experimental results provide confidence that, for both normal and abnormal operating conditions, the design of the boron carbide safety rod is acceptable.

Irradiation response of the materials comprising the rod indicate that helium generation during the five year design life is negligible. In the event of gamma heating of these rods to 1000°C, rod integrity will not be lost due to internal pressurization. In the event that a rod were to be irradiated, left in the core at 50% power, for one month, neither helium pressurization nor the pellet swelling will result in a challenge to the rupture strength of the sheath.

Boron carbide is compatible with stainless steel at temperatures less than 700°C. At 1000°C, cladding penetration by chemical attack as a result of the interaction between boron carbide and the steel would require several hundred hours. There is no degradation of boron carbide pellets exposed to moderator.

Corrosion susceptibility of the boron carbide rods is precluded by the moisture and purity specifications of the pellets. All steel parts other than the 302 SS spring are corrosion evaluated 304L stainless. The pellet moisture acceptance criterion is <750 ppm in assembled rods. Moisture testing of pellets indicates that, due to pellet density and particle size, the fabricated pellets moisture content plateaus at about 250 ppm when exposed to 100% humidity. The average moisture content of pellets removed from one of the test rods was 120 ppm.

Calculations of the safety rod dynamic behavior during scram scenarios focused upon the worst case; mechanical snubbing with no electrical snubbing. The damping effects of fluid resistance and reactor superstructure were not considered. It was calculated that, for these conservative assumptions, the bottom end fitting would be subjected to an impact loading of 6000 pounds. RMP provided roll joint specimens for testing during development of the technique used in fabrication. Those roll joints were pull tested to failure in the 7000 to 10,000 pound range. Additionally, EES drop tested three rods on mechanical snubbers, in air, with no roll joint failures. See the EES summary for more information.

Concerns regarding the sensitivity of these rods to mishandling have been addressed through controlled flexibility, bowing response and mishandling tests. The rod is approximately 60% as stiff as the cadmium safety rod. Two person handling, supporting the rod at the ends only, caused no damage to pellets or the rod geometry. One person handling resulted in rod deformation.

Thermal response tests of a shortened version of the safety rod that maintained the gas/volume ratio of the full scale rod were successful. The rod was radiographed and dimensionally measured prior to testing. The unit was then subjected to three separate tests, each prototypic of a postulated gamma heating event, at 600, 800, and 1000°C. Temperature and internal pressure data were recorded during the testing. Measurements and radiographs indicated no damage to the safety rod following these tests.

EES Testing Program

M. D. McKay, the task leader for the Equipment Engineering Section (EES) safety rod program, presented the results of testing completed at the time of the design review. The EES program consists of three sets of tests, described in References 6 and 7.

The first EES tests discussed involved verifying that the design rod would function mechanically in an acceptable manner, experiencing no hang ups and scrambling rapidly enough. For comparative purposes, both a cadmium rod from spares and a test rod were scrambled with electrical snubbing into a water filled tank. EES reported that there was no observable dynamic behavior difference between the two rod types. The elapsed time between applying the trip signal until the electrical snubbing voltage was applied to the clutch was observed to be 0.01 second longer for the boron carbide rod than the cadmium rod. At the onset of electrical snubbing, the rods were seven to eight feet into the tank. The boron carbide rod travel time from trip signal applied to fully inserted was reported as 0.2 second longer. Neither rod type experienced any partial insertions during testing.

EES conducted drop tests of three test rods to examine damage characteristics. Two test series were run, one with electrical snubbing and the other with mechanical snubbing only. These drop tests were in air, to be more conservative and more likely to induce pellet or rod damage. In the first series, each rod was radiographed prior to testing, scrambled in air with electrical snubbing once, re-radiographed, and scrambled 25 additional times. No damage to the pellet columns or rods was caused by these drop tests. One rod experienced a latch failure and subsequent mechanical snubbing. That rod was radiographed before further testing; one boron carbide pellet was found, through very close examination of the films, to have been chipped very slightly. The rod was returned to the electrical snubbing tests and suffered no additional damage.

The same three rods drop tested with electrical snubbing were then scrambled in air with mechanical snubbing only. As discussed in the MTS presentation, large impact loading was calculated for mechanical snubbed insertions. Although mechanical snubbing occurs infrequently in reactor operations, it was of concern that the rod behavior be understood and acceptable when it happens. After each drop, the rods were radiographed and the snubber replaced. Two rods were mechanically snubbed only twice, the third was mechanically snubbed five times. The average number of pellets damaged in any way - chipped, cracked or broken following two drops was 10 (of 104). As expected, the number of pellets damaged increased with the number of mechanically snubbed insertions. Appendix C,

Item 3, contains a graph that illustrates the progressive accumulation of boron carbide pellet damage in the one rod subjected to five mechanically snubbed drops in air. Rod disassembly and examination revealed that a total of 58 pellets were chipped and 10 were cracked or broken. In no instance was the integrity of the rod compromised; there was no failure of the roll joints that secure the end fittings. Mechanically snubbed insertions in water are expected to result in even less pellet damage due to the damping effect of the liquid.

In order to test the design for impact on the safety rod thimble and cup, a vibration test was developed by EES. Current one-inch thimble service life is three years, based on operating history of thimble failures in safety rod and other one-inch positions. This test was performed in lieu of full scale prototypic flow testing, facilities for which do not exist at SRS. The exact flow velocity distributions for all flow conditions and all one-inch positions cannot be mocked up outside of the reactor tank.

The vibration testing involved installing thimbles and cups in the 305-A mock up tank, in which a cadmium rod and a boron carbide rod were mechanically vibrated over a range of low amplitude frequencies (0.5-5 Hz) for 16 hours. The rods, thimbles and cups were examined for wear; no measurable wear was found. The interior surface of the boron carbide rod had not yet been examined for wear of the stainless steel by the harder boron carbide pellets.

Reactor Materials Production Readiness

L. D. Dollar, RMET, discussed the 300 Area production readiness. Experience gained during the production of the test rods has been proceduralized to improve the quality of the final product. Improvement areas include counterbore depth control, cleaning, spring compression verification, evacuation and helium backfilling, and roll joint positioning.

The consultants questioned the completeness of the spring compression verification, and recommended adding the recording of verification that each spring used was dimensionally correct prior to rod assembly.

All 304L stainless steel parts will be corrosion evaluated (CE) material. A drawing revision was necessary to specify exclusive use of 3/4 inch tubing for the long spacer in the inactive region of the rod, because CE piping was not available.

The production run schedule assumed September 3 as a start date. Given that start date, the fabrication, certification, and shipment of 80 rods will be completed by October 7, 1991.

General Discussion

N. P. Baumann, SCS, was asked to explain the status of Nuclear Test Gauge (NTG) specifications and calibration. Reference 8 documents the SCS work on this topic.

Rod worths will be checked in the 300 Area using the Nuclear Test Gauge. A standard rod was fabricated for use with the NTG under the Request for Product (Test Rods) written by Reactor Programs. The test rods that were run through the NTG possessed nuclear characteristics well within the specifications. The NTG procedures and equipment necessary to support full production of safety rods are ready.

Committee Discussion

The Committee discussion followed, resulting in the recommendations and observations provided in the Summary section of this report. The consultants were present and participated. The Committee was verbally polled and unanimously agreed that the boron carbide safety rod full production run should proceed.

REFERENCES

1. R. N. Lutz, *Preliminary Design Review of Proposed Safety Rod (U)*. WSRC-TR-91-426, Savannah River Site, Aiken , SC 29802 (July 1991).
2. R. N. Lutz, *Interim Design Review of Boron Carbide Safety Rod (U)*. WSRC-TR-91-438, Savannah River Site, Aiken , SC 29802 (July 30, 1991).
3. Materials and Mechanical Design Analysis of Boron Carbide Reactor Safety Rods Task Plan (U), Task Number 91-047-1, (June 17, 1991).
4. Materials and Mechanical Design Analysis of Boron Carbide Reactor Safety Rods Task Quality Assurance Plan (U), Task Number 91-047-1, (June 17, 1991).
5. J. M. Marra, *Materials and Mechanical Design Analyses of Boron Carbide Reactor Safety Rods, Interim Report*, SRL-MTS-914036. (To be issued in September 1991).
6. Equipment Engineering Section Task Technical Plan 22053 - TTP Rev. 0.
7. Equipment Engineering Section Task Quality Assurance Plan 22053 - TQAP Rev. 0.
8. N. P. Baumann, *Substitute Safety Rods -- Physics Design and NTG Calibration (U)*, WSRC-TR-91-427, Savannah River Site, Aiken , SC 29802 (July 1991).
9. M. R. Louthan et al., memorandum to J. D. Spencer, "Anticipated Behavior of Safety Rods During a Post LOCA Thermal Excursion," SRL-MTS-910177, September 12, 1991.

APPENDIX A

Safety Rod Final Design Review Attendance

Committee:

R. N. Lutz	RP
C. E. Apperson	SCS
P. A. Hines	RMQ
R. G. Mayhew	ROD
M. A. Nadeau	RE
D. T. Rankin	MTS
J. W. Runnels	RMP

Others:

J. J. Banks	RE
N. P. Baumann	SCS
L. D. Dollar	RMET
M. J. Donohue	RMET
T. C. Easterling	SRL/SARM
T. M. Fleck	RMET
H. Garkisch	WAESD
N. T. Hightower	SRL/SARM
B. Howard	EES
N. J. Iyer	MTS
D. R. Leader	MTS
M. D. McKay	EES
C. E. Morgan, Jr.,	SAG
J. M. Morrison	RP
I. K. Paik	SAG
K. L. Planz	RMET
K. Radford	WSTC
M. Rosser	RE
E. R. Selden	RMET
M. K. Stewart	RMQ
W. Stubbs	DOE/SRSPO
D. A. Walkowiak	SAG
W. W. F. Yau	SRL

APPENDIX B

BORON CARBIDE SAFETY ROD DESIGN REVIEW AUGUST 30, 1991

AGENDA

0830	MTS Analytical and Testing Results	N. Iyer
0930	EES Testing Results	M. McKay
1030	Production Readiness	L. Dollar
1100	Additional Items	As Required
1130	Committee Discussion	

APPENDIX C

CONTENTS

1. L. D. Dollar, Slide Package, "Reactor Materials Production Readiness."
2. N. C. Iyer, Slide Package, "Materials & Mechanical Design Analysis of Boron Carbide Safety Rods."
3. M. D. McKay, et al., Slide Package, "EES Testing of the Boron Carbide Safety Rods."

Reactor Materials Production Readiness

**L. D. Dollar, RMET
August 30, 1991**

Production Issues

- **Counterbore Depth**
- **Filing Removal from Counterbore**
- **Verification of Spring Compression**
- **Evacuating and Backfilling Verification**
- **Joint Position Improvements**
- **Fabrication Schedule**

Counterbore Depth

- **Concern stated on examination of test rods that counterbore depth was greater than specifications**
- **Process Improvements:**
 - **Counterbore depth measured as In-process Inspection**
 - **Tolerance will meet drawing requirement of ± 0.050 "**

Filings from Counterbore

- **Filings Identified in Test Rods, resulting from Counterbore Operation**
- **Process Improvements:**
 - **Tubes will be brushed after Counterbore Operation**
 - **Tubes will be cleaned after brushing**
 - **Previous process required cleaning before counterboring tube**

Verification of Spring Compression

- **Tube length verified prior to assembly**
- **Stack length verified prior to assembly
and after assembly into housing tubing**
- **Top fitting length inspected**
- **Measurements ensures correct
compression of spring**

Evacuating and Helium Backfilling Verification

Process Modified to Verify Evacuation and Helium Backfill of Rod:

- **Gage placed on non-welded bottom end**
- **Rod evacuated through top roll joint**
- **Evacuation and backfill of rod verified
by gage on bottom end**

Joint Position Improvements

- **First safety rod assembly process did not position joint in center of groove**
- **Process improvement implemented to install mechanical stops to accurately position tooling**

Fabrication Process

- **All Corrosion Evaluated Stainless Steel except Spring Material**
- **Drawing Revision Necessary to permit exclusive use of 3/4" Tubing instead of Pipe**
- **All Product will be Certified by Reactor Materials Quality and Certification Letter Delivered with Product**

Fabrication Schedule

- **Fabrication process to begin 9/3/91**
- **First completed rod scheduled for 9/6/91**
- **Fabrication, certification, and shipment of 80 rods to be complete by 10/7/91**

Materials & Mechanical Design Analysis of Boron Carbide Safety Rods

**N. C. Iyer
MTS / SRL**

*Final Design Review
B₄C Safety Rod
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Task Team

J.C. Marra (Task Leader)
N.C. Iyer
D. R. Leader
N. Bauman
W.W. F. Yau
G.R. Caskey, Jr.
M. R. Louthan, Jr.
B. Howard

*Final Design Review
B₄C Safety Rod
August 30, 1991*

Program Goal:

Establish the materials and mechanical design basis for the Boron Carbide Safety Rod.

***Final Design Review
B₄C Safety Rod
August 30, 1991***

B₄C Safety Rod Design

Design Considerations

Materials

- Irradiation Response
- Chemical Compatibility
- Corrosion Considerations
- Moisture Considerations

Mechanical Design

- Dynamic Behavior -
scram scenarios
- Flexibility/Bowing
- Thermal Response

- Surveillance Program

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August 30, 1991*

Irradiation Response

- Normal Operating Condition (rod withdrawn)
- He Generation negligible during design life
Internal pressure = 19 psi, Hoop stress = 155 psi
- Gamma Heating Accident Scenario at 1000C
He pressure well below clad rupture stress
Internal pressure = 66 psi, Hoop stress = 530 psi

**Final Design Review
B₄C Safety Rod
August 30, 1991**

Irradiation Response

- Rod Inadvertently Irradiated
 - Considered 1 month irradiation -> historical worst case < 2 weeks
- He Pressure well below clad rupture strengths
 - Internal pressure = 91 - 317 psi, Hoop stress = 744 - 2590 psi
- Swelling - $\Delta D = 0.00073$ " (Gray & Lyman)
 - $\Delta D = 0.00022$ " (Homan)
 - Design Clearance: 0.041"

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B₄C Safety Rod
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Chemical Compatibility

• B₄C - Stainless Steel Compatibility :

- No interaction with stainless steel < 700 C
 - *Normal Operating Conditions (100C)*
- Gamma Heating Scenario -
 - *At 1000 C, 550 - 785 hours to penetrate the clad.*

• B₄C - Moderator Compatibility :

- No degradation of pellets exposed to moderator.
 - *< 0.2 wt% water soluble boron in B₄C.*

**Final Design Review
B₄C Safety Rod
August 30, 1991**

Corrosion Susceptibility

- Moisture Specifications for safety rods preclude corrosion susceptibility.

Considerations:

- Leaching of Chlorine in B₄C due moisture pick-up during assembly.
 - Chlorine specification in pellet < 0.0075wt%
 - Leaching Experiments (5 days at 22 C in water)
 - < 8 ppb (pellet) & 100 ppb (powder) Cl leached out.
- Break up of passive film through formation of iron oxide. (< 0.12 wt% Fe; spec. < 0.6 wt% Fe in B₄C).
 - None observed in assembled safety rods.
 - Experiments being conducted to demonstrate benign nature of Fe.

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Moisture Considerations

Moisture Criteria: < 750 ppm in assembled rod.

- Measurements by Coulometry at A.R.T. per ASTM C791-83.
- As received pellet : 100 -150 ppm
- 100 % humidity up to 4 hours : < 250 ppm
- Initial Assembly criteria: 2 hours
- Pellets from assembled & tested safety rod
 - > moisture avg. 120 ppm
- Recommend exposure limit during assembly increase to 4 hours.

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B₄C Safety Rod
August 30, 1991*

Thermal Response Tests

Test Rod:

Test Conditions:

- 2 ft pellet column in high temperature zone.
- Test temperature: 600 C, 800C and 1000C
- 1 atm He pressure
- Temperature and Pressure monitored.

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B₄C Safety Rod
August 30, 1991*

Thermal Response Tests

RESULTS

"Prototypical Ramp Rate"

- Samples exposed to 600 & 800C radiographed - no change.
- Sample exposed to 1000 C radiographed - no change or internal damage observed.

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B₄C Safety Rod
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Dynamic Analysis

Scram Scenario: Mechanical snubbing with no electrical snubbing.

Conservative Estimate - Fluid resistance & reactor superstructure not considered.

Analytical Results:

- B₄C safety rod resistant to impact loading conditions.
- 304 L housing tube may elongate max. 0.42".
- Spring - will not lose spring compression and will not cause separation between pellet/spacer.
- 6000 lbs force on bottom fitting.

Test Results:

- 7,000 to 10,000 lbs load to failure on the bottom fitting.
- Other results -> EES

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B₄C Safety Rod
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Flexibility/Mishandling

- Stiffness: B_4C ~ 60% Cd safety rod.
- Bowing: No pellet damage.
- Drop Test (off a bench): slight pellet damage.
- Handling at ends: no pellet or clad damage.
- Handling in middle: permanent deformation.

*Final Design Review
 B_4C Safety Rod
August 30, 1991*

Future Work

- Issue interim reports.
- Close out administrative NCRs.
- Complete irradiation analysis.
- Confirmatory thermal tests.
- High temperature burst tests on clad material.
- Thermal tests with imposed He pressure.
- Surveillance Program
- Final Report.

*Final Design Review
B₄C Safety Rod
August 30, 1991*

EES

Testing of the Boron Carbide Safety Rods

**Mark D. McKay
Mark Killian
Mark Ferencz
Terry Fields
Boyd Howard**

Objectives

**Compare the effects of *vibration*,
insertion and *drop* testing on the
Boron Carbide Safety Rod (BCSR)**

TESTS

Insertion Test -- 723-A Mockup (complete)

Drop Test -- 723-A Mockup (complete)

Vibration/Wear Test -- 305-A Mockup

Insertion Test

Objective

Compare the insertion time of an existing Cadmium rod to a Boron Carbide rod

Test

- ☐ **Drop both a Cadmium rod and a Boron Carbide rod using electrical snubbing into a Rx. mockup**
- ☐ **Compare the drop times of both rods**

BCSR INSERTION TEST MOCKUP IN 723-A HIGH BAY

BCSR Insertion Test EES-FP-260

Rod Type	Test Number	Snub Time	L-Link Time	Insertion Time	Rod Type	Test Number	Snub Time	L-Link Time	Insertion Time
CS	1	1.03	22.58	22.81	BCSR	1	1.00	23.15	23.25
CS	2	1.00	22.56	22.81	BCSR	2	1.00	22.65	22.85
CS	3	1.00	22.60	22.85	BCSR	3	1.00	22.82	23.12
CS	4	1.00	22.58	22.78	BCSR	4	1.00	22.45	22.70
CS	5	1.02	22.53	22.90	BCSR	5	1.00	22.53	22.77
CS	6	1.00	22.43	22.65	BCSR	6	1.03	22.65	22.90
CS	7	0.99	22.10	22.42	BCSR	7	1.03	22.70	22.90
CS	8	1.00	22.52	22.74	BCSR	8	1.05	22.70	22.95
CS	9	0.99	22.30	22.58	BCSR	9	1.00	22.67	22.95
CS	10	1.00	22.50	22.76	BCSR	10	1.03	22.71	22.95
Average		1.00	22.47	22.73			1.01	22.70	22.93
Maximum		1.03	22.60	22.90			1.05	23.15	23.25
Minimum		0.99	22.10	22.42			1.00	22.45	22.70
Standard Dev.		0.01	0.16	0.14			0.02	0.19	0.16

Drop Test

Objective

Determine the effects on the Boron Carbide rods from drops with Electrical and Mechanical snubbing

Test

- ☐ **Drop the Boron Carbide rods 25 times each using electrical snubbing**
- ☐ **Drop the Boron Carbide rods 2 times each using mechanical snubbing only**
- ☐ **Radiograph each rod before and after the first drop and after 24 consecutive drops and after each mechanical snub drop.**

Electronic Drop test

- Each rod was dropped 25 times using the electronic snubber. The average snub time was BR010 .9825 sec BR011 .9704 sec and BR015 .9776 sec.
- No damage to the B4C pellets was observed (Except in the BR010 after latch failure).

B4CSR Mechanical Snub test

EQUIPMENT ENGINEERING SECTION NDE CONSULTATION GROUP				RADIOGRAPHIC FILM ANALYSIS FORM		REPORT NO. 29	
SAFETY ROD ID: <u>BR015</u>		COMPANY PERFORMING RADIOGRAPHIC TESTING: EDASCO SERVICES INC.		DATE RADIOGRAPHY PERFORMED: <u>8-28-91</u>		DATE ANALYZED: <u>8-28-91</u>	
RT PROCEDURE: <u>EDASCO-002-1</u> REVISION 1		RRR PROCEDURE: <u>EES-PP-261, RAYCO</u>		RT PERSONNEL CERTIFICATION LEVEL:		RT ANALYST CERTIFICATION LEVEL:	
"INFORMATION ONLY"							
DESCRIPTION: <u>RADIOGRAPHS TAKEN AFTER FIVE PLANNED FREE-FALL DROP TEST OF ROD.</u>							

AXIAL POSITION (IN INCHES)	CONDITION OF PELLETS (NUMBERS START FROM BOTTOM OF ROD)						REMARKS
0-10	1 SC 1 SC						
10-20	2 C						
20-30	3 C						
30-40	22 23 SC 24						
40-50	25 B 26 SC 28 B 29 30 SC						
50-60	31 SC 33 SC 35 SC 36						
60-70	38 42 SC						
70-80	44 SC 47 SC 48						
80-90	51 C						
90-100	55 56 SC 57 59 SC						
100-110	61 62 64 SC 66 SC						
110-120	67 SC 68 SC 69 SC 71 72						
120-130	73 SC 74 77 SC						
130-140	79 80 81 82 83 84 85 86 87 88 89 90 SC						
140-150	91 92 93 94 95						
150-160	96 97 98 100 SC 101 102 SC						
160-170	103 104 105 106 107 108						
170-180	109						

RADIOGRAPHIC TECHNIQUE:
SOURCE OF RADIATION: Iridium 192
SOURCE FOCAL SPOT SIZE: 0.141" diameter
SOURCE TO FILM DISTANCE: 15"
FILM TYPE: Kodak I.

LEGEND:
OK indicates that the pellet is in-tact.
C indicates that the pellet is chipped.
B indicates that the pellet is broken or cracked.
P indicates that the pellet has been pulverized or is crushed.

■ - INDICATES CHIPPED OR BROKEN PELLETS SEEN WITH RADIOGRAPHY, VERIFIED VISUALLY.
△ - INDICATES CHIPPED OR BROKEN PELLETS NOT SEEN WITH RADIOGRAPHY BUT VERIFIED VISUALLY. **SC** - VERY SMALL CHIPS.

Vibration/Wear

Objective

Inspect the vibration induced wear of a Boron Carbide rod with respect to an existing Cadmium rod

Test

- ☐ **Inspect both the Cadmium and Boron Carbide rods**
- ☐ **Shake both the Cadmium rod and a Boron Carbide rod at a frequency ranging from .5 to 5 Hz for 16 hours.**
- ☐ **Examine the rods, thimbles, and thimble cups for wear**

Vibration/Wear

- After 16 hours of vibration testing on the B4CSR no detectable wear was found.

EQUIPMENT ENGINEERING SECTION NDE CONSULTATION GROUP				RADIOGRAPHIC FILM ANALYSIS FORM		REPORT NO. _____	
SAFETY ROD ID: <u>BR016</u>		COMPANY PERFORMING RADIOGRAPHIC TESTING: <u>BRASCO SERVICES INC.</u>		DATE RADIOGRAPHY PERFORMED <u>8-30-91</u>		DATE ANALYZED: <u>8-30-91</u>	
RT PROCEDURE: <u>SRG-NDE-002-1</u> REVISION 1		SRG PROCEDURE: <u>EES-EP-261, REV.0</u>		RT PERSONNEL CERTIFICATION LEVEL: II		RT ANALYST CERTIFICATION LEVEL: III <u>BH</u>	
DESCRIPTION: <u>RADIOGRAPHS TAKEN AFTER VIBRATION TEST.</u>							

AXIAL POSITION (IN INCHES)	CONDITION OF PELLETS (NUMBERS START FROM BOTTOM OF ROD)						REMARKS
0-10	1 OK	2 OK	3 OK	4 OK	5 OK	6 OK	
10-20	7 OK	8 OK	9 OK	10 OK	11 OK	12 OK	
20-30	13 OK	14 OK	15 OK	16 OK	17 OK	18 OK	
30-40	19 OK	20 OK	21 OK	22 OK	23 OK	24 OK	
40-50	25 OK	26 OK	27 OK	28 OK	29 OK	30 OK	
50-60	31 OK	32 OK	33 OK	34 OK	35 OK	36 OK	
60-70	37 OK	38 OK	39 OK	40 OK	41 OK	42 OK	
70-80	43 OK	44 C	45 OK	46 OK	47 OK	48 OK	
80-90	49 OK	50 OK	51 OK	52 C	53 C	54 OK	
90-100	55 OK	56 OK	57 OK	58 OK	59 OK	60 OK	
100-110	61 OK	62 OK	63 OK	64 OK	65 OK	66 OK	
110-120	67 OK	68 OK	69 OK	70 OK	71 OK	72 OK	
120-130	73 OK	74 OK	75 OK	76 OK	77 OK	78 OK	
130-140	79 OK	80 OK	81 OK	82 OK	83 OK	84 OK	
140-150	85 OK	86 OK	87 OK	88 OK	89 OK	90 OK	
150-160	91 OK	92 OK	93 OK	94 OK	95 OK	96 OK	
160-170	97 OK	98 OK	99 OK	100 OK	101 OK	102 OK	
170-180	103 OK	104 OK	105 OK	106	107	108	

RADIOGRAPHIC TECHNIQUE: SOURCE OF RADIATION: <u>Iridium 192</u> SOURCE FOCAL SPOT SIZE: <u>0.141" diameter</u> SOURCE TO FILM DISTANCE: <u>35"</u> FILM TYPE: <u>Kodak T</u>	LEGEND: OK indicates that the pellet is in-tact. C indicates that the pellet is chipped. B indicates that the pellet is broken or cracked. P indicates that the pellet has been pulverized or is crushed.
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**DATE
FILMED**

7/17/92