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EXTERNAL REFERENCE / VERSION

Report

VVPSS Rupture Disk Testing BS&B Phase 2

Additional testing report for the VVPSS Rupture Disks. This second round was completed by BS&B without additional charge to try to minimize disk fragmentation. It was agreed that this test would fulfill the first contract and additional development would need to be covered by a new contract if required.

Approval Process			
	Name	*Action*	*Affiliation*
Signatory	**Meekins M.**	**03 Jun 2015:signed**	**IO/DG/COO/TED/VV/CRST**
Co-signatories			
Reviewers			
Approver	**Sekachev I.**	**28 Jun 2015:approved**	**IO/DG/COO/TED/VV/CRST**
Document Security: Internal Use *RO: Meekins Michael*			
Read Access	**AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO**		

BS&B SAFETY SYSTEMS LIMITED

ITER 32" Rupture Disk Follow-Up Testing

ITER International Fusion Energy Organization

Lead Engineer: Mitchel Rooker – Account Manager: Max Bugliosi

5/19/2015

Confidential Information
Contract reference IO/CT/11/4300000564

This report details the observations and conclusions from follow up full scale performance testing conducted at BS&B's PremcoLA facility in Monterey, Mexico between 26th February and 5th March 2015. The focus of this testing was rupture disk and safety head fragmentation control and enhancements were tested. The earlier work was completed under BS&B references SO 12311007 to procedure EI-SF-0011.

Table of Contents

1 Abstract

This testing project was conducted to complement the original contract (SO 12311007; procedure EI-SF-0011, original report issued in July 2014). The objective was to minimize the fragmentation of the disks observed during testing in June 2014 with a double disk configuration and vacuum between the 2 rupture disks. A special safety head hinge was designed and built for both disk locations. Testing included 8" prototype evaluation and full-scale 32" trials.

The upstream disk (high pressure JRS) was fully successful.

The observation of fragmentation of the downstream disk seal (VSP-SH), resulted in changing the design during the test program to a special Low Pressure (LP) JRS. This new design was tested and found to be promising, but was not fully effective in its initial form. The Low Pressure JRS is recommended for future additional investigation outside of the current test agreement

Testing with vacuum between the two rupture disk devices and at the outlet side of the 2nd (downstream) disk, which is outside the scope of EI-SF-0011, revealed an increase in fragmentation tendencies.

These tests provided us with a better understanding of the application challenges involved. It is unknown how well the 36 inch diameter x 23.6 foot length test vessel with air fluid (BS&B test facility in Monterrey) replicates the large service volumes with steam process fluid at ITER. In emergency service venting, the long duration venting may pose a further fragmentation risk due to flow turbulence fatigue of disk pieces.

There are several potential solutions to minimize fragmentation. A further phase of testing could include a long duration flow, using a high pressure blower (likely on a choked or small scale). To minimize the potential for flutter fatigue, an improved JRS design is suggested. This would include changes to the hinge tooth design and possibly to the opening petal. It must be specified if the downstream disk must be fully functional for both the double-vacuum field service condition and a single-disk rupture event, venting into ambient air.

2 Background and preparations

This is a follow-up study to the rupture disk report of June 23, 2014. In the original study, the leak-tightness (with thermal cycling), burst pressures, and open area were validated. However, there was fragmentation of the upstream disk and a major part of the downstream disk.

Full-scale testing was conducted in Monterrey Mexico February 26 to March 5, 2015. In attendance were Michael Meekins of ITER, Max Bugliosi of BS&B Sales, Mitchel Rooker of BS&B Engineering, and the BS&B PremcoLA test lab team and plant support, led by Victor Vega.

Prior to the full-scale 32" testing, 8" prototype tests were conducted in Tulsa. The 8" test results reflected well what later occurred in full scale. The upstream disk was successful with the new 32" safety head hinge, but not the downstream disk.

For all full-scale testing sharp pins were installed on the safety head hinge of the downstream low pressure disk side, but not the upstream high pressure disk side. Pin height was 0.38". The sharp pins of the safety head hinge did not decrease or increase fragmentation of the downstream disk. Also no benefit was found from increasing the safety head hinge length.

Before Michael Meekins arrived on site to witness testing, two start-up tests were conducted (test #1 & #2). These were start-up, system verification tests, but provided valuable data. 6 tests were performed in total in Monterrey.

3 Timeline

Key tasks are listed below:

Task	Dates
First Report submission	04/07/2014
Meeting at ITER to review report	16/07/2014
Proposal for further work submitted	01/10/2014
8" scale development and trials	Oct 2014 to Jan 2015
32" hinges production	Jan 2015
32" disks productions	Dec 14 & Jan 2015
Procurement of new data acquisition software and GoPro video	Jan 2015
Shipment of equipment to Monterrey	Jan 2015
Testing in Monterrey 6 tests in total	26 Feb to 5th March 2015
Outline of follow up project report issued	30/03/2015
Report issued	19/05/2015

4 Test procedure

The same test procedure as of the June 2014 was followed. A drawing of the assembly is in the first report, Annex A.14, page 2 of 2.

The data acquisition system used for the follow-up testing, for measuring the shock wave, was TracerDAQ® ProA. The data collection rate is 1200 data points per second for the slow card and 5000 data points per second for the fast card. The fast card was delivered to the test site and used beginning with test #4. However, due to the USB connection the true collection rate was less. This rate was estimated by counting the number of repeat data points, and calculating an average rate of non-repeating data. Full data speed is achievable with a data card installed on the motherboard.

The modified VSP-SH used for test #3 and the new configuration LP JRS downstream disk (test #5 and #6) were not fully developed designs. They had a burst pressure of 1.5 to 3.5 PSI (the specification is for 3.0 PSI). These are prototype disks that allowed for speed and flexibility to test the configurations and implement modifications according to the results and observation.

5 Summary of results

The upstream high pressure disk (20 PSI JRS) successfully wrapped around the special safety head hinge and locked on firmly. This good result was repeated all 5 times (test #1 did not use the hinge). The ambient burst pressure of the JRS was slightly less than that of the previous lot. This is normal as the disks are rated at elevated temperature and the temperature factor can vary with disk material and crown height.

Management of fragmentation for the downstream low pressure disk was not achieved using the VSP-SH rupture disk design. While the support dome of the VSP-SH was made thinner & the seal dome thicker, an unacceptable level of fragmentation occurred. Changing the design of the downstream disk to a low pressure JRS is recommended for follow on test evaluation. Fragmentation was reduced as the disk pieces were not thrown out of the piping. This is likely due to incomplete fragmentation during the initial venting flow, and full fragmentation due to the reverse flow, which is a feature of the limited test volume arrangement. While the ITER full scale venting system will not exhibit reverse flow during venting, the observed low pressure JRS large disk petal retention is recommended for improvement. The disk petal was likely held on very weakly. The videos seem to confirm this. A disk petal that can be blown backwards off the head hinge by the weaker reverse flow can detach if not locked (latched) onto the hinge securely.

Further investigations should explore the performance of the safety head hinge variations to prevent tear propagation on a low pressure JRS disk petal, an improved cutting tooth design for lower pressure opening and cleaner cutting, latching devices on the disk or hinge, thicker disk, etc. This should be first done in small scale trials (recommend 8" size based upon the acceptable correlation of observations found in this series of tests.).

6 Test results

6.1 Test #1 – 26/02/2015 – damaged JRS – no vacuum

Customs agents at the border removed the cover of a crate containing four 32" JRS disks. They placed a 15 pound cardboard box on top of the disks. Therefore the top disk was marked by the abrasion where the box touched the disk. That disk must be considered damaged in transit. This is similar to what was expected to cause the low burst in the original June 2014 testing. This suspect disk was tested as a shake-down test. Vacuum was not pulled in the mid-flange due to leakage. Leaks were located and plugged after this test.

- Mid-Spool vacuum: None (ambient) (0.0 PSI)
- First disk burst pressure was 16.0 PSI.
- The maximum mid-flange shock wave pressure as 5.2 PSI

The JRS and VSP-SH openings were poor due to the low burst pressure. These results illustrate the need for a service proof pressure test after being fully installed in heads. This ITER service is of such a critical nature that at least the first disk should be proof tested before installing the assembly into service. It may also be of benefit to video tape the test assembly disassembly and installation into service to ensure the disk is not damaged after proof testing.

6.2 Test #2 – 27/02/2015 – JRS and VSP-SH standard

A second full-scale test was conducted before Michael Meekins arrived. The test was open venting, with vacuum in the mid-flange. No Go-Pro video was taken.

- First Disk: JRS with double tooth ring, .14 mpa @ 100ºC (20.3 PSI @ 212ºF)
- Second Disk: VSP-SH, Burst Pressure of .02 mPa (2.9 PSI) @ 20ºC. This is the same design as "Design 2" of 20 June 2014.
    - Support dome 0.060" thick
    - Seal dome 0.004" thick
- One transducers in mid-flange.
    - Data collection rate: set at 1200 points/sec, each channel (slow data card).

- Actual collection rate is 1070 points/sec

Pressure Measurements:

- Vessel pressure at moment of burst was 6.02 PSI
- Mid-Spool & end-pipe vacuum was -13.00 PSI
- First disk burst pressure was 6.02 +13.00 = 19.02 PSI.
- The maximum mid-flange shock wave pressure was 8.67 PSI.

Fragmentation Observations:

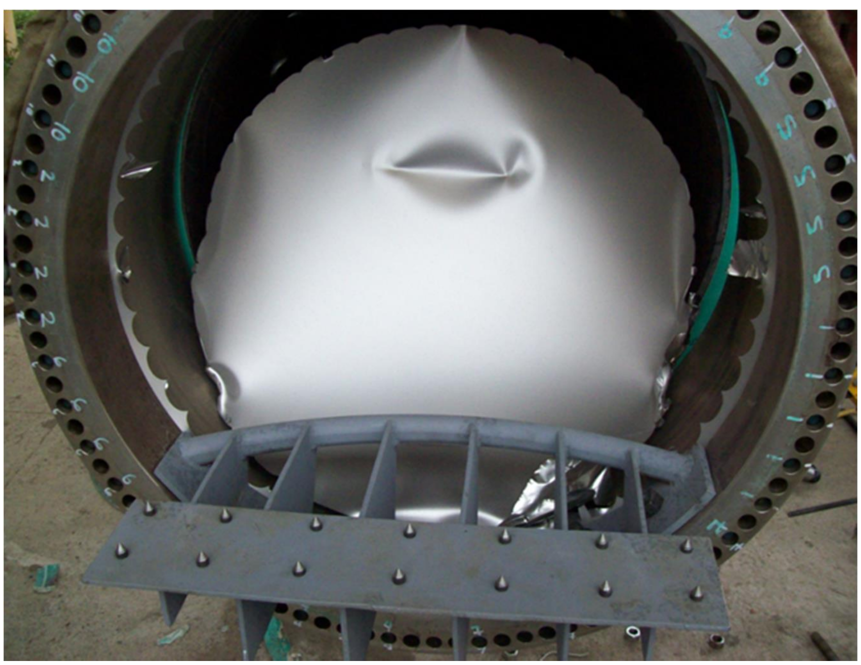
The upstream disk (JRS) opened fully, exhibited no fragmentation and it latched to the bottom of the safety head hinge.

The opening of the VSP-SH was partial, as it did not bend around the new safety head hinge. This was anticipated from 8” prototype test results. A back-up plan was implemented and ready for the arrival of Michael Meekins.

Two of the JRS teeth reversed. This indicated that the cutting teeth were not of sufficient thickness. To prevent uncertainty of the opening dynamics of further tests, a second back-up tooth ring was added to the JRS (upstream high pressure disk) for the following tests.

P2-1: Test Assembly (Double-Disk)

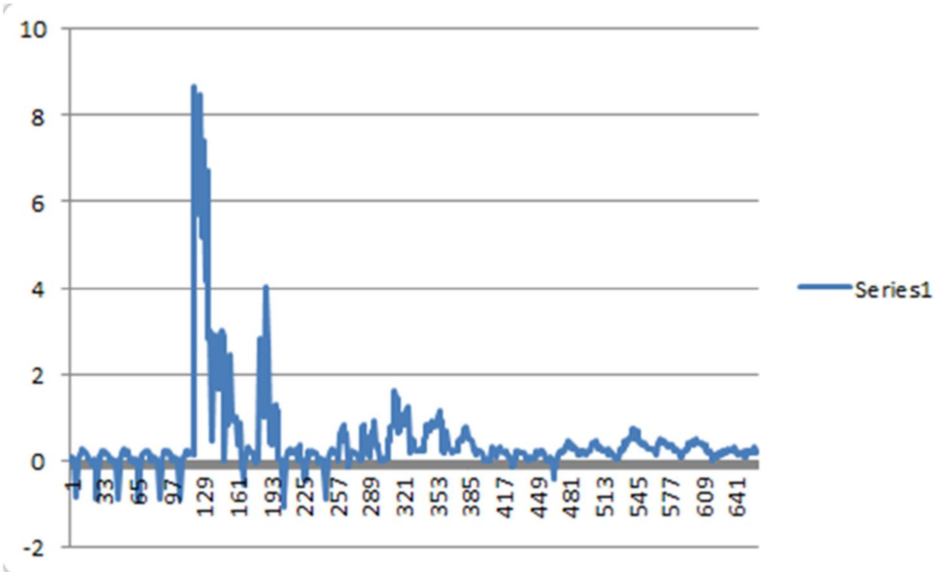
P2-2: Upstream high pressure disk (JRS).



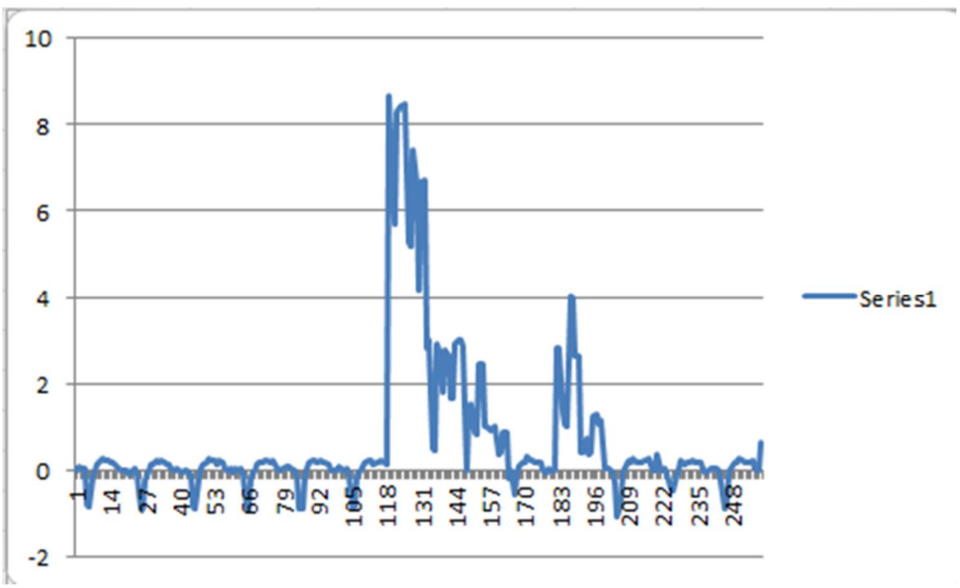
P2-3: Downstream disk VSP-SH. View looking into the piping with the end spool removed.

P2-4: Downstream disk (VSP-SH) with partial fragmentation of seal dome. Disk support is shown in reversed direction, as removed. Bend line is from hitting the first disk safety head hinge during reversal flow.

P2-5: Downstream disk (VSP-SH) is being held down in outflow direction, illustrating the minimal bending around the safety head hinge, and the reduced opening.



P2-6: Shock wave pressure in mid-flange – data capture



P2-7: Shock wave pressure in mid-flange - enlargement

6.3 Test #3 – 02/03/2015 – JRS and VSP-SH seal and support dome thickness modified

All tests witnessed by Michael Meekins for this one.

This was an open-venting test, with vacuum in the mid-flange. Testing was per EI-SF-0011, 8.0 Phase 2, Test #1; except the mid-flange was 21" long.

- First Disk: JRS with double tooth ring, .14 mpa @ 100ºC (20.3 PSI @ 212ºF)
- Second Disk: VSP-SH, special mock-up; burst pressure = 1.2 to 3 PSI

- Support dome 0.036" thick (special thin to better bend on the safety head hinge)
- Seal dome 0.006" thick (special thick to prevent or reduce fragmentation)

Pressure Measurements:

- Vessel pressure at moment of burst was 6.91 PSI
- Mid-Spool vacuum was -12.06 PSI
- First disk burst pressure was 6.91 +12.06 = 18.97 PSI.
- The maximum mid-flange shock wave pressure as 8.67 PSI.
  - One transducer in mid-flange.
  - Data collection rate: 1200 points/sec (slow data card) .
  - Actual collection rate is about 1030 points/sec.

Fragmentation Observations:

The upstream high pressure disk (JRS) opened fully, exhibited no fragmentation, and it latched to the bottom of the safety head hinge.

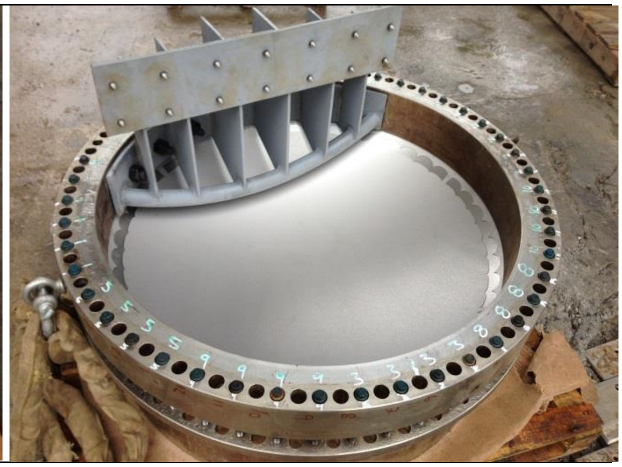
The downstream low pressure disk (VSP-SH) seal blew out of the assembly; apparently during the second out-flow. It appears to have hit the bottom of the safety head hinge of the upstream disk. If so it was not torn off during the first outward flow but was bent backward due to flow reversal in the test arrangement, and then was torn during the second outward flow.

The VSP-SH support dome did not fragment. It was heavy enough to not even tear at its base. However, it did not latch. It was too heavy to have wrapped around the bottom of the safety head hinge. However it did partly bend at the bottom. It did hit the sharp pins of the safety head hinge but only those at the sides. The pins did not penetrate the support petal. During the first reverse flow, the support petal apparently was blown fully backwards and hit the upstream safety head hinge hard enough to imprint a second bend line.

Conclusions:

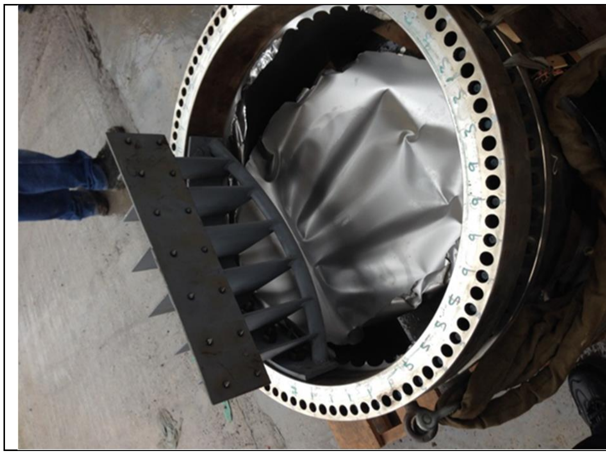
These results are in the right direction. The upstream disk continues to perform well. The dwonstream disk seal was not totally fragmented during the first outward flow, and the support did hit the head hinge but not with enough energy to latch, as designed. This drives us toward a single-petal disk with a thickness between the VSP-SH seal and support dome.

P3-1: Upstream Disk (JRS)

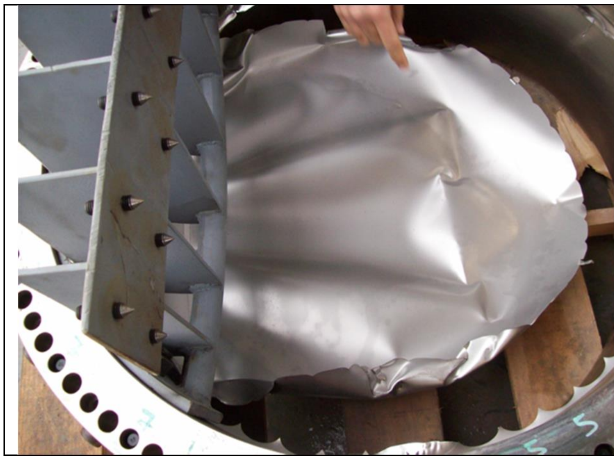


P3-2: Downstream Disk (VSP-SH)

P3-3: View into piping after opening, before disassembly.




P3-4 & P3-5: Downstream Disk (VSP-SH) support dome



P3-6: Downstream Disk (VSP-SH) support.

P3-7: Downstream VSP-SH seal fragment.

P3-8: Downstream Disk (VSP-SH) seal; fragmented.

P3-9 & P3-10: Upstream JRS Disk

P3-11: The fragmented VSP-SH seal was placed on the JRS disk to illustrate where it hit during the first reverse flow.

The GoPro video frame rate was 240 frames per second. Below are the frames of interest. Each white-out is the exhaust of vessel air (water mist condensation). The frames show the buckling of the VSP-SH disk, followed by burst, and then white-out, then reverse flow back into the tank, then subsequent cycles of flow and reverse flow. The reverse flow lifted the VSP-SH off the hinge and bent it backwards toward the tank, slamming it on the safety head hinge of the upstream disk.

P3-12: Pictures A1 to X2 below from GoPro video from test#3

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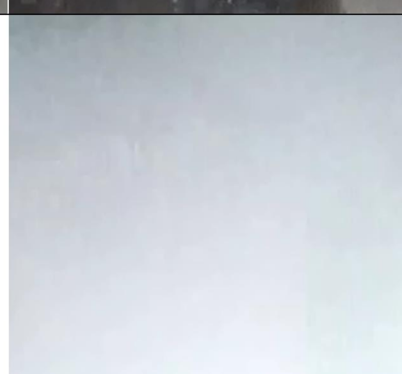
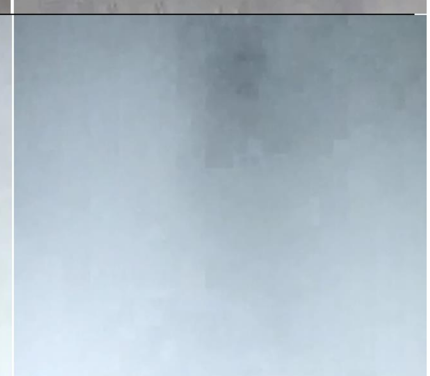
C			

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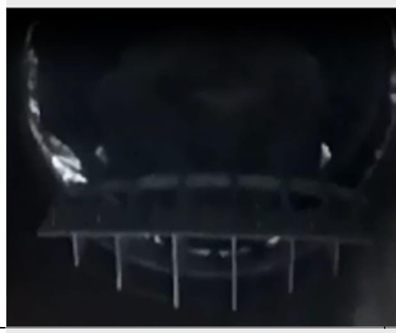
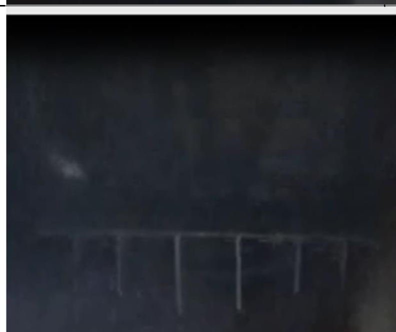
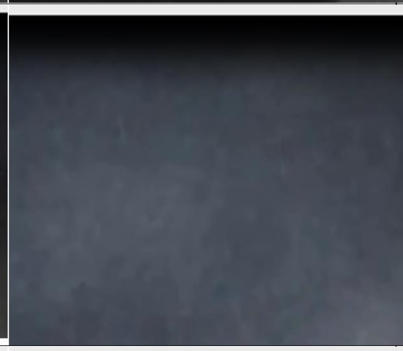
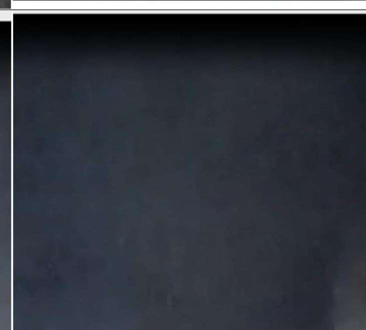
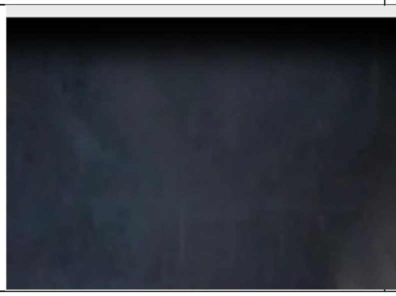
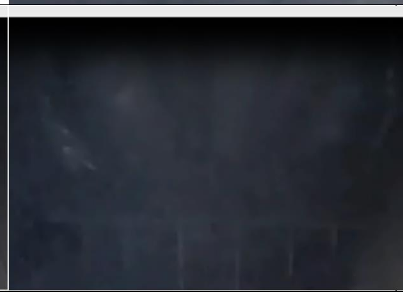
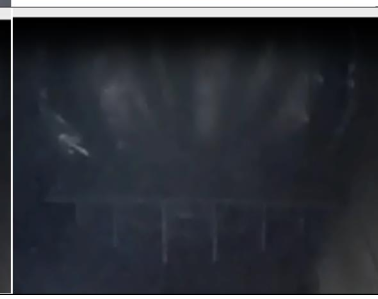
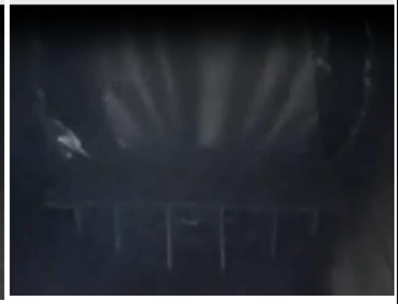
F			
G			
H			

I			
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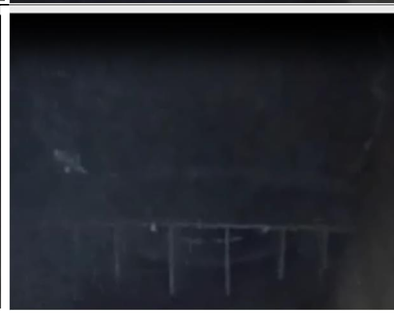
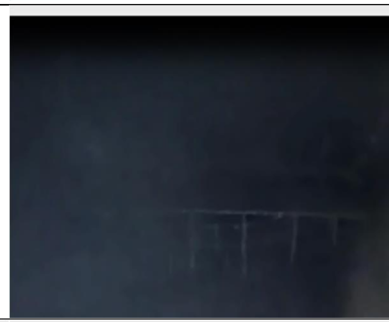
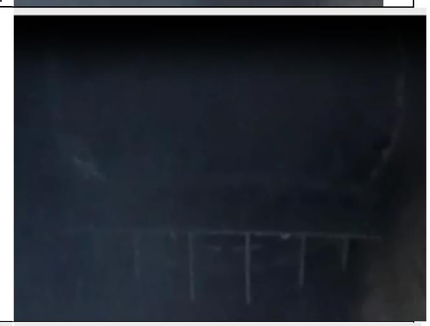
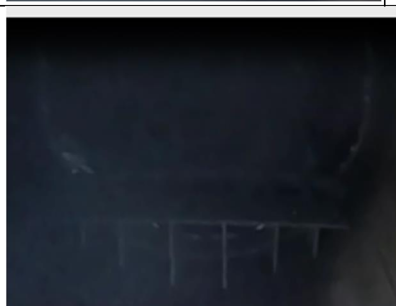
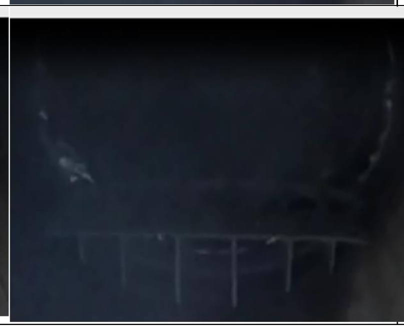
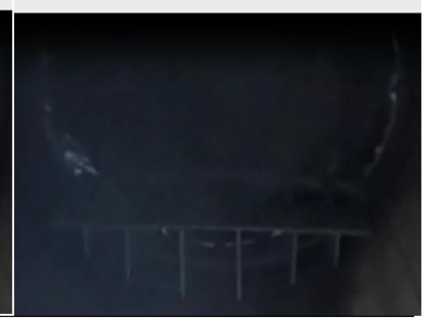
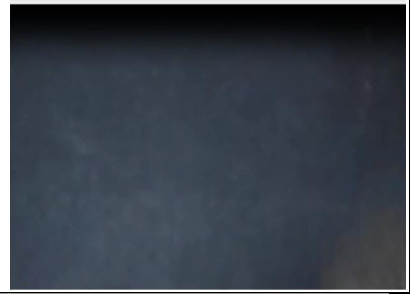
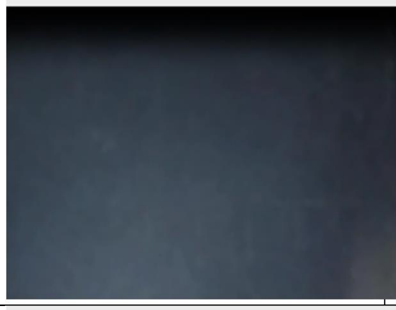
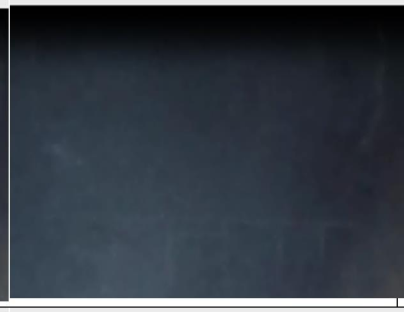
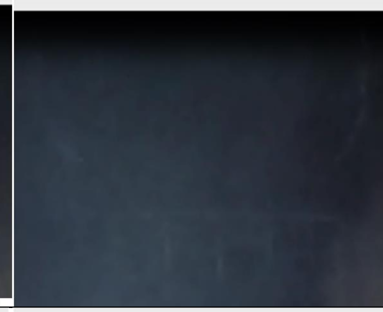
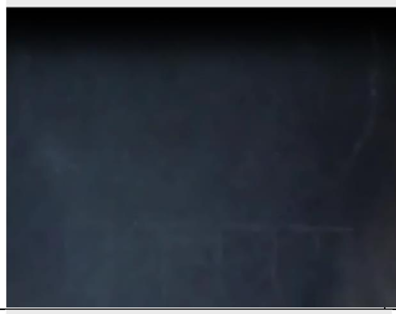
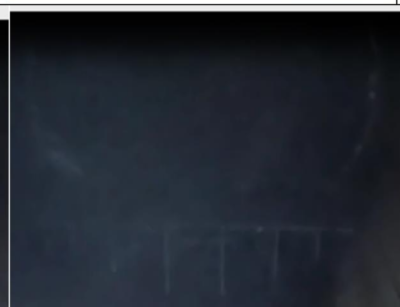
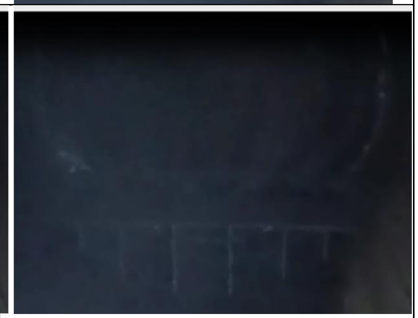
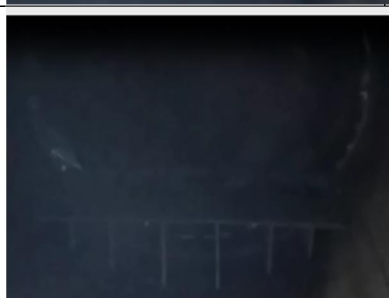
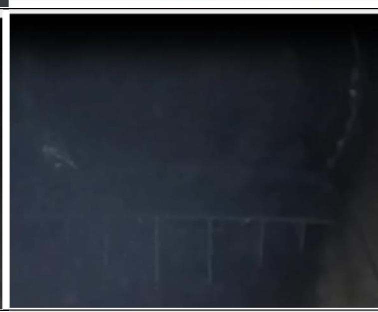
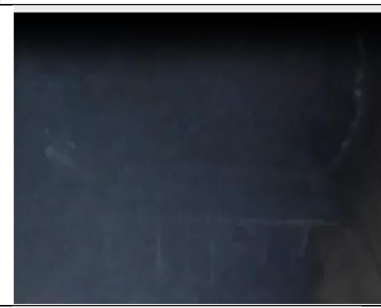
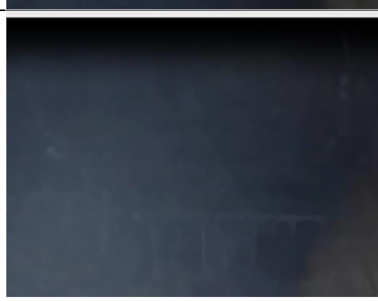
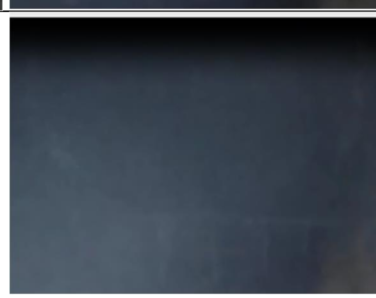
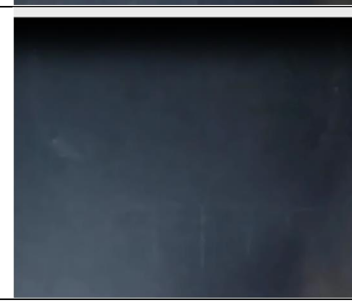
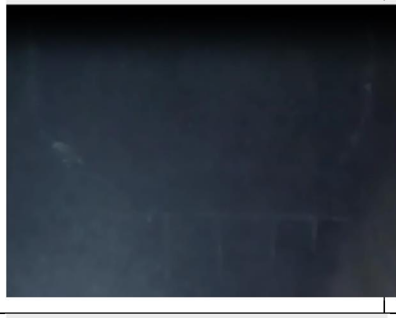
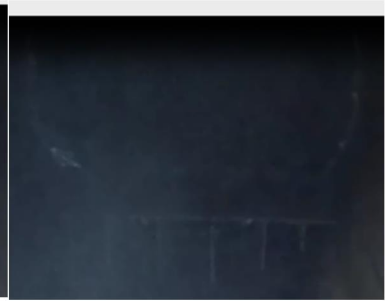
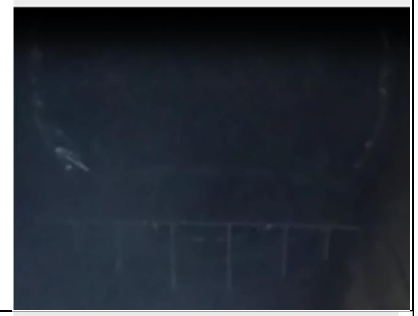
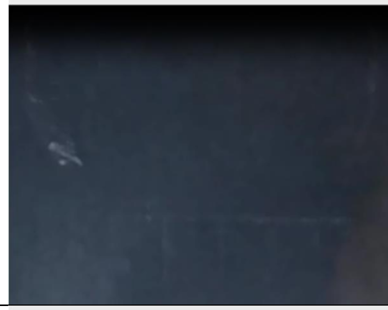
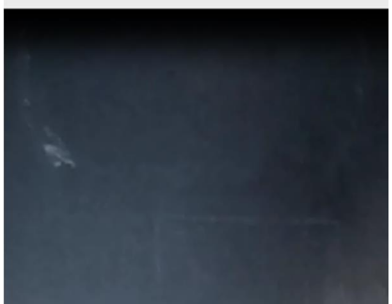
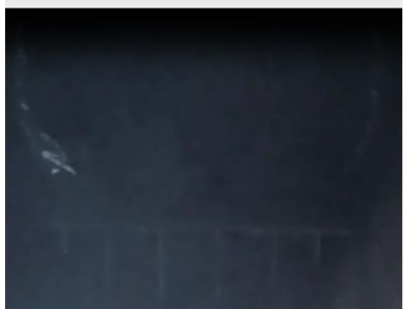
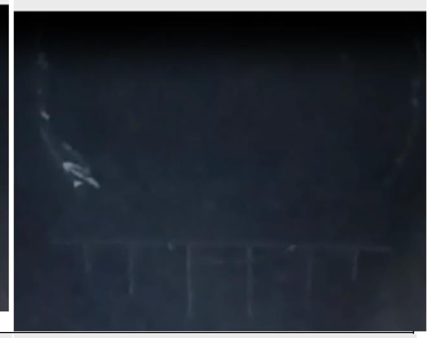
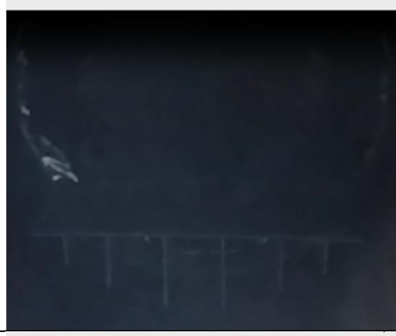
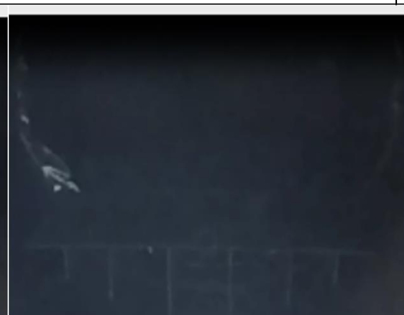
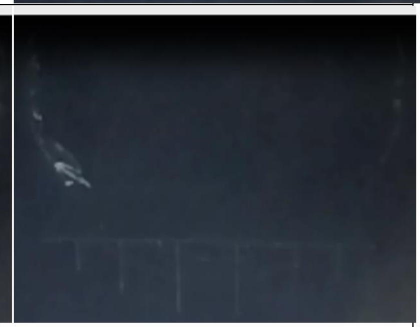
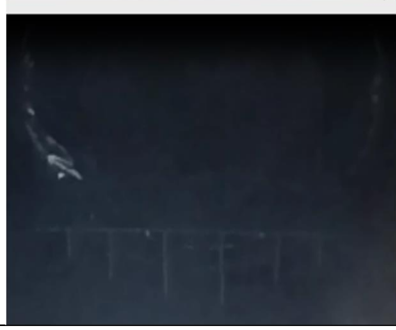
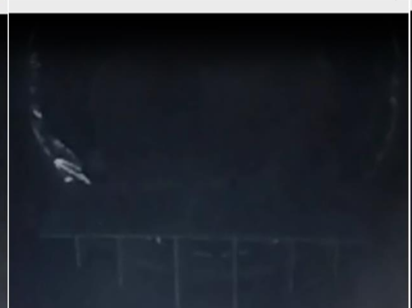
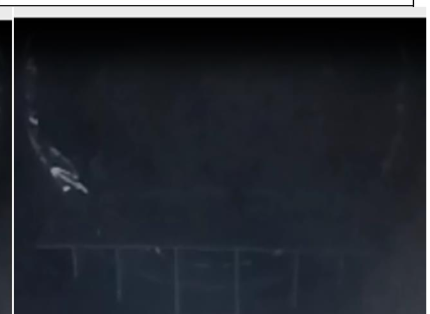
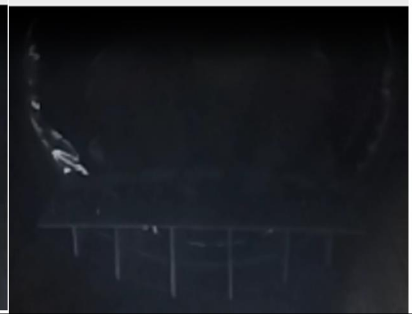
K			
L			
M			

N			
O			
P			
Q			
R			

S			
T			
U			
V			
W			

X			P3-12: Pictures A1 to X2 below from GoPro video
	1	2	3

6.4 Test #4 – 03/03/2015 – closed assembly test – double vacuum

This was a closed assembly test, with double-vacuum. Vacuum was applied to the 21" mid-flange and 57" long outlet side. There is a 32" blind flange capping the 57" spool. Testing was per EI-SF-0011, 8.0 Phase 2, Test #2; except the mid-flange was 21" long and vacuum was in both spools. There was no GoPro video as there was no method available to install the camera inside of the piping.

- First Disk: JRS with double Jaws Ring, .14 mpa @ 100ºC (20.3 PSI @ 212ºF)
- Second Disk: VSP-SH, Burst Pressure of .02 mPa (2.9 PSI) @ 20ºC.
- This is the same design as "Design 2" of 20 June 2014.
  - Support dome 0.060" thick
  - Seal dome 0.004" thick

Pressure Measurements:

- Vessel pressure at moment of burst was 8.14 PSI
- Mid-Spool & end-pipe vacuum was -12.65 PSI
- First disk burst pressure was 8.14 +12.65 = 20.80 PSI.
- The maximum mid-flange shock wave pressure as 11.30 & 11.94 PSI.
  - Two transducers, both in mid-flange
  - Data collection rate: set at 2000 points/sec for each channel (fast data card)
  - Actual collection rate is about 1070 points/sec per channel.

Fragmentation Observations:

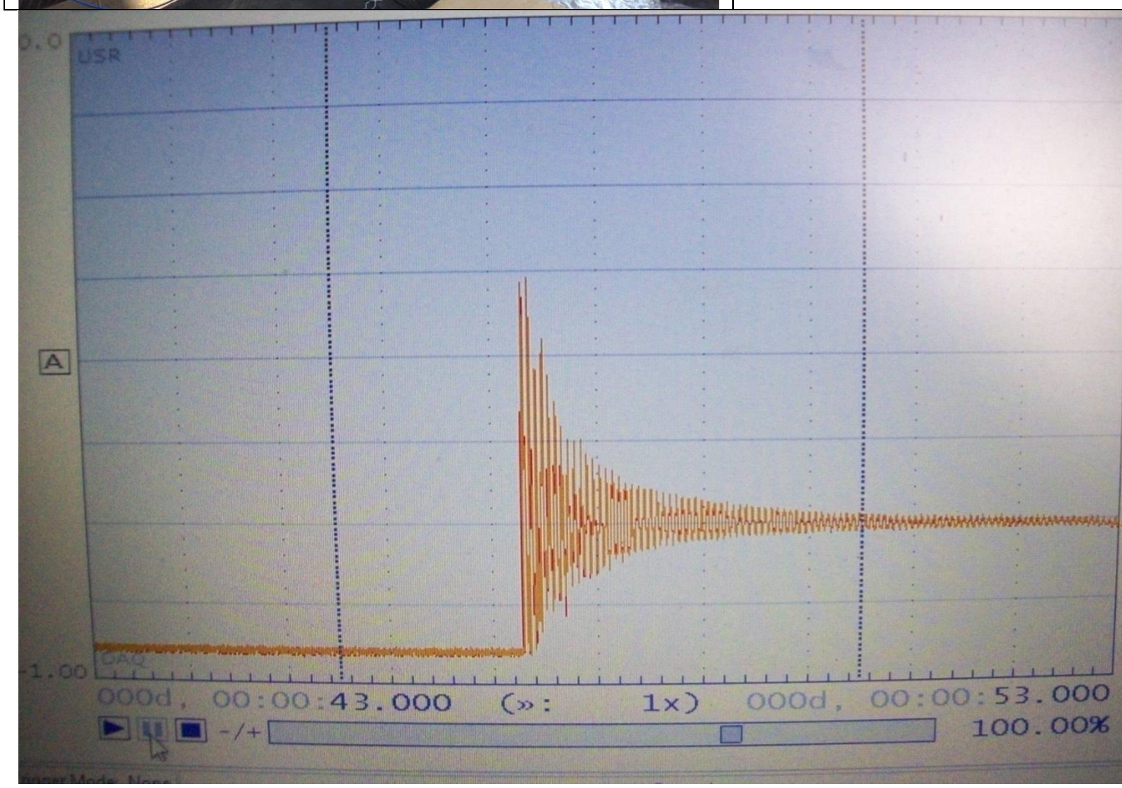
The upstream high pressure disk (JRS) opened fully, exhibited no fragmentation, and it latched to the bottom of the safety head hinge.

The downstream low pressure disk (VSP-SH) seal did tear off and fragment into smaller pieces. There is no way to determine at what point the seal tore off. The safety head support and seal domes both had penetration marks from the pins. They both hit the safety head hinge hard. This indicates that when venting into ambient air, atmospheric pressure air has a dampening effect.

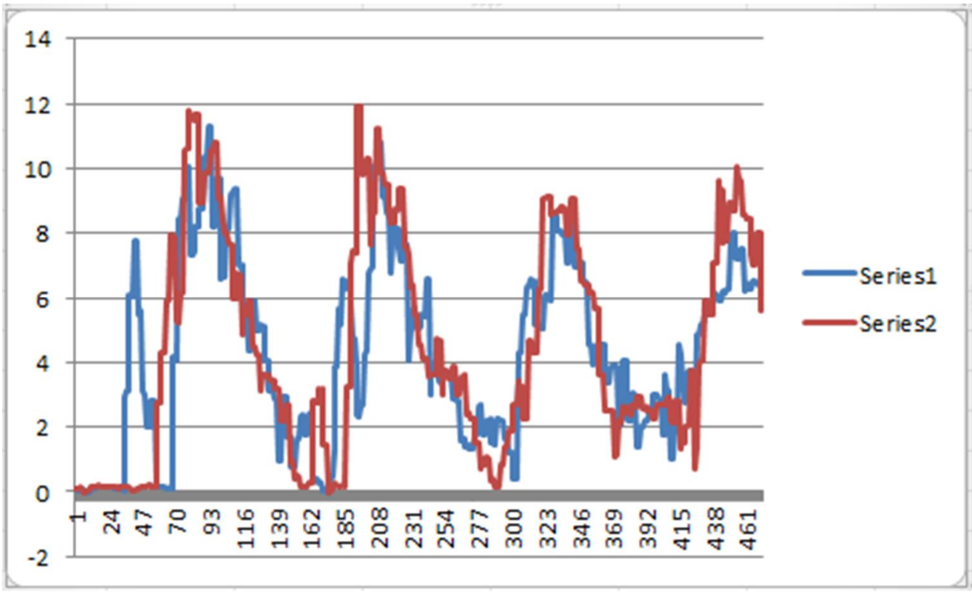
Conclusions:

The double-vacuum does not affect the performance of the upstream high pressure disk but has a large effect upon the downstream low pressure disk.

P4-1: Test Assembly: Vacuum gauge on both spools



P4-2: Shock wave pressure chart from screen shot.

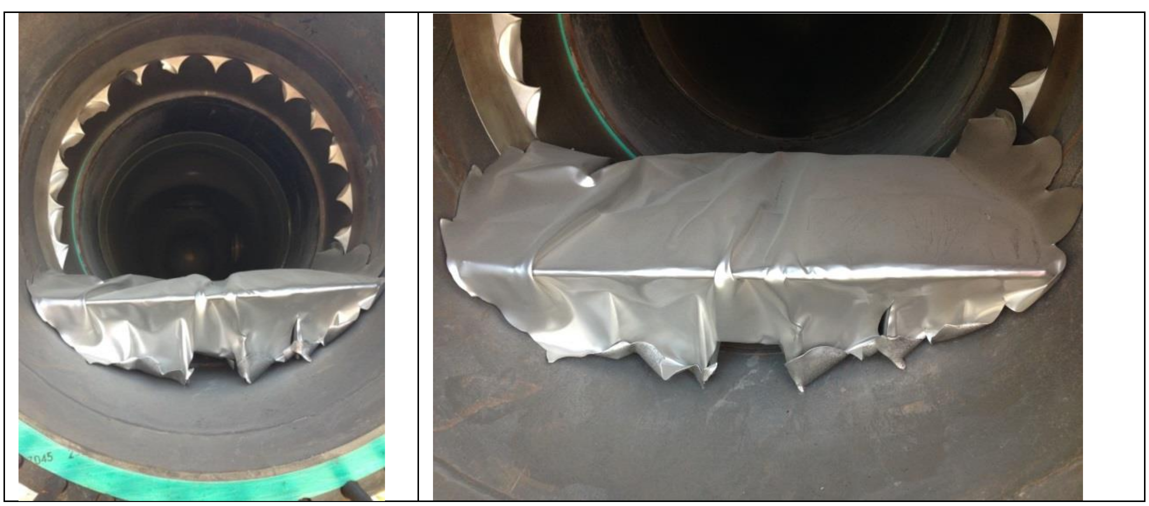


P4-3: Shock wave pressure chart – data recorded

P4-4, P4-5 & P4-6: View after blind flange is removed.

P4-7, P4-8 & P4-9: downstream low pressure VSP-SH - penetration holes and fragmentation.

P4-10 & P4-11: VSP-SH seal dome close up.



P4-12 & P4-13: Upstream high pressure Disk (20 PSI JRS)

6.5 Test #5 – 04/03/2015 am – JRS and LP JRS

This was an open-venting test with vacuum in the mid-flange. Testing was per EI-SF-0011, 8.0 Phase 2, Test #1; except the mid-flange was 21" long.

- Upstream Disk: JRS with double Tooth Ring, top .030" thick, .14 mpa @ 100ºC (20.3 PSI @ 212ºF)
- Downstream Disk: LP (Low Pressure) JRS, special prototype disk; burst pressure = 2.2 to 3.5 PSI
  - Single Tooth Ring (standard design)
  - Top is 0.011" thick, with 8.0" crown height

Pressure Measurements:

- Vessel pressure at moment of burst was 8.13 PSI
- Mid-Spool vacuum was -12.75 PSI
- First disk burst pressure was 8.13 +12.75 = 20.88 PSI.
- The maximum mid-flange shock wave pressure as 6.81 PSI.
- One transducer in mid-flange.
  - Data collection rate: set at 5000 points/sec
  - Actual collection rate is about 1480 points/sec

Fragmentation Observations:

The upstream high pressure disk (JRS) opened fully, exhibited no fragmentation, and it latched to the bottom of the safety head hinge.

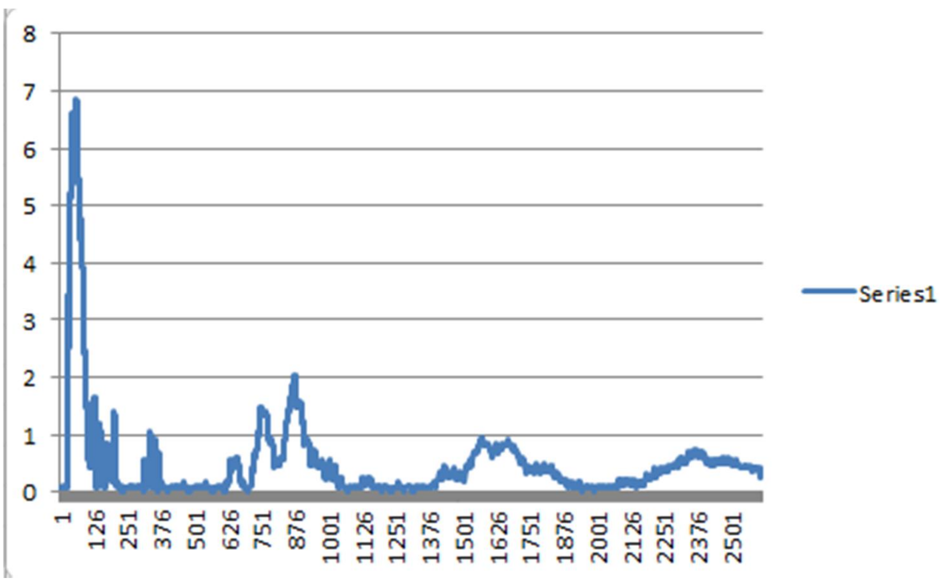
The downstream disk (low pressure LP JRS prototype) mostly fragmented and blew out. It appears the tearing initiated from the two half-teeth of the tooth ring, nearest to the safety head hinge. It may be that removing these teeth will prevent fragmentation.

P5-1: Upstream disk (JRS)

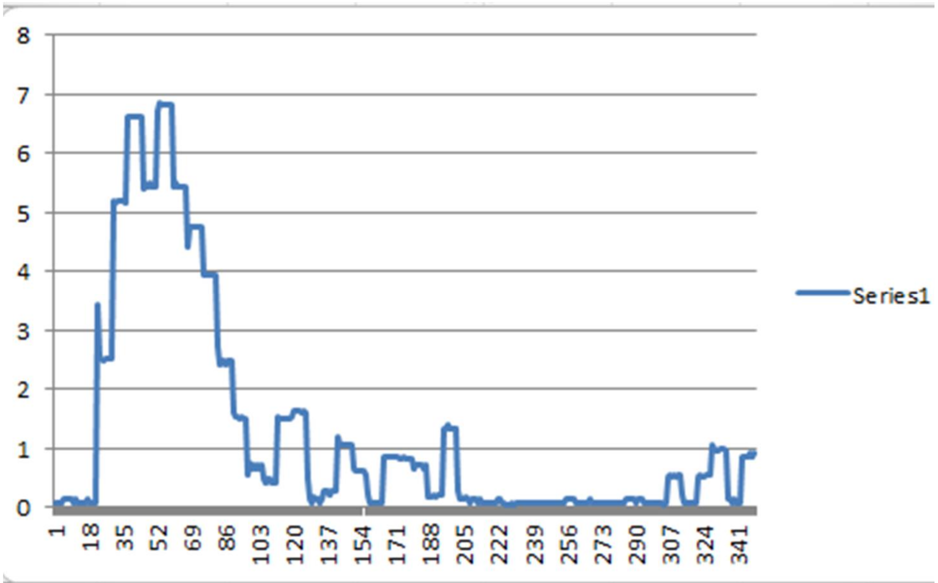
P5-2: Downstream disk (LP JRS)

P5-3: Upstream disk (JRS)

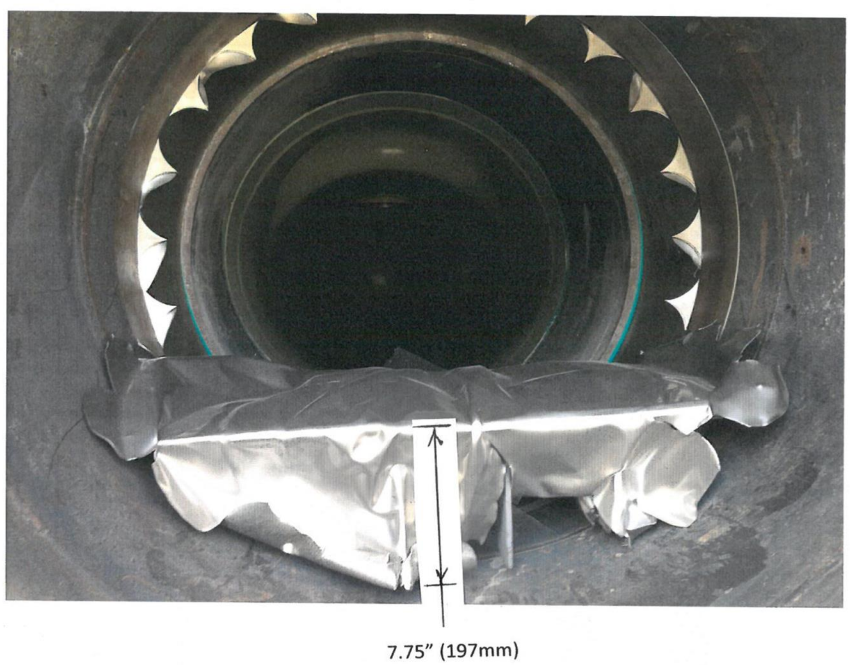
P5-4: Downstream disk (LP JRS)



P5-5: Shock wave pressure chart, in mid-flange (21” spool) - overview

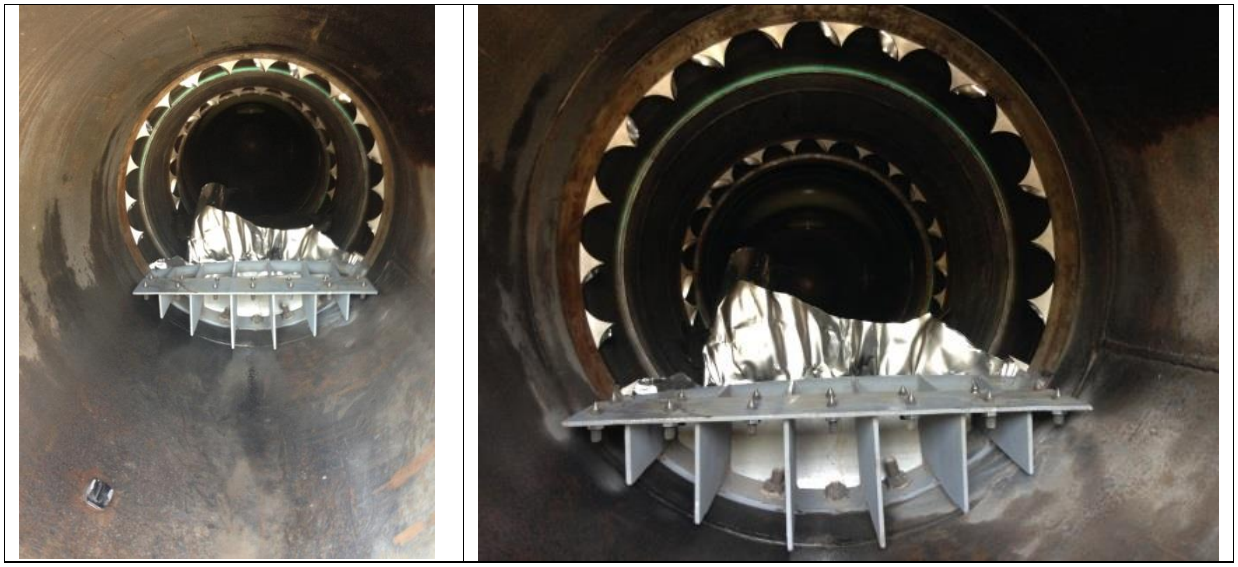


P5-6: Shock wave pressure chart, in mid-flange (21" spool) – main spike

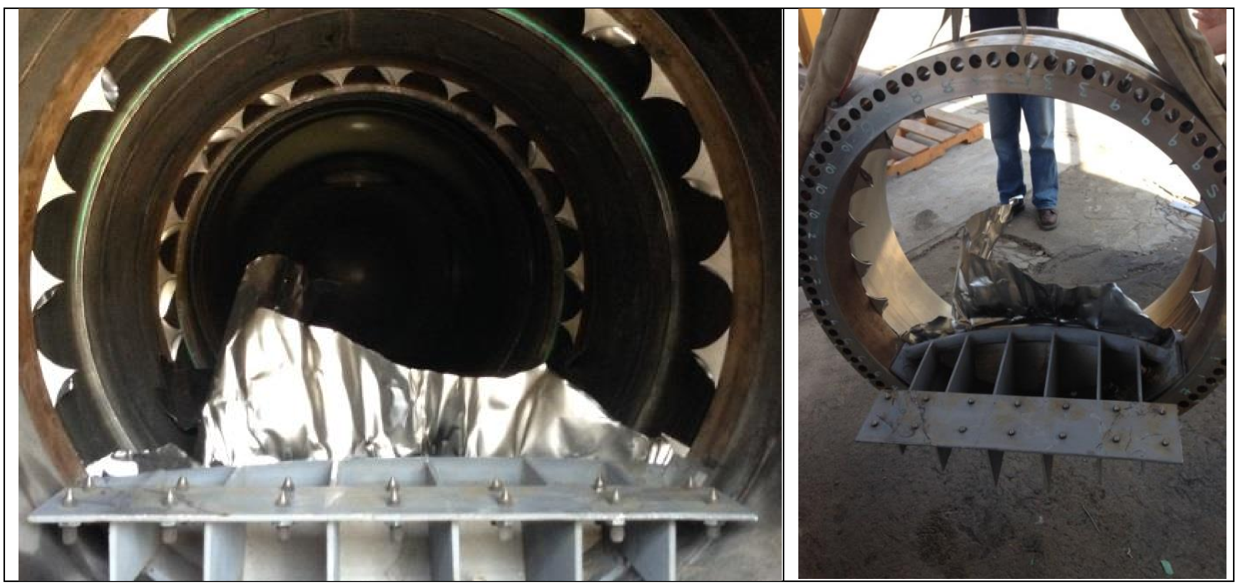


P5-7: upstream disk (JRS) measurements

Shown above is the upstream disk, after opening. The 7.75" hinge height of flow obstruction, includes an approximation of the average disk petal thickness above the safety head hinge. The spool inside diameter is 31.25". The cutting tooth ring has 18 teeth exposed (the 2 half-teeth are covered by the disk petal).



P5-8 & P5-9: Downstream disk (LP JRS).



P5-10 & P5-11: Downstream disk (LP JRS).

P5-12: Downstream disk (LP JRS) fragments and tear along tooth

Below are pictures from GoPro High Speed Video. Frame rate is 240 frames per second:

P5-13, P5-14 and P5-15: Downstream disk (LP JRS) view - initial opening

P5-16 & P5-17: Downstream disk (LP JRS) view - fragmentation

P5-18: Downstream disk (LP JRS) view – camera swivelled due to blow – fragment

6.6 Test #6 – 04/03/2015 pm – JRS and LP JRS modified

This test is the same as #5 except the second disk tooth ring has the two half-teeth cut off. Also two transducers were installed, one in each spool.

Pressure Measurements:

- Vessel pressure at moment of burst was 6.70 PSI
- Mid-Spool vacuum was -12.43 PSI
- Upstream disk burst pressure was 6.70 +12.43 = 19.13 PSI.
- The maximum mid-flange shock wave is 7.25 PSI in mid-flange and 3.88 PSI in end spool.
- One transducer in mid-flange. One transducer in the end spool.
    - Data collection rate: set at 2000 points/sec (fast data card)
    - The actual collection rate is about 1100 points/sec

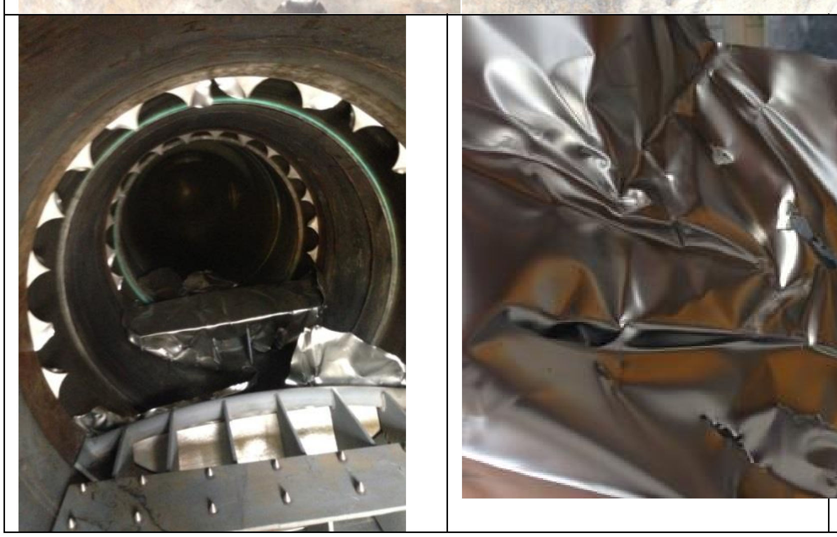
Fragmentation Observations:

The upstream disk (JRS) opened fully, exhibited no fragmentation and it latched to the bottom of the head hinge. This is 5 tests with no fragmentation problems from the upstream disk.

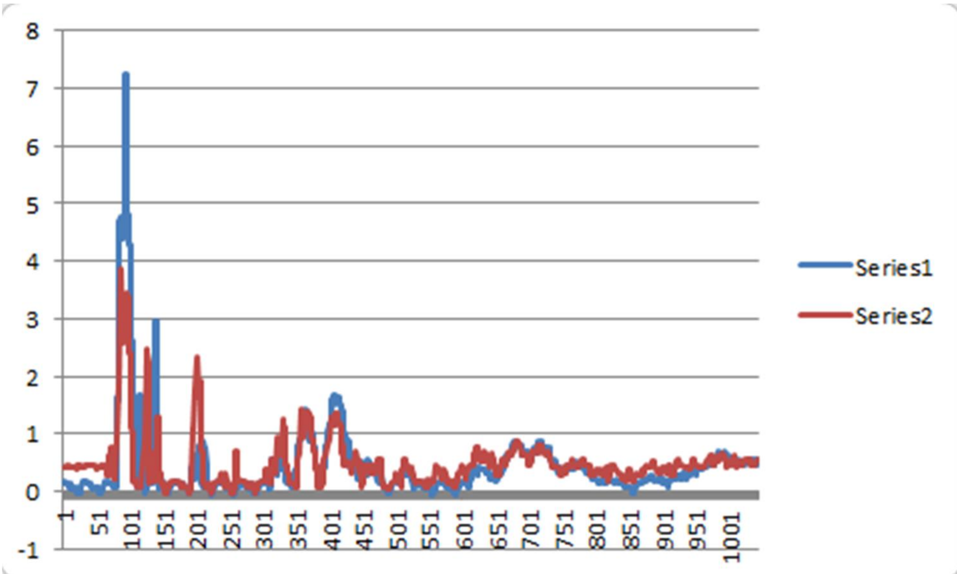
The downstream disk (LP JRS Modified prototype) did fragment. It did not blow out, but stayed in the piping. This indicates that it did not fragment during the first outward flow. The reverse flow bent it backwards, apparently tearing it off during one of the reversals.

	P6-1: LP JRS Modified prototype

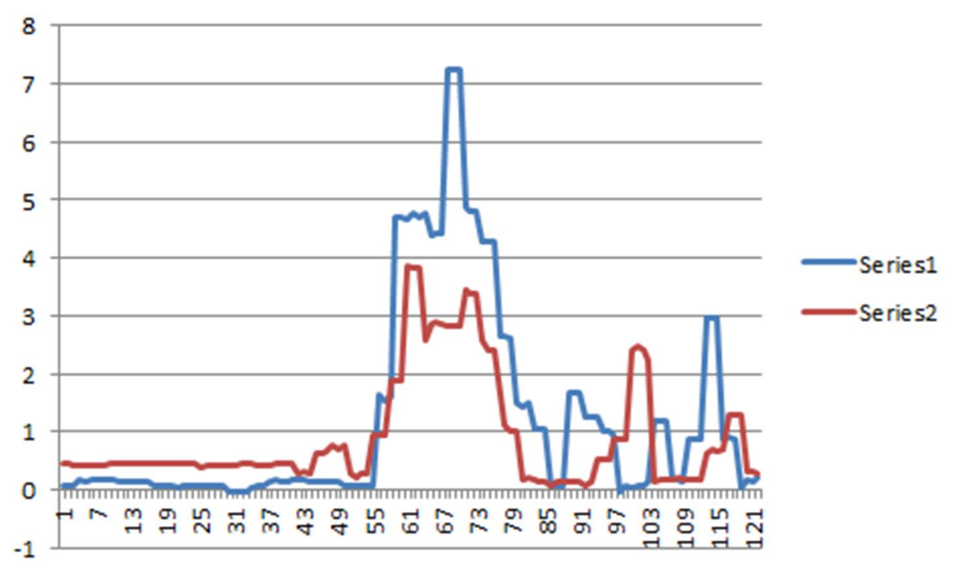
P6-2: Two half-teeth cut off on second disk low pressure JRS LP.



P6-3, P6-4, P6-5,
P6-6, P6-7
Overview after opening test #6

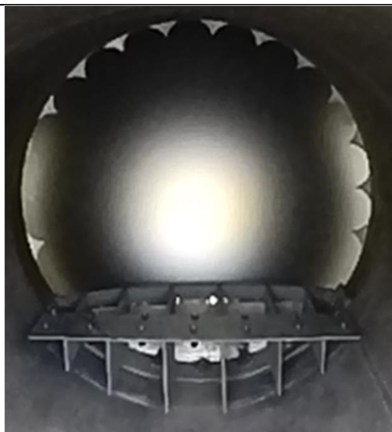
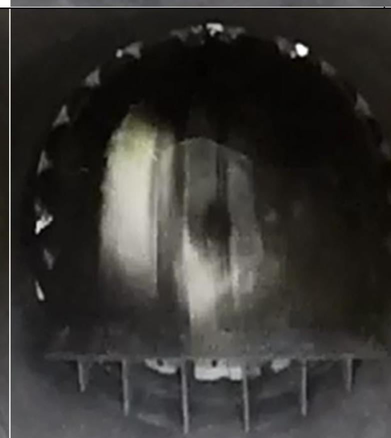
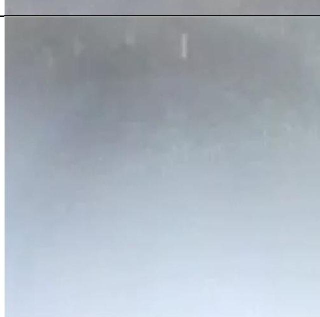
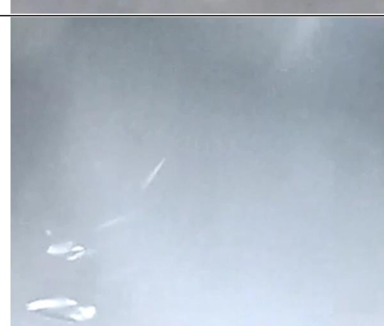


P6-8: Shock wave pressure chart, in mid-flange (21" spool) - overview



P6-8: Shock wave pressure chart, in mid-flange (21" spool) – main spike details

P6-9: Pictures below A1 to I3 below from GoPro video test#6. Frame rate is 240 frames/s.

	1	2	3
A			
B			
C			
D			

E			
F			
G			
H			

I			
	1	2	3

P6-9: Pictures above A1 to I3 below from GoPro video test#6. Frame rate is 240 frames/s.

7 Conclusions & Recommendations

The objective of this follow up work was to minimize the fragmentation of the disks observed during testing in June 2014 with a double disk configuration and vacuum between the 2 rupture disks. A special safety head hinge was designed and built for both disk locations. Testing included 8" prototype evaluation and full-scale 32” trials.

The upstream disk (high pressure JRS, 20 PSI) was fully successful, wrapped around the hinge during opening and did not fragment.

For the downstream disk (low pressure, 3 PSI), observation of fragmentation resulted in changing the design during the test program to a special Low Pressure (LP) JRS. This new design was tested and found to be promising, but was not fully effective in its initial form. The Low Pressure JRS is recommended for future additional investigation outside of the current test agreement

Limitations of the testing rig (gas, smaller vessel volume) compared the large service volume and steam conditions of ITER, also contribute to the complexity of the assessment (fragmentation exacerbated due to the fact the disk experience cycles of reversing flow in the test conditions).

The vacuum impact is significant and further development is recommended to achieve a suitable solution for ITER requirement. Some of the parameters have changed since the beginning of this project. The configuration and operating conditions would have to be confirmed (spool length between the disks, vacuum after the downstream disk, burst rating of the downstream disk).