*MASSIVE PELLET TESTING AT ORNL IN SUPPORT OF DISRUPTION MITIGATION ON DIII-D**

S.K. Combs, S.J. Meitner, L.R. Baylor, T.C. Jernigan, and D.A. Rasmussen
Fusion Energy Division
Oak Ridge National Laboratory, Oak Ridge, TN

VLT Conference Call – Technical Highlight
December 17, 2008

*** Presentation is taken from one given at the ITER Fueling Workshop, ITER Cadarache, December 1-3, 2008**

Shattered Massive Pellet *Is Good Candidate for Delivering Large Quantities of Gas for Disruption Mitigation*

- **Offers some advantages over massive gas injection alone**
  - **Pellet injector can be located a distance from the plasma boundary**
  - **Flow not limited by conductance of delivery tube**
  - **All of the pellet inventory is delivered in a relatively short time window**

- **Work at ORNL and DIII-D**
  - **Used existing pipe-gun injector facility for feasibility tests**
    - **Largest pellet used in fusion energy research to date (16.5 mm)**
    - **First - made a solid pellet and accelerated it**
    - **Second - shattered it effectively downstream (typical of plasma boundary)**
    - **Different species (D_2 and Ne)**
  - **New tube assembly that will accommodate both the large pellets and "MEDUSA" valve array (for gas injection) has been built at ORNL, delivered to General Atomics in San Diego, and most recently installed in DIII-D**
  - **"Vintage" ORNL pipe-gun pellet injector will be refurbished, fitted with a large barrel, tested in the lab, and installed on DIII-D in the near future**
  - **Experiments on DIII-D are tentatively planned for 2009**

Size of Massive Pellet in Lab Experiments Was Selected to Match DIII-D Plasma Volume – Rosenbluth Fraction Is a Key Parameter

Pellet Size Nominal D	Cyl D	Length	Volume (mm^3)
1.8	1.35	2.35	3.36
2.7	2.20	2.75	10.45
4.0	3.50	4.00	38.48
8.0	8.00	8.00	402.12
10.0	10.00	10.00	785.40
14.0	14.00	14.00	2155.13
16.7	16.00	16.00	3216.99
30.0	30.00	30.00	21205.75

Rosenbluth Fraction

Pellet Size / Species	D2	Ne	Ar	CH4
1.8	1.62E-04	1.17E-03	1.18E-03	4.56E-04
2.7	5.04E-04	3.63E-03	3.67E-03	1.42E-03
4	1.85E-03	1.34E-02	1.35E-02	5.22E-03
8	1.94E-02	1.40E-01	1.41E-01	5.45E-02
10	3.79E-02	2.73E-01	2.76E-01	1.06E-01
14	1.04E-01	7.48E-01	7.57E-01	2.92E-01
16.7	1.55E-01	1.12E+00	1.13E+00	4.36E-01
30	1.02E+00	7.36E+00	7.45E+00	2.87E+00

mass (grams)

Pellet Size / Species	D2	Ne	Ar	CH4
1.8	6.73E-04	4.84E-03	5.45E-03	1.51E-03
2.7	2.09E-03	1.51E-02	1.69E-02	4.70E-03
4	7.70E-03	5.54E-02	6.23E-02	1.73E-02
8	8.04E-02	5.79E-01	6.51E-01	1.81E-01
10	1.57E-01	1.13E+00	1.27E+00	3.53E-01
14	4.31E-01	3.10E+00	3.49E+00	9.70E-01
16.7	6.43E-01	4.63E+00	5.21E+00	1.45E+00
30	4.24E+00	3.05E+01	3.44E+01	9.54E+00

Q (Torr-liters)

Pellet Size / Species	D2	Ne	Ar	CH4
1.8	2.86E+00	4.12E+00	2.32E+00	1.61E+00
2.7	8.90E+00	1.28E+01	7.21E+00	5.01E+00
4	3.28E+01	4.72E+01	2.65E+01	1.84E+01
8	3.42E+02	4.93E+02	2.77E+02	1.93E+02
10	6.69E+02	9.63E+02	5.42E+02	3.76E+02
14	1.83E+03	2.64E+03	1.49E+03	1.03E+03
16.7	2.74E+03	3.94E+03	2.22E+03	1.54E+03
30	1.81E+04	2.60E+04	1.46E+04	1.02E+04

Pressure in DIII-D

Pellet Size / Species	D2	Ne	Ar	CH4
1.8	2.86E+00	1.09E-04	6.10E-05	4.24E-05
2.7	2.34E-04	3.37E-04	1.90E-04	1.32E-04
4	8.62E-04	1.24E-03	6.98E-04	4.85E-04
8	9.01E-03	1.30E-02	7.30E-03	5.07E-03
10	1.76E-02	2.53E-02	1.43E-02	9.90E-03
14	4.83E-02	6.95E-02	3.91E-02	2.72E-02
16.7	7.21E-02	1.04E-01	5.84E-02	4.05E-02
30	4.75E-01	6.84E-01	3.85E-01	2.67E-01

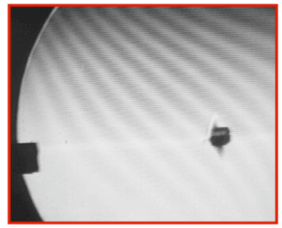
- **Calculations provided by Tom Jernigan (ORNL colleague working full time on DIII-D and has coordinated all of the ORNL R&D activities in support of disruption mitigation studies on DIII-D)**
- **DIII-D vessel volume: ≈25 m3**
- **Actual pellet size tested in the lab**
  - **Gun barrel bore: 16.5 mm bore**
  - **Freezing zone length: 16.5 mm**
- **Largest pellet size shown is likely more suitable for the huge volume of ITER**

Pellet Size of 16.5 mm Is Significantly Larger Than Anything Previously Used in Fusion Energy Research

ORNL 2000-1170C EFG

Small Innovative Confinement Experiments

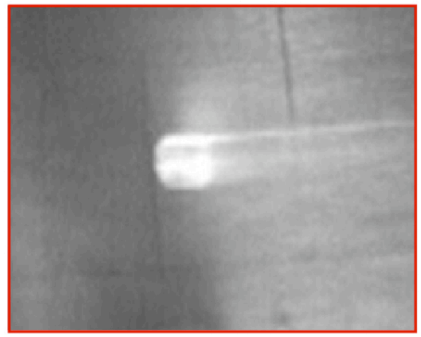
1-mm-diam
~5 x 10^{19} D^o



Damage from 6-mm pellet

DIII-D
(Large size for plasma volume - 1.8 mm pellet more typical)

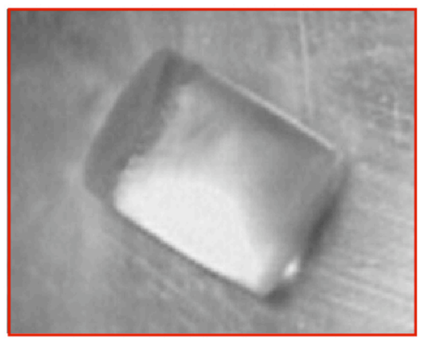
2.7-mm-diam
~10^{21} D^o



≈ITER Size

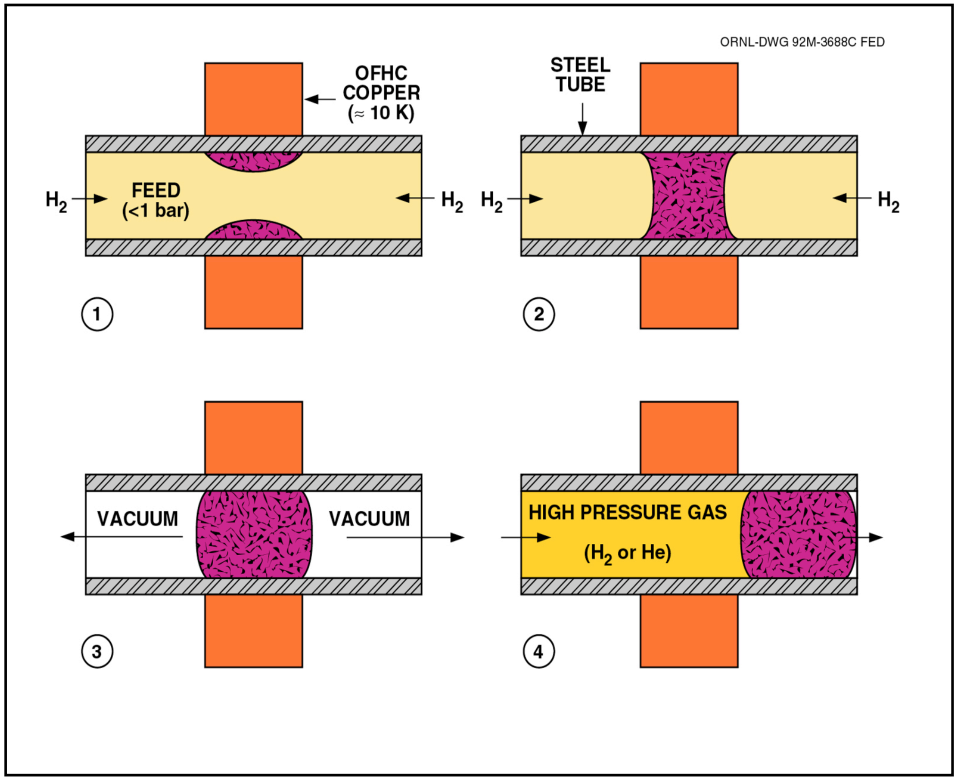
Reactor
(Size tested for ITER earlier in the program)

10-mm-diam
~5 x 10^{22} D^o



(Photographs of In-flight D_2 Pellets; Nominal Sizes Are Listed)

Pellets Formed and Accelerated with Simple Pipe Gun

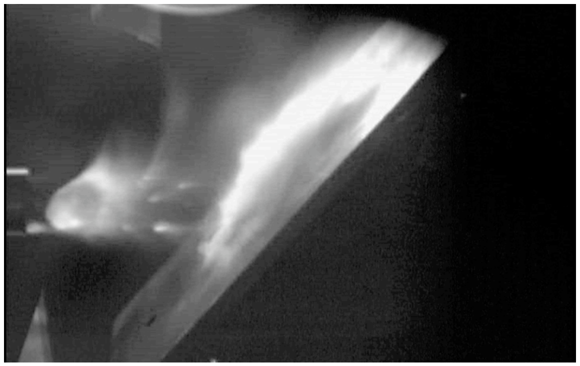


H_2 pellet formation is shown; however, only tests with massive D_2 and Ne pellets have been carried out to date

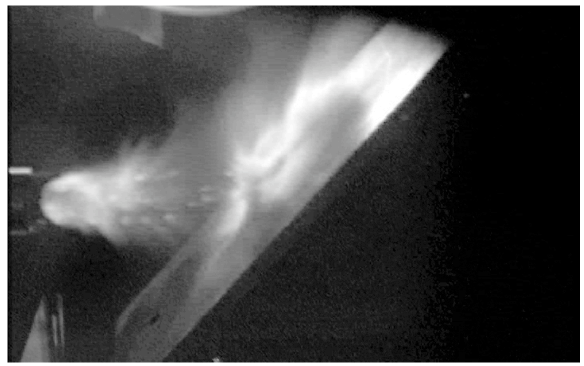
- With the cryogenic refrigerator and the rather large barrel (16.5 mm bore), the freezing zone temperature was ≈12 K
- D_2 and Ne pellets formed and accelerated
  - Long formation times (~1 hr or greater)
  - Long pellets: ~23 mm/D_2 (1 g or 4200 Torr-L); ~26 mm/Ne (8 g or 6900 Torr-L)
  - Propellant gas was H_2 at 70 bar

After Discovering Proper "Recipe" to Make Massive D_2 Pellets, Formation and Acceleration Were Straightforward

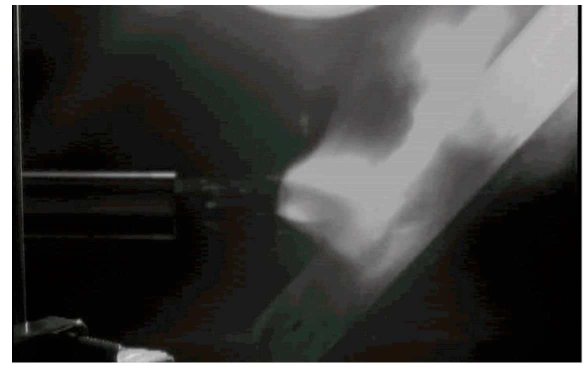
Test 2444 630 m/s



Test 2446 630 m/s



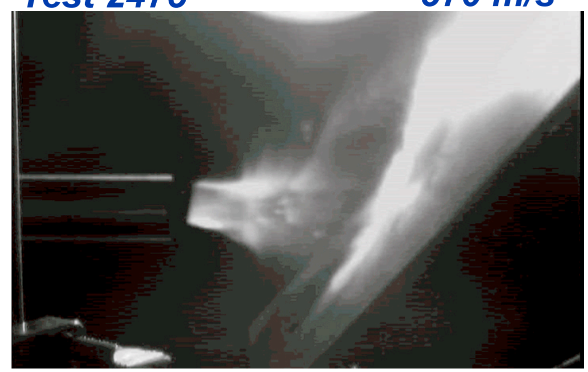
Test 2461 640 m/s



Test 2463 640 m/s

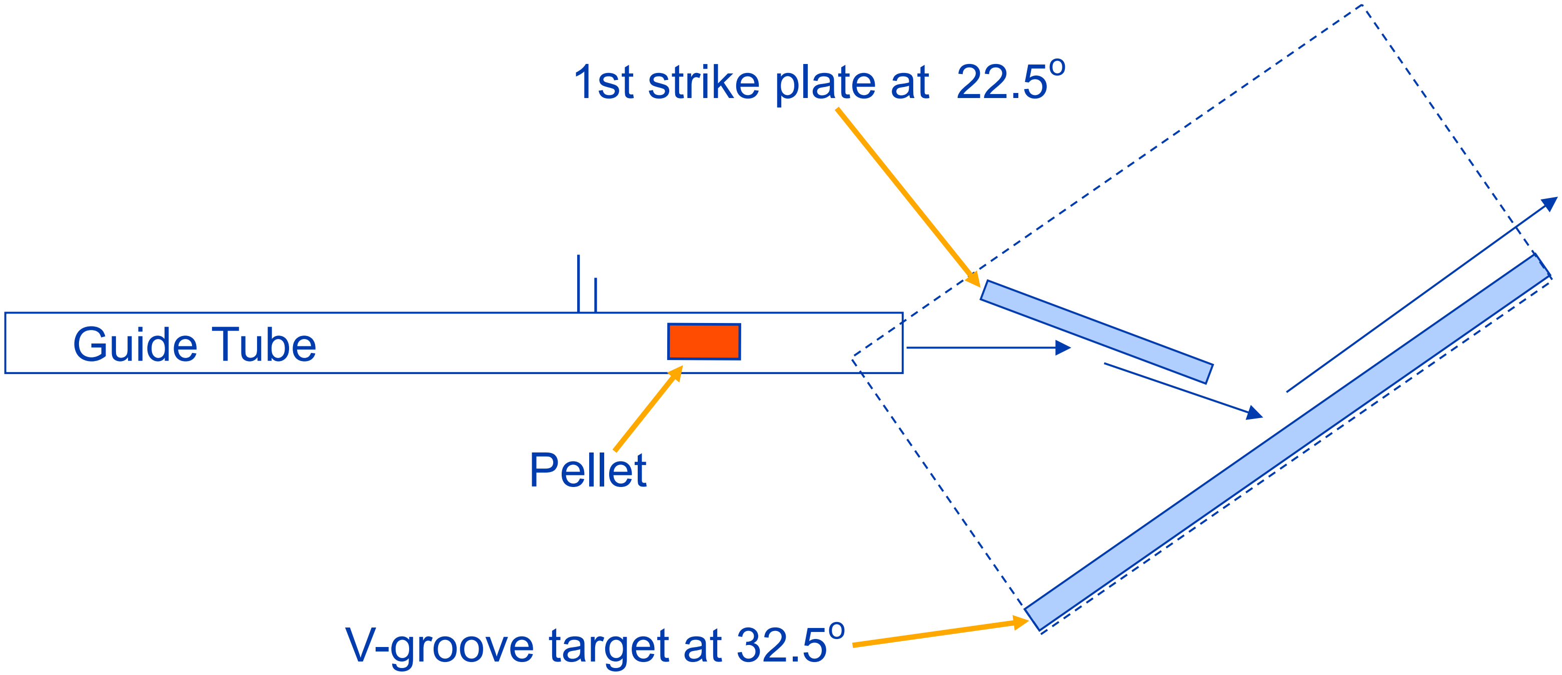
Test 2468 640 m/s

Test 2475 570 m/s



- **Capturing these in-flight photos was quite challenging and took a bit of "luck" – strobe flash was triggered on small debris accompanying and in front of the pellet (issue with shock threshold)**
- **Final guide tube with 25.4 mm OD is on the left and a target plate at angled at ~45º is on the right**
- **For the last test shown, the propellant gas was limited to ≈1000 Torr-L (thus, lower speed)**

Double-Bounce Target Developed to Ensure Breakage



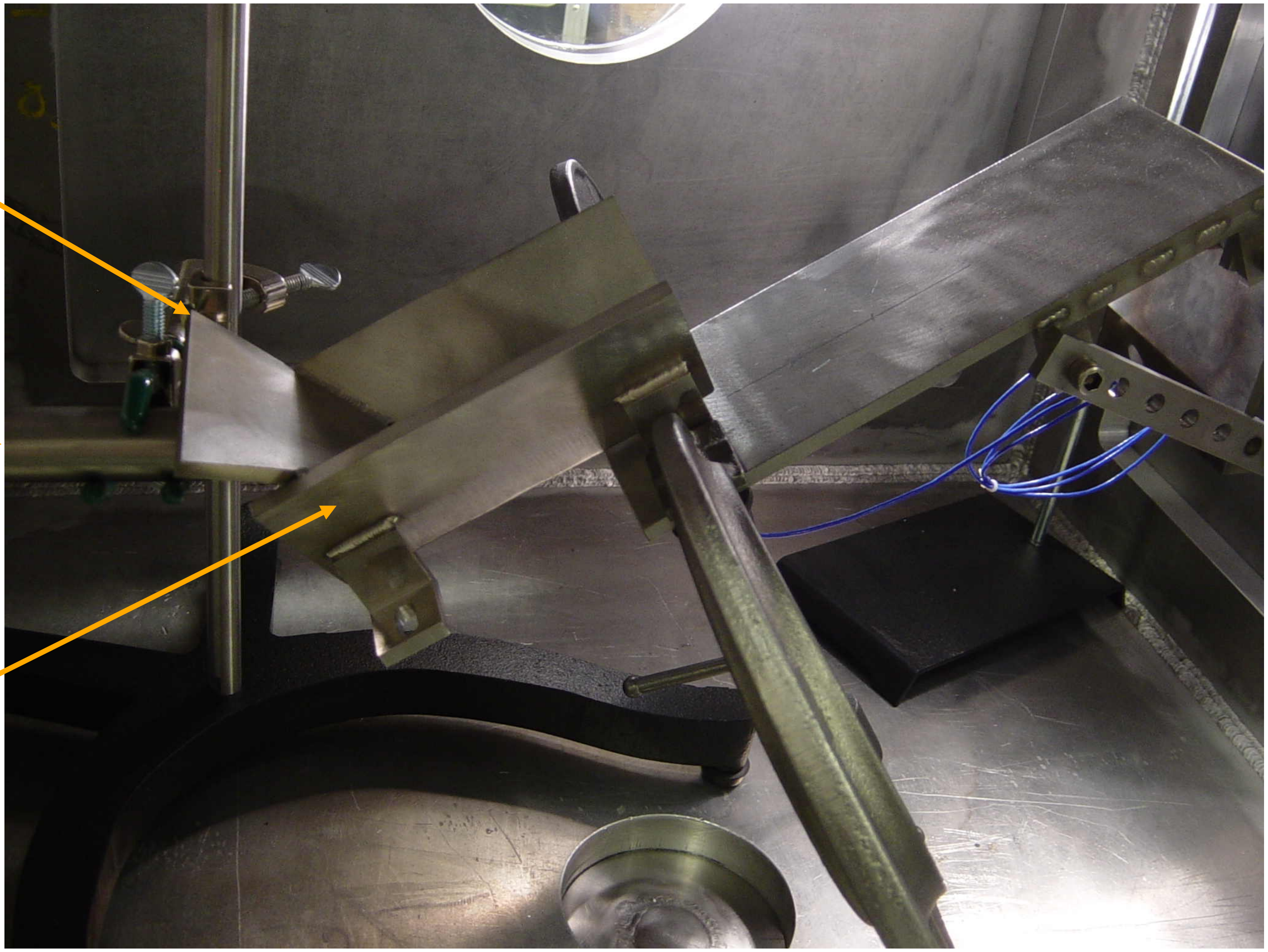
- **First plate deflects pellet into V-groove at a more normal angle**
- **V-groove limits the horizontal spread in the debris field**

Double-Bounce V-Groove Target Test Assembly

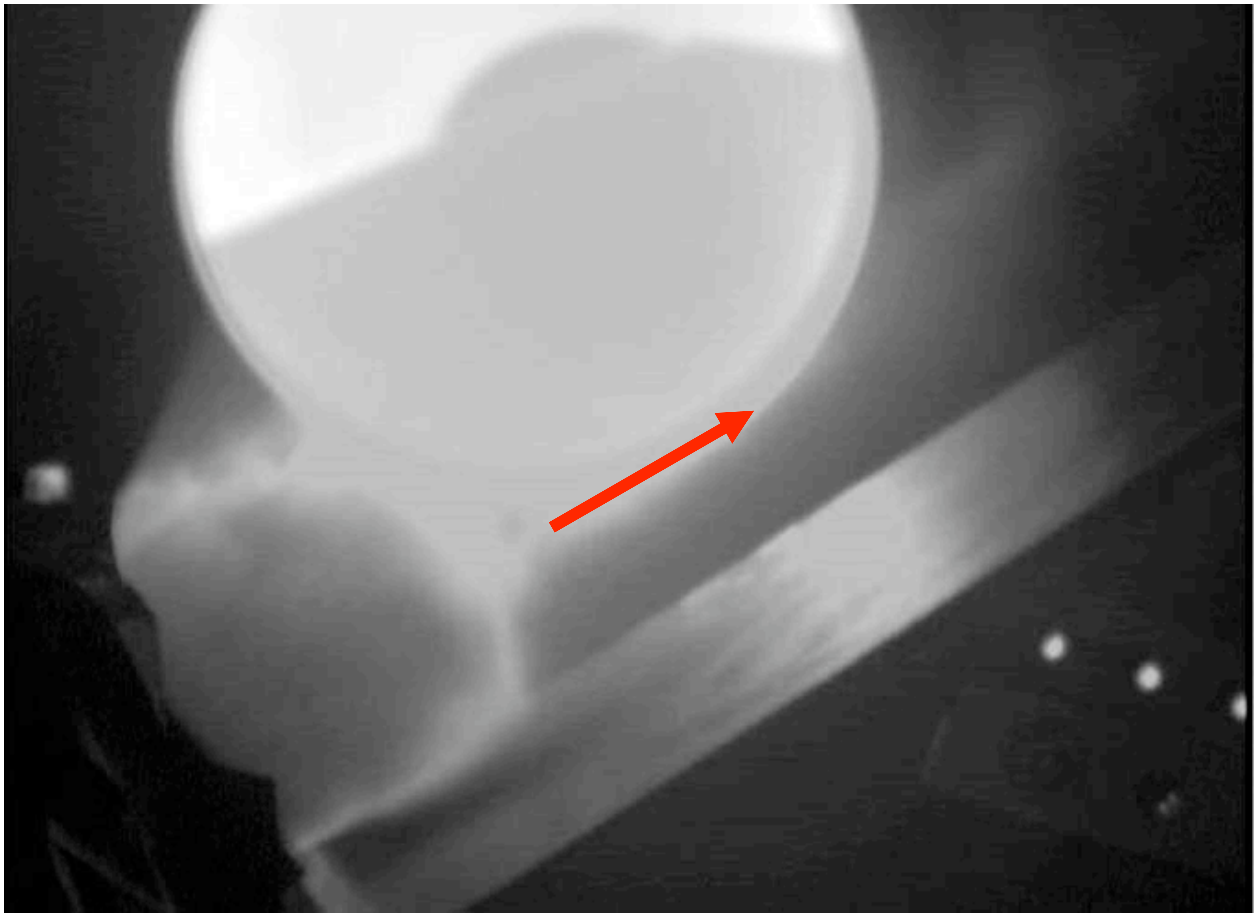
First deflector plate

Guide tube

V-groove target



Debris Cloud of Shattered D_2 Pellet Is Shown Exiting V-Groove Target after Double Impacts at ~600 m/s



- **Very difficult to capture this type event without dedicated high-speed camera**
- **Dense cloud of gas, liquid, and solid fragments**
- **Direction of motion shown by arrow**
- **Killer fog?**

Typical Results with Massive Pellets & Double-Bounce V-Groove Target

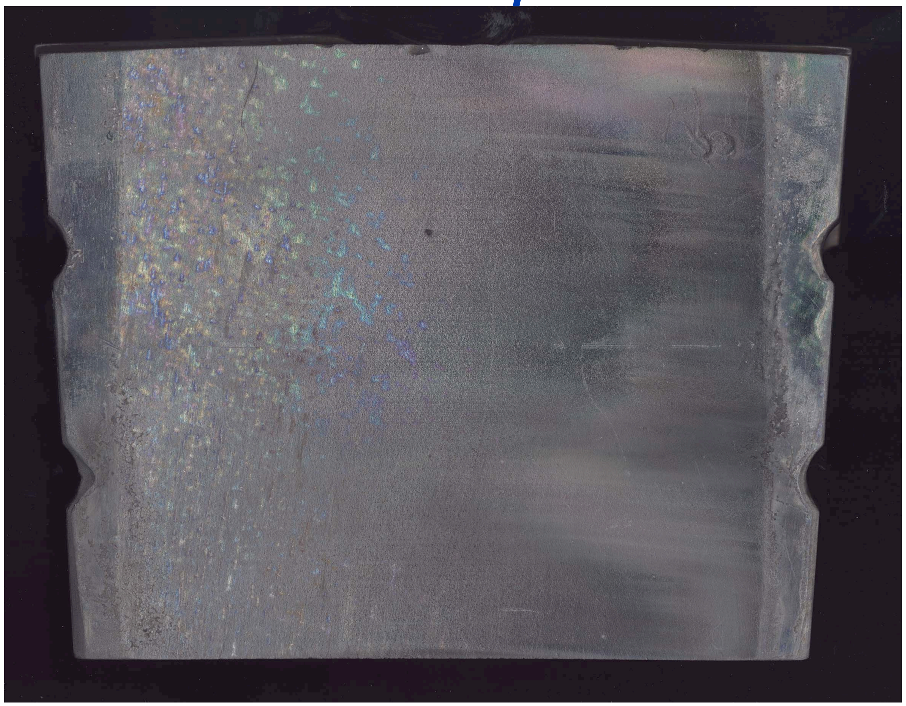
D_2 Pellet
(600 m/s)

Ne Pellet
(270 m/s)

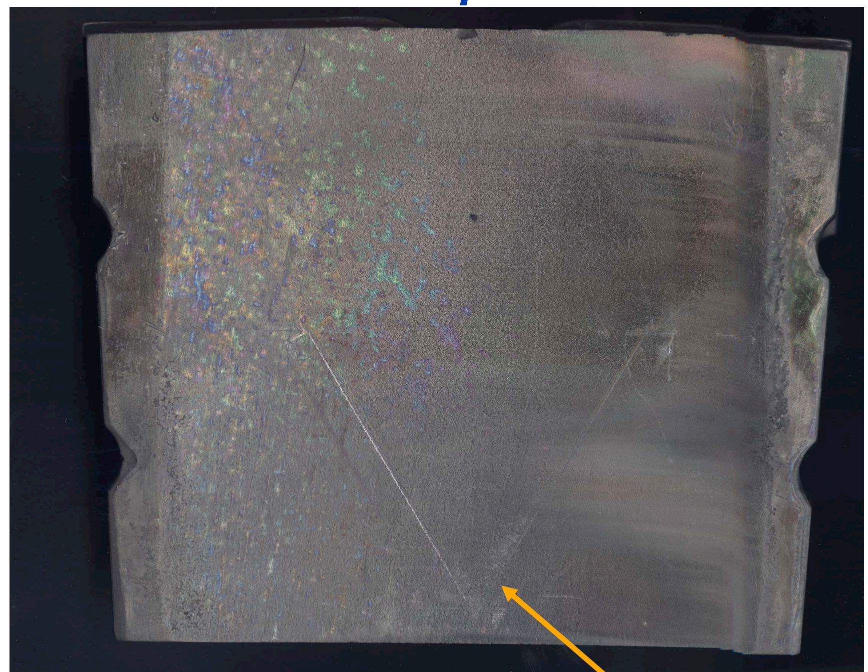
- **Notice the greatly reduced angular spread of the debris as defined by a "V"**
- **More Ne fragments survive – result of lower speed and stronger material**

In the Final Lab Test, a DIII-D Graphite Tile Was Mounted in Close Proximity to the Target and Hit with Debris from a Massive Pellet

Before Impact

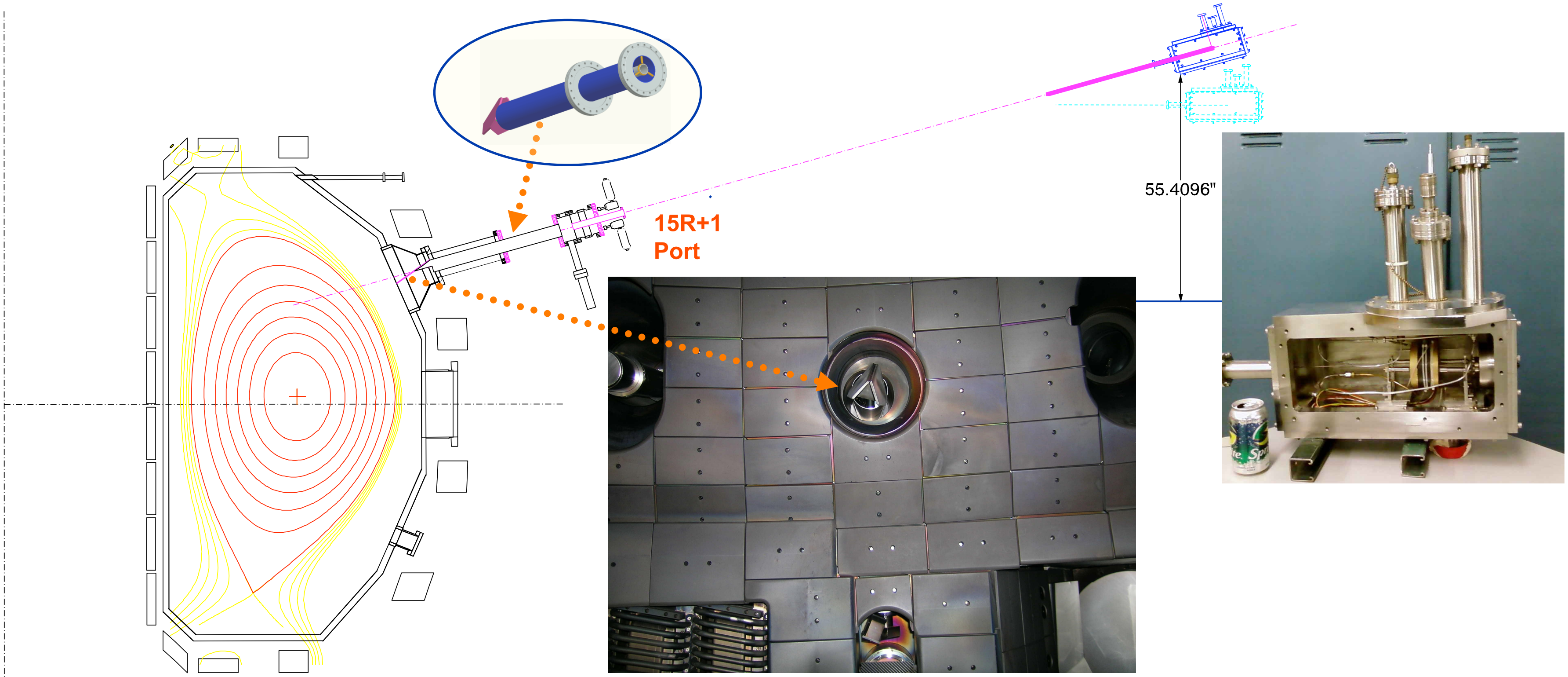


After Impact



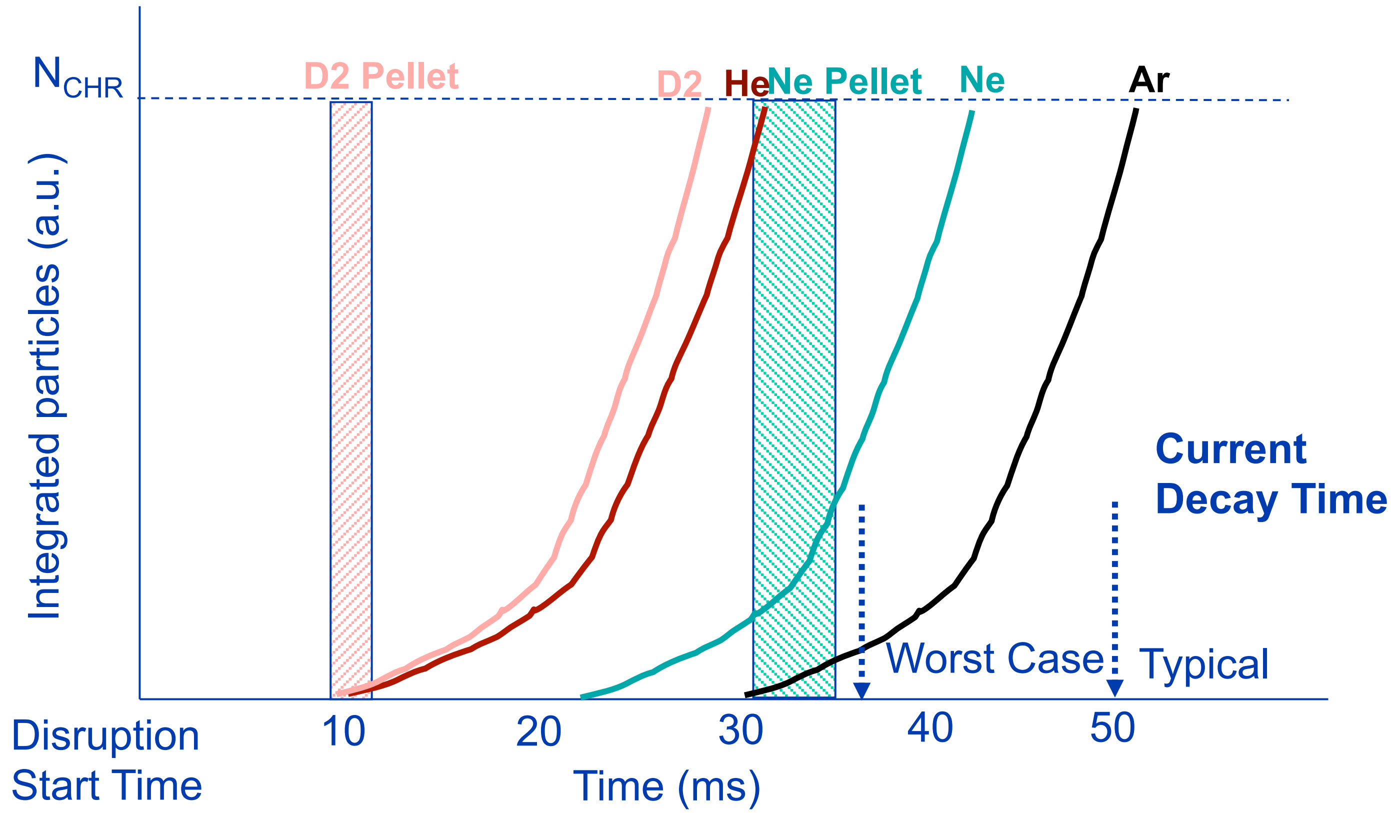
- **This surface was place against output side of V-Groove target, and V-pattern was etched on plate with pencil before shot**
- **Only minor surface erosion is visible – no appreciable damage from "worst" case scenario with massive Ne pellet at ~250 m/s**

Based on Successful Lab Tests with Massive Pellets, Components Are Being Prepared for Installation on DIII-D



- Tube assembly with double-bounce V-groove target has already been constructed at ORNL and installed on DIII-D – it also accommodates “MEDUSA” array (six fast valves for massive gas injection)
- “Vintage” ORNL pipe-gun pellet injector will be refurbished, fitted with a large barrel, tested in the lab, and installed on DIII-D
- Experiments on DIII-D are tentatively planned for 2009

Representation of the ITER Time Scale for Delivery of Different Gas/Pellet Species - Provided by Larry Baylor



*** Assumes DM system is 10 m from plasma – ignores initial gas shock**