*Status of ORNL/ENEA-Frascati Collaboration on IGNITOR High-Speed Pellet Injector**

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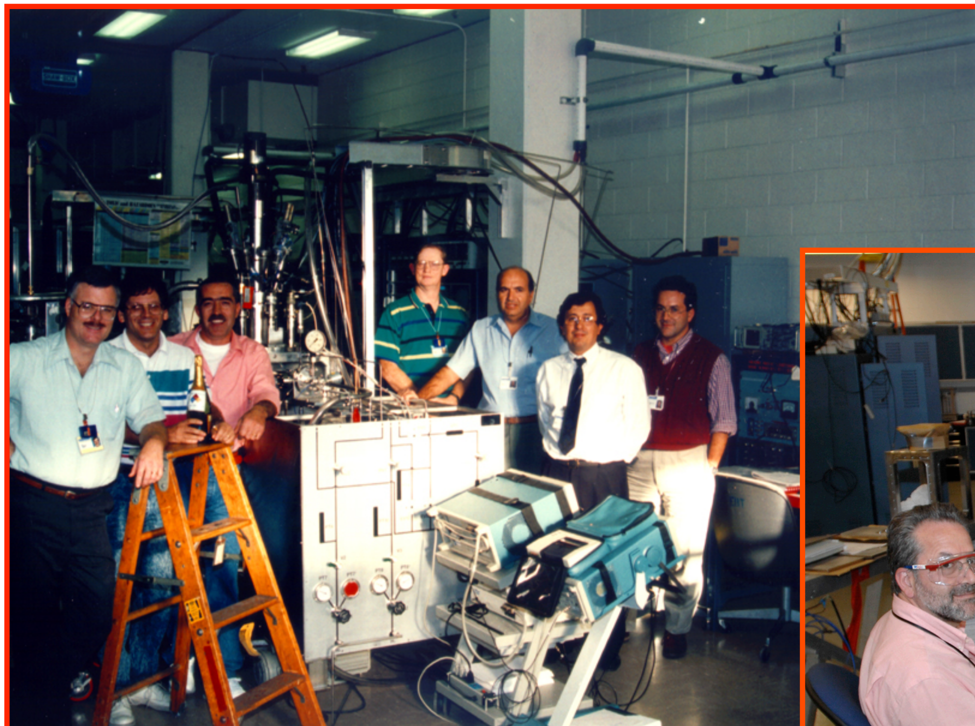
Background – ORNL History with High-Speed Pellet Injection

- **Two-stage light gas development**
  - **Accelerated plastic projectiles (4 and 6 mm) up to 5 km/s (single pellets)**
  - **QUICKGUN Algorithm for estimating the performance of two-stage guns developed by Milora et. al (*ORNL/TM-1156, September 1990*)**
  - **Accelerated D_2 pellets (4 mm) up to 3 km/s (single pellets)**
  - **Operation of repetitive two-stage gun demonstrated at 1 Hz and 3 km/s with plastic projectiles (4 mm)**
  - **Two-stage light gas gun developed for TFTR & installed/used for experiments in 1992**
  - **Sabot separation technique demonstrated with plastic pusher/surrogate pellet arrangement (6 mm size at speeds of >3 km/s)**
  - **In an ORNL/ENEA Frascati collaboration (1991-1994), operation of repetitive two-stage gun demonstrated at 1 Hz and up to 2.5 km/s with D_2 pellets (2.7 mm)**
  - **ORNL/ENEA collaboration on high-speed pellet injection systems has resumed with development of a compact 4-pellet system for IGNITOR (2005 – present)**
- **R&D efforts on a rail gun, an electro-thermal gun, and an electron beam heated rocket were also carried out previously in the ORNL Pellet Program**

VLT Virtual Laboratory for Technology For Fusion Energy Science

ORNL/ENEA-Frascati Collaboration on High-Speed Pellet Injection Has Now Spanned 20 Years



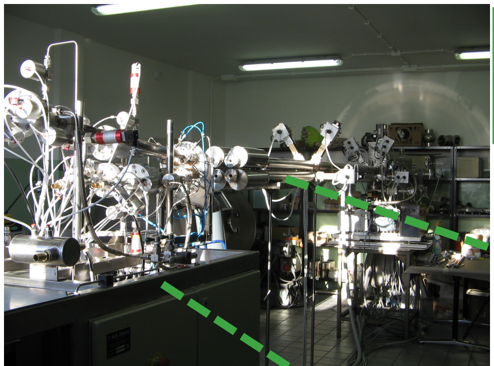
1991 (Y-12 Plant)

Present (ORNL)

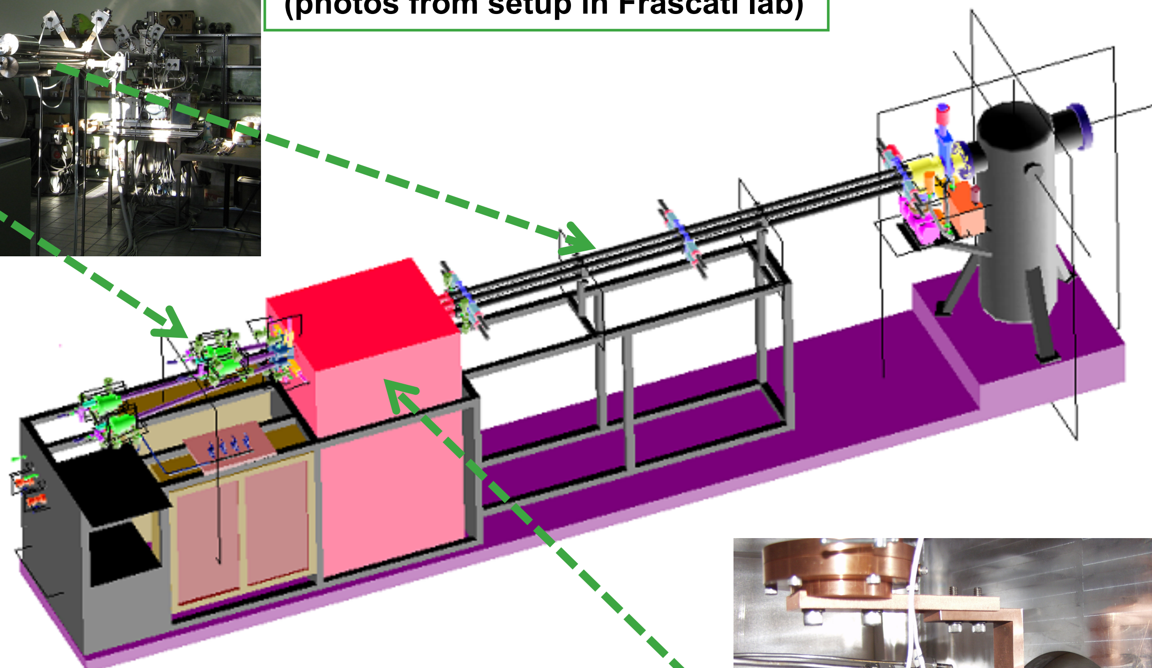
ENEA

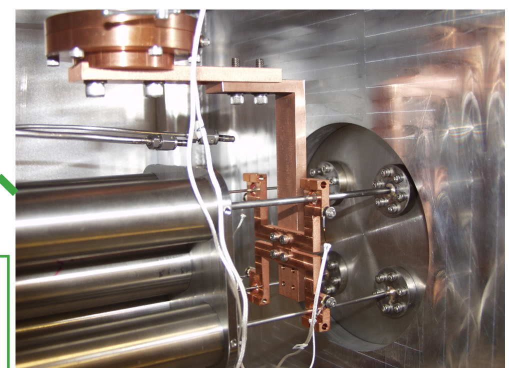
Oak Ridge National Laboratory

IGNITOR High-Speed Pellet Injector Test Facility Has Been Established at ORNL



ENEA provides Two-Stage Guns and Gas Removal Components (photos from setup in Frascati lab)



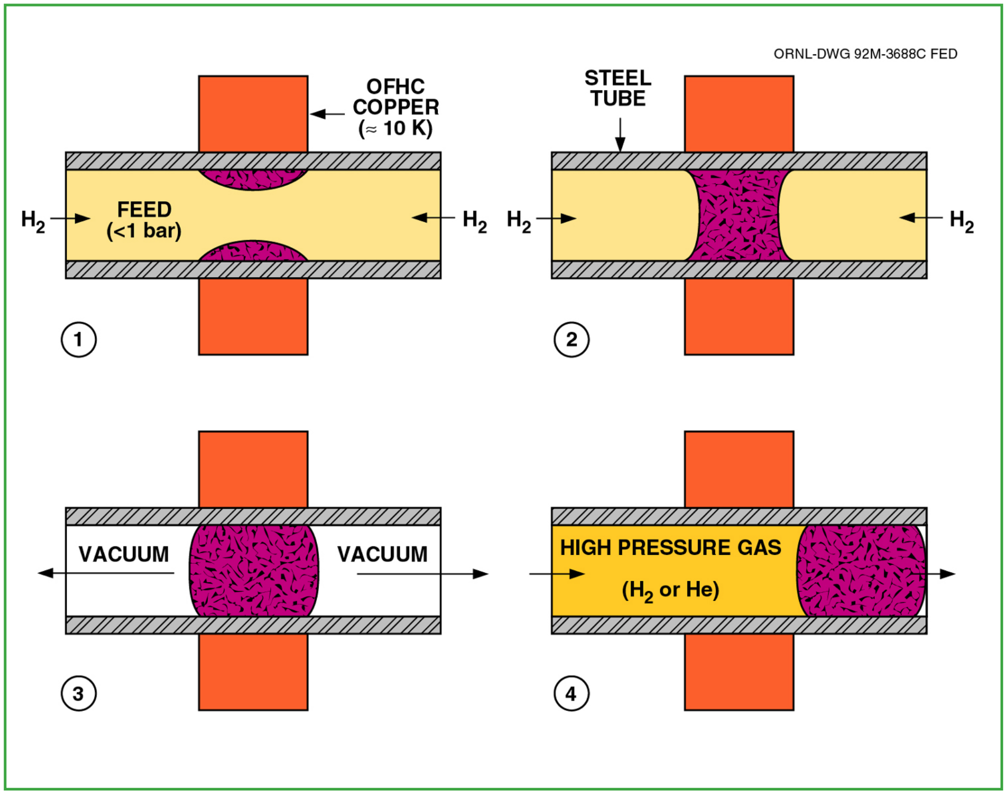


ORNL provides cryostat/gun barrels and pellet diagnostics (not shown)

Key Features of System and Collaborative Effort

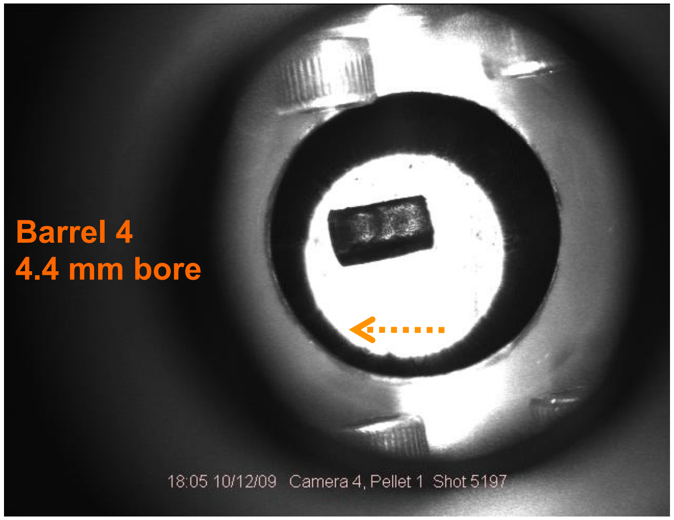
- **No. of pellets: 4**
- **Pellet material / sizes: D_2 / 2–5 mm nominal diameters**
- **Type of cryostat / temperature: pipe gun with cryocooler / ~10 K (option for LHe supplement / ~7 K)**
- **Propulsion: ORNL propellant valves and ENEA-Frascati two-stage pneumatic drivers (special feature of gas pulse shaping)**
- **Pellet speed: ~1 km/s with ORNL propellant valves and up to 2.5 km/s (or greater) with Frascati two-stage guns**
- **Diagnostics: piezoelectric ballistic transducers, light gates, in-flight pellet photography, microwave cavity mass detector, and impact targets equipped with shock accelerometers**
- **Gas removal system: special design with fast-closing valves (reduces overall size and avoids use of large ballast tanks)**
- **Each party prepared and tested their hardware independently, and the systems have been combined for joint testing at ORNL (several experimental campaigns carried out at ORNL to date)**

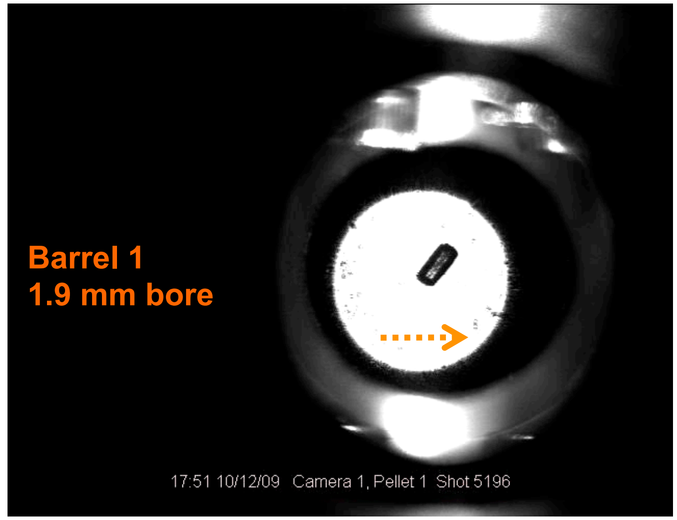
Pipe Gun Refers to In-Situ Pellet Formation

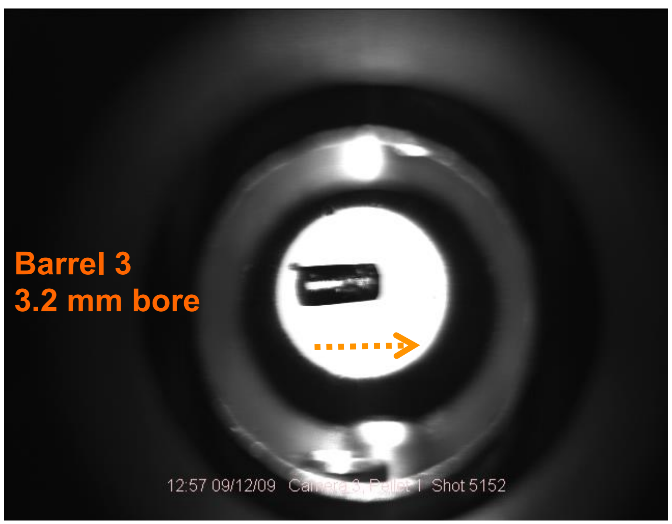


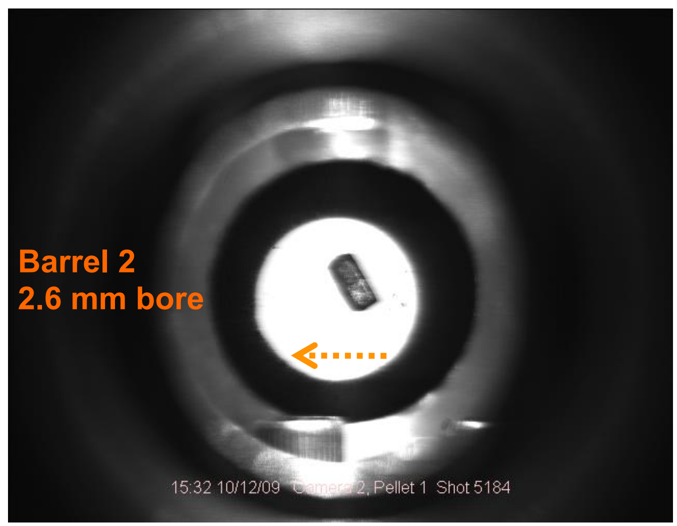
- Room temperature gas is fed/ controlled at low pressure (<100 mBar) until the pellet is formed (L/D is parameter)
- Upstream and downstream barrel heaters can control the local temperature gradients and limit the pellet length
- Frozen D_2 pellets are accelerated by high pressure gas from a propellant valve or two-stage pneumatic guns
- Lower temperatures are desirable for the acceleration with two-stage guns, since the strength of the frozen solid increases

Example of D_2 Pellets Produced and Accelerated in the Test Facility with ORNL Propellant Valves



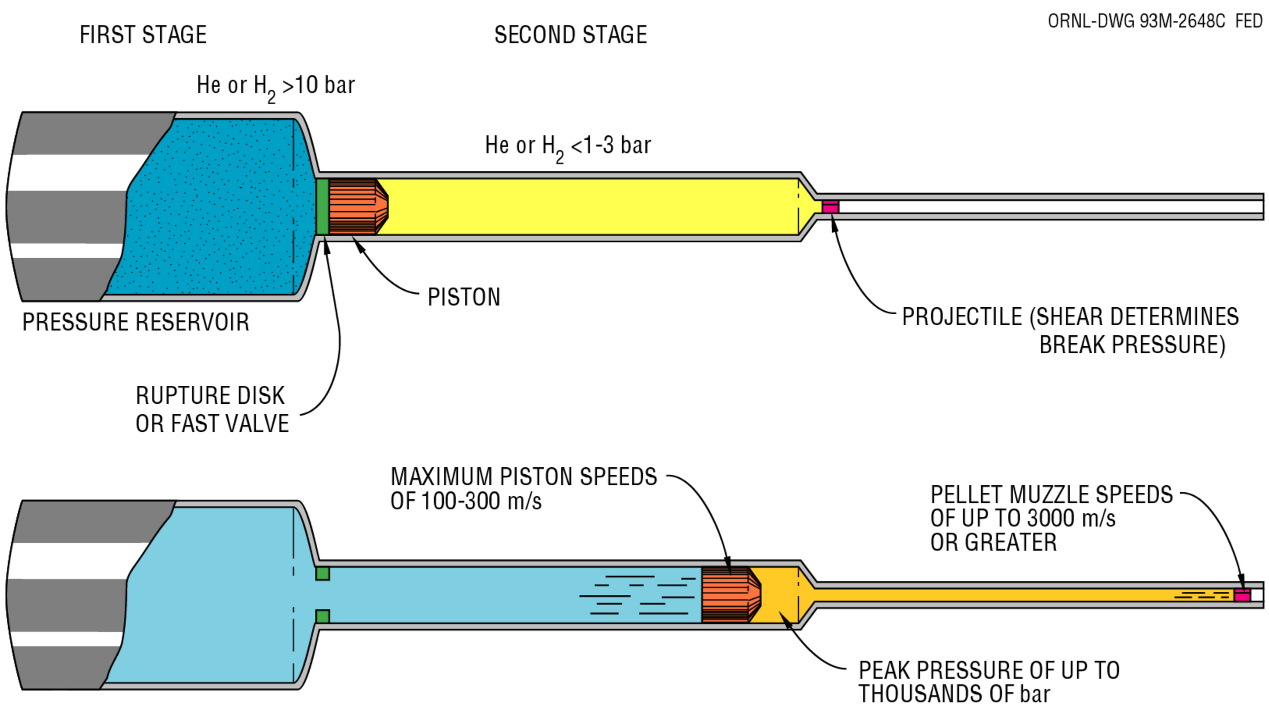






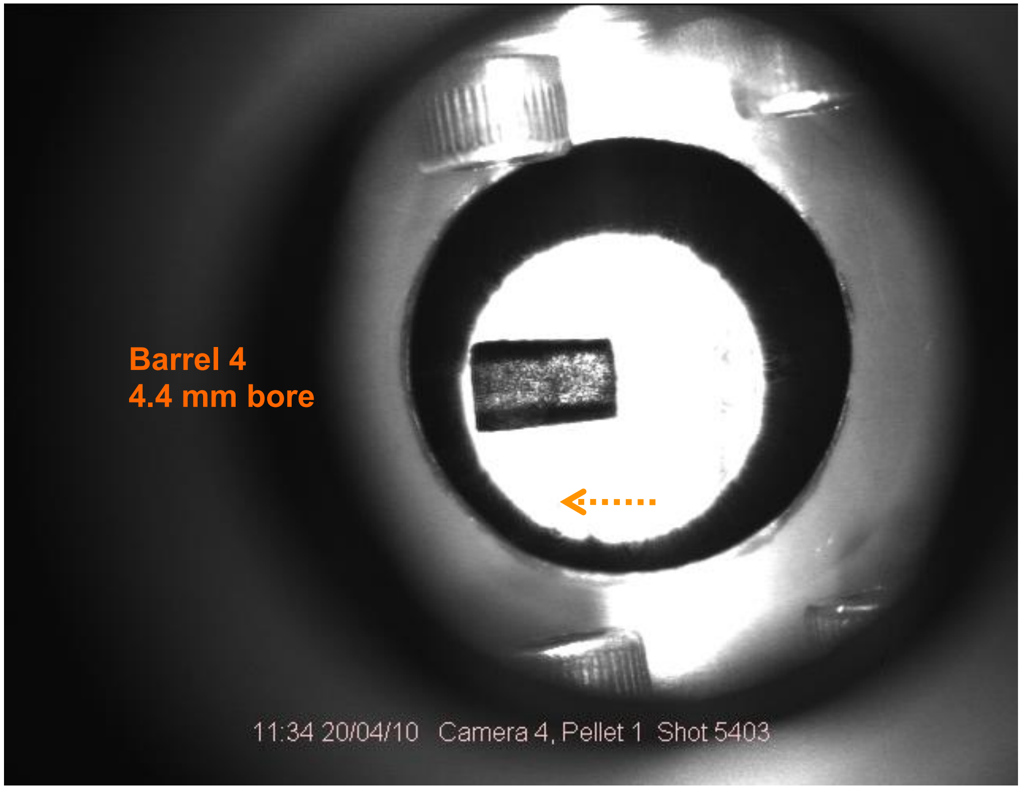
- **Speeds~ 1000 m/s**
- **Pellets 2 & 4 are traveling right to left in photo**
- **Pellets 1 & 3 are traveling left to right in photo**
- **Reliability and repeatability of system with the ORNL propellant valves are excellent**

Two-Stage Gun Systems Overcome Intrinsic "Speed of Sound" Limitation for Acceleration with Room Temperature Propellant Gas



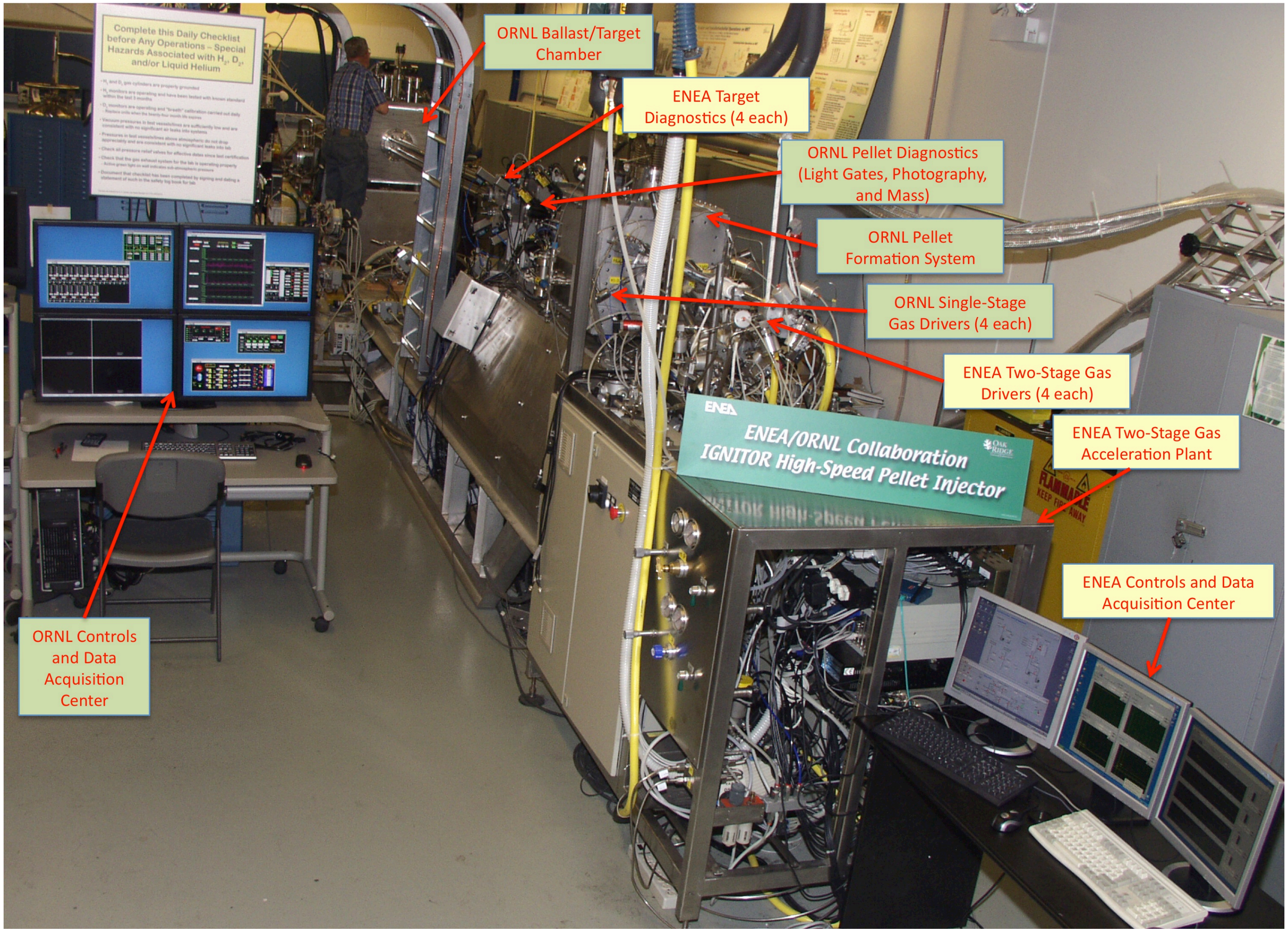
The key is the increase in temperature as the propellant gas is adiabatically compressed by the high-speed piston, resulting in higher sound speeds.

Example of D_2 Pellet Produced & Accelerated with ENEA Two-Stage Gun

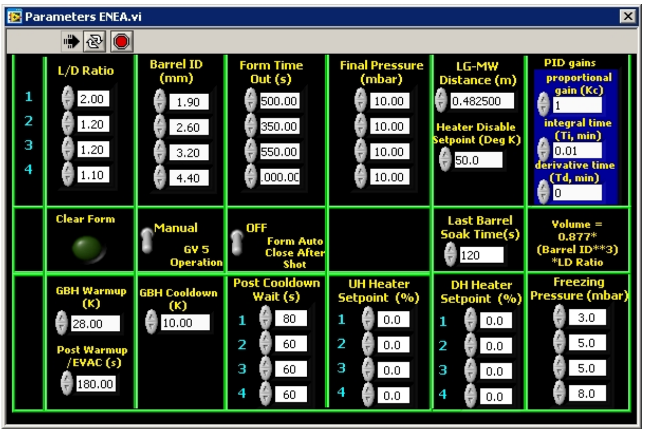


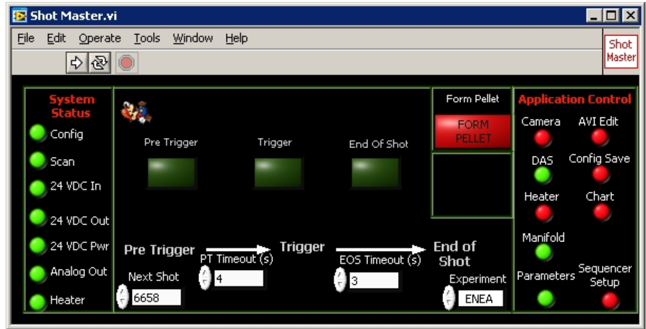
- **Pellet is nominal 4.4 mm D_2**
- **Pellet is traveling right to left at 2000 km/s, which is about two times the speed with ORNL propellant valve**
- **Speeds up to ~2300 m/s have been recorded in experiments to date; however, the pellet quality tends to degrade at the higher speeds**
- **Key remaining test objective is to consistently attain higher pellet speeds (≥2500 m/s) while maintaining pellet quality**

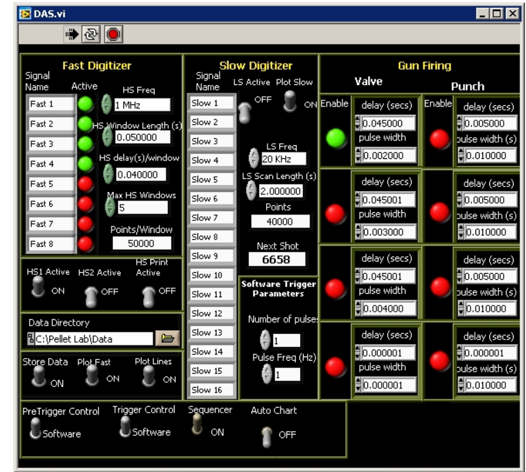
Present Setup of High-Speed Test Facility at ORNL

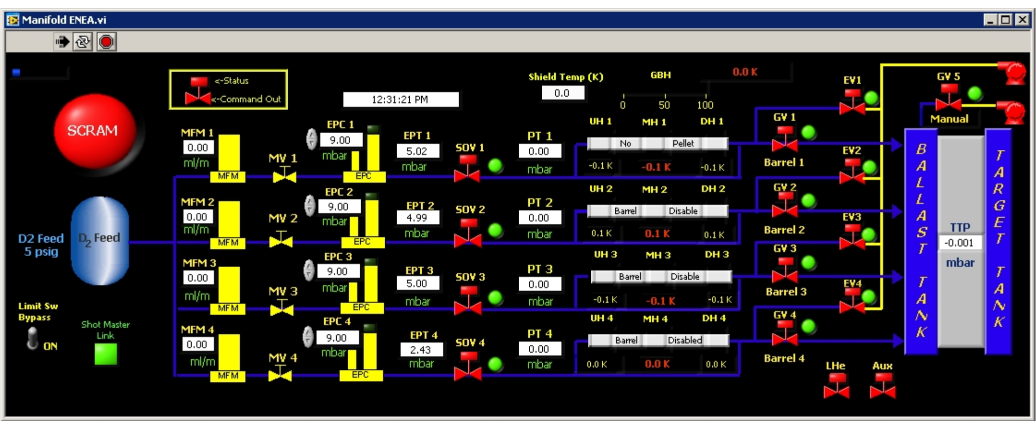


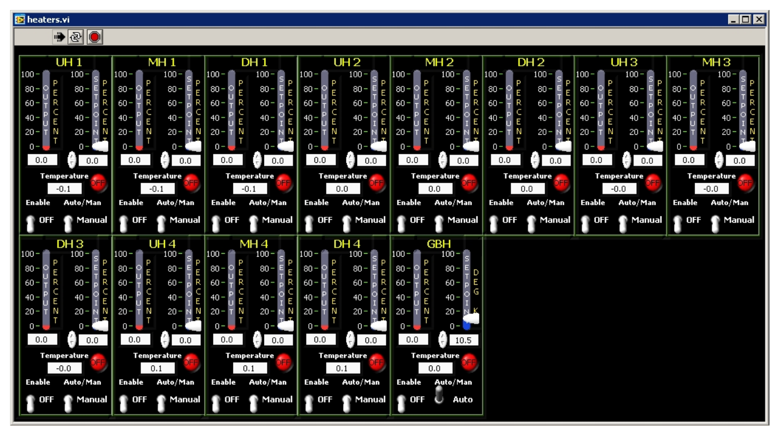
LabView-Based Control and Data Acquisition System Is Impressive and Gives Operator "Everything One Could Ever Ask For"



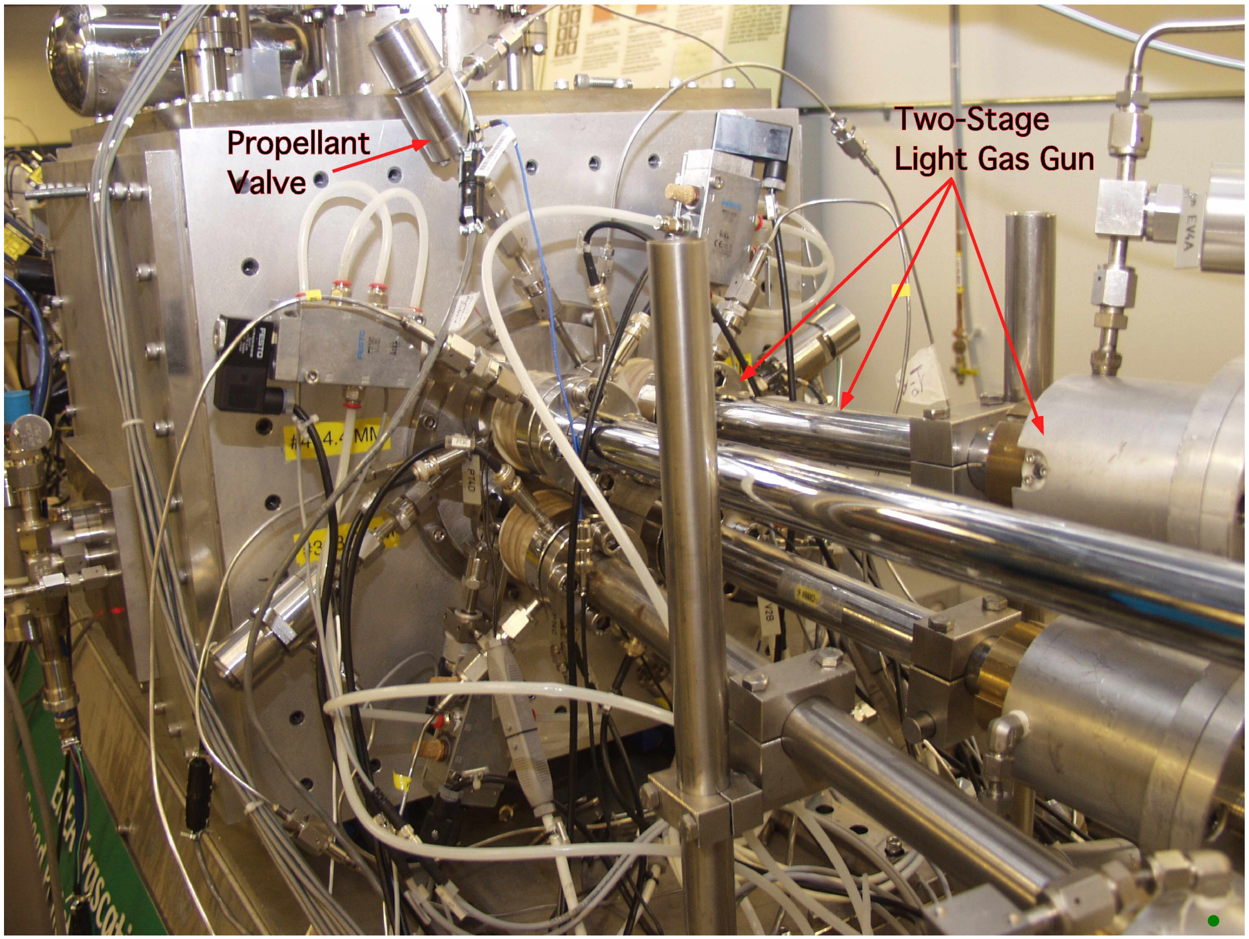








Each Barrel Is Equipped with Both Propellant Valve and Two-Stage Gun



- This is unique feature never before available on pellet injector systems
- Check valves isolate propellant valves from high-pressure hot gas generated by two-stage drivers
- For each test, operator can select number of pellets and acceleration type for each barrel
- Will provide great flexibility in plasma experiments by offering a wide range of pellet sizes and speeds

Major Tasks/Accomplishments to Date and Future Activities

- The systems from ORNL and ENEA-Frascati have been combined to establish a high-speed pellet injection test facility at ORNL
- Several "joint" experimental campaigns have been carried out
- Pellet formation process and acceleration with propellant valves have been optimized, including the highest levels of reliability and repeatability
- One key remaining test objective is to consistently attain higher pellet speeds (≥2500 m/s) with two-stage gas drivers while maintaining pellet quality
  - Cooling system modified to include liquid helium to supplement cryogenic refrigerator (temperatures as low as 6.5 K achieved – thus stronger "ice")
  - Original thin-wall barrels have been replaced with thicker-wall barrels to improve physical stability and pellet dispersion
  - Recent ORNL modifications were made to ensure free flight through diagnostics; ENEA developed/supplied new target diagnostics to measure pellet dispersion
- Integrating the ENEA-Frascati gas removal system will be the last phase of the project
- System could be made available for deployment on a fusion experiment in near future

The R&D collaboration was initiated and has been carried out in support of Italy's proposed IGNITOR fusion experiment.