NCNR Pressure Vessel Stored Energy Limit Calculation

All high pressure systems and components must conform to the applicable ASME Boiler and Pressure Vessel Code, Section VIII, Division 3 "Rules for Construction of Pressure Vessels", and the strictest applicable state and local codes. Moreover, when national consensus codes are not applicable (due to pressure range, vessel geometry, use of special materials, etc.), proper measures must be implemented in order to provide equivalent protection and ensure a level of safety greater than or equal to that of ASME or applicable state or local code.
Measures must include the following:

- Design drawings, sketches, and calculations must be reviewed and approved by a qualified independent design professional (i.e., professional engineer).
- Non-destructive tests, and acceptance test must be done by qualified personnel.
- Documentation, traceability, and accountability must be maintained for each pressure vessel or system, including descriptions of design, pressure conditions, testing, inspection, operation, repair, and maintenance.

A pressure limit approach based upon stored energy was adopted by NCNR in order to pose minimal risk to personnel during operation. These limits, which DO NOT take into account flammability, are:

- **STORED ENERGY LIMIT 1:** 1,356 Joules (1000 lbf-ft) of stored energy. Below this limit there are minimal requirements and no formal approvals are required.
- **STORED ENERGY LIMIT 2:** Between 1,356 Joules (1000 lbf-ft) and 16,270 Joules (12,000 lbf-ft) of stored energy. The NCNR high pressure activity responsible reviews the experiment within this pressure range and may determine to approve the experiment.
- Above 16,270 Joules (12,000 lbf-ft) of stored energy. The NCNR high pressure activity responsible requests that any pressure equipment or sub-system thereof be submitted to the NCNR Hazard Review Committee prior to its use at NCNR.

Experiments containing a flammability risk will be assessed for adiabatic expansion as well as flammability risk.
Stored energy has historically been calculated for gases or vapors above the boiling point by assuming isentropic expansion as shown in the following equation:

$$W = \left(\frac{P_1 \cdot V_1}{k-1}\right)\left[1 - \left(\frac{P_1}{P_2}\right)^{\frac{(1-k)}{k}}\right]$$

Where:
W = Work Energy
k = Ratio of Specific Heats
P_1 = Initial Pressure
P_2 = Final Pressure
V_1 = Initial Volume

For liquids below their boiling point, the stored energy is calculated using the bulk modulus of the liquid, or a conservative value if one is unknown. The formula below is used in this case:

$$W = \frac{1}{2} \cdot \beta \cdot P^2 \cdot V$$

Where:

W = Work Energy

V = Initial Volume

Β = Compressibility (1/Bulk Modulus)

P = Pressure

Reference: Pressure Systems Stored-Energy Threshold Risk Analysis PNNL-18696.

BLAST WAVE CALCULATIONS and MINIMAL SAFETY DISTANCE			
	ENERGY (Joules)	ENERGY EQUIVALENT (Kg TNT)	Minimal Safety distance for eardrum rupture avoidance(meters)
Compressed Gas Cylinder	1,332,270	0.288836136	2.05
Standard Air Compressor, 50 gal	215,604	0.046742947	1.12
Standard Air Compressor, 20 gal	86,784	0.018814771	0.82
Propane Tank (grill, compressed gas expansion only)	47,460	0.010289328	0.67
Paint Ball Tank (20 oz)	28,883	0.006261791	0.57
M-80 (2.5 grams of powder)	23,052	0.004997674	0.53
STORED ENERGY LIMIT 2 (minimal mitigated risk to personnel at 1 meters)	**16,272**	**0.00352777**	**0.47**
10 kbar Pressure Cell	14,507	0.003145022	0.45
6.5 kbar Pressure Cell	9,351	0.002027335	0.39
Car Tire	6,916	0.001499302	0.35
Mountain Bike Tire	3,024	0.000655577	0.27
CO2 2L Pop Bottle Bomb	2,373	0.000514466	0.25
Typical CO2 Cartridge (16 gram)	1,713	0.000371298	0.22
STORED ENERGY LIMIT 1	**1,356**	**0.000293981**	**0.21**
BMX Bike Tire	1,241	0.000268992	0.20
Road Bike Tire	1,112	0.000241064	0.19
Typical CO2 Cartridge (12 gram)	881	0.000191088	0.18
Typical Firecracker (50 mg powder)	461	9.99535E-05	0.14
Dust Spray Can	454	9.84836E-05	0.14
Soccer Ball	434	9.40739E-05	0.14
Party Balloon	346	7.49651E-05	0.13
Basketball	339	7.34952E-05	0.13
E Type (12cc) Vanadium Can	2.9	6.31288E-07	0.03