Novel Cryogenic High Voltage Breaks (CHVB)

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Topic: 37c

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Outline

- e2P Overview
- Program Motivation
- Phase II Program Overview
- CHVB Schematic, Design, & Analysis
- CHVB Testing
- Commercial Outreach
- Path Forward

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e2P – A Company Introduction

Energy to Power Solutions (e2P)- performs **early-stage R&D** of both Low Temperature Superconducting (LTS) & High Temperature Superconducting (HTS) devices, their associated cryogenics, and cryogenic High Voltage (HV) components→ enabling technologies for **military, space, fusion energy, commercial &** ***medical application applications***

- **Founded 1999**
- ~50 % (US Govn't contracts) & ~50 % (commercial)
- Labs Located @ TCC in Tallahassee, FL

Program Motivation

- Cryogenic High Voltage Breaks (CHV-Breaks) & Bushing (CHV-Bushings) electrically isolate cryogenic devices & equipment operating at High Voltages (HV) from grounded components & structures. CHV-Bushings also transmit electrical power into cryogenic space.

- State-of-the-Art (SOA) *ceramic* CHVB's are *notoriously unreliable* and prone to frequent *micro-cracking* & hence *leaking*.

- CHVB's leaking into cryogenic vacuum spaces can be prohibitively expensive to repair (e.g. ITER, CERN, etc.) or lead to premature failure (e.g. power equipment)

- For V_{op} > 100 kV or non-magnetic there is no suitable commercial product

- **Requirements:** Low cost, mechanically robust, HV standoff, radiation resistant, hermetic, repeated thermal cycling, high internal pressure, non-magnetic

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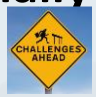
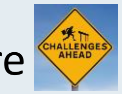
Phase II Program Overview

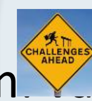
Work Scope A: Thermally Insulating CHVB for ANL w/ R. Vondasek

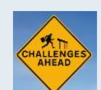
- V_{op} ~ 150 kV 

- Interior medium: LN2, Exterior medium: atmosphere 

- Radiation: No
- Mechanical/Structural: NA
- Quantity: 2-3
- Commercial opportunity: Low

Work Scope B: Radiation Tolerant CHVB for Commercial Fusion

- V_{op} ~ 30 kV
- Interior medium: GHe, Exterior medium: vacuum 

- Radiation: 10 MGy 

- Mechanical/Structural: 500 PSI internal pressure
- Quantity: > 1000
- Commercial Opportunity: Very high

Phase II Program Overview

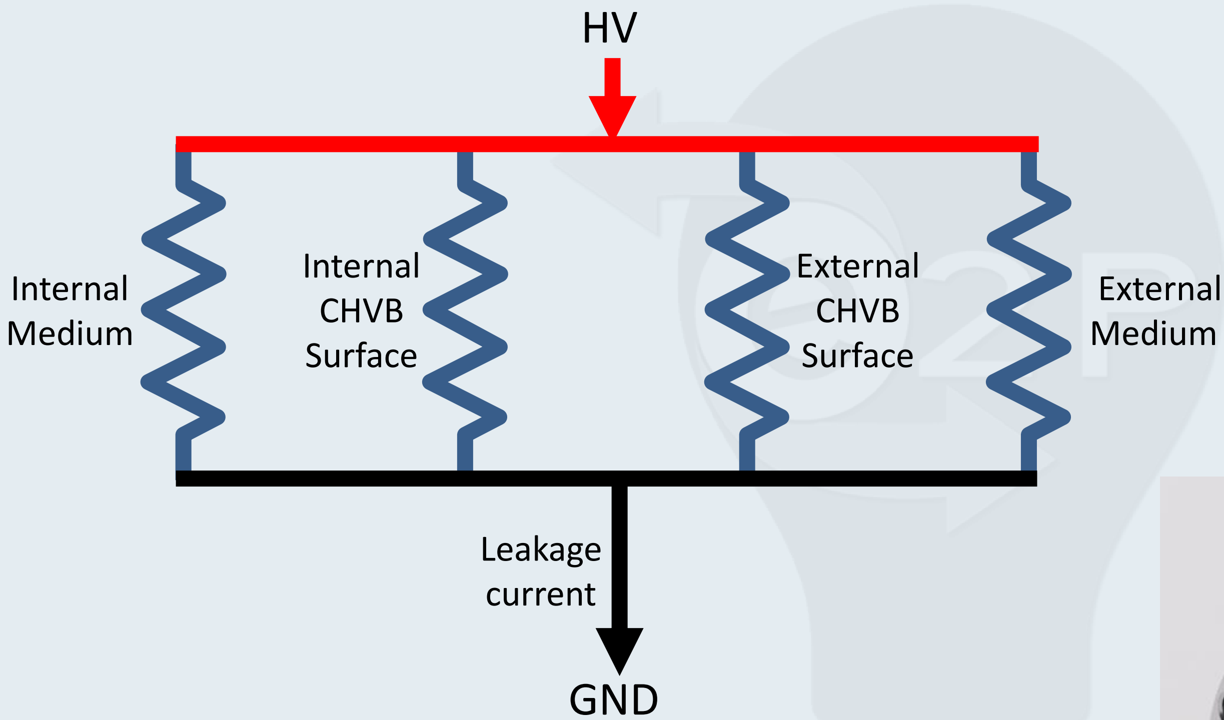
Work Scope C: General R&D for CHVB Design & Fabrication

- V_{op} ~ 375-750 kV
- Interior medium: 2 K LHe, Exterior medium: vacuum
- Radiation: NA
- Mechanical/Structural: 100 PSI internal pressure
- Quantity: > 4-5
- Commercial Opportunity: low

CHVB Requirements

Properties		E2P CHVB	SOA Ceramic	PI Testing	PII Testing
Electrical	High Voltage >100kV				X
	Breakdown			X	
	Creep			X	
Mechanical	Thermal Cycling Resilience			X	X
	Compressive Strength			X	
	Tensile Strength				X
	Torsional Strength				X
	High Internal Pressure				X
Other	Hermetic			X	
	Accelerated Life*				X
	Non-magnetic			X	
	Radiation Resistance				X
*commercial order pending	Low Cost				X

CHVB Electrical Schematic



- CHVB's have 4 parallel electrical paths
- Must insure all 4 electrical paths have high R
- Vacuum (easy) $V_B > 10^{6-7}$ V/cm
- Atmosphere (difficult) $V_B \sim 10^4$ V/cm
- LN2 (moderate) $V_B \sim 5e10^5$ V/cm

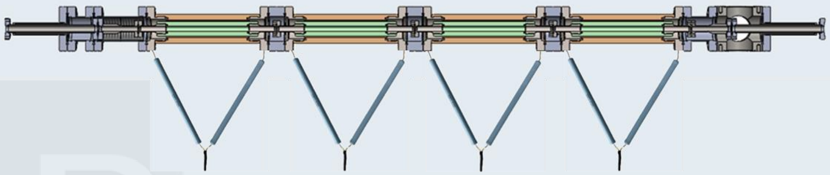
CHVB Design Process

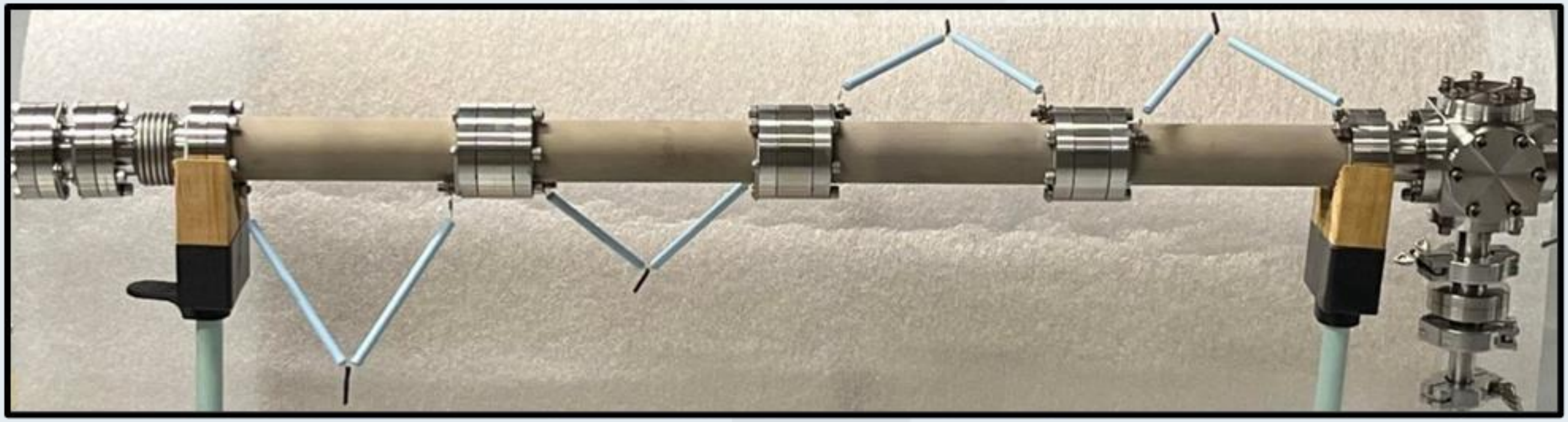
1) Rapid Virtual Prototyping
   - Large number of rough/approximate E-field simulations
   - Simplified CAD models
2) Down selection based upon E-field Stress Reduction (EFSR)
3) Detailed designs
4) Manufacture
5) Test
6) Iterate designs as needed

Thermally Insulating CHVB @ ANL

HV LN2 Transfer Line: CHVB Electrical Testing

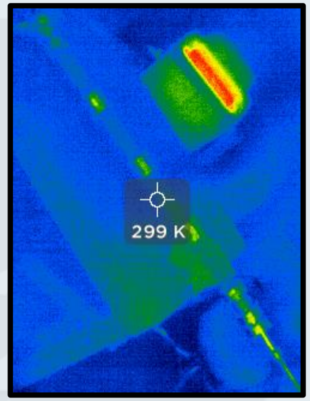
- Hipot to 80 kV w/o LN2
- Hipot to 80 kV w/ LN2 interior annulus
- GHe leak test w/LN2 interior annulus
- ANL to test on CARIBU > 150 kV
- 2nd Generation design for outdoor use in electrical grid





Testing: Thermal Gradient

- LN_2 pumped through array over 15-minute period
- Thermal imaging used to capture thermal gradient and determine cold points
- Surfaces remained ≥ 295K (reference device in background @ ~318K ~45C)
- Device should not develop exterior surface condensation under expected conditions
- 2nd Gen unit needed for Grid applications



T_1 = 299K
t_1 = 0m

T_5 = 296K
t_5 = 7m

T_8 = 295K
t_8 = 15m
T_{ref} = ~318K

Radiation Tolerant Epoxy Evaluation

- Mechanical testing of:
  - Tensional Strength (ASTM D638)
  - Compressive Strength (ASTM E9)
  - Torsional Strength (ASTM D4065)

- ASTM compliant procedures include:
  - sample design
  - Fabrication
  - Testing
  - post-processing of data

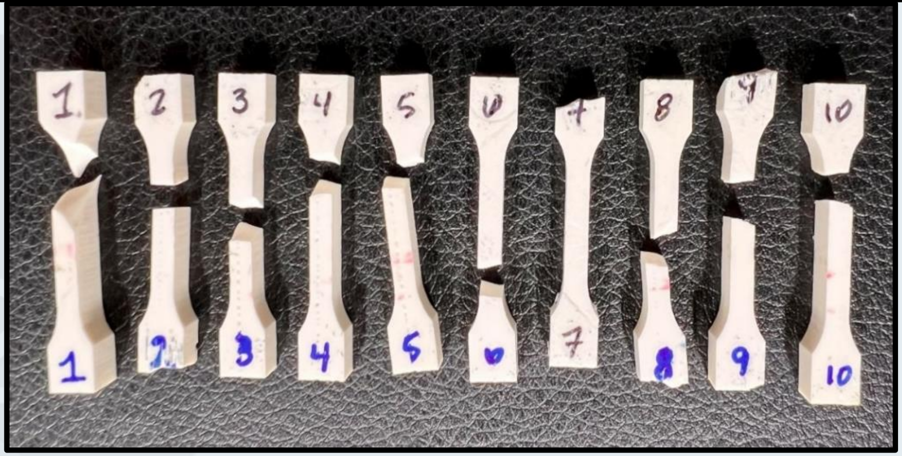
- Procedures will be used to determine compliance of materials and components

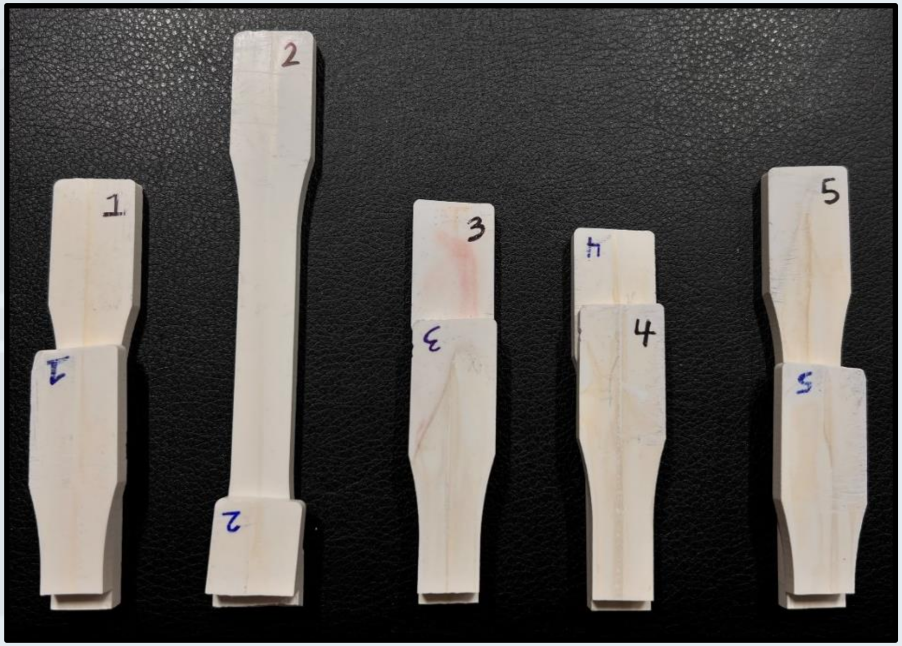
Radiation Tolerant Epoxy Evaluation

Mechanical Testing:

- Pictured top: Small form factor (SFF)[1] tension samples
- Pictured bottom: Large form factor (LFF) tension samples
- Both small and large samples utilize the same ASTM D638 & E9 "dog-bone" shape and proportions i.e. gauge[2] length is ~4x the gauge width

1) shape, proportions
2) reduced cross-sectional area section of sample





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Testing: Mechanical Data

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- UTS data for epoxy PEB-C
- Results inconsistent: emphasizing need for process improvement

Sample	Ultimate Tensile Strength (MPa)	
	Small FF	Large FF
1	-	14.96
2	29.52	-
3	-	25.65
4	-	22.10
5	27.66	13.36
6	25.32	-
7	-	-
8	24.05	-
9	26.12	-
10	28.24	-
Average ± Standard Deviation	**26.82 ± 2.02 MPa**	**19.02 ± 5.82 MPa**

Path Forward

- **Work scope A: >90 % complete**
  - Field test @ ANL (R. Vondrasek) → 100 %
- **Work scope B: Low Cost, High Throughput Manufacturing & Component Testing**
  - Develop low-cost volume manufacturing techniques
  - Develop low-cost/repeatable/reliable high volume LN2 thermal cycle testing techniques
  - Develop low-cost/repeatable/reliable high volume GHe testing techniques
- **Work scope C: Component Test Multiple Prototypes**
  - Continue UTS, UCS, and torsional testing of CHVB's & rad.-tolerant epoxies
  - Expand into CHV-Bushings
- **Commercial Outreach**
  - Commercial Fusion companies
  - ORNL NP
  - Electrical Grid (possible PII-B or PII-C)
  - Others in progress

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