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Parametric study for use of stainless steel as a material for thermal shield in PIP2IT transferline at Fermilab

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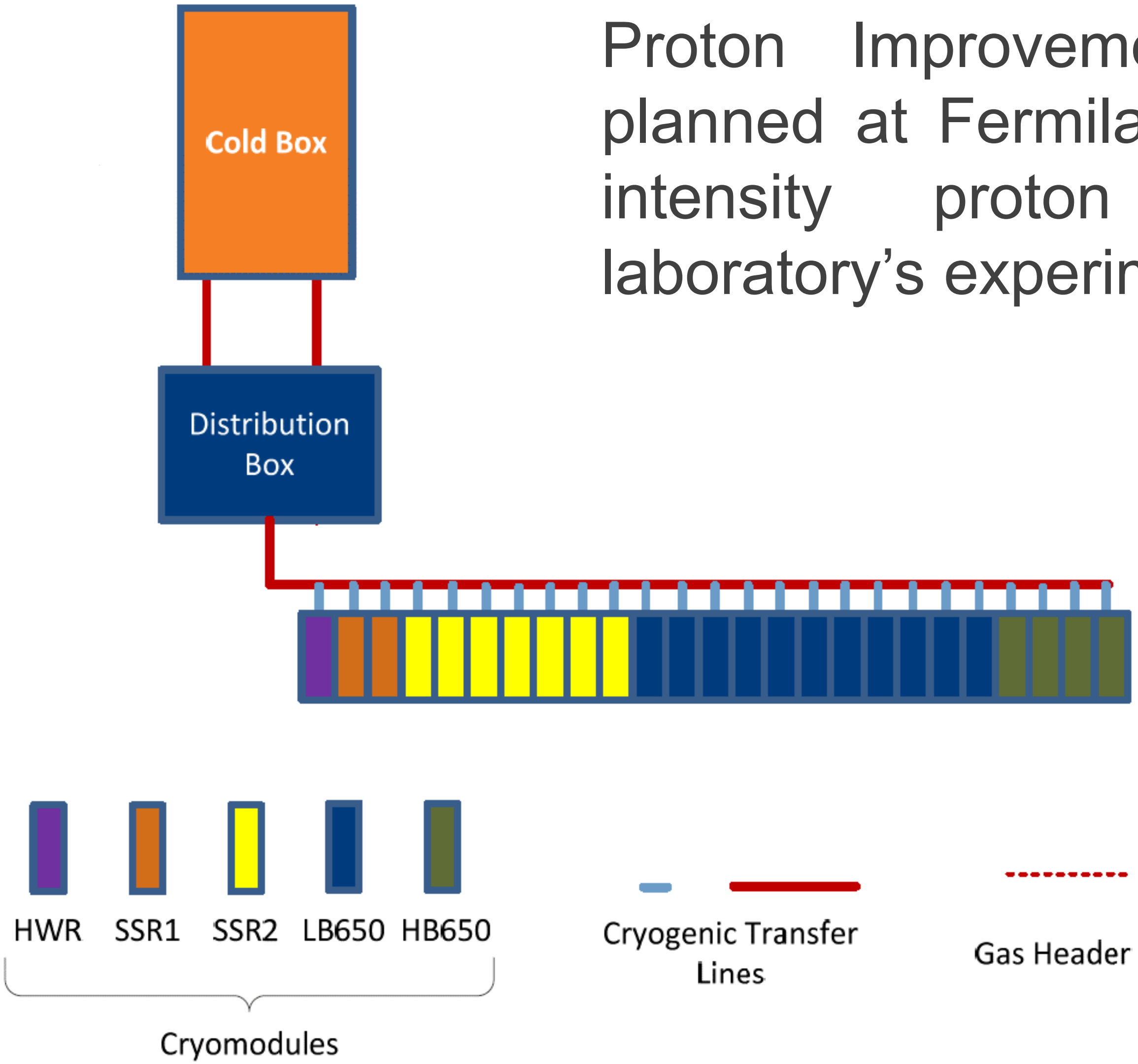
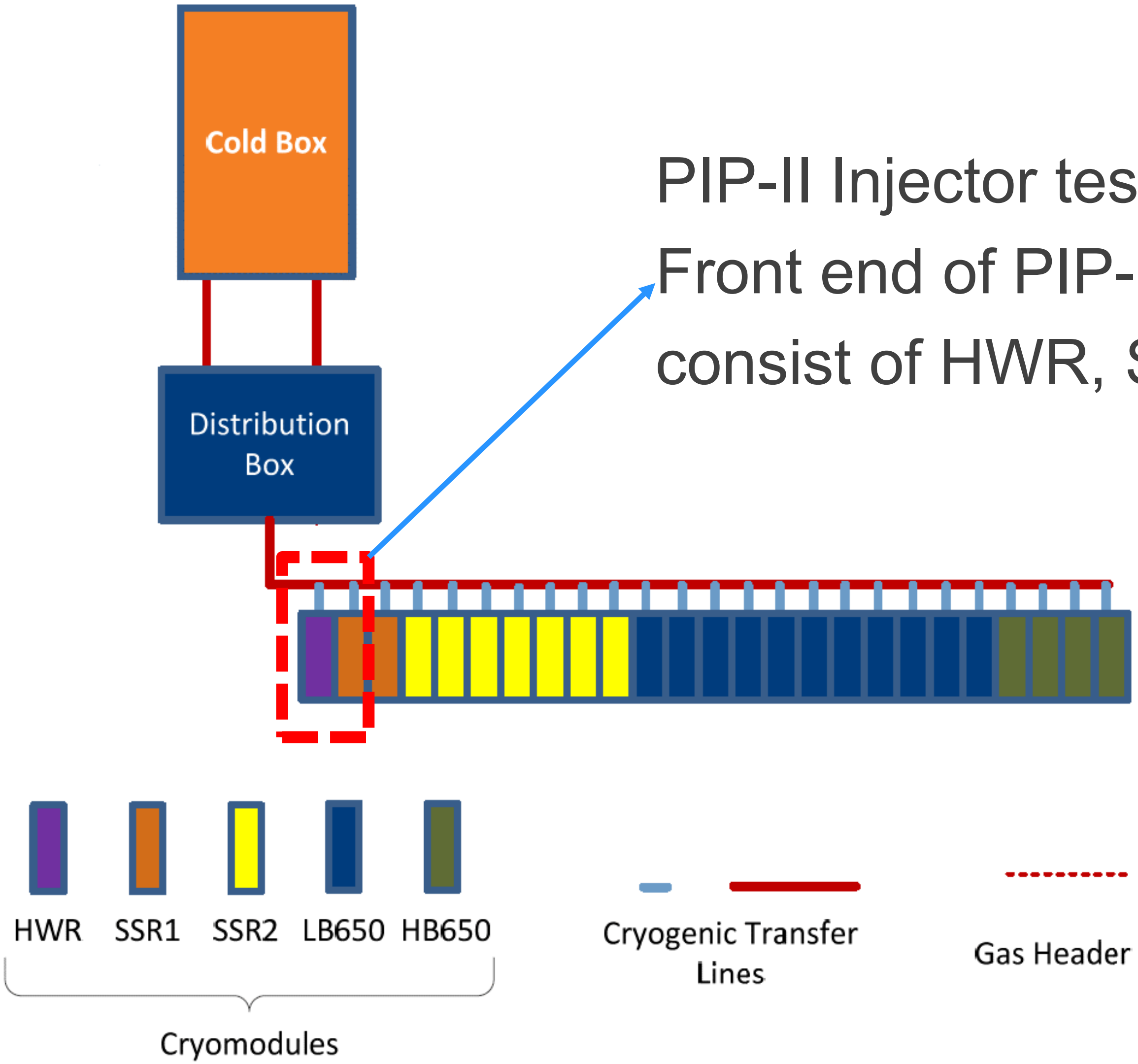
Introduction

Proton Improvement Plan–II (PIP-II) planned at Fermilab for providing high-intensity proton beams to the laboratory's experiments



SOURCE: CDR PIP-II FERMILAB

Introduction



PIP-II Injector test (PIP2IT)

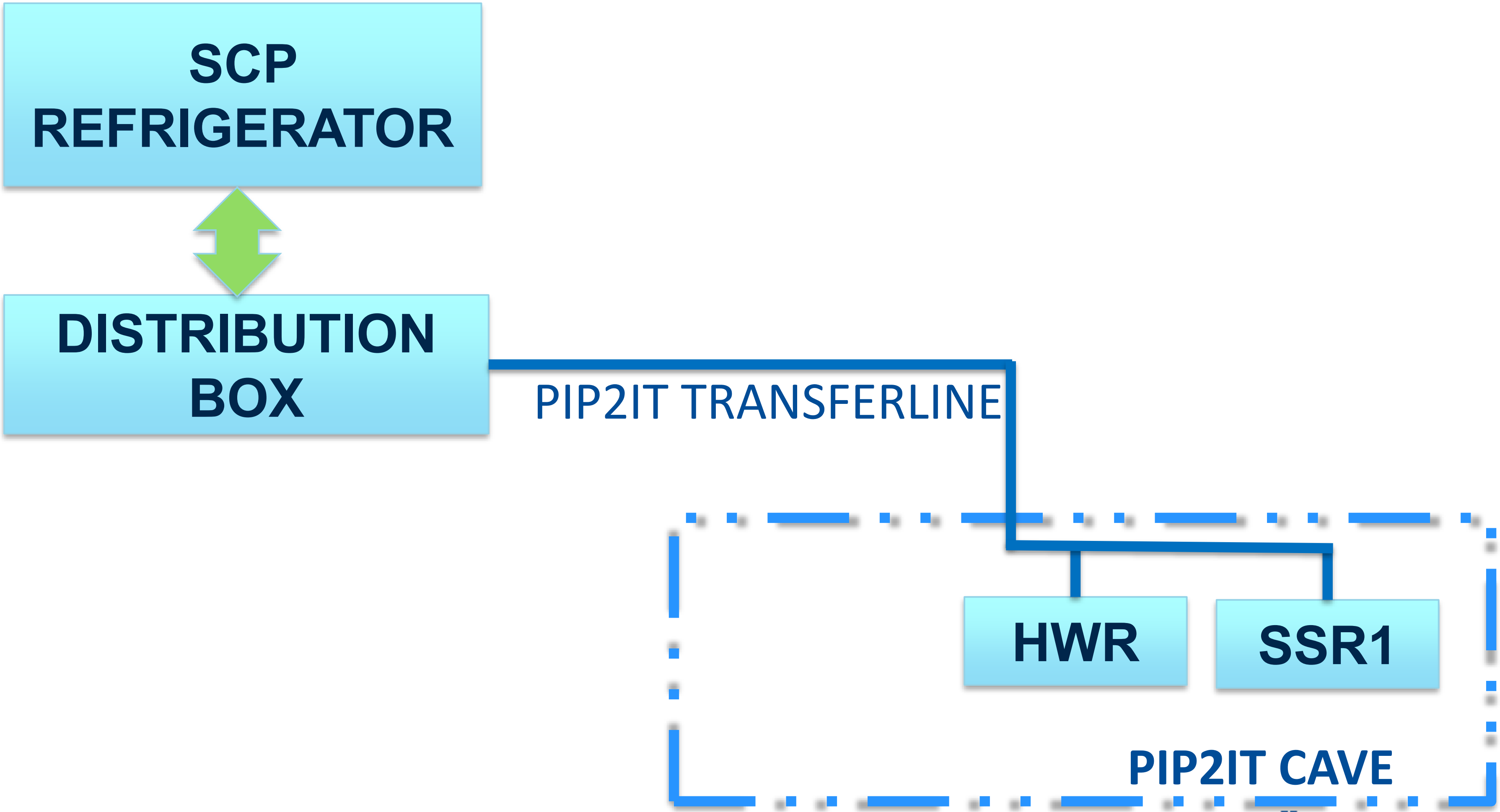
Front end of PIP-II

consist of HWR, SSR1 cryomodules

SOURCE: CDR PIP-II FERMILAB

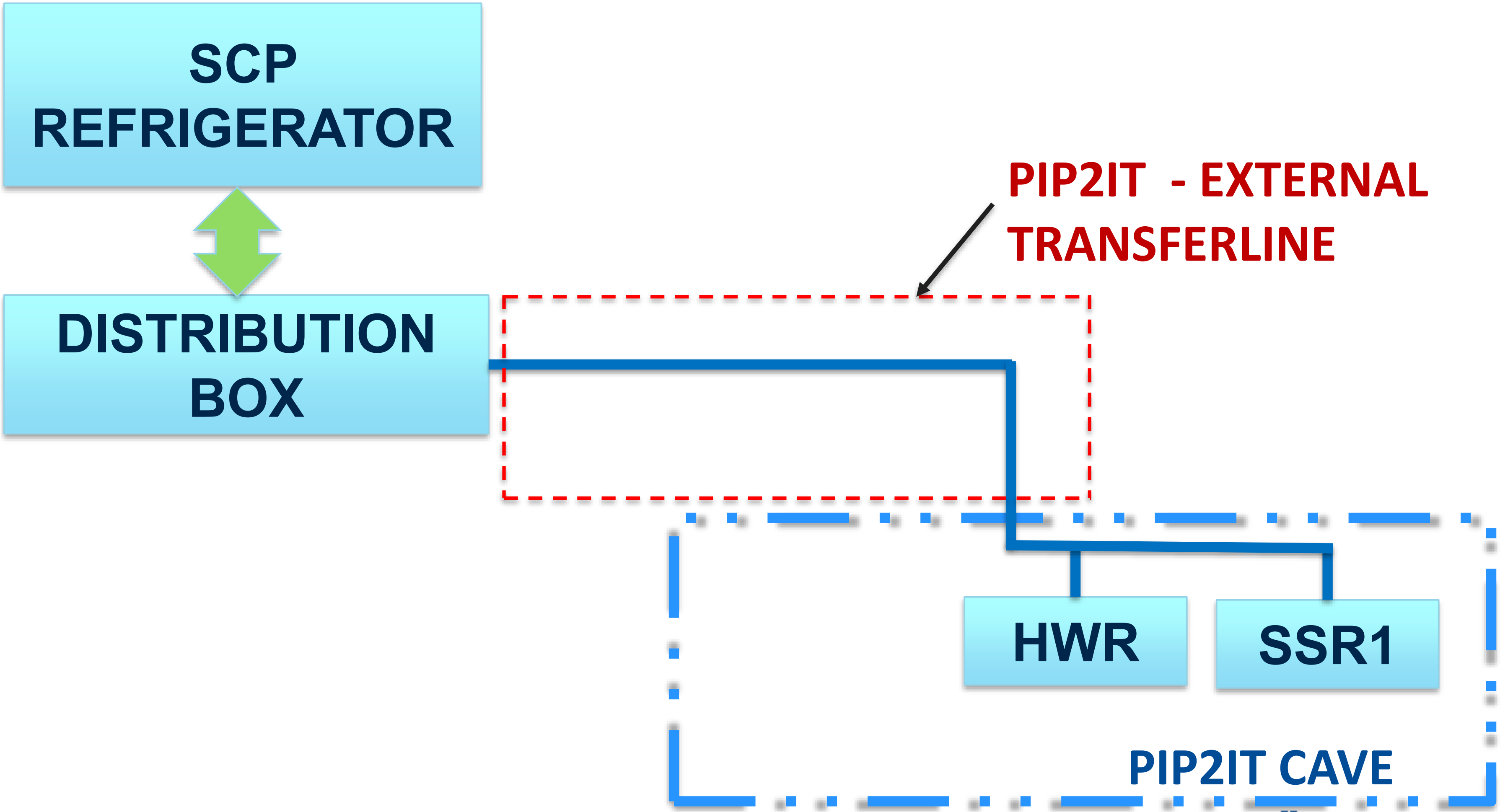
Introduction

PIP2IT tests will be conducted in CMTF building at Fermilab



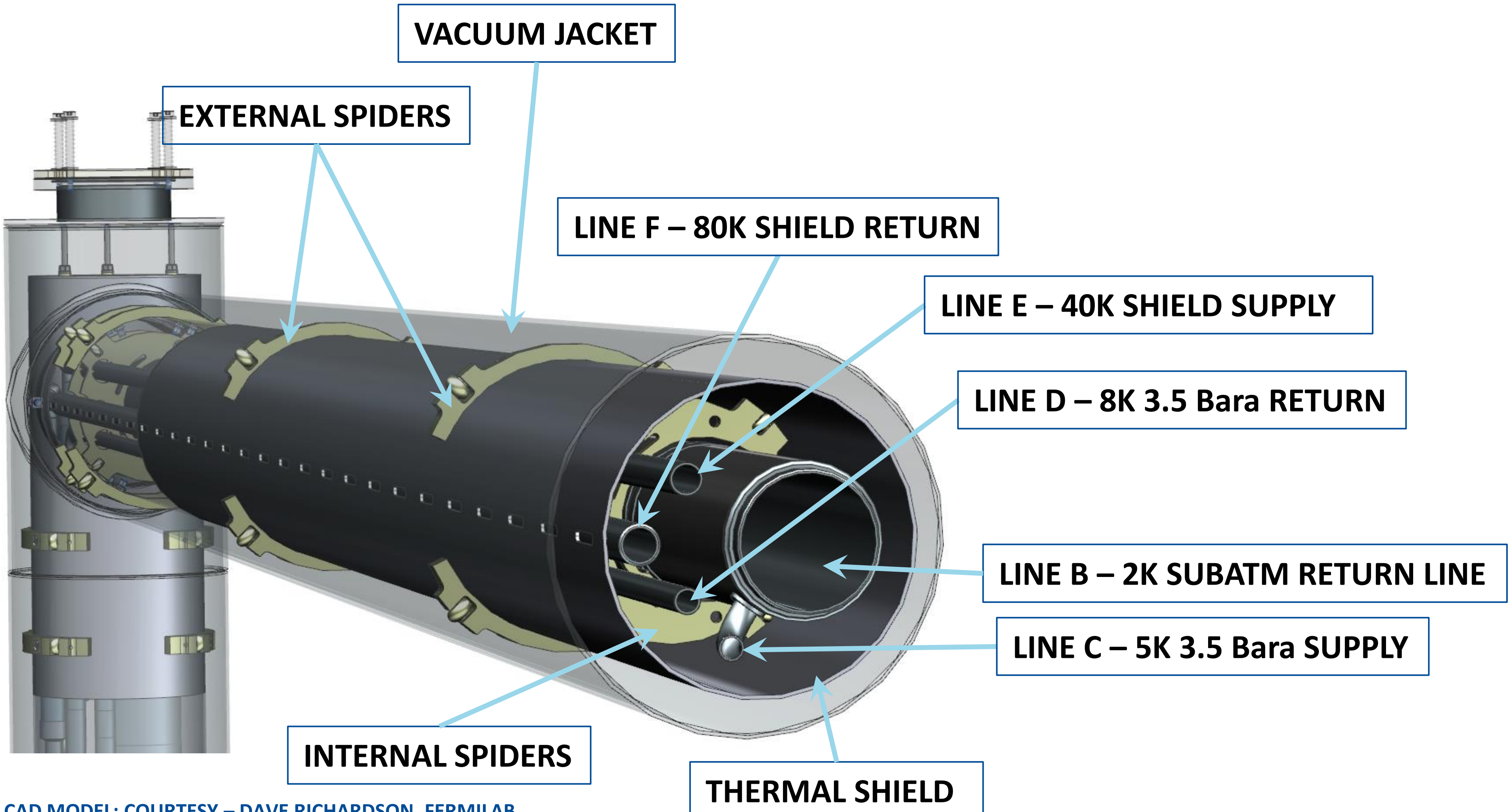
Introduction

Present paper is related to the thermal shield of the PIP2IT external transferline



Introduction

Sectional view of part of the PIP2IT transferline



CAD MODEL: COURTESY – DAVE RICHARDSON, FERMILAB

Problem Description

Copper or Aluminium are preferred materials for the thermal shield because of higher thermal diffusivity

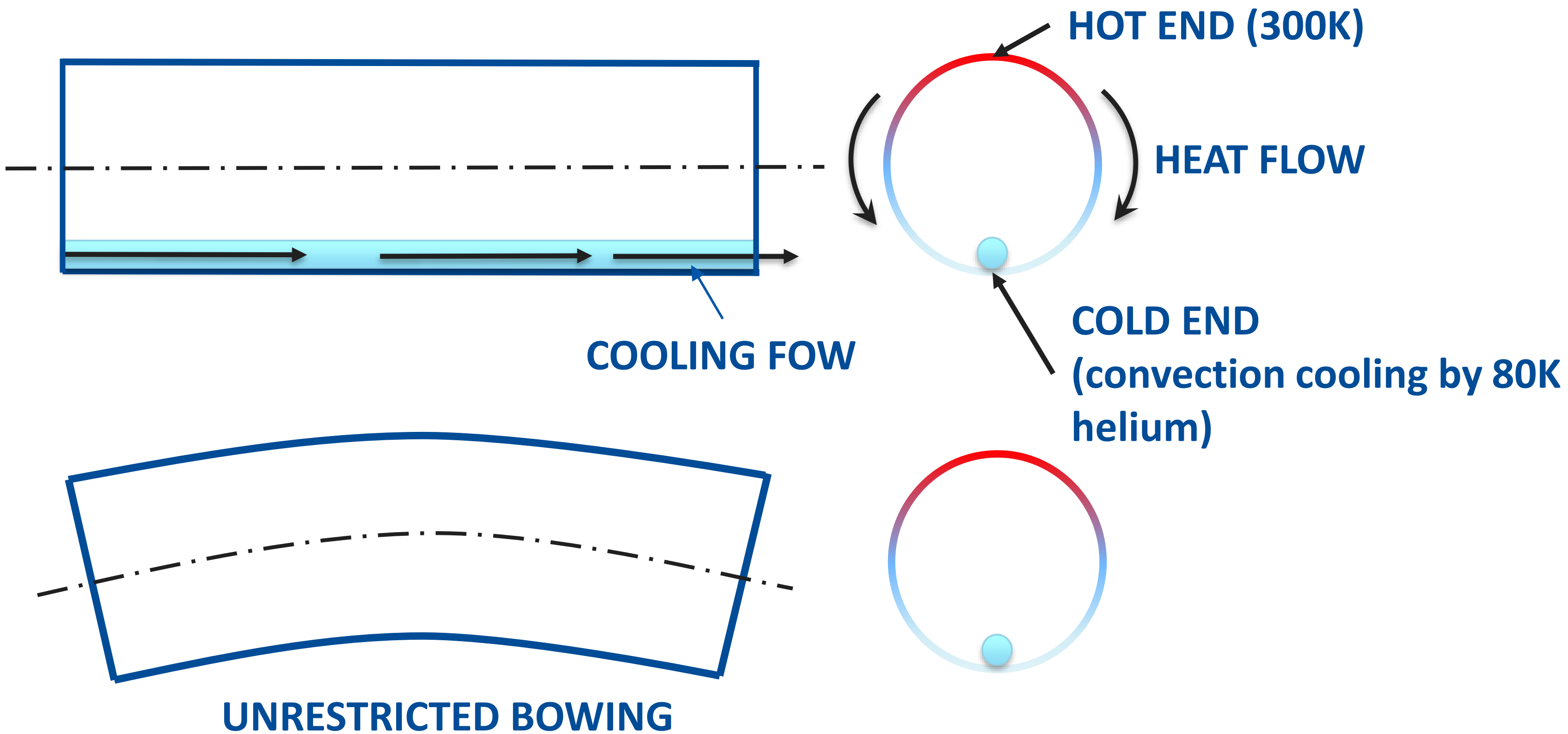
However, stainless steel has been selected for fabrication of PIP2IT thermal shield due to following advantages—

- Easy availability of seam welded 10inch OD tube
- Reduced cost as compared to copper or Aluminium shield
- Higher strength of SS
- Welding Stainless steel (SS) shield to SS pipe is easier than brazing of Copper/Aluminium to SS

Problem Description

During cooldown, large thermal gradients occur on the surface of the thermal shield, due to low thermal diffusivity

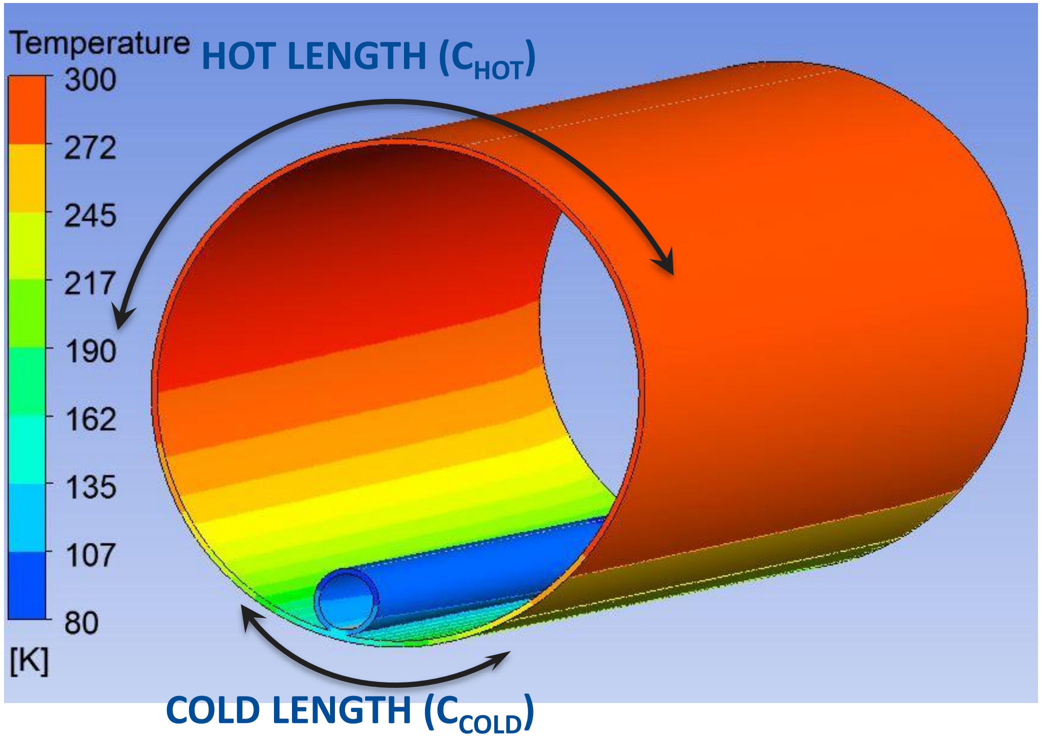
This gives rise to thermal stresses and strains



Problem Description

Stresses are induced because of following two reasons--

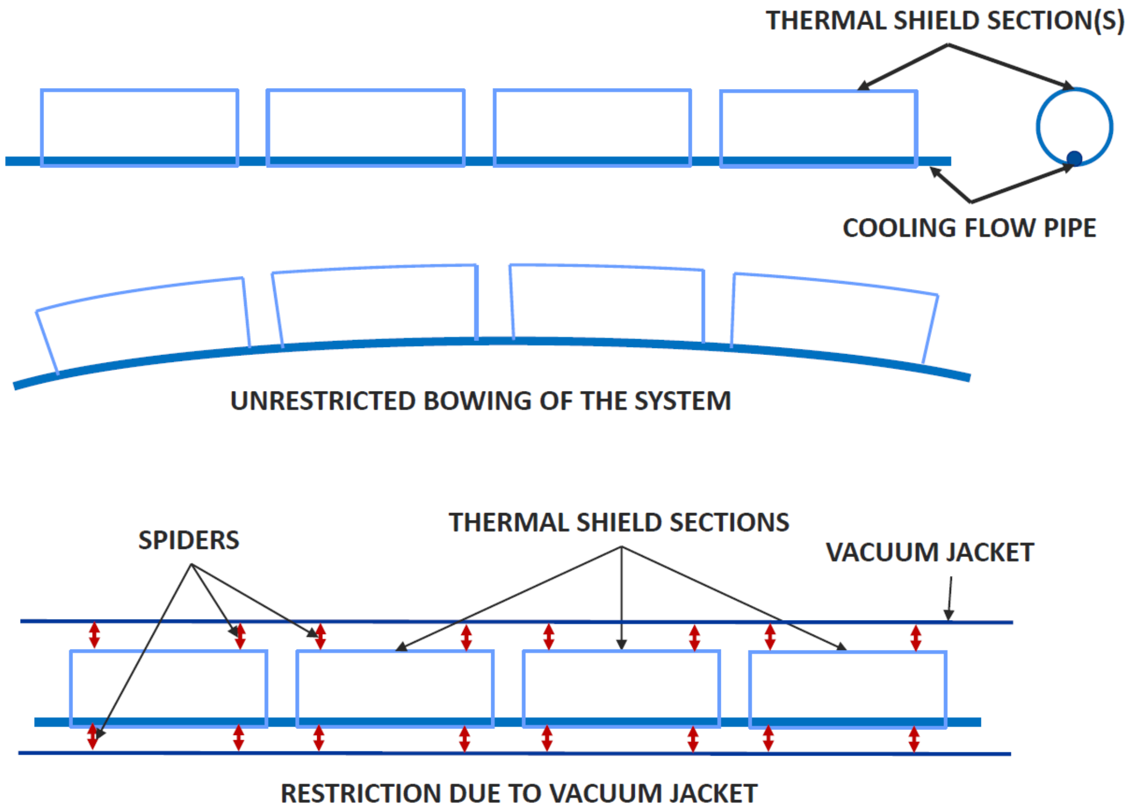
1. Hot part of the shield resists the contraction of the cold part (Thermal stresses)



Problem Description

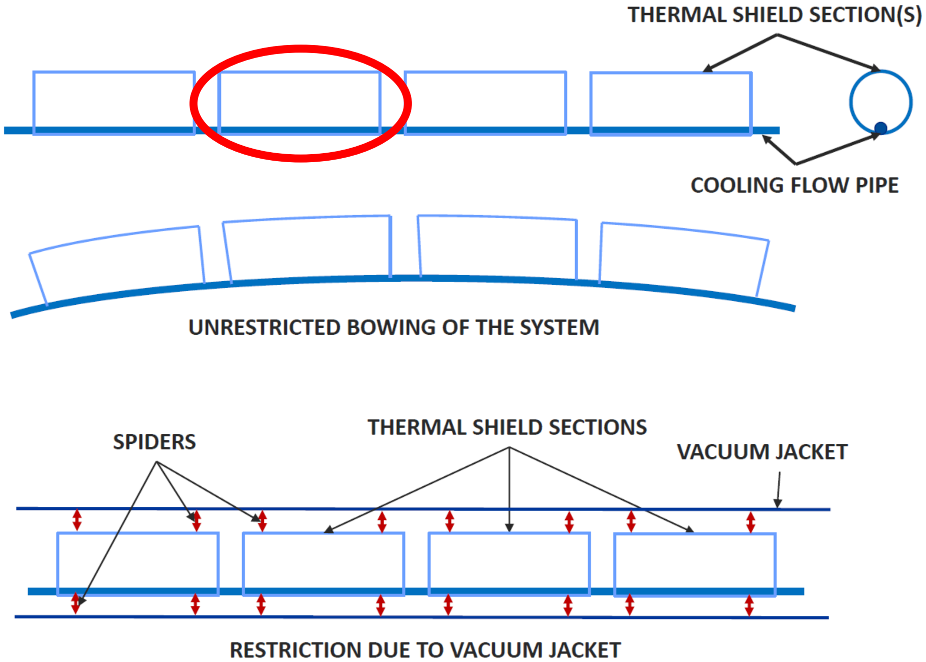
Stresses are induced because of following two reasons--

2. The vacuum jacket and the Line F prevent bowing deflection of the shield sections (bowing stresses)



Objective and Procedure

If the length of the shield section decreases, the thermal strains decrease, thus reducing the stresses



Geometric model of fixed diameter and thickness and variable length

↓

Apply supports and load

↓

Vary length to arrive at allowable value for safe stresses

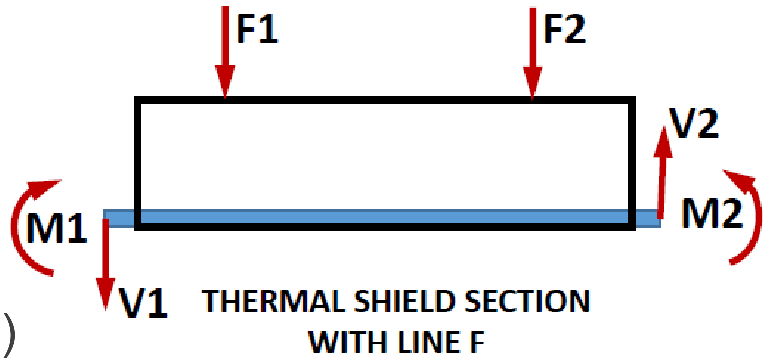
For diameters 6“ to 16”, thickness 3mm, 5mm

Modeling of the problem-Supports

1. Support conditions:
   – Forces F1, F2, V1, V2 and moments M1, M2 do not allow bowing deflection

(F1, F2 – forces exerted by the vacuum jacket)

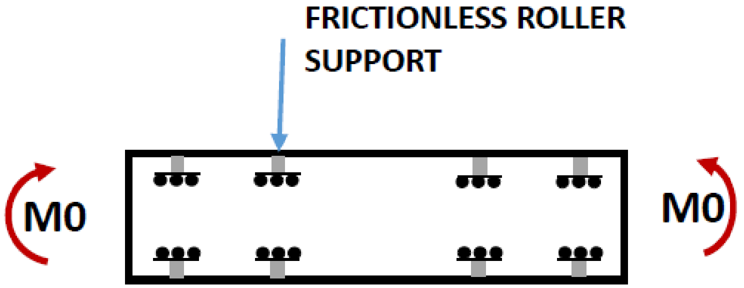
(M1, M2, V1 and V2 are the end reactions)



Support conditions: Approximated

Pure bending with symmetrical frictionless roller supports

(M0 is moment reaction due to supports)



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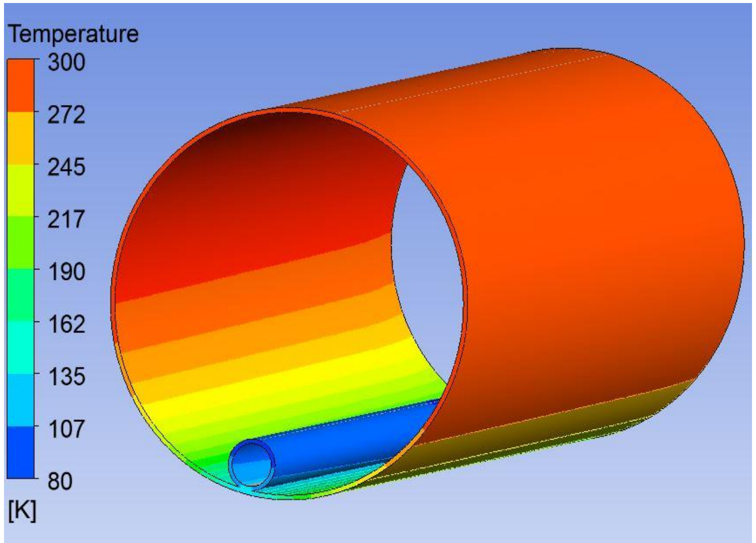
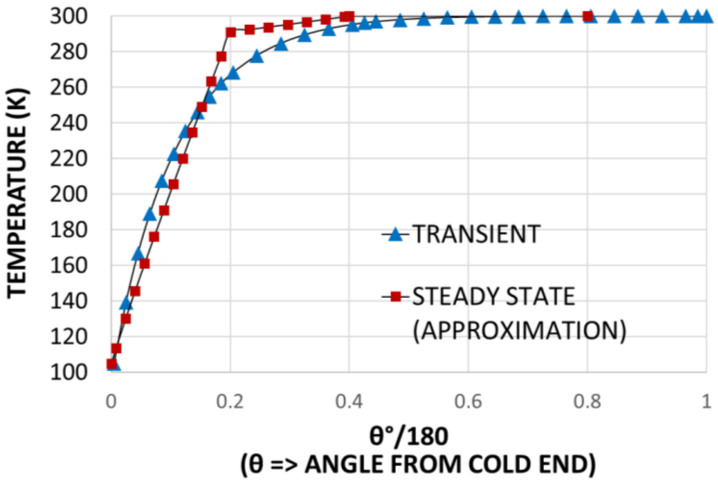
Modeling of the problem-Load

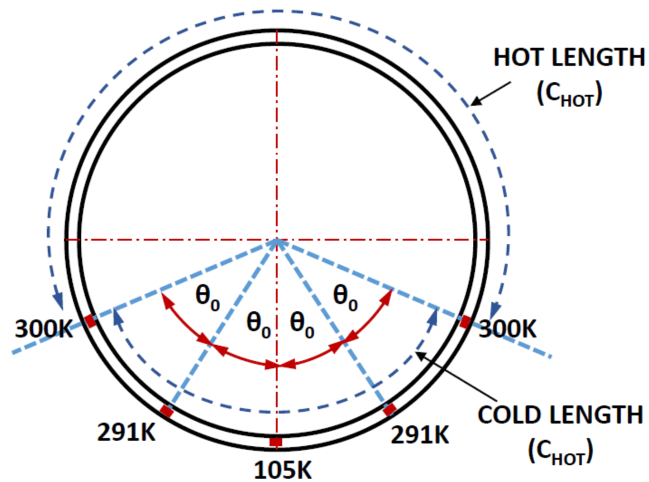
2. Load (temperature distribution)
   - Temperature distribution in case of transient cooldown problem
   - ϕ10” shield section, 10ft long
   - 10g/s helium flow at 12bara, 80K



Load (APPROXIMATED)

Approximated as steady state distribution





STEADY STATE DISTRIBUTION (θ_0=36°)

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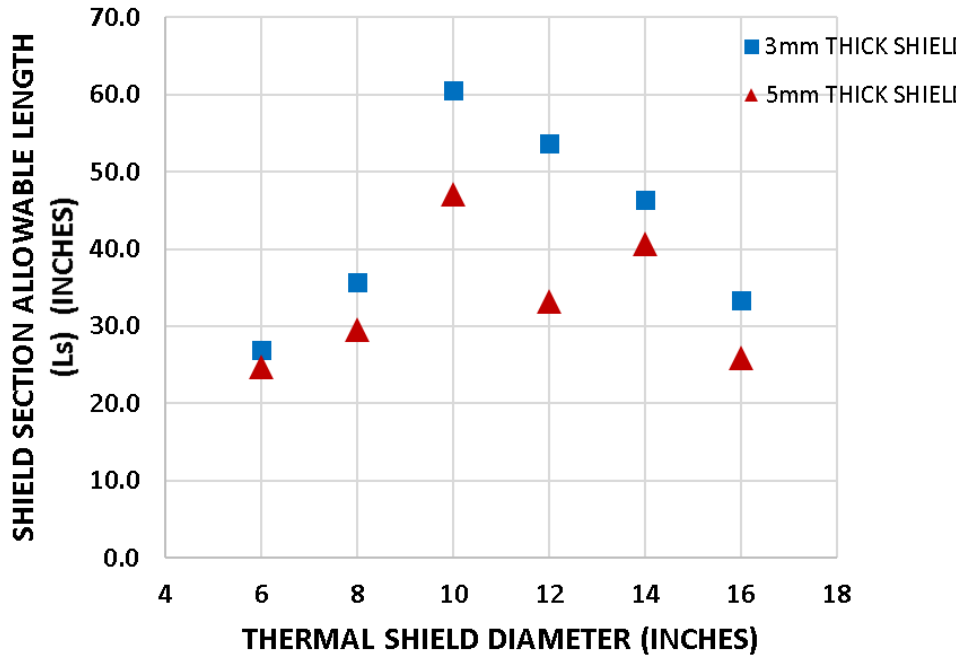
Assumptions

Key Assumptions:-

- 10g/s of helium, at 12bar and 80K, through Line F is considered as the maximum possible cooling flow
- Temperature is constant along thickness
- The thermal strains incident on the thermal shield do not have nature of a cyclic load. Hence, these are considered as primary loads for evaluation of safe stresses

Results and discussions

The allowable lengths (Ls) of the thermal shield sections are plotted for different diameter values on X-axis for thickness 3mm and 5mm as shown in the figure



Criteria for allowable stress

$P_l + P_b \leq S_{pl}$ ....ASME VIII, Div 2

$P_l = Primary\ local\ membrane\ stress$

$P_b = Primary\ local\ bending\ stress$

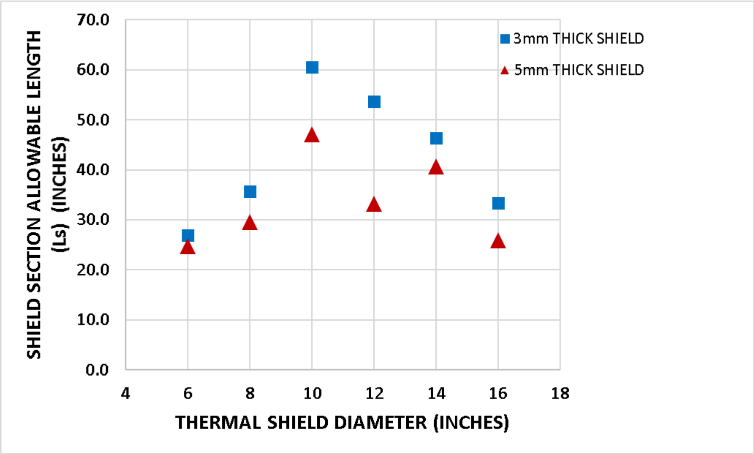
$S_{pl} = Allowable\ stress\ value$

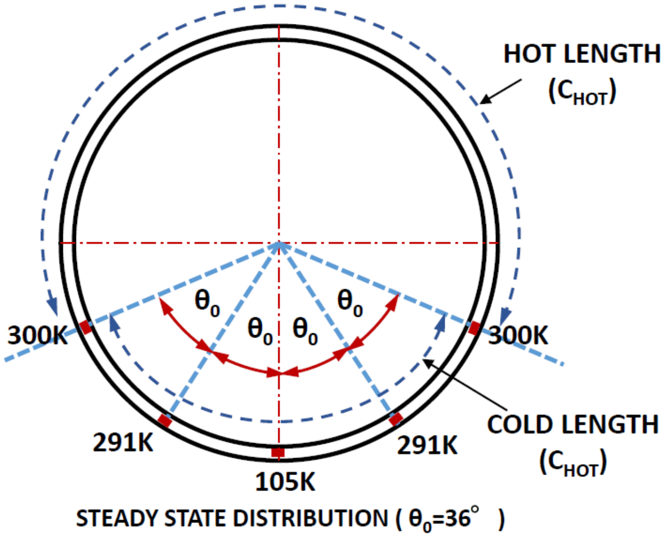
$S_{pl} = Yield\ stress\ (S_y) forStainless\ steel$ (2.07 X 10^8 N/m^2)

Results and discussions

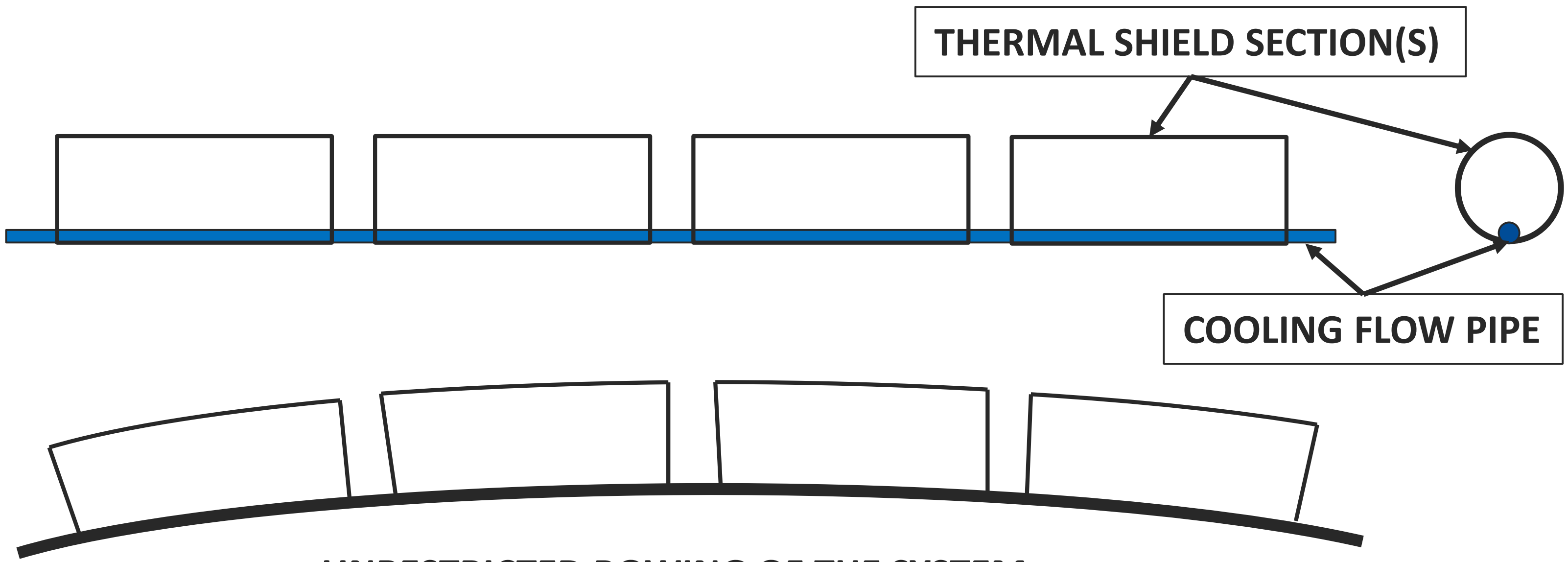
- Flexibility decreases with increase in diameter
- Flexibility decreases with increase in thickness
- As diameter increases the hot length increases. however the angle θ_0 is not modified for smaller diameters - hence conservative loads due to higher thermal gradients

Safe lengths can be selected for equal or lower thickness from the data points without rigorous analysis

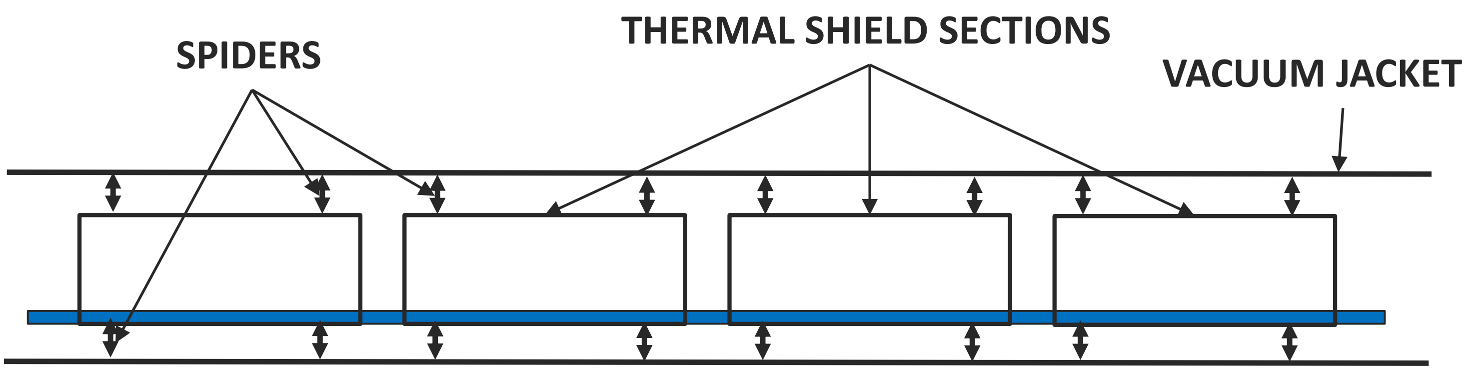




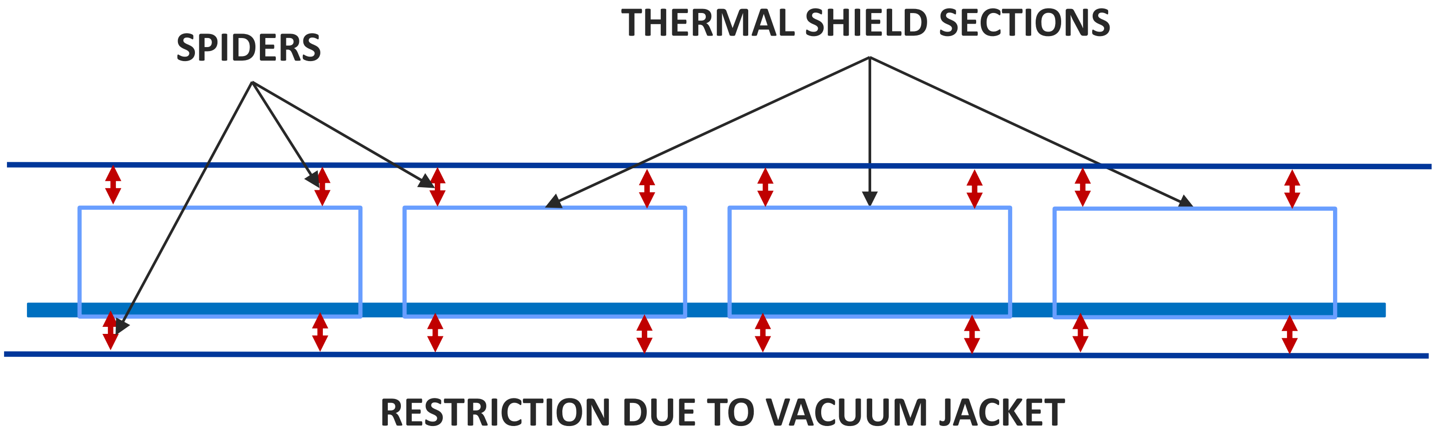
Thank you for your attention

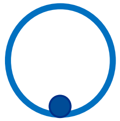


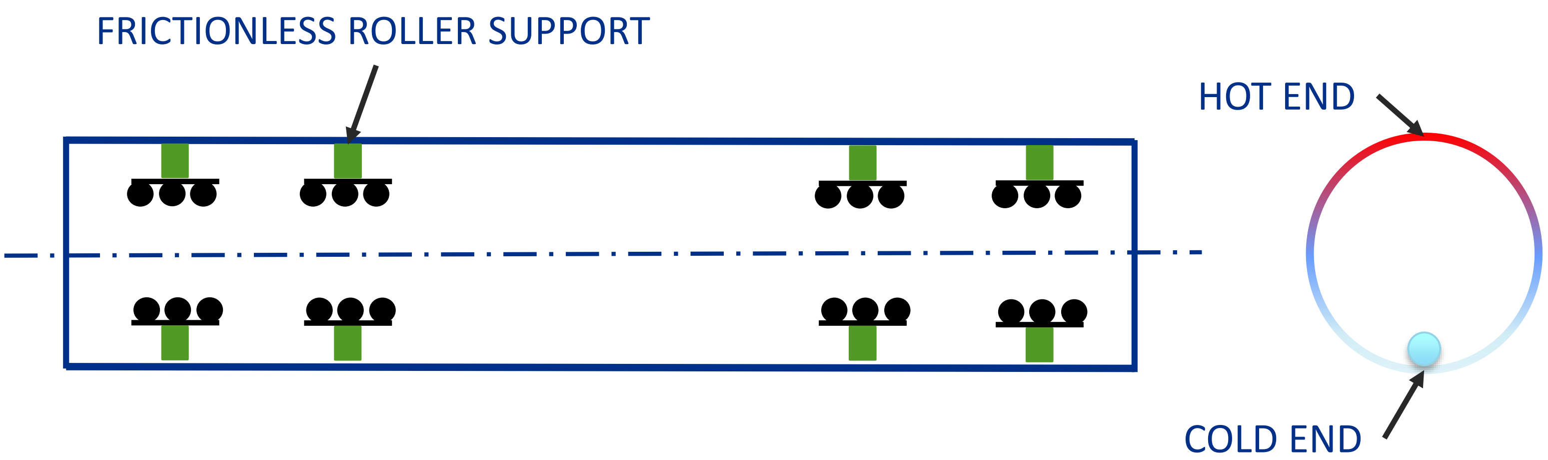
UNRESTRICTED BOWING OF THE SYSTEM



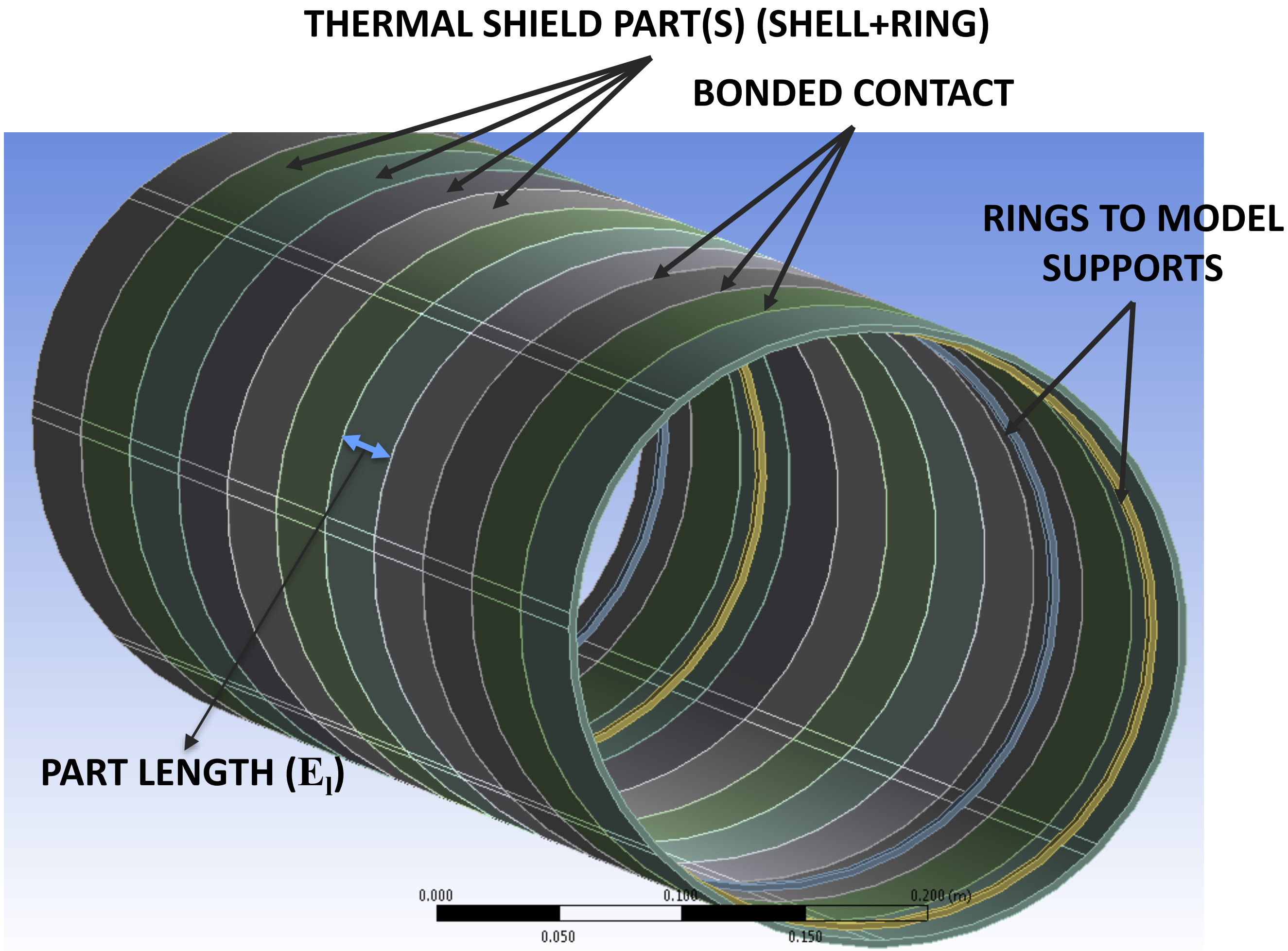
RESTRICTION DUE TO VACUUM JACKET


SPIDERS
THERMAL SHIELD SECTIONS
RESTRICTION DUE TO VACUUM JACKET

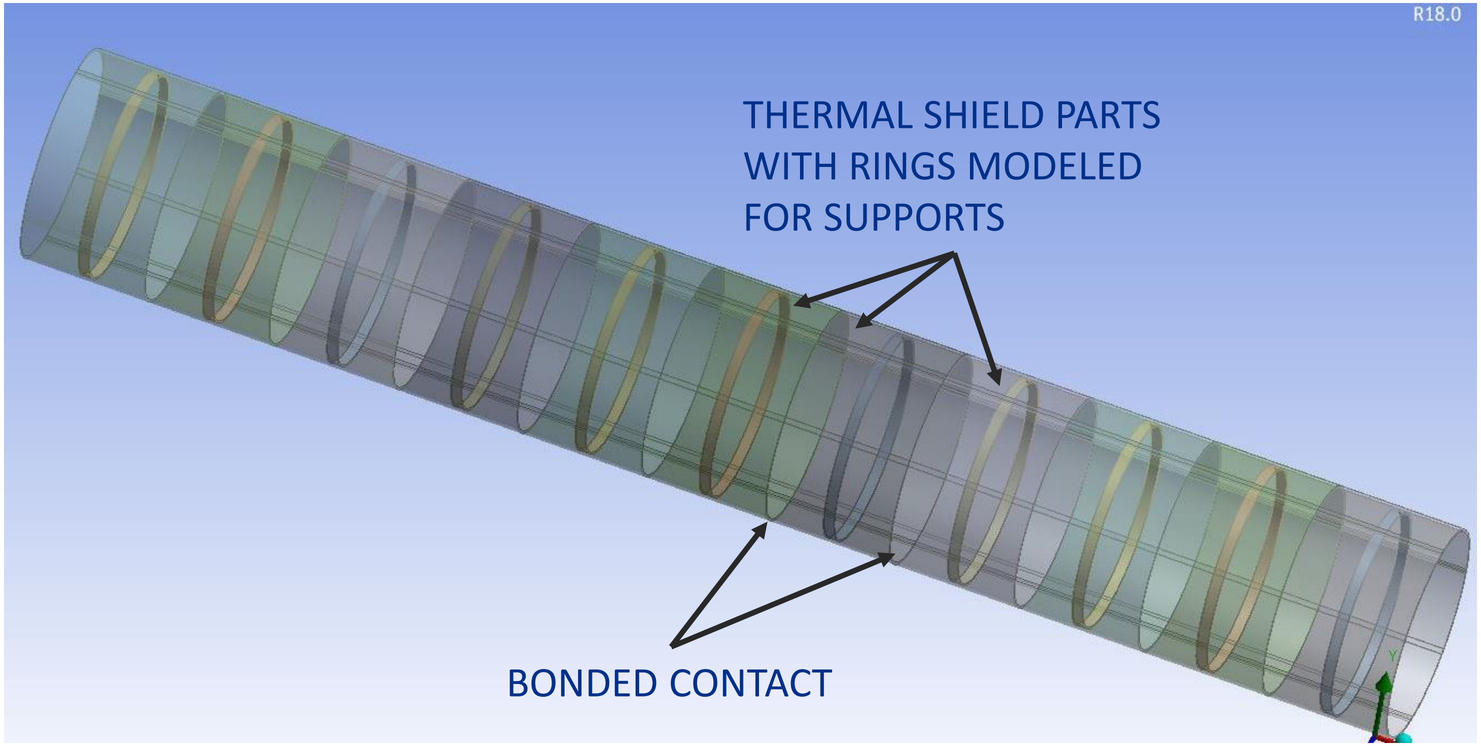




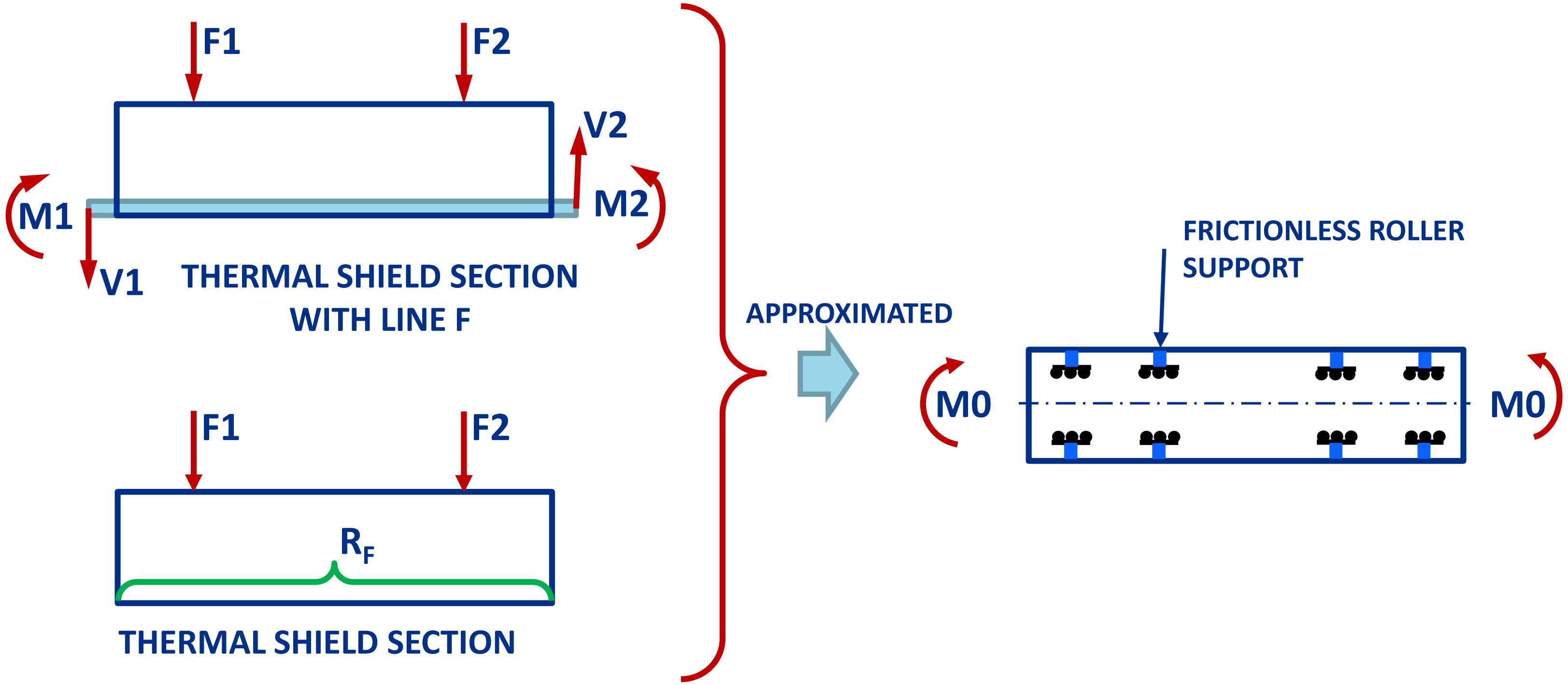
BOUNDARY CONDITIONS FOR SIMULATING THE RESTRICTIONS TO FREE DEFORMATION



GEOMETRIC MODEL OF THERMAL SHIELD FOR STRUCTURAL ANALYSIS (UNWANTED RINGS AND PARTS SUPPRESSED)

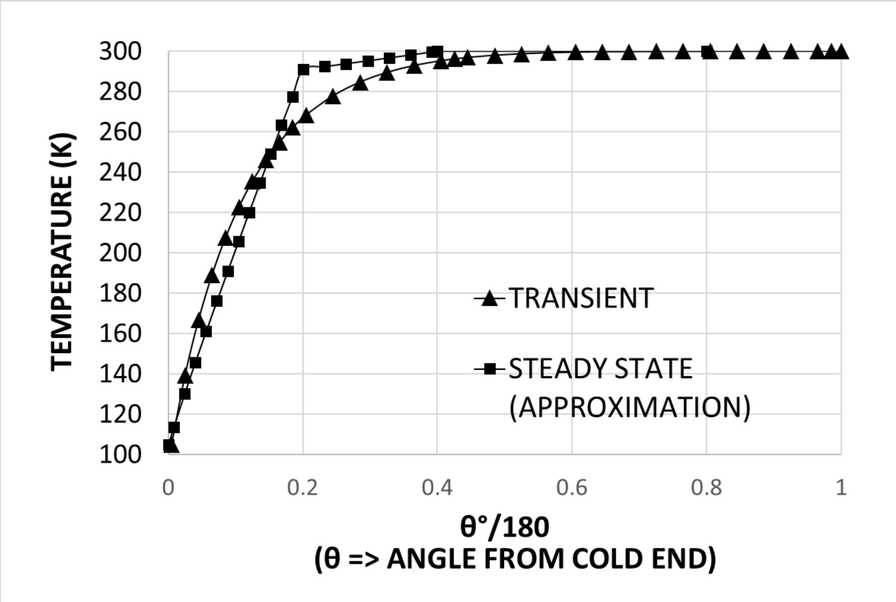


GEOMETRIC MODEL FOR THERMAL SHIELD ANALYSIS

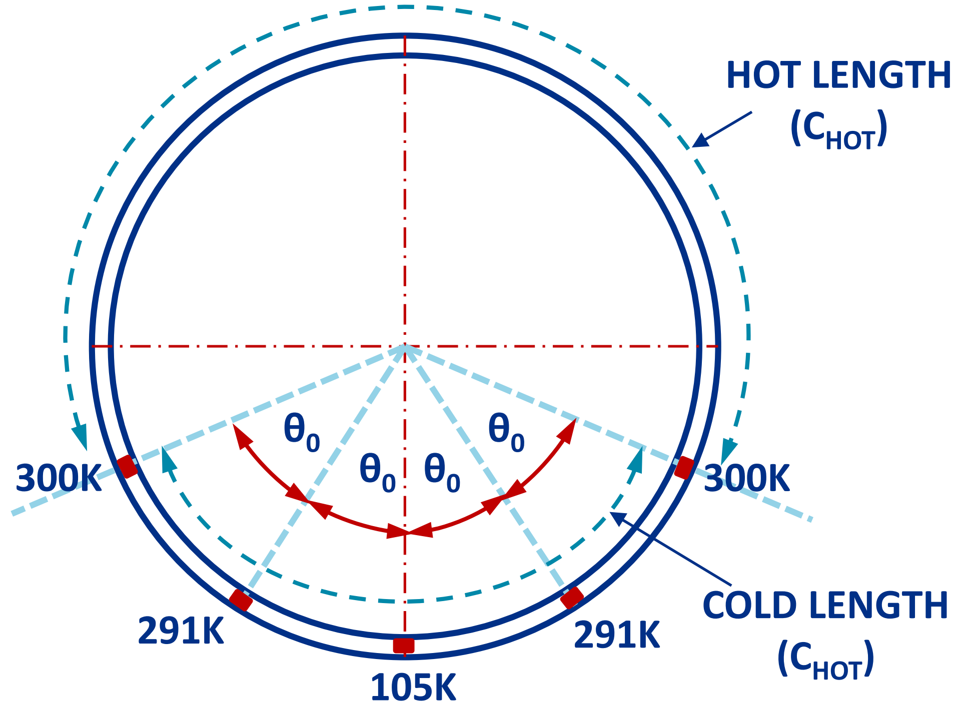


FREE BODY DIAGRAM FOR THE THERMAL SHIELD AND CONSEQUENT APPROXIMATION OF THE SUPPORT CONDITIONS

THERMAL SHIELD SECTION – SUPPORTS AND REACTION LOADS



TEMPERATURE (K)
300
280
260
240
220
200
180
160
140
120
100
0
0.2
0.4
0.6
0.8
1
TRANSIENT
STEADY STATE
(APPROXIMATION)
θ°/180
(θ => ANGLE FROM COLD END)



HOT LENGTH
(C_{HOT})
θ0
θ0
θ0
θ0
300K
300K
291K
291K
105K
COLD LENGTH
(C_{HOT})
STEADY STATE DISTRIBUTION (θ_0=36°)