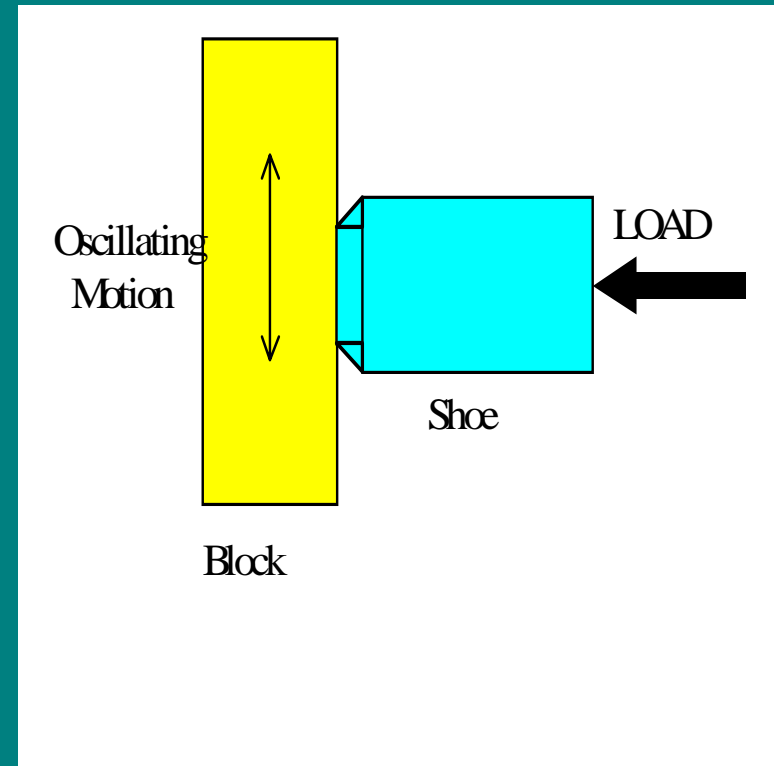


*Results of Wear and Corrosion Testing
Performed in Accordance with
Gas Turbine Engine JTP*

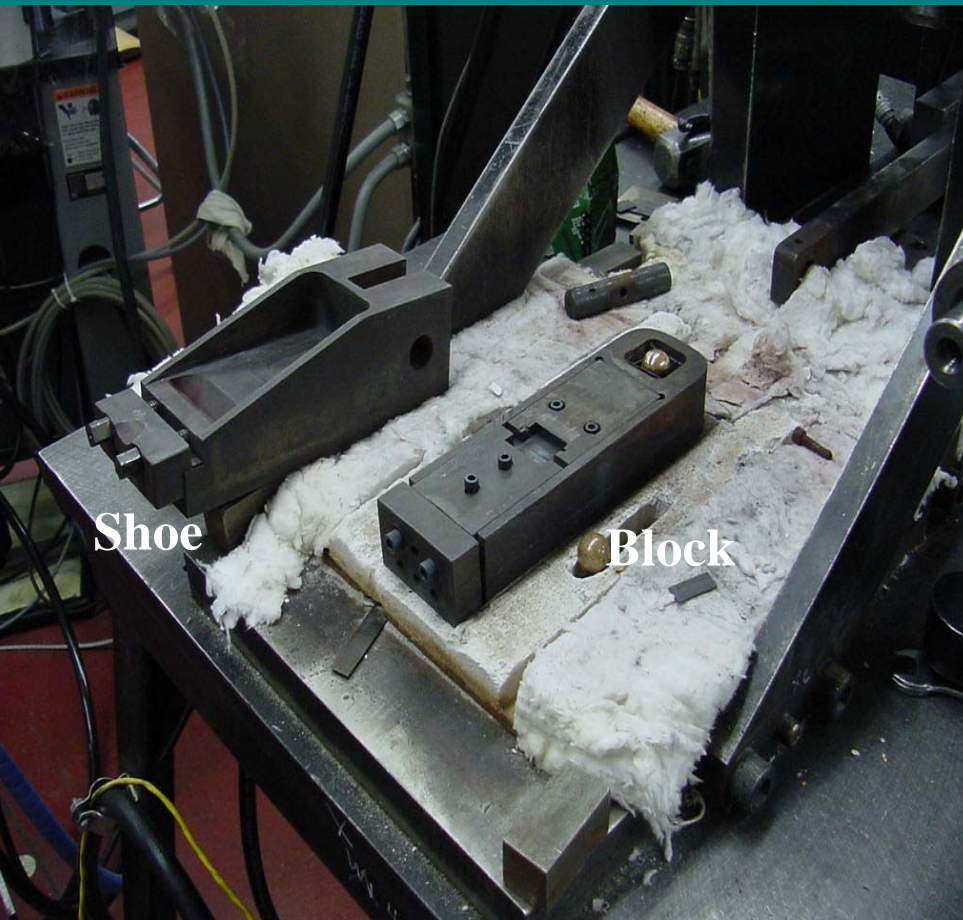
*Presented at:
HCAT Meeting
20-21 July 2004*

Wear Testing

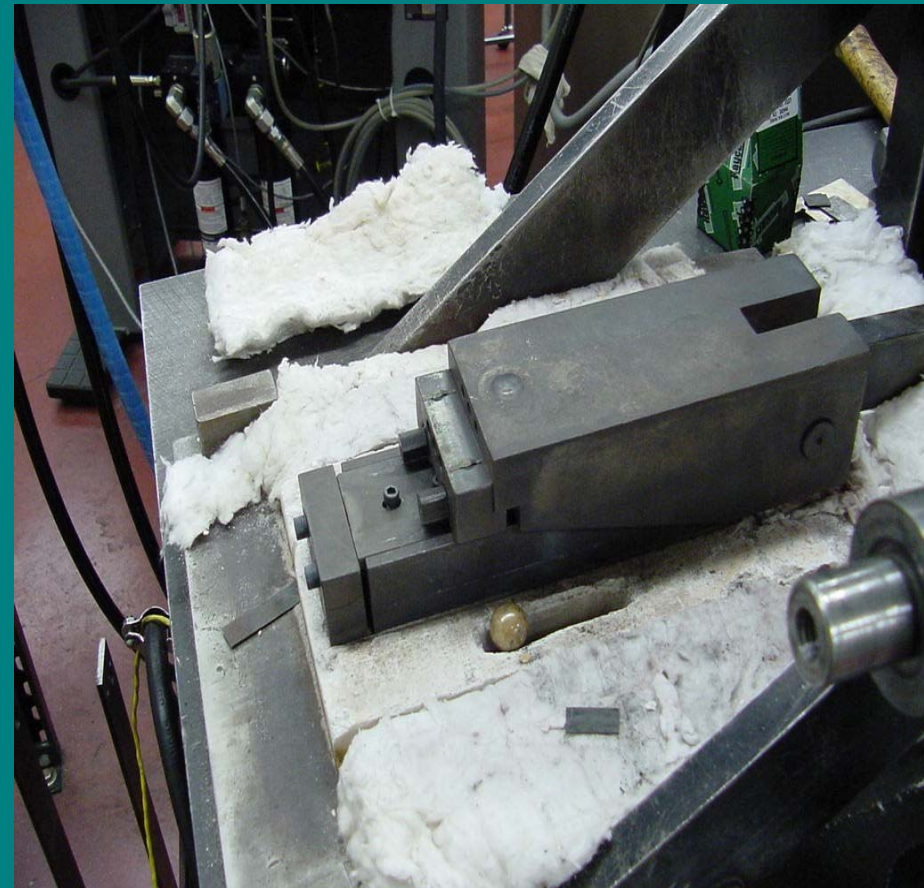
- *Fretting wear test; uncoated shoes sliding against coated 4340 blocks*
- *Coatings tested: EHC, HVOF WC/Co, HVOF Cr₃C₂/NiCr, HVOF T-800 and plasma T-400 (all thicknesses 0.003")*
- *Shoes tested: M50 steel, IN-718, IN-901 and 17-4PH (size of contact area is 0.06" x 1.125")*
- *Load 3600 lbs (stress 53 ksi)*
- *Duration: 25,000 cycles (except 12,500 cycles of IN-901 shoes)*
- *Frequency: 4 Hz*
- *Stroke length: 0.060"*
- *Temperature: 300 or 750 °F*
- *Lubrication: none*



Wear Test Apparatus



**Components of Wear Test Apparatus
Disassembled**



**Components of Wear Test Apparatus
Assembled**

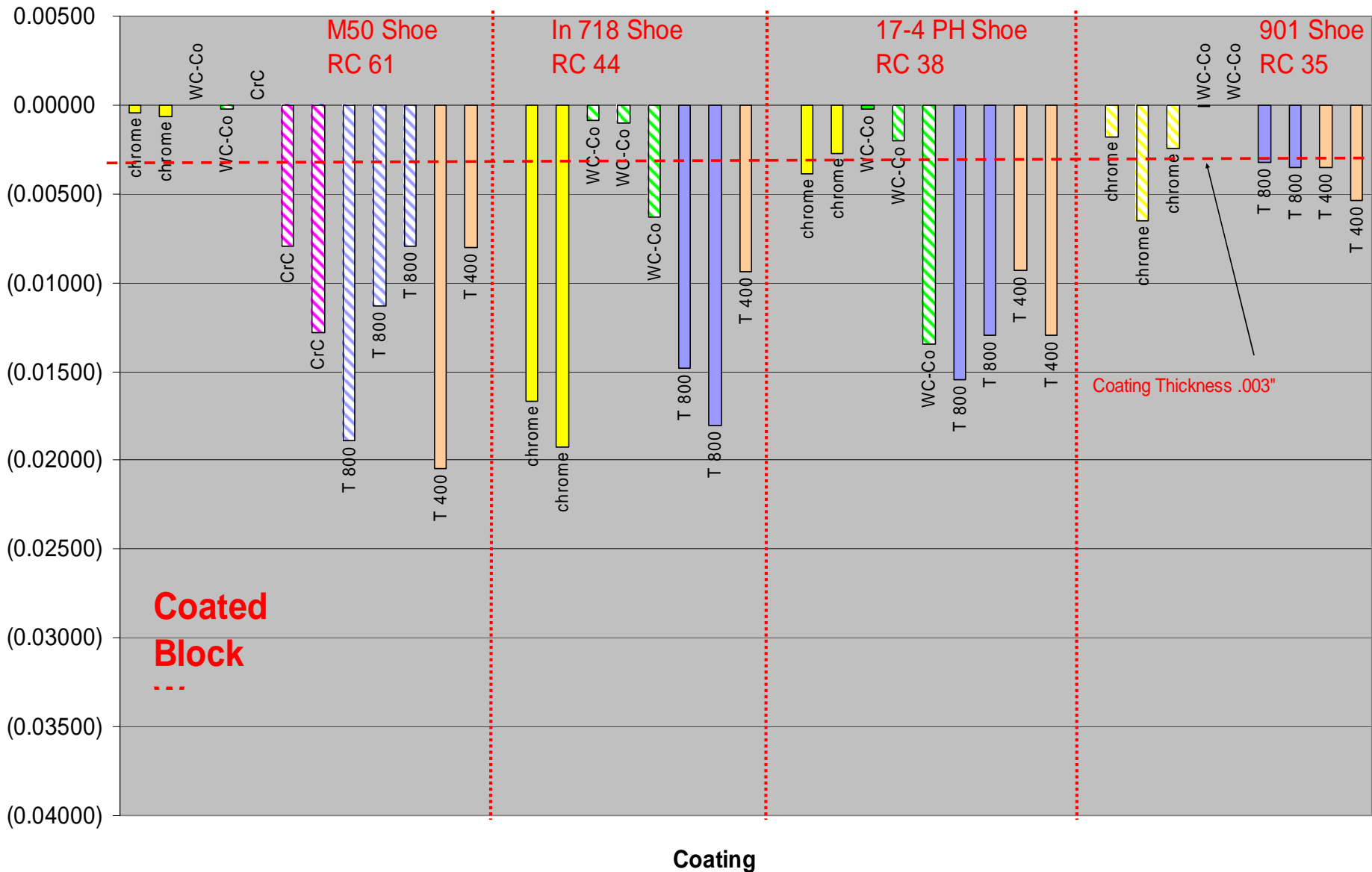
Wear Testing

- *In general, two tests conducted for each specific condition of coating/shoe/temperature*
- *Wear coefficients on coated blocks determined by taking average of nine equally spaced measurements of the depth relative to original surface made across width of wear scar*
- *Wear coefficients on shoes determined by taking nine equally spaced measurements of material removed across width of the face*
- *Where widely different results obtained for two tests, a third test was conducted*
- *Unfortunately, amount of wear on coated block greatly exceeded thickness of coating*

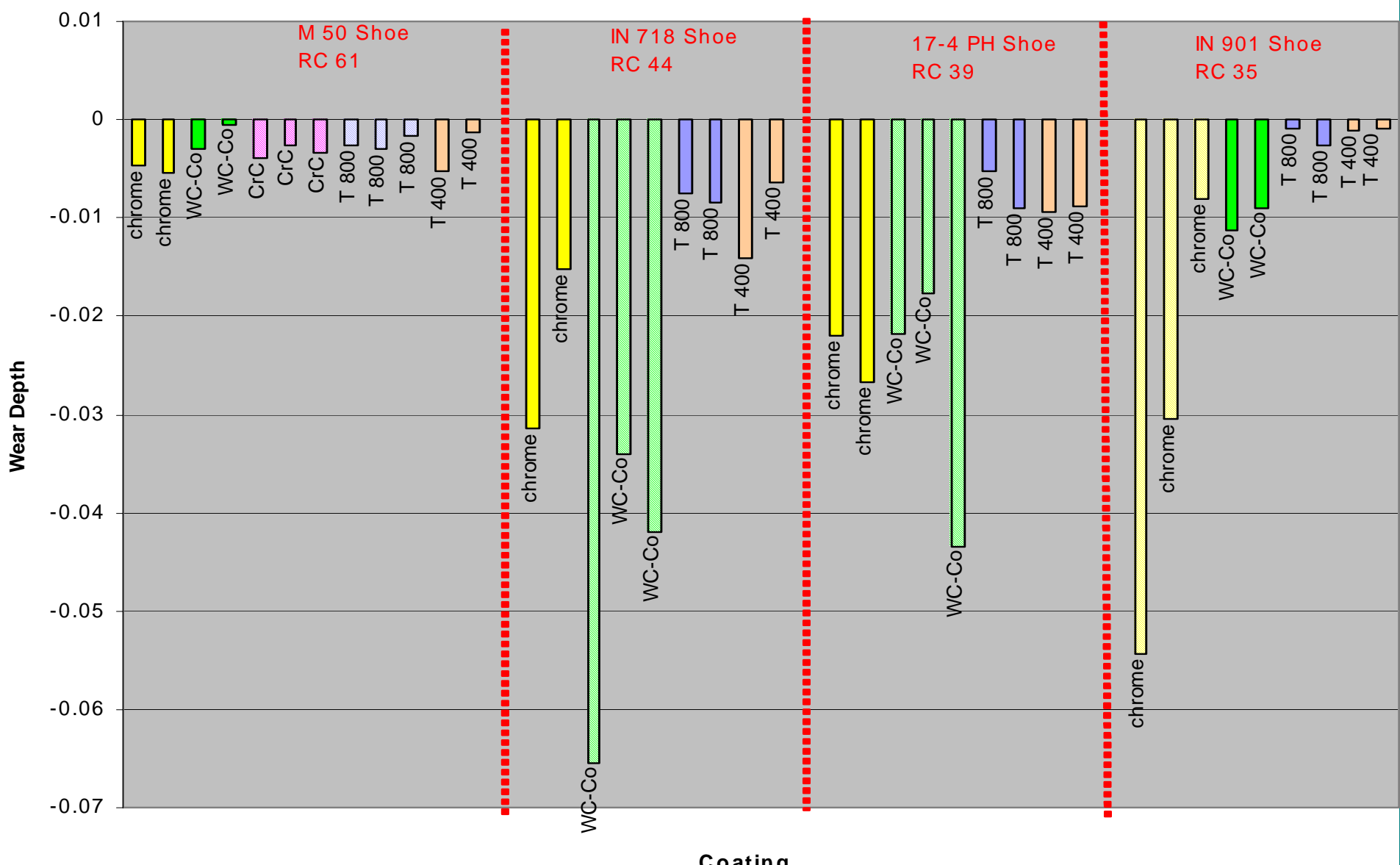
Vickers Hardness Values for Coatings and Test Shoes

<u>Coating</u>	
EHC	950
HVOF WC/Co	1100
HVOF Cr ₃ C ₂ /NiCr	1000
HVOF T-800	700
PS T-400	550
<u>Shoe</u>	
M50	720
IN-718	430
17-4PH	380
IN-901	340

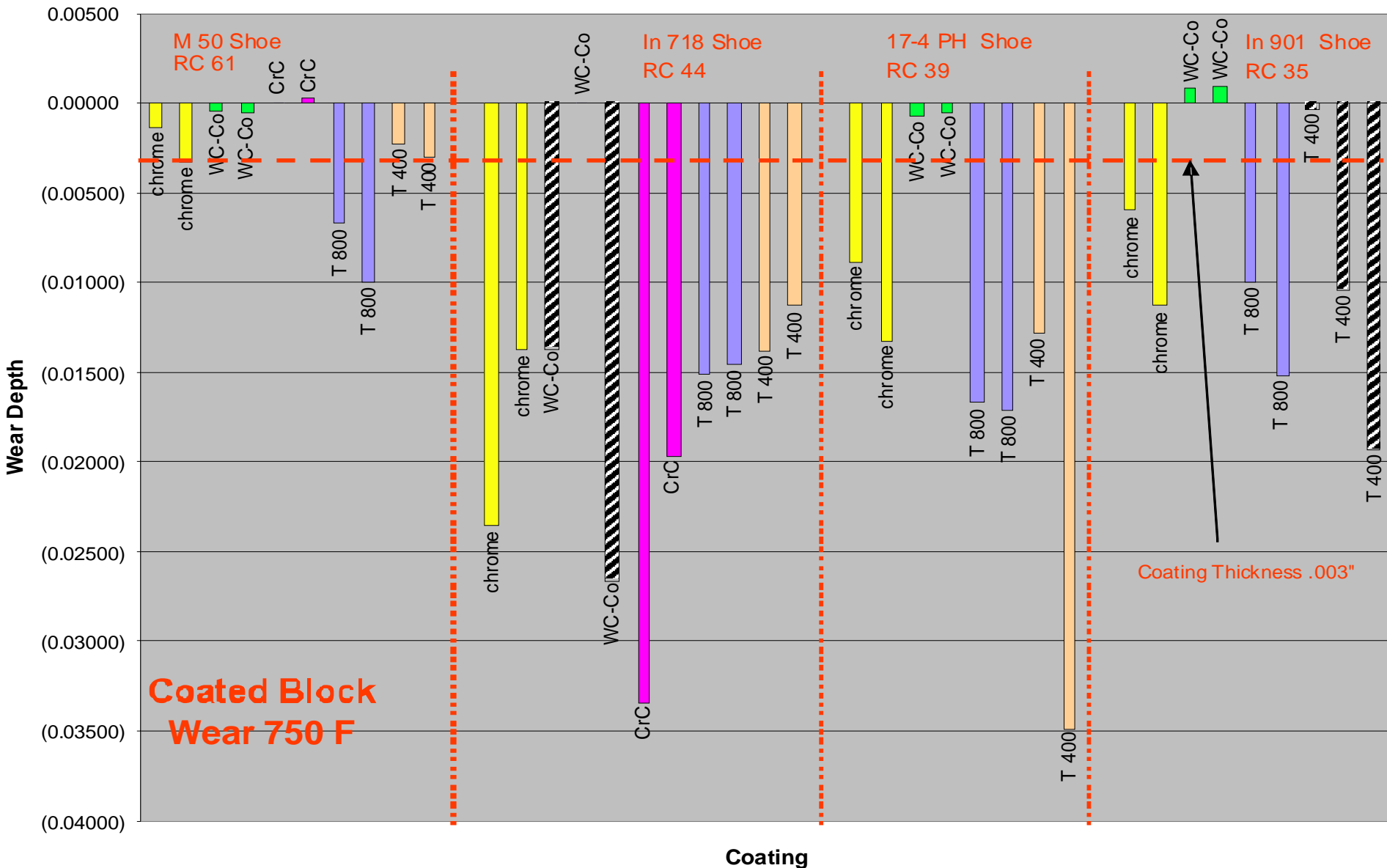
Wear Depths for Coated Blocks Sliding Against Four Different Shoe Materials at 300 °F



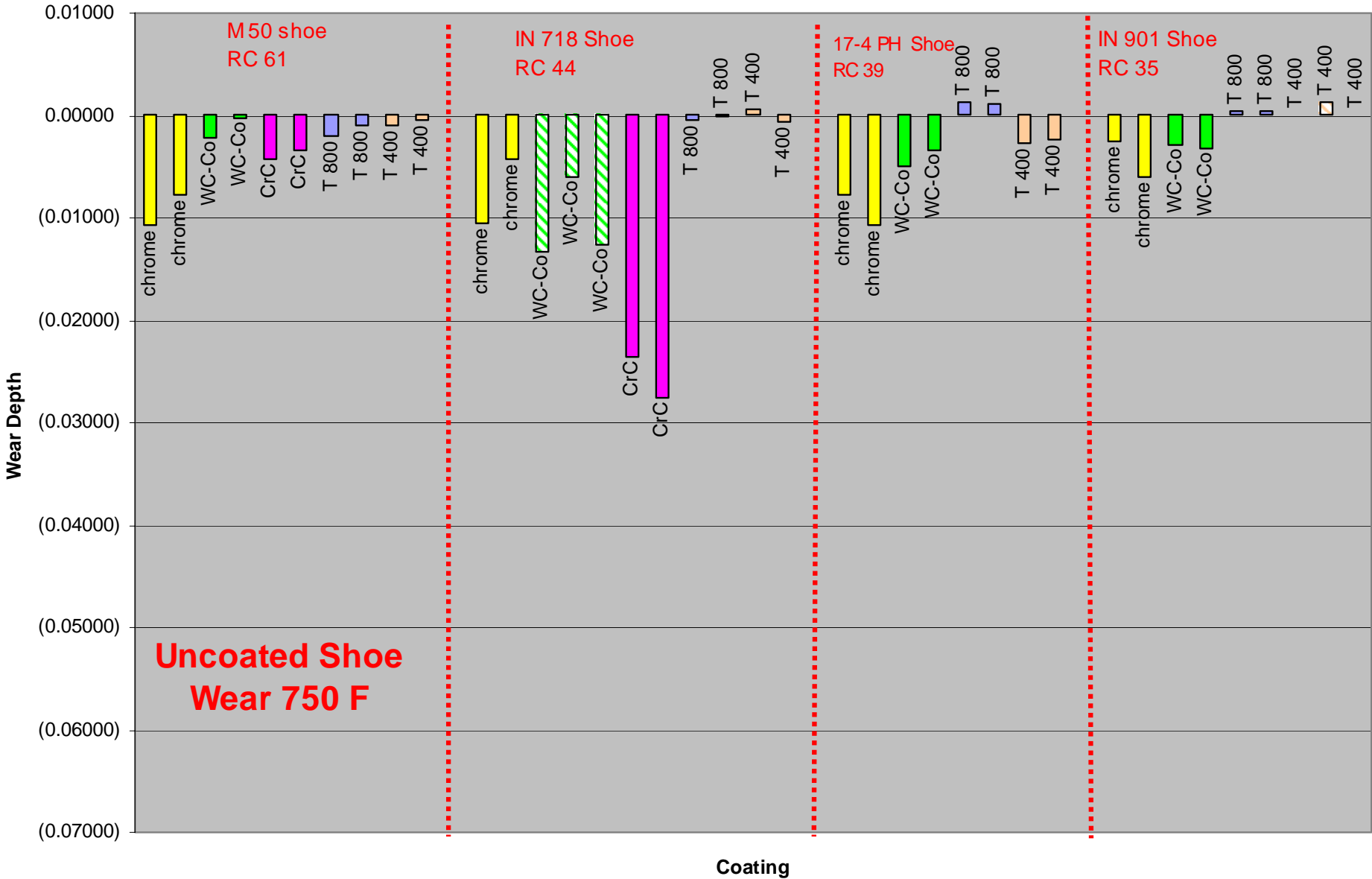
Wear Depths for Shoes Sliding Against Indicated Coatings at 300 °F



Wear Depths for Coated Blocks Sliding Against Four Different Shoe Materials at 750 °F



Wear Depths for Shoes Sliding Against Indicated Coatings at 750 °F



Summary of Wear Test Results

- *Analysis of wear on coated blocks complicated by fact that for some tests all of coating had been removed early in the test*
- *Reasonably definitive results for testing at 750 °F*
 - *WC/Co performed significantly better than EHC and other thermal spray coatings for all mating materials except for the IN-718 shoes where performance was comparable to EHC (valid for coating wear and total system wear)*
- *Results for testing at 300 °F less definitive*
 - *For sliding against M50, WC/Co is superior coating*
 - *For sliding against IN-718, wear rates of WC/Co low but wear of IN-718 shoe very high; HVOF T-800 and PS T-400 provide total system wear comparable to EHC*
 - *For sliding against 17-4PH, total system performance for all thermal spray coatings comparable to EHC*
 - *For sliding against IN-901, WC/Co coatings superior to EHC for coating wear and total system wear*

Corrosion Testing

- *Specimens were 4340 3" x 4" x 0.25"-thick plates, 4340 1"-diameter x 6"-long rods or IN-718 1"-diameter, 6"-long rods*
- *Coatings evaluated were EHC (in some cases with 0.0015"-thick sulfamate Ni underlayer), HVOF Tribaloy 400, HVOF Tribaloy 800, HVOF Cr₃C₂/NiCr, or plasma spray Tribaloy 400; coating thicknesses after grinding were 0.003" or 0.015"*
- *Three specimens for each condition*
- *ASTM B117 testing performed in salt fog generated from 5% NaCl solution with pH between 6.5 and 7.2; temperature at 35 C*
- *Total exposure time 1000 hours, at which time specimens removed and loose corrosion product and blisters removed using abrasive pad; protection ratings assigned based on ASTM B537 protocol*

Coated 4340 Steel Plates After 1000 Hours

PS T400

HVOF T400

EHC

0.003''-
thick

4340-01

4340-22

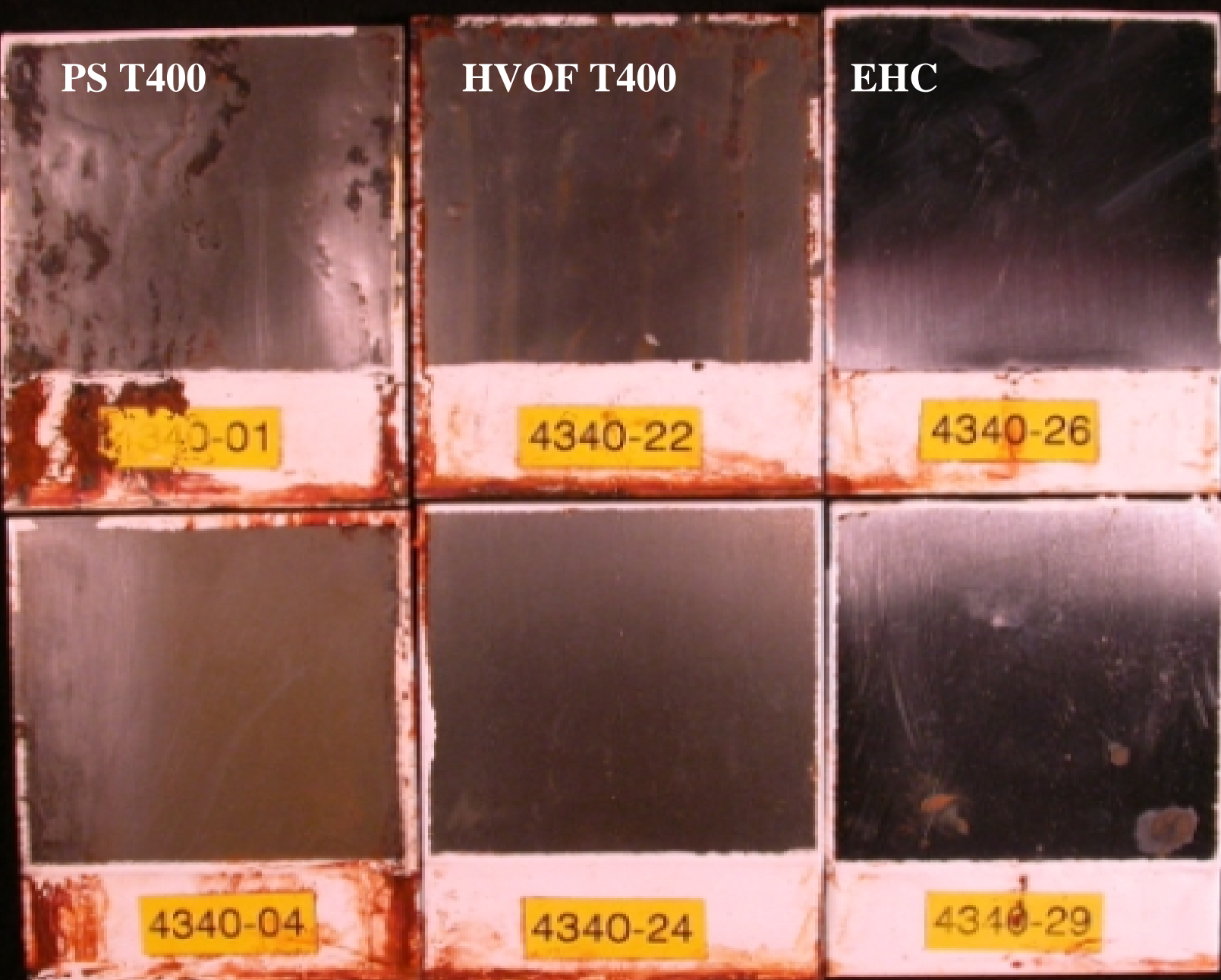
4340-26

0.015''-
thick

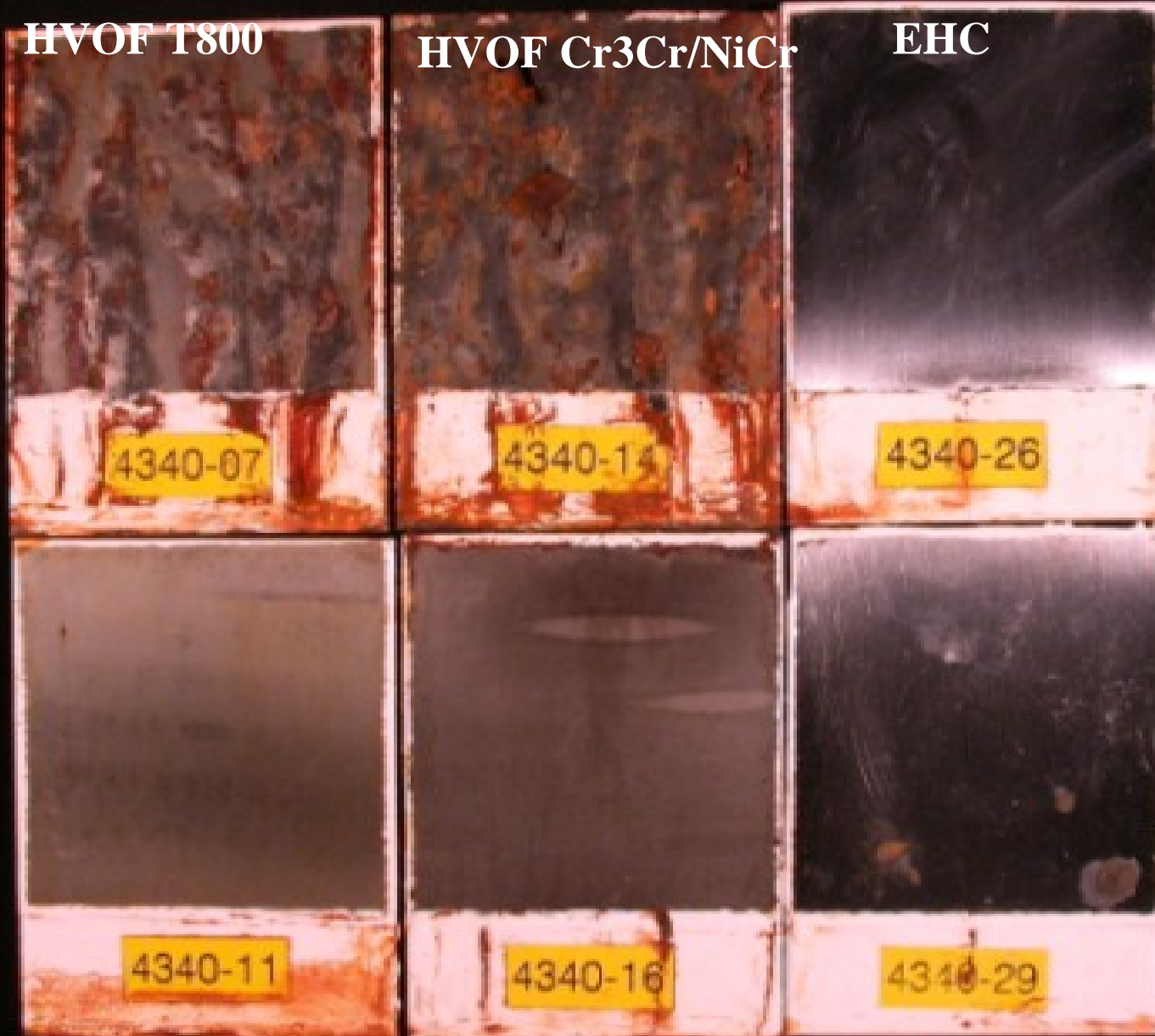
4340-04

4340-24

4340-29



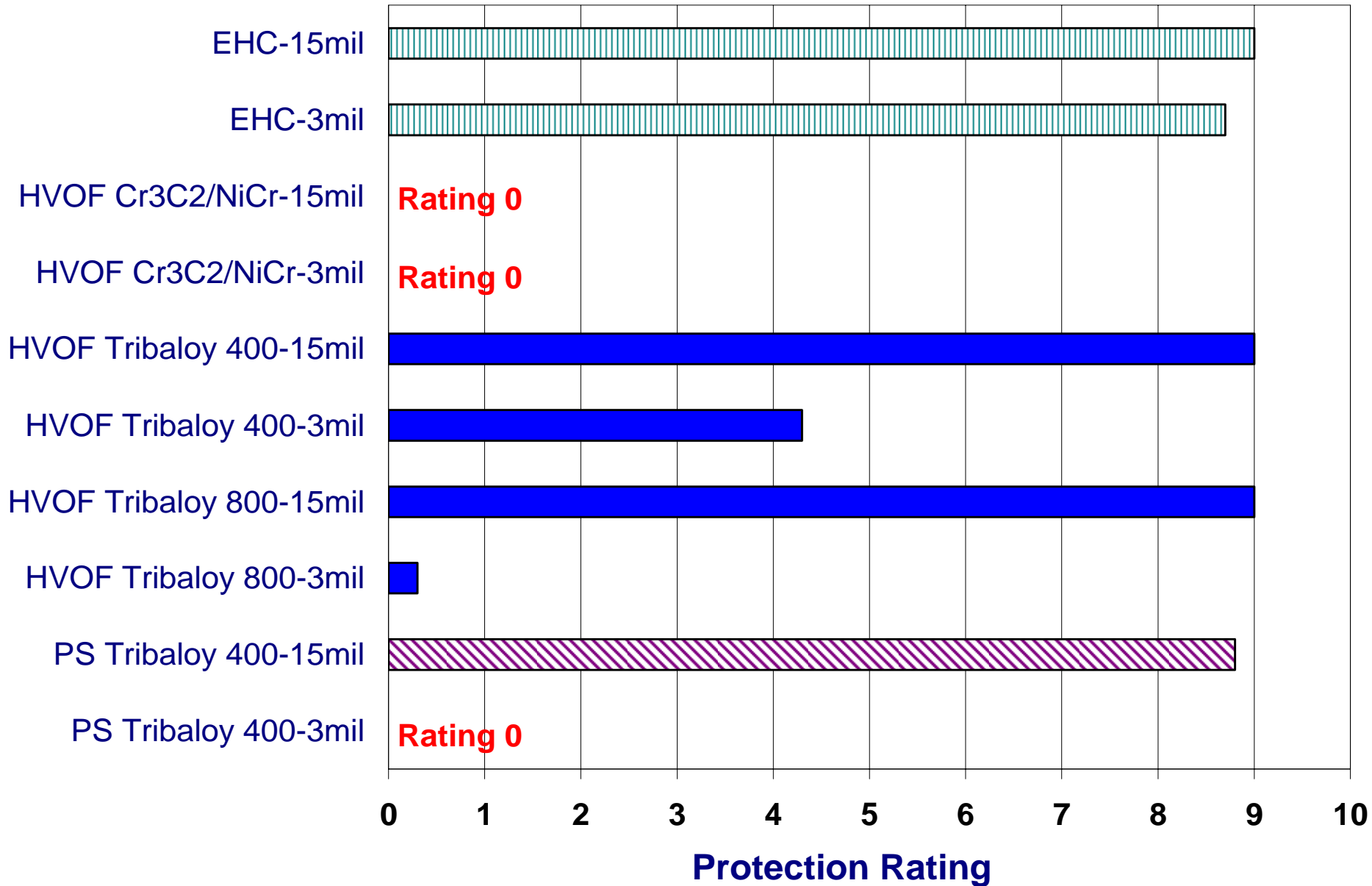
Coated 4340 Steel Plates After 1000 Hours



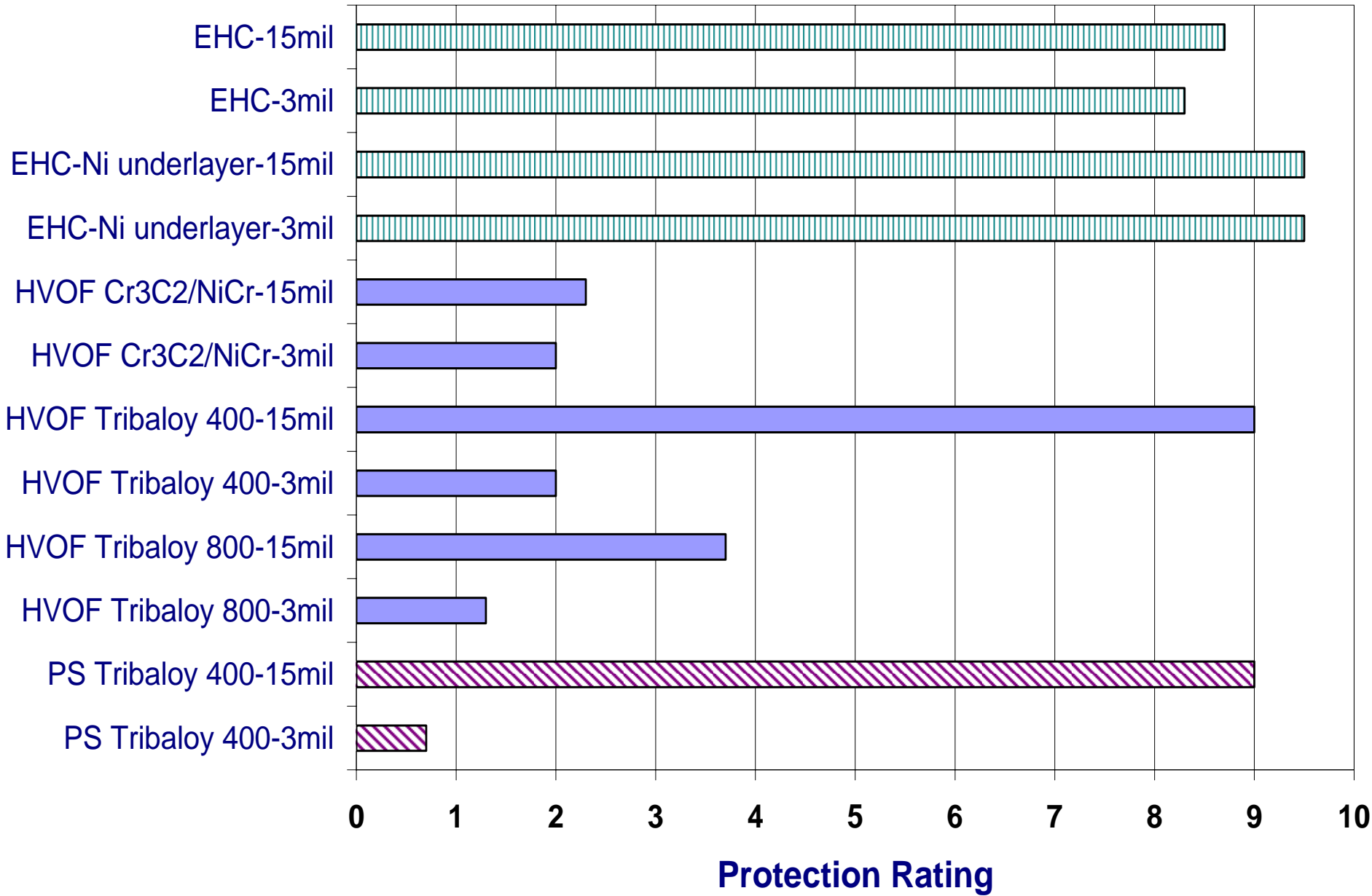
0.003"-
thick

0.015"-
thick

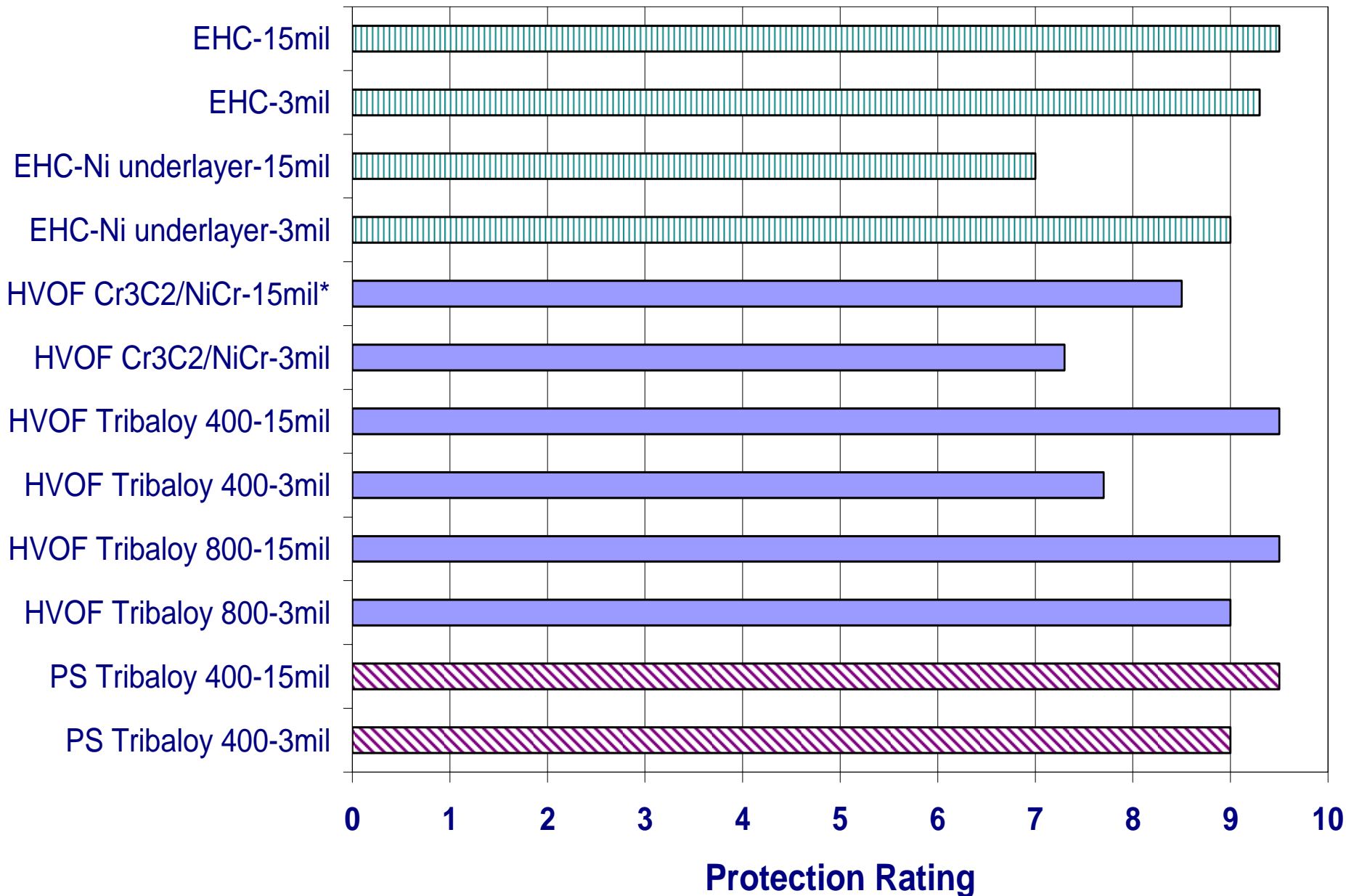
Protection Ratings for Coated 4340 Plates



Protection Ratings for Coated 4340 Rods



Protection Ratings for Coated 4340 Rods



Summary of B117 Corrosion Results

- *For 0.003"-thick coatings on 4340 steel, EHC coatings were substantially superior to all thermal spray coatings*
- *For 0.015"-thick coatings on 4340 steel, performance of all thermal spray coatings was comparable to EHC except for $\text{Cr}_3\text{C}_2/\text{NiCr}$ which was inferior*
- *For all coatings deposited on IN-718, performance of thermal spray coatings was equivalent to that of EHC (very little corrosion in all cases)*