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DELAYED COKER DRUM CRACKING

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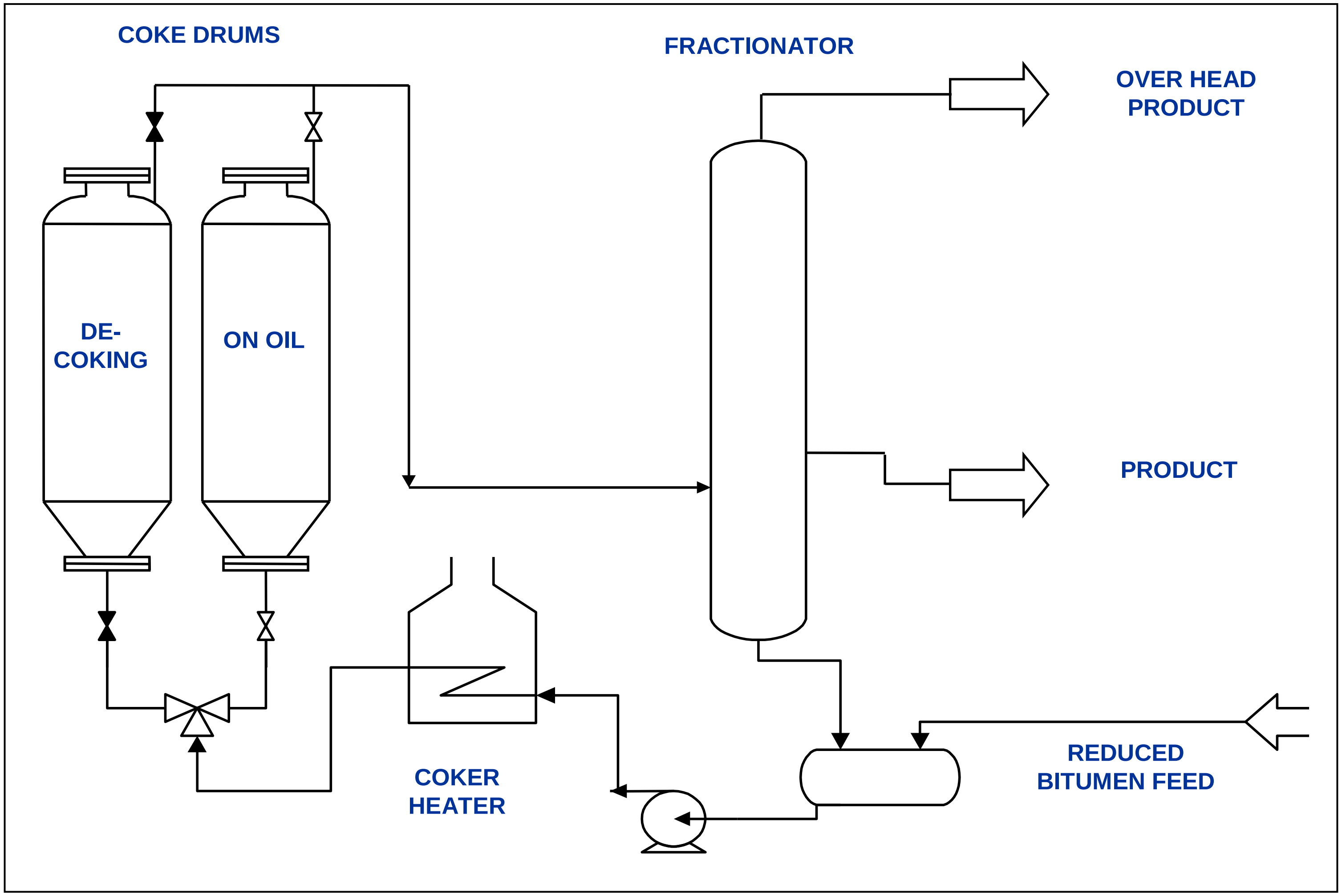
- Overview

  - Design code & criteria
  - Reliability & safety issues
  - Analytical study
  - Implications
  - Invitation

Why do coke drums fail?

Because they are [not intentionally] designed to fail.

- Delayed Coker Unit – DCU Operation



- Coker drums
  - large diameter [20’ – 30’]
  - long length [80’ – 90’]
  - materials of construction
    - carbon steel,
    - C – ½ Mo,
    - Cr – Mo [1, 1¼, 2¼, 3 Cr]
    - clad – TP 405, 410S
  - loading - cyclic pressure, thermal, live; dead weight

- Design code considerations
    - Vessels constructed to ASME VIII Div 1
    - ASME VIII Div 1
        - minimum thickness design based on pressure
        - UG 22 loadings to be considered include cyclic and dynamic reactions due to
            - pressure, temperature & mechanical loadings
    - recent design specifications refer to cyclic service conditions imposed by coke formation and decoking operations, BUT specific conditions are undefined, although *designer is asked to "consider these cyclic service conditions"*

    → designer *will ignore since specifics in "design spec" are lacking*

- Jurisdictional considerations

  - Jurisdictions have not challenged design procedure in past since

    - installations are successful
    - experience indicates that these specific vessel pressure boundary failures are reliability issues rather than pressure safety issues
    - however, need to be mindful of failure mechanisms and long life being achieved on some units → incubation period at end of which, failure rate may accelerate due to da/dn – i.e. crack growth is cycle dependant, loads are statistically distributed

- Reliability Issues

  - Weil & Rapasky – 1958 API coke drum survey
  - Thomas – 1968, 1980 API coke drum survey
  - 1996 API coke drum survey

  - major, consistent findings
    - deformation, growth & cracking of shell
    - irregular local warping of shell
    - cracking of skirt attachment weld

- Reliability Issues

  - Weil & Rapasky – 1958 API coke drum survey

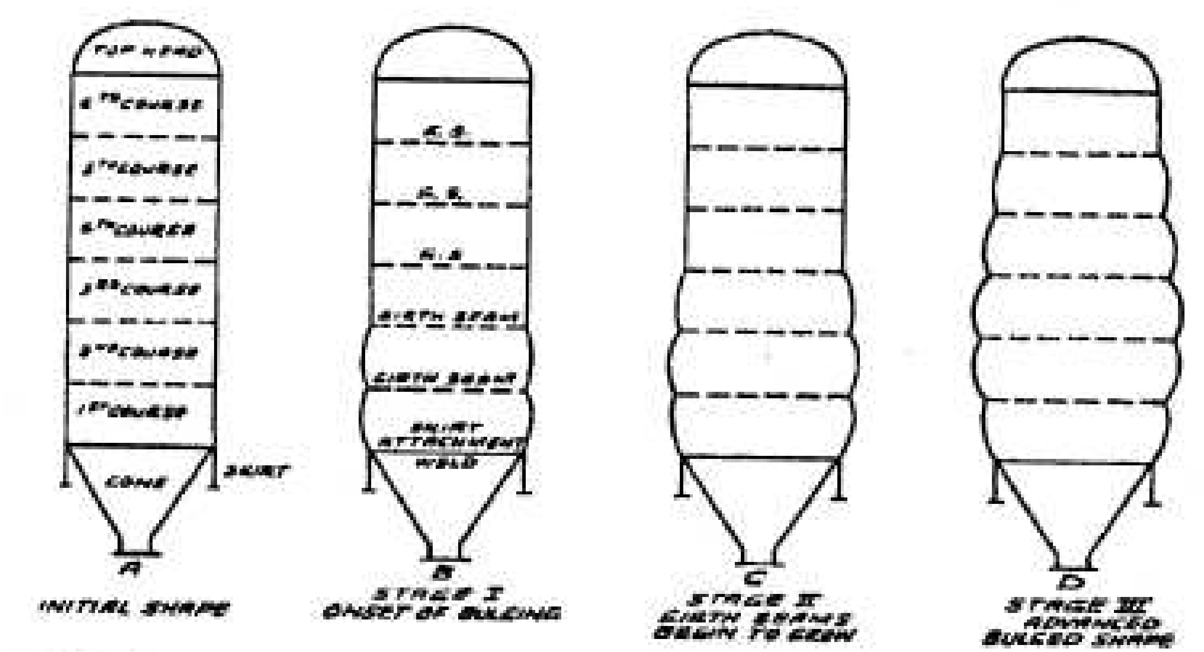
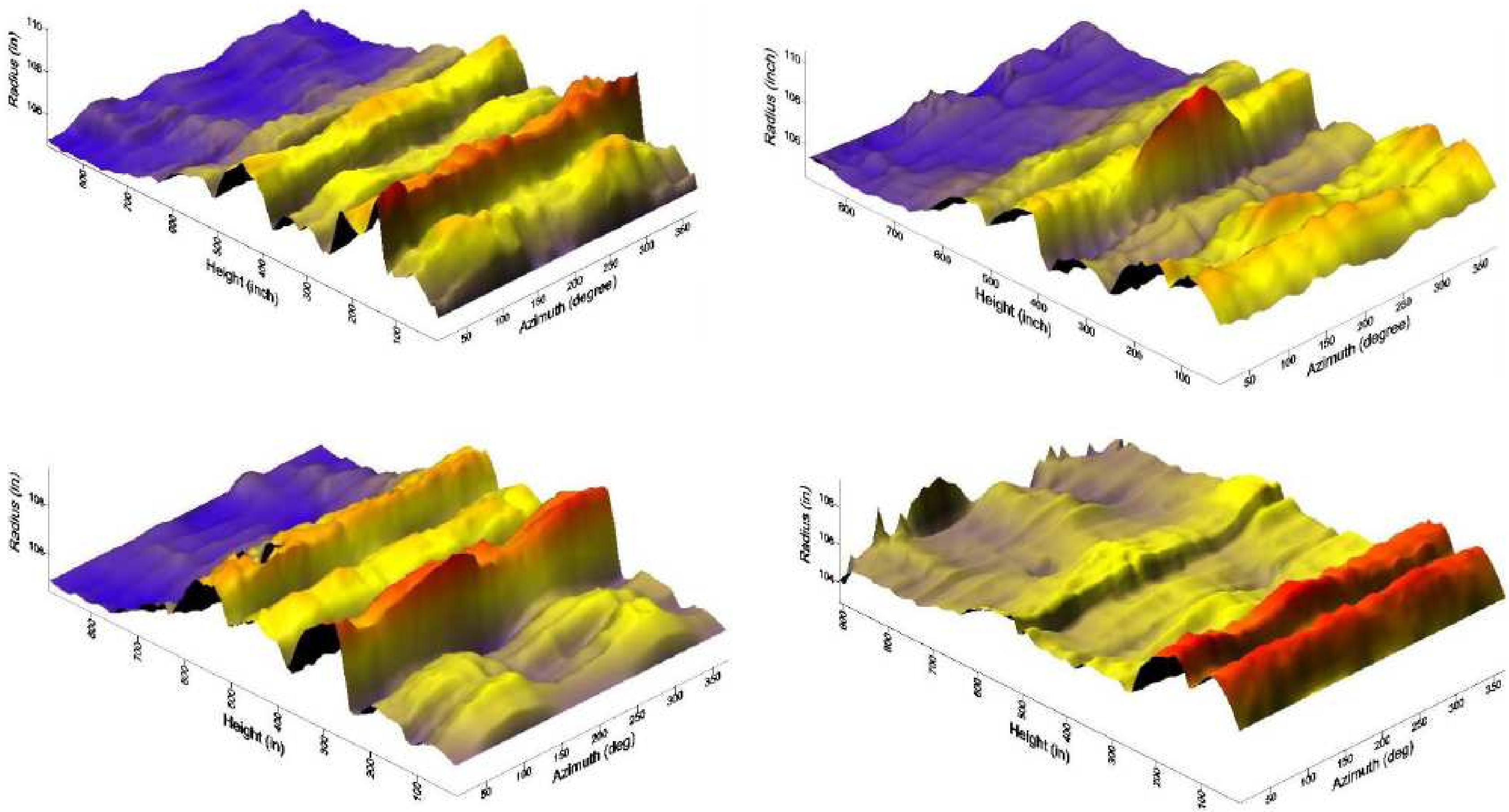


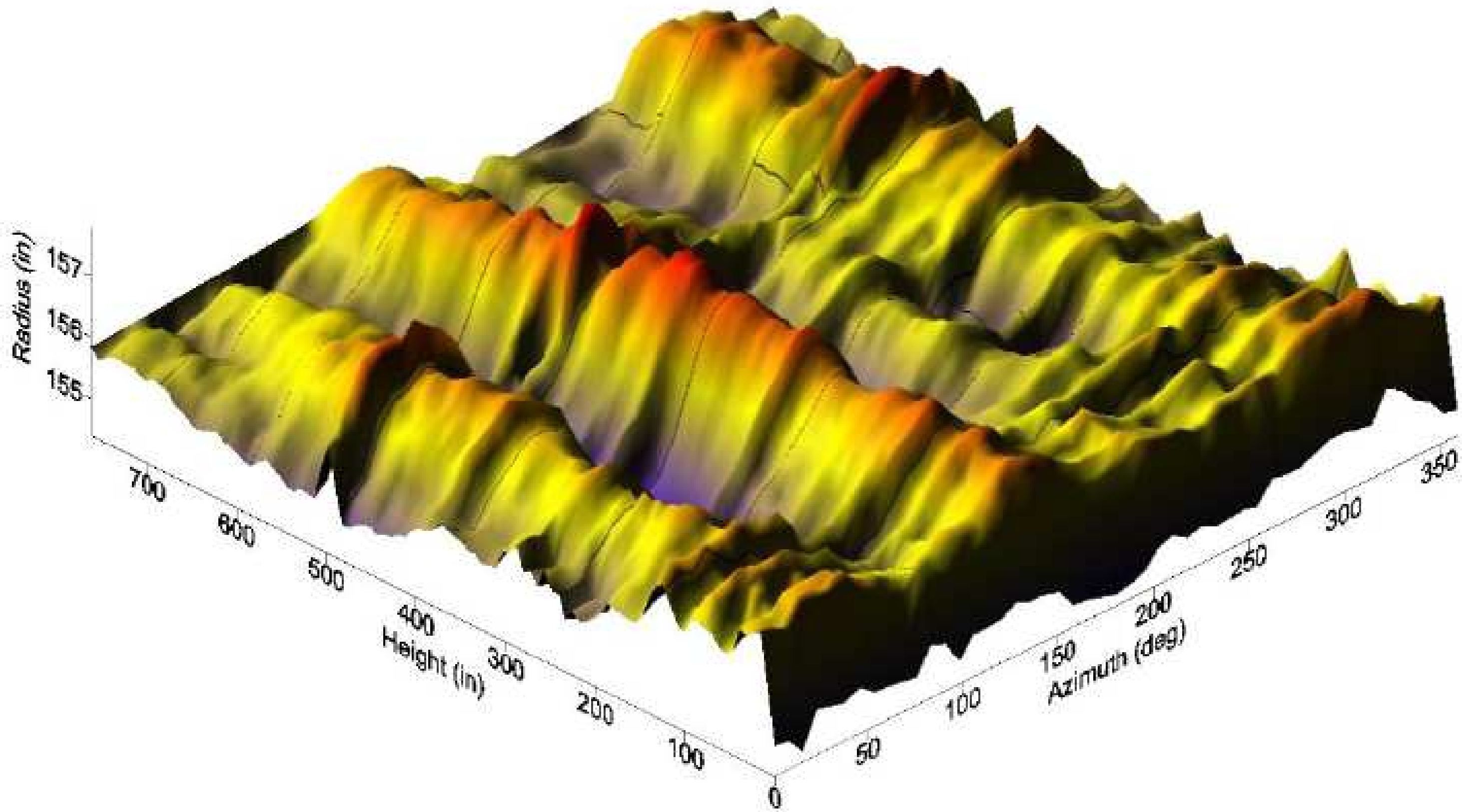
FIG. 1—Successive Stages in Bulging Deformation in Coke Drums (to an Exaggerated Scale).

- actual bulge behavior



Courtesy of CIA Inspection, Hannon ON & Stress Engineering, Houston TX

- actual bulge behavior



Courtesy of CIA Inspection, Hannon ON & Stress Engineering, Houston TX

- cracking associated with circumferential welds

- Safety Issues

  - Drum safety with regard to shell integrity issues is good
    - 1996 survey - 17 of 145 drums reported fires – but none damaging to adjacent equipment
    - not all through wall cracks resulted in fires
    - cracking can occur without bulging, but is not usual case

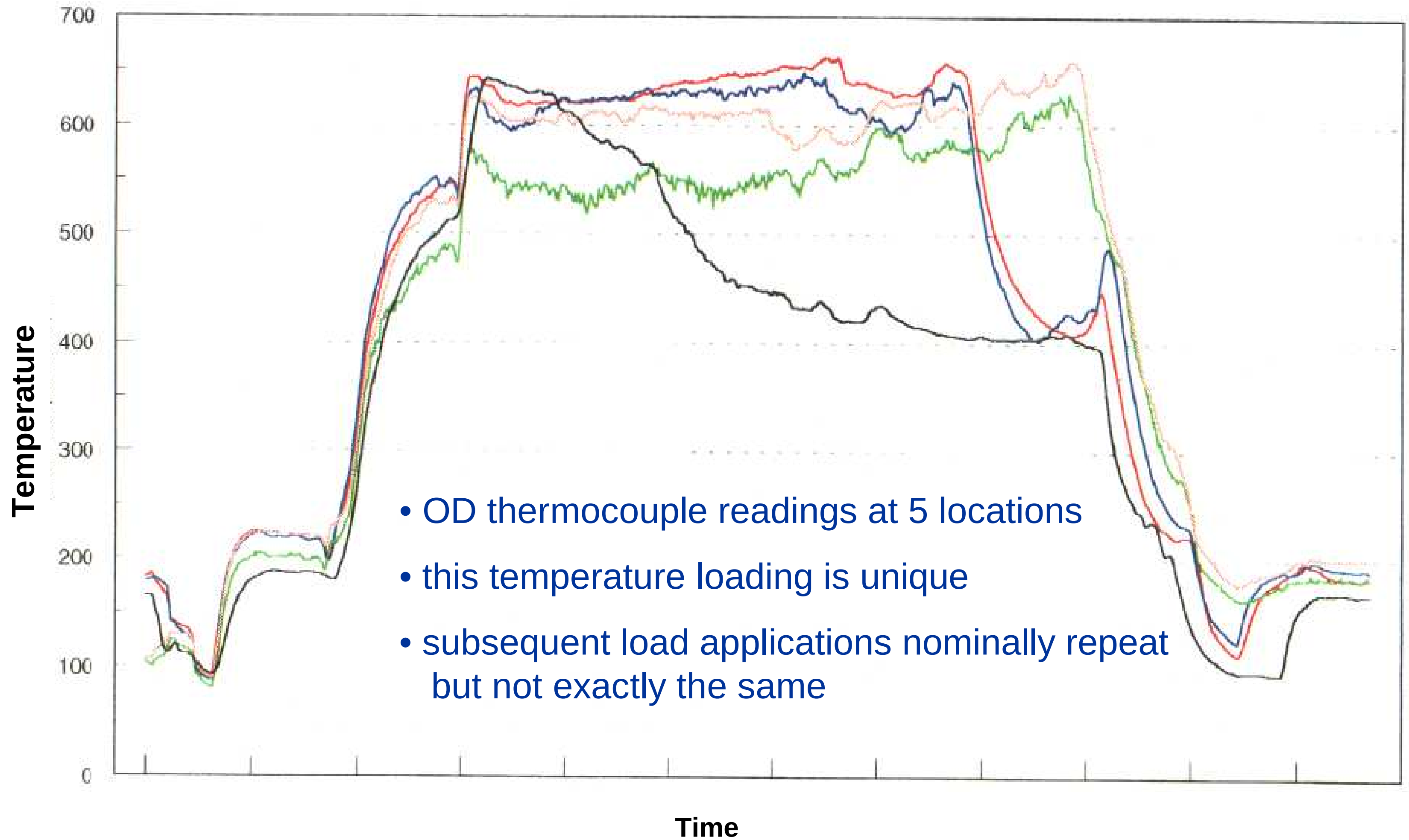
- Analytical Study
    - load definition
    - numerical & mathematical simulations
    - findings
    - opportunities
    - additional data needs

- Loading Definition

  - temperature cycling
    - steam test
    - vapor heat
    - oil in
    - steam quench
    - water quench
  - pressure cycling
    - pressure rise at start of cycle, nominally constant through cycle, pressure decline to atmospheric at end of cycle
  - live weight cycling
  - deadweight

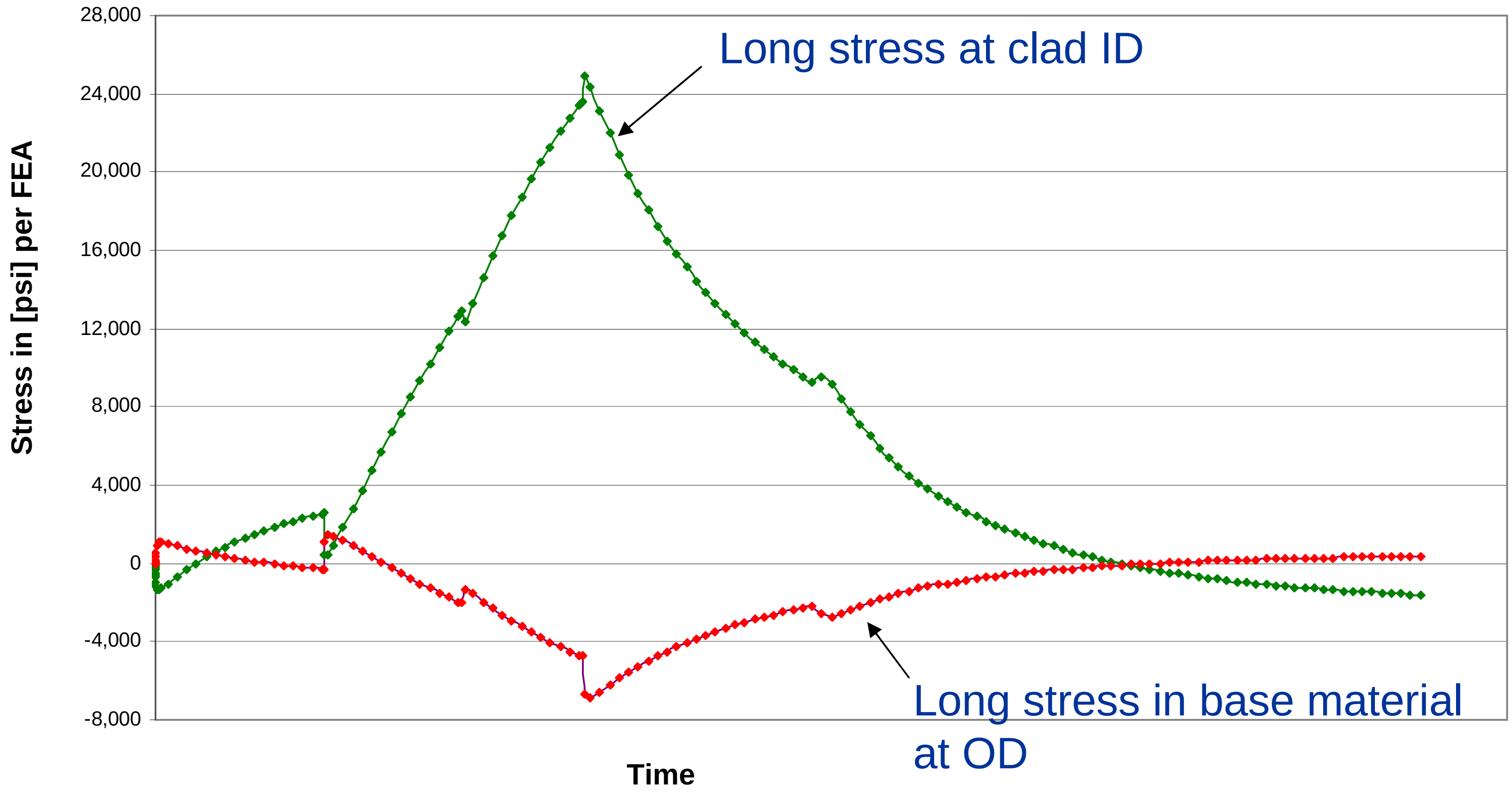
→ Total Load, $TL_{cycle} = \sum [L_i(x,y,z, t) + D_i(x,y,z,t)]$

- Temperature loading

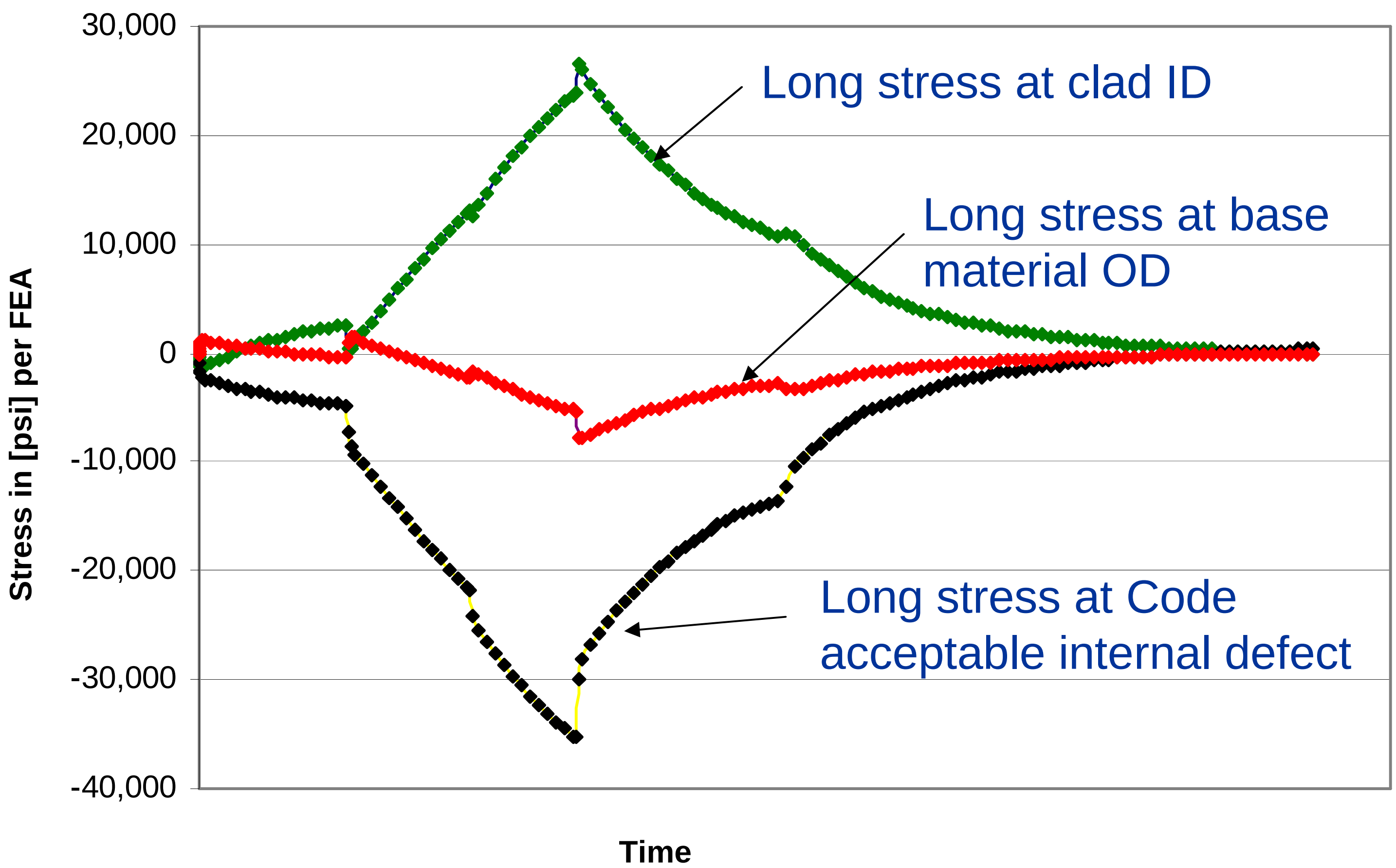


- OD thermocouple readings at 5 locations
- this temperature loading is unique
- subsequent load applications nominally repeat but not exactly the same

- Longitudinal stress at shell ID and OD due to temperature
  - industry assumption is that clad ID is in compressive loading!



- Longitudinal stress plot at shell surfaces & defects



- Estimate of crack initiation & propagation
  - for specific defect model -
    - strain concentration leads to very high notch strain ~ 11,900 με
    - using Coffin-Manson relationship for low cycle fatigue
      - N = 1,967 cycles → 5.4 years [12 hour fill, 24 hour cycle time]
      - this is for crack initiation !
    - to assess propagation - use fracture mechanics approach
      - $\frac{da}{dn} = C \cdot \Delta K^m = 9.84 \cdot 10^{-4}$ mm/cycle
      - $n = \int \frac{da}{C \cdot \Delta K^m} = 2{,}581$ cycles → 7 years !
      - compare to experience

• API Coke Drum Survey – First Thru Wall Cracks

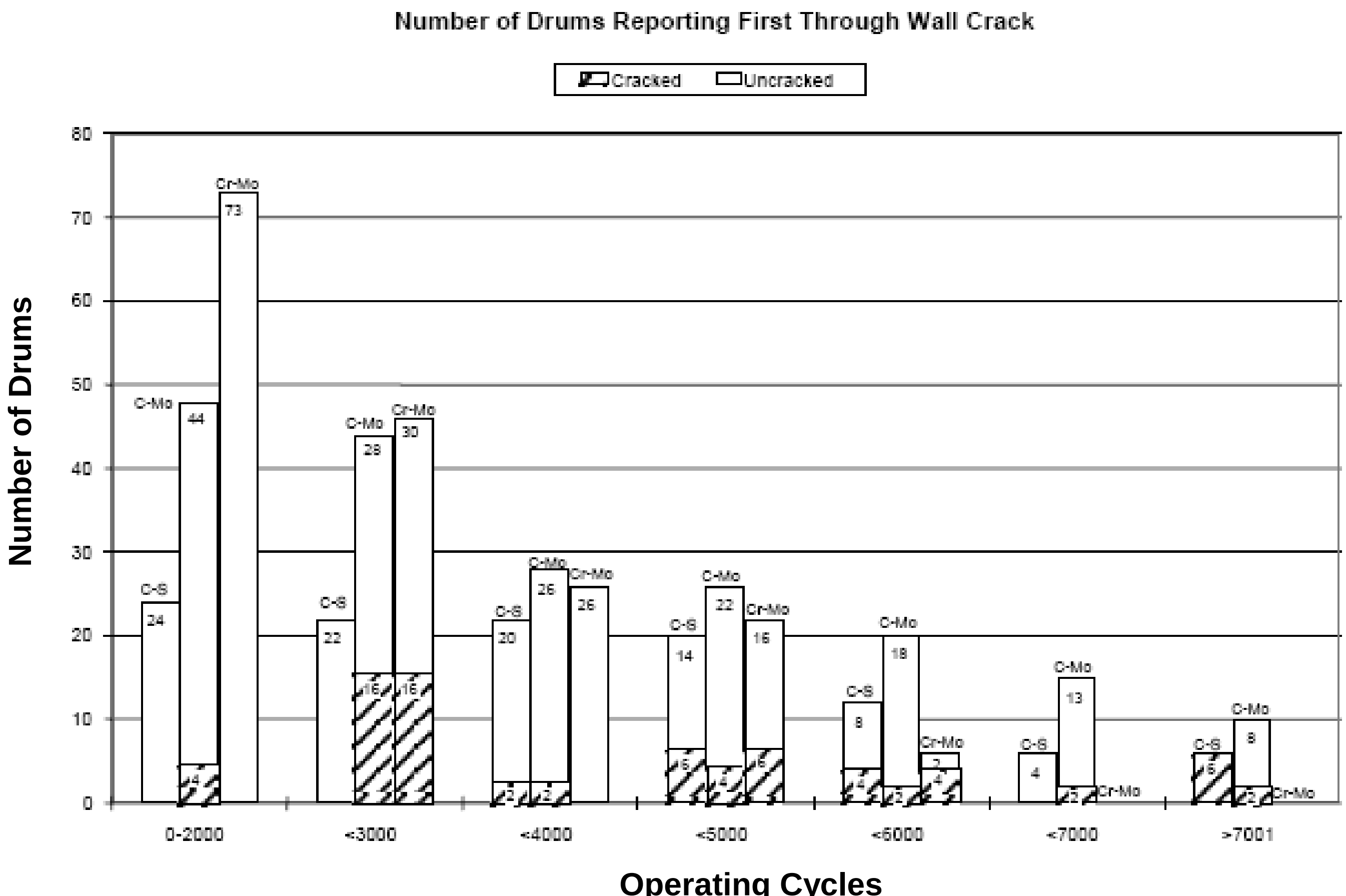
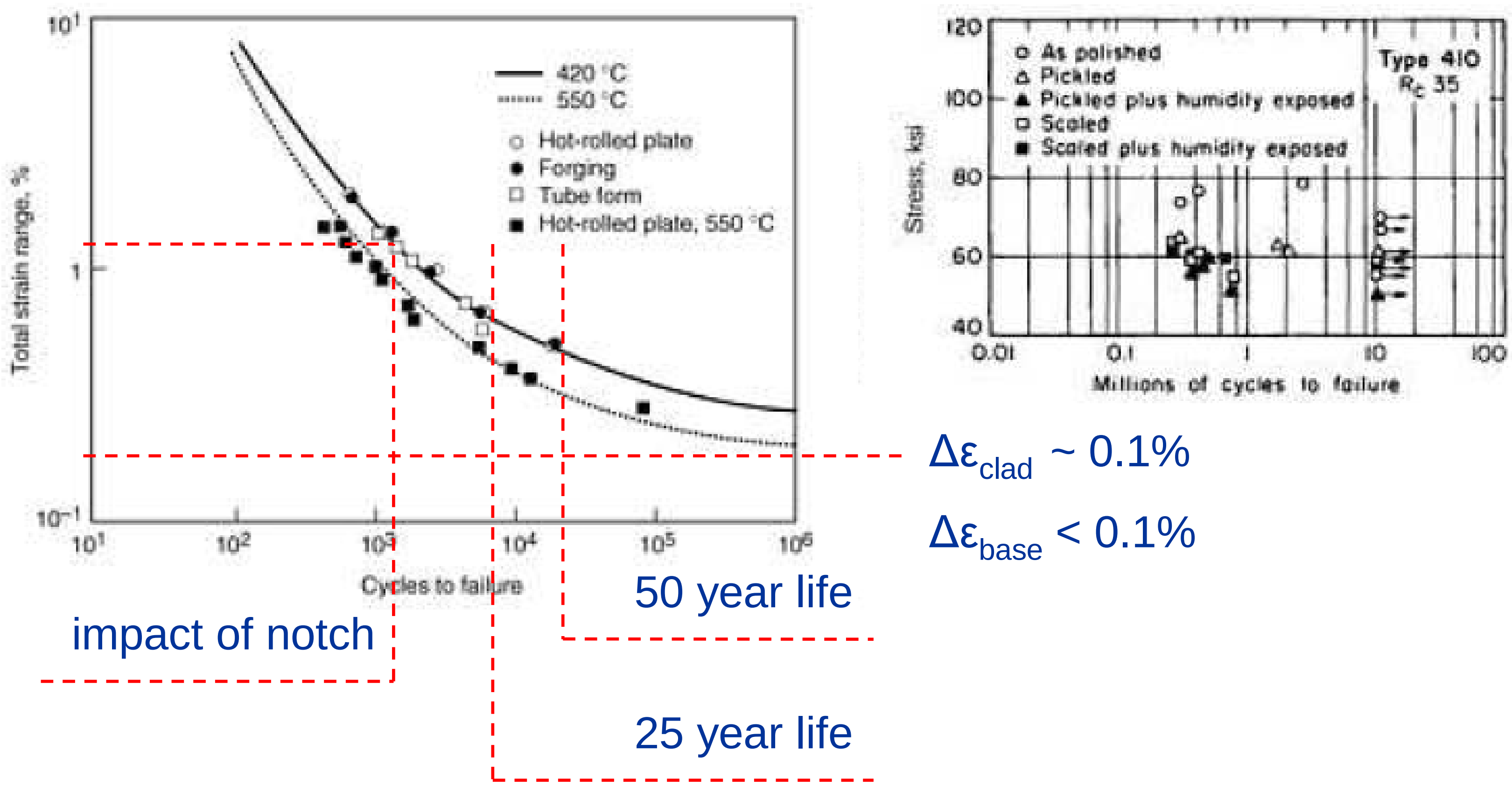


Figure 8.01c

Source: API Proceedings, 1996 API Coke Drum Survey – Final Report

• Reconciling theory with experience



Sources: Fatigue Data Sheet 7, 2 ¼ Cr – 1 Mo National Research Institute for Metals, Tokyo, 1978

Factors affecting fatigue properties of stainless steels, ASM Metals Handbook, 8th Ed. Vol 1

- Reconciling theory with experience

  - failure experience
    - SEM measured cracking rates of $2.7 \cdot 10^{-4}$ to $2.3 \cdot 10^{-3}$ mm/cycle
    - cleavage fracture occurs through majority of crack surface !
    - fast crack growth once ID surface crack manifests

  - evaluation
    - calculated crack rate of $9.84 \cdot 10^{-4}$ mm/cycle in earlier slide
    - once crack propagates through clad, K ≈ 18.6 MPa√m
      - SCC / HE enabled → $\frac{da}{dt} = 1 \cdot 10^{-8} \Rightarrow 1 \cdot 10^{-5}$ m/sec
      - t = 29 days to < 1 hour ! → coincides with observation

- Conclusions

  - initial failure dependant on fatigue mechanism / initial defect
    - initiates in clad – clad weld – base material weld
    - apparent driver is nominal load cycling, L = L(x,y,z,t)
    - moderately to severely aggravated by superimposed local deviation load conditions, such as bulging & hot spots - D = D(x,y,z,t)

      → Total loading = L + D, da/dn failure initiation mechanism

    - final failure due to time dependant environmentally assisted corrosion mechanism

      → HEAC, IHAC, da/dt failure fast-propagation mechanism

- opportunities to improve unit availability & reliability

  - design
  - fabrication
  - operation
  - inspection & maintenance

→ there are key factors influencing crack initiation and propagation

→ use existing general knowledge & techniques

  - for specification of more failure resistant designs
  - for better estimation of expected service life

- how ?
  - specific knowledge, tools & techniques mostly in place
  - certain key methodologies being developed or planned
  - lacking
    - data – easily obtained but not retained by purchasers
    - data – not currently available but needed for general application for condition and life assessments
    - data – not currently available but needed for accurate individual application for condition and life assessments

- invitation

  - joint industry program
    - recover data applicable to general assessments
    - apply existing & new tools using the collected data
    - customize to specific operations

  - contact

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