Lifing Approaches and Ageing Algorithms

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Outline

- Aim:
  - Outline algorithms and requirements for capturing ageing processes of energetic materials
  - Basis for improved munition lifing predictions

- Part I: The System in which the Algorithm Operates
- Part II: Four Situations for Algorithms
- Part III: The Algorithms

Part I: The System

Influences:

- Information available as input
- Nature of output (i.e. what information it must provide to be of use)

Must understand:

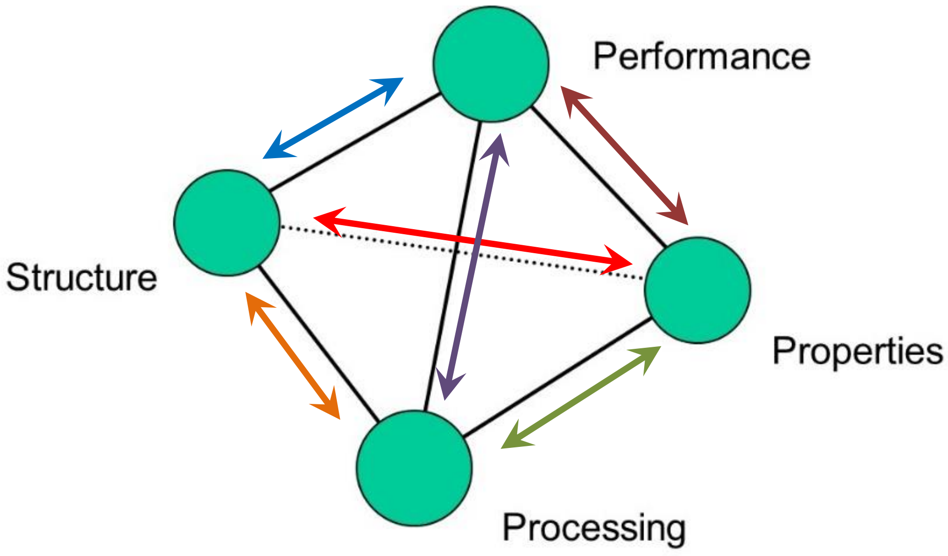
- What constitutes “end-of-life” for a munition / energetic material
  - Understanding of environment within which munitions operate
- National munition safety practices, including:
  - Approaches to life management
  - Procurement strategies
  - Environmental testing programs employed
  - In-service surveillance (ISS) practices, incl. munition health monitoring (MHM)

Part I: The System

- Munitions exposed to natural and induced mechanical and climatic environments

- Leads to mechanical and thermomechanical forces being imparted onto munitions
  - Chemical ageing
  - Mechanical damage

Part I: The System



- What is "End-of-Life"?
  - Equivalent environmental exposure
  - Point at which material composition / structure or properties are out of tolerance
    - E.g. remaining stabilizer levels
  - Point at which there is an adverse effect on performance or safety
    - Hazard properties
    - IM response
    - Burning rate / blast / pyro output etc.
- Material, system and application dependent

National munition safety practices:

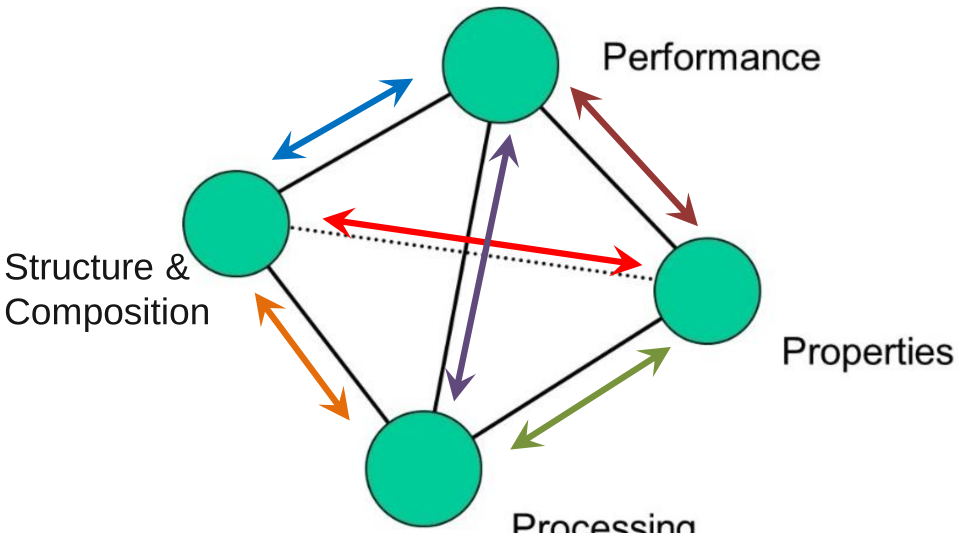
- Different national approaches to lifing:
  - **Definite Life:** end-of-life defined by environmental exposure or time – based on environmental testing undertaken
    - e.g. 10 years storage, 1,000 flight hours, 10,000 km road transport
  - **Indefinite Life:** end-of-life defined by a condition, as monitored through ISS
    - e.g. stabilizer remaining, strain to failure, observed cracking
  - Reflective of national risk tolerance (perhaps as legislated); also customary

Part I: The System

- Life Cycle Environmental Profile (LCEP)
  - Foreseen at the time of design and qualification vs actual exposure
- Environmental Testing Program
  - Use of time compression
- Procurement Scheme (e.g. MOTS, COTS, FMS)
  - Determines what information will be available

It is within this, sometimes ill-defined, context that a lifing algorithm is expected to function.

Part II: Four Situations for Algorithms



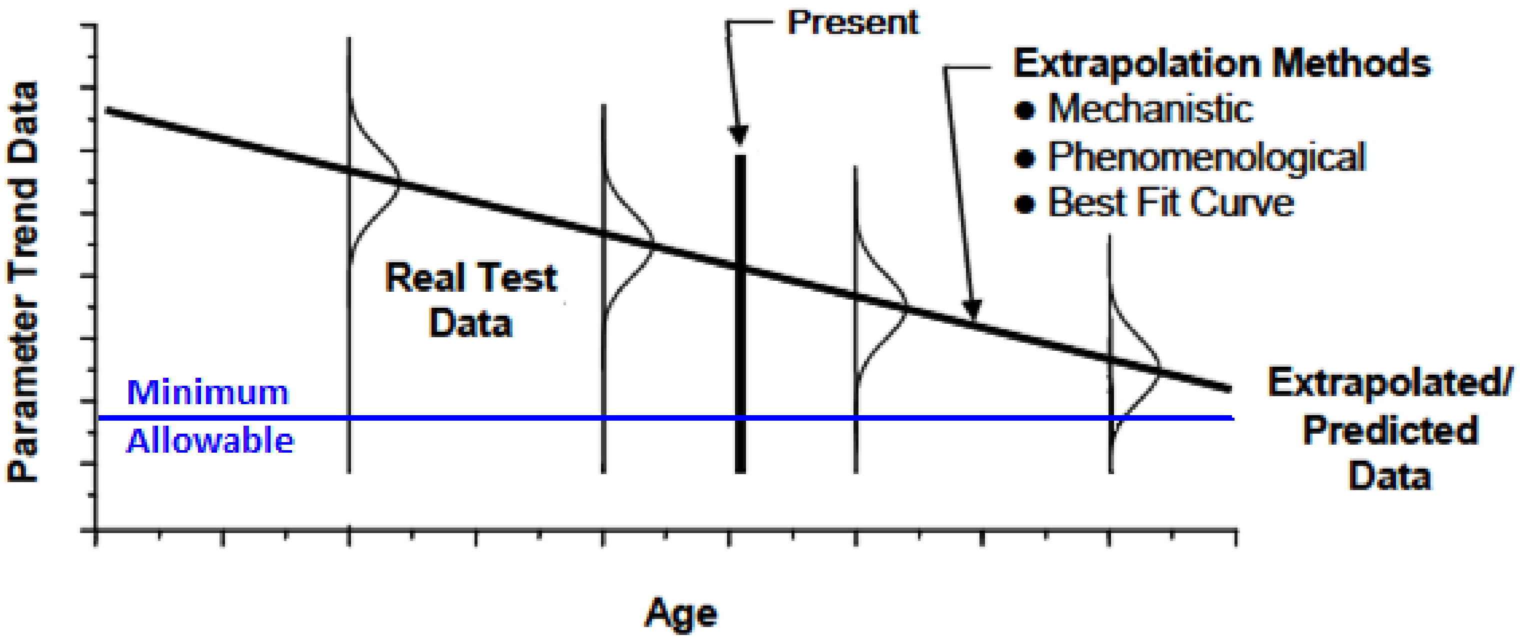
- Calculations that determine any or all of:
  - The end-of-life based on occurrences
  - Conditions for inspection interval / next inspection
  - Changes to material property and compares it to a defined value
  - Consequences on performance for different functions or roles

Part II: Four Situations for Algorithms

- Situation 1: Definite life after a set of occurrences (exposure)
  - Environmental qualification and service limits, service exposure, and models for equating processes
  - Can be simple to very complex accounting schemes
  - Differences in LCEP can cause issues
- Situation 2: Material composition limits, there are suitable degradation models to predict next inspection / test
  - Situation with gun propellants
  - Manage stocks and prioritize use

Part II: Four Situations for Algorithms

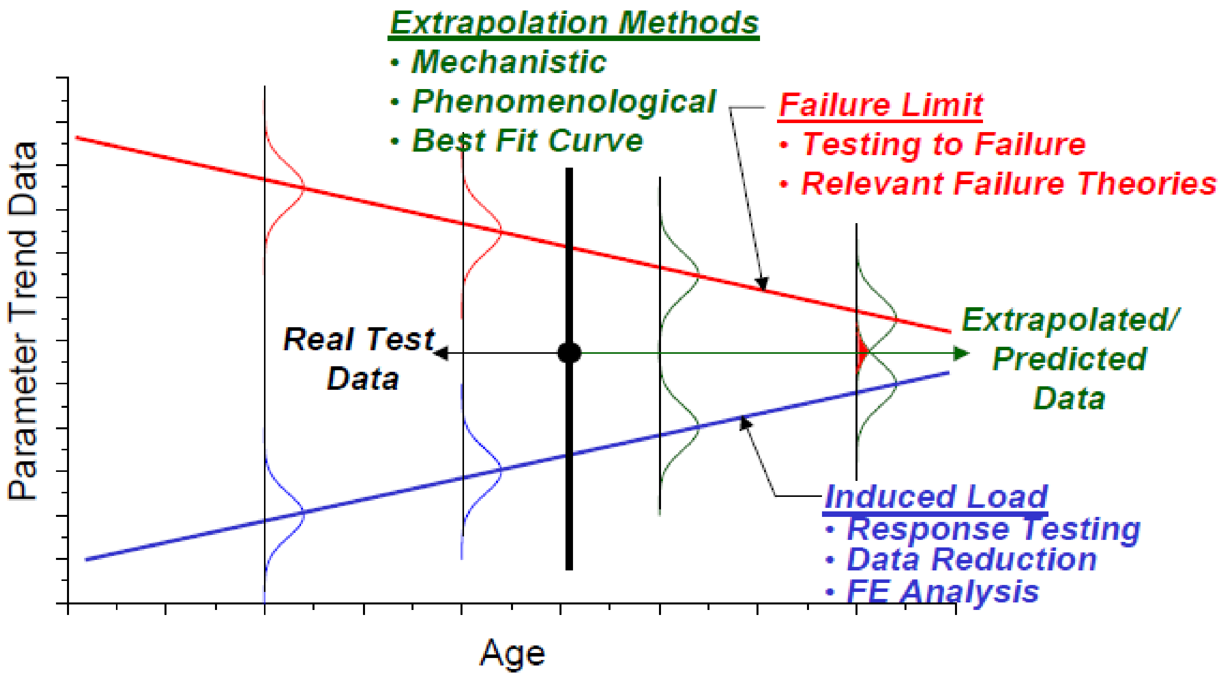
- Situation 3: Material property tolerances
  - Combines environmental service limits, material degradation modes and associated models, and actual service exposure



Adapted from Hyde, 2002

Part II: Four Situations for Algorithms

- Situation 4: Material Performance
    - Complete engineering design data set, required material properties, tolerances, environmental service limits, material degradation modes and associated models, and actual service exposure.



Hyde, 2002

Span of Data

Design

Performance translated to material shape, property requirements

Manufacture

Material property specification and tolerances

In-Service

What was delivered and state with respect to time

Exposure data

End-of-life decision

Disposal

When?

How?

Situation 4

Situation 3

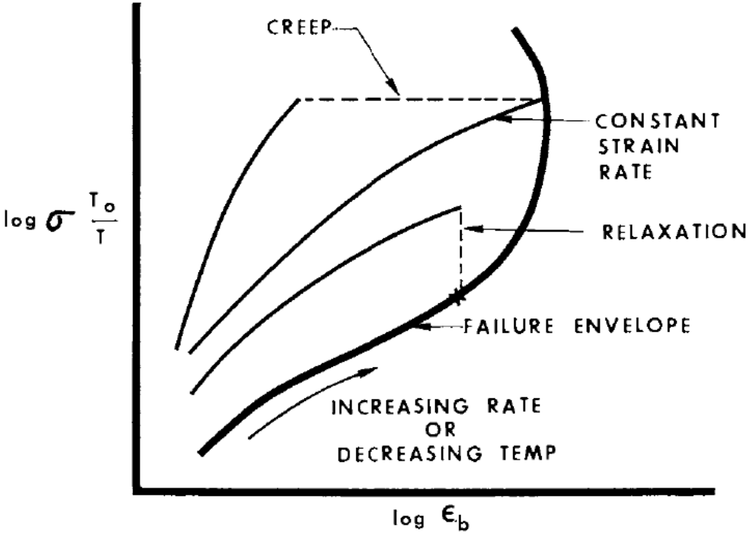
Situations 1 & 2

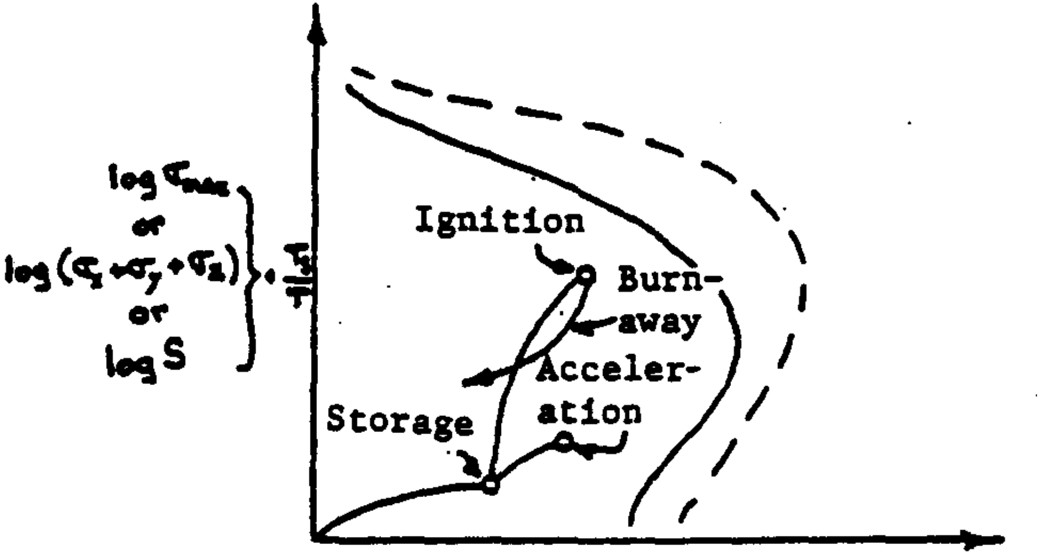
Part III: The Algorithms

- Algorithms track physical and chemical changes in a material that result in "failure":
  - Rupture
  - Fatigue & Damage
  - Activated Process: Diffusion
  - Impact and Shock
  - Thermal Fatigue

Failure Algorithms: Rupture

- Rupture
  - Smith Failure Envelope – used for rubber components, some solid rocket motor formulations

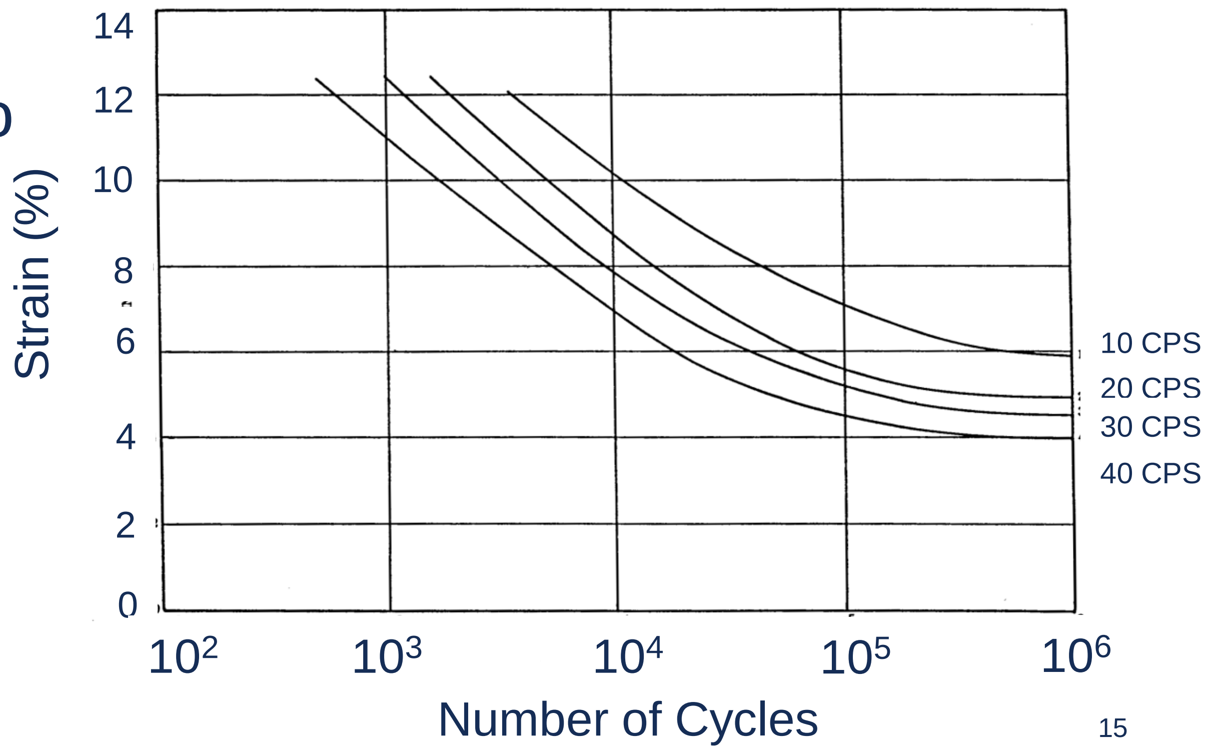




Failure Algorithms: Fatigue

- Miners Rule: $C = \sum_{i=1}^{j} \frac{n_i}{N_i}$
- But order and frequency of loads affect cycles to failure for polymeric materials
- Incorporate damage into constitutive models to account for effects of damage on strength

$$\sigma' = \frac{\sigma}{1 - D}$$



Activated Processes

- A general form for the reaction rate constant is:

$$k = A_0\, T^n e^{\left(-E_a/_{RT}\right)} e^{f(s)[C + D/_{RT}]}$$

- Reaction rate for consumption of, say, A:

$$\frac{dN_A}{dt} = -k\,[A]^{\alpha}[B]^{\beta}$$

- Similar dependency for diffusion and creep constants:

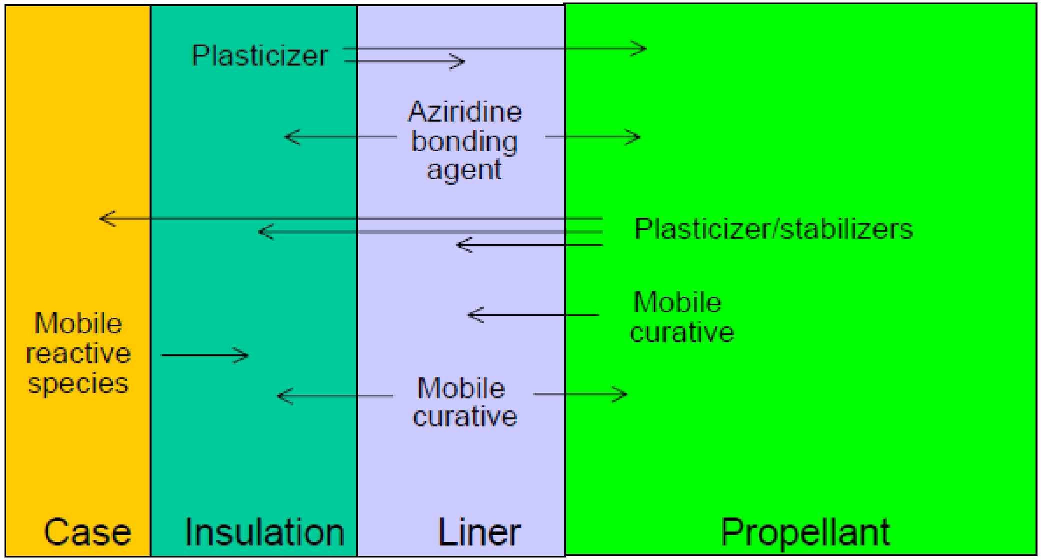
$\mathrm{D} = D_0 e^{\left(-E_a/_{RT}\right)}$ in $\frac{\partial\varphi}{\partial t} = D\,\nabla^2\varphi$ and $\dot{\varepsilon} = A_0\, e^{\left(-E_a/_{RT}\right)} 2\, sinh\left(\frac{w}{RT}\right)$

- Diffusion can be influenced by:
  - Stress
  - Other diffusing species

Diffusion: Rocket Motor Bond Integrity

- Six different groupings across two to four materials
- Each material / species represents one differential equation
  - Two (or more) parameters to be fit for each equation
  - Each equation requires initial conditions

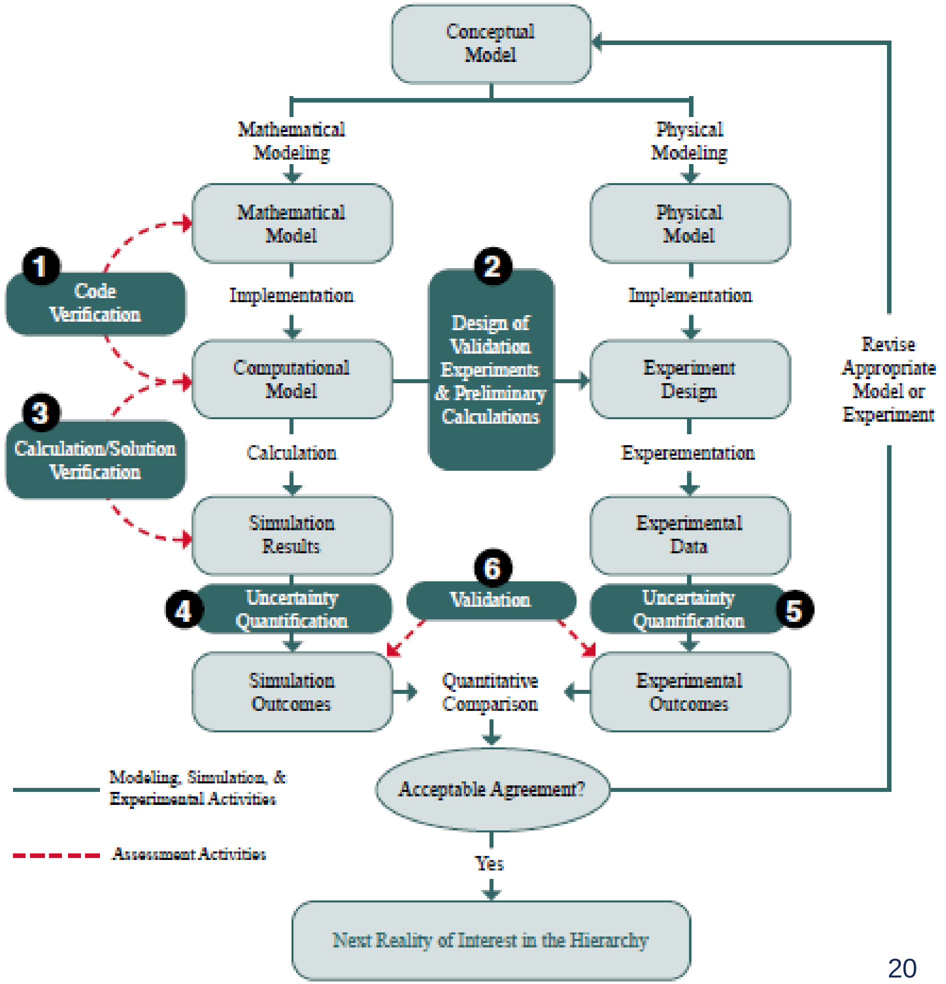
$$D = D_0 e^{\left(-E_a/_{RT}\right)}$$



- Considering the individual arrows, have 24 equations
  - 48 parameters
  - 24 initial conditions starting...
  - May need to account for stress
  - Diffusion cross coefficients
  - Uncertainty and error

Verification and Validation

- Continuous, ongoing process
- Not well covered in research and academia
  - Very few peer review articles
  - Includes uncertainty quantification
- It is a disciplined, rigorous, and often underestimated, process



Summary

- The System in which the Algorithm Operates
  - “End-of-life”
  - National munition safety practices
- Four Situations for Algorithms
- The Algorithms
  - Data Requirements and Avalaibility
  - Verification and Validation

- More information in MSIAC report L-281 Lifing Approaches and Ageing Algorithms