The NASA Electronic Parts and Packaging (NEPP) Program

An Overview

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<th>Acronym</th>
<th>Definition</th>
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<tr>
<td>Aero</td>
<td>Aerospace</td>
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<tr>
<td>AFRL</td>
<td>Air Force Research Laboratory</td>
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<tr>
<td>BME</td>
<td>Base Metal Electrode</td>
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<td>BOK</td>
<td>Body of Knowledge</td>
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<tr>
<td>CBRAM</td>
<td>Conductive Bridging Random Access Memory</td>
</tr>
<tr>
<td>CCMC</td>
<td>Community Coordinated Modeling Center</td>
</tr>
<tr>
<td>CDH</td>
<td>Central DuPage Hospital Proton Facility, Chicago Illinois</td>
</tr>
<tr>
<td>CMOS</td>
<td>Complementary Metal Oxide Semiconductor</td>
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<tr>
<td>CNT</td>
<td>Carbon Nanotube</td>
</tr>
<tr>
<td>COP</td>
<td>Community of Practice</td>
</tr>
<tr>
<td>COTS</td>
<td>Commercial Off The Shelf</td>
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<tr>
<td>CRÉME</td>
<td>Cosmic Ray Effects on Micro Electronics</td>
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<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DLA/DSCC</td>
<td>Defense Logistics Agency Land and Maritime</td>
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<tr>
<td>EEE</td>
<td>Electrical, Electronic, and Electromechanical</td>
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<tr>
<td>ELDRS</td>
<td>Enhanced Low Dose Rate Sensitivity</td>
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<td>EP</td>
<td>Enhanced Plastic</td>
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<td>EPARTS</td>
<td>NASA Electronic Parts Database</td>
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<tr>
<td>ESA</td>
<td>European Space Agency</td>
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<tr>
<td>FPGA</td>
<td>Field Programmable Gate Array</td>
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<tr>
<td>FY</td>
<td>Fiscal Year</td>
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<td>GaN</td>
<td>Gallium Nitride</td>
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<td>GSFC</td>
<td>Goddard Space Flight Center</td>
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<tr>
<td>HUPTI</td>
<td>Hampton University Proton Therapy Institute</td>
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<td>IBM</td>
<td>International Business Machines</td>
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<td>IPC</td>
<td>International Post Corporation</td>
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<td>IUCF</td>
<td>Indiana University Cyclotron Facility</td>
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<td>JEDEC</td>
<td>Joint Electron Device Engineering Council</td>
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<td>JPL</td>
<td>Jet Propulsion Laboratories</td>
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<td>LaRC</td>
<td>Langley Research Center</td>
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<tr>
<td>LEO</td>
<td>Low Earth Orbit</td>
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<tr>
<td>LLUMC</td>
<td>James M. Slater Proton Treatment and Research Center at Loma Linda University Medical Center</td>
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<tr>
<td>MGH</td>
<td>Massachusetts General Hospital</td>
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<tr>
<td>MIL</td>
<td>Military</td>
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<tr>
<td>MLCC</td>
<td>Multi-Layer Ceramic Capacitor</td>
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<td>MOSFETs</td>
<td>Metal Oxide Semiconductor Field Effect Transistors</td>
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<tr>
<td>MRAM</td>
<td>Magnetoresistive Random Access Memory</td>
</tr>
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<td>MRQW</td>
<td>Microelectronics Reliability and Qualification Working Meeting</td>
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<td>MSFC</td>
<td>Marshall Space Flight Center</td>
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<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
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<td>NAVY Crane</td>
<td>Naval Surface Warfare Center, Crane, Indiana</td>
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<td>NEPAG</td>
<td>NASA Electronic Parts Assurance Group</td>
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<td>NEPP</td>
<td>NASA Electronic Parts and Packaging</td>
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<td>NEPSL</td>
<td>NASA Parts Selection List</td>
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<tr>
<td>PBGA</td>
<td>Plastic Ball Grid Array</td>
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<tr>
<td>POC</td>
<td>Point of Contact</td>
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<td>POL</td>
<td>Point of Load</td>
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<tr>
<td>ProCure</td>
<td>ProCure Center, Warrenville, Illinois</td>
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<tr>
<td>RERAM</td>
<td>Resistive Random Access Memory</td>
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<td>RF</td>
<td>Radio Frequency</td>
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<tr>
<td>RHA</td>
<td>Radiation Hardness Assurance</td>
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<tr>
<td>SAS</td>
<td>Supplier Assessment System</td>
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<tr>
<td>SEE</td>
<td>Single Event Effect</td>
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<tr>
<td>SEU</td>
<td>Single Event Upset</td>
</tr>
<tr>
<td>SIC</td>
<td>Silicon Carbide</td>
</tr>
<tr>
<td>SME</td>
<td>Subject Matter Expert</td>
</tr>
<tr>
<td>SOC</td>
<td>Systems on a Chip</td>
</tr>
<tr>
<td>SOTA</td>
<td>State of the Art</td>
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<tr>
<td>SPOON</td>
<td>Space Parts on Orbit Now</td>
</tr>
<tr>
<td>SSDs</td>
<td>Solid State Disks</td>
</tr>
<tr>
<td>TI</td>
<td>Texas Instruments</td>
</tr>
<tr>
<td>TMR</td>
<td>Triple Modular Redundancy</td>
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<tr>
<td>TRIUMF</td>
<td>Tri-University Meson Facility</td>
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<tr>
<td>VCS</td>
<td>Voluntary Consensus Standard</td>
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<tr>
<td>VNAND</td>
<td>Vertical NAND</td>
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INTRODUCTION TO NEPP
The NEPP **Mission** is to:

- Provide guidance to NASA for the selection and application of microelectronics technologies
- Improve understanding of the risks related to the use of these technologies in the space environment
- Ensure that appropriate research is performed to meet NASA mission assurance needs.

NEPP’s **Goals** are to:

- Provide customers with appropriate and cost-effective risk knowledge to aid in:
  - Selection and application of microelectronics technologies
  - Improved understanding of risks related to the use of these technologies in the space environment
  - Appropriate evaluations to meet NASA mission assurance needs
  - Guidelines for test and application of parts technologies in space
  - Assurance infrastructure and support for technologies in use by NASA space systems
Taking a Step Back…
A Simple View of NEPP’s Perspective

NEPP Efforts Relate to Assurance of EEE Parts –
It’s not just the technology, but how to view the need for safe insertion into space programs.
Overview

- NEPP consists of the following Activities:

<table>
<thead>
<tr>
<th>NEPP Activity</th>
<th>Description</th>
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<tbody>
<tr>
<td>EEE Parts Reliability</td>
<td>New technology evaluation, test method development</td>
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<tr>
<td>Radiation Assurance</td>
<td>New technology evaluation, test method development</td>
</tr>
<tr>
<td>EEE Radiation Effects</td>
<td>New technology evaluation, test method development</td>
</tr>
<tr>
<td>EEE Parts Packaging</td>
<td>New technology evaluation, test method development</td>
</tr>
<tr>
<td>EEE Parts Assurance (NEPAG)</td>
<td>Standardization, MIL spec coordination, problem investigations</td>
</tr>
<tr>
<td>Operational</td>
<td>Website, Admin, Events</td>
</tr>
</tbody>
</table>
A View of NASA Electrical, Electronic, and Electromechanical (EEE) Parts Needs – *Diversity!*

- **Commercial Crew**
  - Focus on fail-safe architecture/electronics

- **Manned Mars**
  - Focus on reliability and radiation tolerance

- **Small Missions**
  - Focus on cost-consciousness and low power electronics

Overlap areas are critical assurance infrastructure (NASA Electronic Parts Assurance Group - NEPAG)

**Without forgetting traditional LEO and Deep-Space Robotic needs**

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What EEE Parts Diversity Entails – NEPP Tenets for Planning Tasks

• Tasks should
  – Learn from the past,
  – Focus on the present, and,
  – Plan for the future.

• Tasks should have widest applicability to Agency needs.
  – Know our customer base: technologists, designers, engineers,…
  – No single NASA center interests or direct flight project support.

• Tasks should leverage partnerships with other agencies, industry, and universities.
  – Partnering with flight projects ONLY when the Agency as a whole benefits.

*Note: A combined perspective on EEE parts allows an equal assurance/engineering approach to NEPP plans.*
NEPP Overview (1)

**Qualification guidance**
To flight projects on how to qualify

**Standards**
Ensures NASA needs are represented

**Manufacturer Qualification**
Support of audits and review of qualification plans/data

**Technology Evaluation**
Determine new technology applicability and qualification guidance

**Test/Qualification Methods**
Evaluate improved or more cost-effective concepts

**Risk Analysis**
For all grades of EEE parts (commercial, automotive, military/aerospace, ...)

**Information Sharing**
Lessons learned, working groups, website, weekly telecons

**Subject Matter Experts (SMEs)**
For NASA programs, other agencies, industry

**NEPP and its subset (NEPAG) are the Agency’s points of contact (POCs) for assurance and radiation tolerance of EEE parts and their packages.**

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NEPP Overview (2)

As opposed to a traditional breakdown of parts, packaging, or radiation, NEPP tasks can be categorized into these five areas.

NEPP Top-Level Task Areas

- Automotive/Commercial Electronics
- Complex Devices (Commercial/Mil-Aero)
- Assurance
- Power Devices (Commercial/Mil-Aero)
- NEPAG

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EEE PARTS ASSURANCE AND RISK
Understanding EEE Parts Risks

• The risk management requirements may be broken into three considerations
    • Relate to the circuit designs not being able to meet mission criteria such as jitter related to a long dwell time of a telescope on an object
  – Programmatic – “The Bad”
    • Relate to a mission missing a launch window or exceeding a budgetary cost cap which can lead to mission cancellation
  – Radiation/Reliability – “The Ugly”
    • Relate to mission meeting its lifetime and performance goals without premature failures or unexpected anomalies.
      • **Assurance falls under this heading.**
  • **Each mission determines its priorities among the three risk types**
EEE Parts Risk Trade Space – Contributing Factors for the “Big Three”

- **Cost and Schedule**
  - Procurement
  - NRE
  - Maintenance
  - Qualification and test

- **Performance**
  - Bandwidth/density
  - SWaP
  - System function and criticality
  - Other mission constraints (e.g., reconfigurability)

- **System Complexity**
  - Secondary ICs (and associated challenges)
  - Software, etc…

- **Design Environment and Tools**
  - Existing infrastructure and heritage
  - Simulation tools

- **System operating factors**
  - Operate-through for single events
  - Survival-through for portions of the natural environment
  - Data operation (example, 95% data coverage)

- **Radiation and Reliability**
  - SEE rates
  - Lifetime (TID, thermal, reliability,…)
  - “Upscreening”

- **System Validation and Verification**
Generalized EEE Parts Assurance Concept

• EEE parts assurance is a spectrum of trade spaces based on two considerations:
  – **Criticality:** whether the mission or application is in the “must work” category, and,
  – **Environment/Lifetime:** how harsh the space environment for the mission is, coupled with length of mission to qualify as success.

• A reminder
  – Additional environment protection can be anything from shielding to thermal control to fault tolerant design.
  – *Anomalies and failures are what happens when the protection isn’t sufficient.*

• Affordable

  **AND, does it HAVE to work or do you just WANT it to work?**
Applying These Concepts to EEE Parts

• The matrix on the following slide illustrates this using a modified risk approach (image on this slide).

NOTE:

– **Green** areas are where commercial off the shelf (COTS) electronics may be OK to use
– **Red** may require traditional EEE parts assurance approaches (i.e., NASA Level 1 or 2 parts – these are equivalent to the Mil/Aero grade components for space).
– **Yellow** may demand a mix of strategies
– While not specifically called out here, other grades between commercial and Mil/Aero such as automotive are part of the trade space.
<table>
<thead>
<tr>
<th>Criticality</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>COTS upscreening/part testing optional; do no harm (to others)</td>
<td>COTS upscreening/testing recommended; fault-tolerance suggested; do no harm (to others)</td>
<td>Rad hard suggested. COTS upscreening/testing recommended; fault tolerance recommended</td>
</tr>
<tr>
<td>Medium</td>
<td>COTS upscreening/testing recommended; fault-tolerance suggested</td>
<td>COTS upscreening/testing recommended; fault-tolerance recommended</td>
<td>Level 1 or 2, rad hard suggested. Full upscreening for COTS. Fault tolerant designs for COTS.</td>
</tr>
<tr>
<td>High</td>
<td>Level 1 or 2 suggested. COTS upscreening/testing recommended. Fault tolerant designs for COTS.</td>
<td>Level 1 or 2, rad hard suggested. Full upscreening for COTS. Fault tolerant designs for COTS.</td>
<td>Level 1 or 2, rad hard recommended. Full upscreening for COTS. Fault tolerant designs for COTS.</td>
</tr>
</tbody>
</table>
Comments on the “Matrix” Wording

• “Optional” – implies that you might get away without this, but there’s possible risk if you don’t.
• “Suggested” – implies that it is a good idea to do this, and there’s some increased risk if you don’t.
• “Recommended” – implies that this should be done and there’s probable risk if you don’t.
• Where just the item is listed (ex., “full upscreening on COTS”) – this should be done to meet the criticality and environment/lifetime concerns. There is definite risk if you don’t.

Good mission planning identifies where on the matrix a mission/application lies.
NEPP FOR THE NEW FRONTIER – “COST CONSCIOUS MISSIONS”:
IS BETTER THE ENEMY OF GOOD ENOUGH?

AGAIN! Does it HAVE to work or do you just WANT it to work?
NEPP Tenets for Cost-Conscious Missions

• The following charts will provide a sampling of our current recommendations and thoughts on “saving money”.

• General topic areas for the following charts:
  – Using existing resources,
  – Grades of EEE parts,
  – Alternate screening/qualification approaches, and,
  – Fault tolerance.

“A typical new car is equipped with more than 50 computers, designed to operate under extreme conditions for extended periods of time.”
Using Spare Parts and Other Resources

• Make use of existing resources.
  – Are there spare devices available at your Agency or within your control?
    • Flight procurements usually include extra device samples.
    • Some may be fully screened and even be radiation hardened/tested.
    • Engage parts/radiation engineers early to help find and evaluate designers’ “choices” of EEE parts.

• If spare parts are not available, try to use parts with a “history of use”.
  – These parts perform similarly to the “legacy” EEE parts
    • BUT not guaranteed

• Higher risk:
  – Choose devices built on the same process/design rules by the same manufacturer.

• If you absolutely need something new, you will pay for the qualification or take the risk.
Background on EEE Parts Grades

• EEE parts are available in grades.
  – Designed and tested for specific environmental characteristics.
    • Operating temperature range, pressure/vacuum, radiation exposure, shock, vibration,…
  – Examples of Grades:
    • Aerospace, Military, Automotive, Medical, Extended Performance/Temperature-Commercial (EP), and Commercial Off the Shelf (COTS).

• Aerospace Grade
  – Traditional choice for space usage.
    • Designed and tested for reliability and often radiation for space usage.
  – Relatively few available parts and their performance lags behind commercial counterparts (speed, power).

• NEPP has a long history of evaluating grades other than Aerospace or Military.
  – Current focus is on Automotive and Commercial.
    • Automotive parts are less expensive than Aerospace counterparts.
      – The BIG question is their reliability/radiation-tolerance in space applications.
A Few Upfront Comments

• **Aerospace Grade** electronics are typically designed and tested to survive a wide range of environment exposures:
  – -55°C to +125°C, as an example.

• This allows a “generic” qualification by a manufacturer to encompass a wide array of user mission needs (i.e., one test for a lot of folks rather than a new test for each customer).

• Commercial off the shelf (COTS) for terrestrial usage aren’t designed/tested to these same levels.
  – This doesn’t mean they won’t work in a mission, but implies that you have to find a means of either reducing or accepting risk.
Temperature Rating Versus “Need”

• Aerospace and Military grades are qualified for usage via exhaustive temperature cycles at -55°C to +125°C.
  – This is a conservative approach allowing vendors to qualify once for the majority of space customers.
  – But what if we want to use parts not rated for this wide range?

• Actual mission profile thermal excursions are mission unique.
  – May be relatively benign when compared to the standard “Mil grade” temperature range.
    • However, there may be thousands of temperature cycles to consider.
  – What’s the appropriate testing? Conservative or reduced levels?

• Operation outside of the rated temperature, while possible, entails risk.
Automotive Electronics – NEPP Tasks

• Develop a body of knowledge (BOK) document, highlighting the Automotive Electronics Council (AEC) documents as well as discussions with manufacturers.

  – Summary implies a need for “relationships” between vendor and buyer is necessary to coordinate screening/qualification requirements.

• Subject of a presentation on Friday morning
Do We Need Traditional Parts Screening/Qualification?

• Traditional testing was developed as a conservative means of bounding risk using temperature and voltage acceleration factors and adequate sample size statistics.
  – Are downscaled or alternate approaches adequate for cost-conscious missions?
• Board level tests – how do they correlate to part level tests?
  – Temperature range for tests are limited to “weakest link” on the board (use 0 to 70/85C).
    • How many temperature cycles are needed to demonstrate reliability?
  – Modern boards usually have localized power conversion.
    • Implies changes to input voltages may not accelerate degradation due to voltage regulation.
  – Besides the stress mechanisms,
    • As opposed to access of every pin and full test vectors, board level has limits on input/output capabilities, operational tests, and visibility of “failures”.
  – Appropriate sample size for statistics also challenges.

• Question to consider: how do we quantify the risk reduction?
Fault Tolerance to Increase “Parts” Reliability?

- Means to make a system more “reliable/available” can occur at many levels:
  - Operational
    - Ex., no operation in the South Atlantic Anomaly (proton hazard)
  - System
    - Ex., redundant boxes/busses or swarms (with spares) of nanosats
  - Circuit/software
    - Ex., error detection and correction (EDAC) of memory devices
  - Device (part)
    - Ex., triple-modular redundancy (TMR) voting of internal logic within the device
  - Transistor
    - Ex., use of annular transistors for TID improvement
  - Material
    - Ex., addition of an epi substrate to reduce SEE charge collection (or other substrate engineering)

*The question remains:*

*How effective is the fault tolerance in increasing reliability?*
Will Fault Tolerance Work When We Haven’t Tested the Parts?

- The System May Work, But What Level of Confidence Exists That It Will?
  - What are the “unknown unknowns”? Can we account for them?
  - How do you calculate risk with unscreened/untested EEE parts?
  - Do you have common mode failure potential in your design? (i.e., an identical redundant string rather than having independent redundant strings)
  - How do you adequately validate a fault tolerant system for space?
    - If, for example, 95% of faults are able to be recovered from, how critical are the other 5%?
    - Is there any “dead time during recovery”?

- If we go back to the “Matrix”, how critical is your function and harsh your environment/lifetime?
  - This will likely provide the “answers” to the above questions.

Good engineers can invent infinite solutions, but the solution used must be adequately validated and the risks accepted.
Summary

• NEPP is an agency-wide program that endeavors to provide added-value to the greater aerospace community.
  – Always looking at the big picture (widest potential space usage of evaluated technologies and NEPP products).
  – We look to the future by learning from our past.

• We’ve provided some thoughts on EEE Parts Assurance for Cost-Conscious Missions.
  – Knowledge is always a key