Brookhaven National Laboratory Practices

THE SAFE CONDUCT OF RESEARCH

BROOKHAVEN NATIONAL LABORATORY

ON THE COVER

Nanofabrication
The Nanofabrication Facility at Brookhaven's Center for Functional Nanomaterials is housed in a class 100/1000 clean room (5,000 sq. ft.) dedicated to state-of-the art patterning and processing of thin films, nanomaterials, and devices.

Center for Functional Nanomaterials

One of ten national laboratories overseen and primarily funded by the Office of Science of the U.S. Department of Energy (DOE), Brookhaven National Laboratory conducts research in the physical, biomedical, and environmental sciences, as well as in energy technologies and national security. Brookhaven Lab also builds and operates major scientific facilities available to university, industry and government researchers. Brookhaven is operated and managed for DOE's Office of Science by Brookhaven Science Associates, a limited-liability company founded by the Research Foundation for the State University of New York on behalf of Stony Brook University, the largest academic user of Laboratory facilities, and Battelle, a nonprofit applied science and technology organization.

PREFACE

Brookhaven Science Associates and the U.S. Department of Energy (DOE) Brookhaven Site Office are working together with Lab management and staff to ensure that Brookhaven is known as a lab that fosters a safe working environment, and is known for its operational excellence. These are key themes for all of us to remember and put into practice. If we don't, our science and technology vision—being the leading U.S. DOE multi-program laboratory with recognized impact on national science needs—will be impossible to attain.

By its very nature, research often moves us into unknown arenas, constantly pushing the boundaries of our experience. It is work typically carried out by those with deep curiosity and natural skepticism, and capable of intense focus. On the cusp of a discovery, sometimes matters that seem ancillary to the research itself can be forgotten. That is when mundane tasks can present significant risk to those who are distracted.

It is imperative that we all keep the safe conduct of research in the forefront as we perform our work. Otherwise, we take the chance that an injury might mitigate the importance of potentially positive research outcomes.

Today, great science increasingly requires complex and powerful equipment, materials that pose substantial risk if mishandled, specialized operations, and teams of researchers supported by very capable technicians and tradespeople. Because of the increased complexity, teamwork is one of the keys to success, and an essential part of this is a shared code of conduct.

And that's what this publication is about.

The Brookhaven Lab Safe Conduct of Research was produced through a collaborative effort between Brookhaven and other Battelle-affiliated laboratories but is focused on our mission, our methods, our culture, and our needs. Its purpose is to codify the principles and practices that we believe ensure Brookhaven Lab's science is performed without unnecessary risk and operational disruptions.

In short, the principles outlined here form the underpinnings of a strong safety culture here at the Lab. They apply to scientists at all stages of their careers as well as to the multitude of staff whose contributions are vital to accomplish our research goals.

Robert Tribble
Deputy Director for Science & Technology
Brookhaven National Laboratory

A NOTE ON USING THIS PUBLICATION

This publication has one primary goal: to make clear that accidents and injuries can be avoided through a set of purposeful actions.

It is not enough for an institution to simply have a "safety program" or a list of procedures. Rules and regulations cannot adequately protect you or your colleagues engaged in research and development (R&D).

Successful research and operations at Brookhaven National Laboratory depend on each researcher, operations person, and manager recognizing the need to conduct work safely and understanding how to achieve that nonnegotiable goal.

This booklet is not designed to replace your individual group's safety program, but rather to explain the ideas and approaches undergirding the Lab's safety processes, procedures, and standards of behavior.

This publication can serve as . . .

- A quick read to orient new employees;
- A template for scientific leaders and managers to drive discussion and set expectations, and;
- A tool to help you and your colleagues organize peer reviews focused on safety.

The ideas that follow underscore your personal responsibility for safety—for yourself, your colleagues, and your staff. This publication should encourage you to keep safety constantly in mind as you go through your day, and it should empower you to intervene before unsafe activities occur.

Take a few minutes to read this publication.

Then conduct yourself according to these standards.

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Aerial view of Brookhaven National Laboratory

Historic aerial view of Brookhaven National Laboratory (1962)

INTRODUCTION

Brookhaven National Laboratory is a world leader in scientific research and performs this work in an environmentally responsible and safe manner. Nothing is more important than the safe conduct of the Lab's research mission. To an increasing degree, basic and applied research requires the cooperation of individuals across a broad range of disciplines and the use of a wide variety of materials and equipment, many of which present unique hazards.

The Safe Conduct of Research describes the essential attributes of conducting research safely. Rather than prescribing a specific program or implementing methods, it addresses basic principles. These principles, associated roles, and attributes—when embraced—will influence values, assumptions, experiences, behaviors, beliefs, and norms that describe what it is like to work at Brookhaven Lab and how things are done. These are the collective traits that must lead us as individuals and organizations to emphasize safety over competing priorities.

This document is complementary to and should be used in conjunction with the Lab's Integrated Safety Management program, Human Performance Improvement principles, as well as other policies and procedures detailed in the Standards-based Management System for conducting work safely.

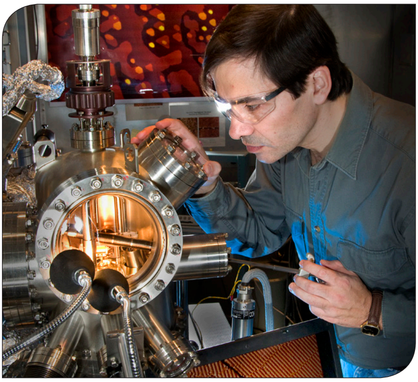
OUR HISTORY

In the early 20th century, the U.S. government maintained limited public research capabilities and provided minimal support for academic research. This all changed with the advent of World War II, as national security considerations drove dramatic increases in federal research investment. Today's federal research budgets are sustained by the recognition that investments in institutions like national laboratories ensure our national security, underpin our economy, and provide essential tools for meeting national needs.

Brookhaven National Laboratory was established in 1947 on the eastern end of Long Island at the former site of the U.S. Army's Camp Upton. Originally built out of a post-World War II desire to explore the peaceful applications of atomic energy, the Laboratory now has a broader mission: to perform basic and applied research at the frontiers of science, including nuclear and high-energy physics; physics and chemistry of materials; nanoscience; energy and environmental research; national security and nonproliferation; structural biology; and computational sciences. The Laboratory's almost 3,000 scientists, engineers, and support staff are joined each year by more than 4,000 visiting researchers from around the world.

Over its history, Brookhaven Lab has housed three research reactors, numerous one-of-a-kind particle accelerators, and other cutting-edge research facilities responsible for discoveries leading to many advances for science and society, as well as seven Nobel Prizes.

BROOKHAVEN LAB'S PHILOSOPHY OF SIMULTANEOUS EXCELLENCE



As a Battelle, Stony Brook University, and DOE institution, Brookhaven Lab is committed to simultaneous excellence in three critical areas: science and technology; laboratory operations; and exemplary stakeholder and community relations. This means that we expect our teams to deliver outstanding results that meet the critical needs of our sponsors and customers; to operate our facilities effectively, efficiently, and in full compliance with all applicable laws, regulations, and client expectations; and to set an example of outstanding corporate citizenship and community service.

As stated in its Environmental, Safety, Security, and Health (ESSH) Policy, each Brookhaven Lab employee, contractor, and guest is expected to take personal responsibility for adhering to the following principles:

Environment: We protect the environment, conserve resources, and prevent pollution.

Safety: We maintain a safe workplace and we plan our work and perform it safely. We take responsibility for the safety of ourselves, coworkers, and guests.

Security: We protect people, property, information, computing systems, and facilities.

Health: We protect human health within our boundaries and in the surrounding community.

Compliance: We achieve and maintain compliance with applicable ESSH requirements.

Community: We maintain open, proactive, and constructive relationships with our employees, neighbors, regulators, DOE, and other stakeholders.

Continual Improvement: We continually improve ESSH performance.

Our research can be outstanding only if it is conducted with the highest regard for safety. The communities in which we work and live rightly expect us to demonstrate our corporate responsibility by preventing accidents and avoiding environmental incidents in research and all of our other activities.

THE IMPORTANCE OF ACCOUNTABILITY

Underlying all of these principles is our shared Laboratory value of accountability.

We define accountability in relatively simple terms—"owning" our work and delivering it, doing what we say we will do, and expecting others to do the same. Our overall goal is to instill a culture of accountability at all levels of the Lab that drives a sustained improvement in operational excellence. In other words, it means fostering a workplace where everyone strives to produce and support science of the highest possible impact that addresses our nation's most critical challenges and needs; to create the greatest value for our customers, collaborators, and partners; and to establish an outstanding reputation for the Laboratory and our staff.

Success will be evident by a shared sense of purpose where teamwork, problem solving, accountability, and leadership result in ongoing improvement within the organization.

To reach the goal, we need to understand what accountability looks like, and where obstacles to accountability exist. We also need leaders who serve as role models for operational excellence and create an atmosphere of trust and respect; are engaged with strong ownership of systems, tools, and performance; and hold those reporting to them accountable for performance and compliance. Finally, we need employees who hold themselves and others accountable and are willing to freely and respectfully speak up.

The following behaviors are considered essential and we encourage everyone to practice them:

- I raise my concern with someone who can take action instead of developing a work-around.
- When someone raises a concern, I listen, take appropriate action, follow-up, and work together to discuss safe, compliant options to complete work.
- When I need to hold others accountable for missing commitments or engaging in work-arounds or other counterproductive behavior, I respectfully talk to them, directly, regardless of the person's level or position.
- When I notice conflicting priorities or expectations, I speak up and propose ways of ensuring we are working toward a common purpose.

When we aren't accountable, supervisors don't manage performance, commitments are not being met, and staff opt out of following a rule, policy, or procedure; there's a lack of transparency/communication, and decisions or policies are communicated with insufficient explanation; and there's poor customer service, where no action is taken on a service request or people engage in a work-around. Productivity suffers, and an "us vs. them" mentality can take hold, impacting respectful workplace conduct. All these actions are barriers to performing work efficiently and reaching organizational goals.

When there is strong accountability, we see clear benefits: communication is respectful, transparent, and clear, with no concern about retaliation for raising an issue or problem; teamwork exists both within a work group and across departmental/organizational boundaries; and there's a positive attitude where staff will go the extra mile to contribute, to take the initiative to make something happen, or make the effort to help someone else.

WHAT IS SAFETY CULTURE?

Because of the special characteristics and unique hazards of R&D, research facilities must incorporate a healthy safety culture that is founded on a collective commitment to put safety first. This commitment applies to everyone in the organization, from the Laboratory director to the individual contributor. No one is exempt from the obligation to ensure protection of people, the environment, and the facility.

The Safe Conduct of Research articulates a set of principles that shape behavior and form the basis for a strong safety culture. Whether you are a principal investigator, visiting scientist, post-doc or intern, group leader, project manager, program manager, senior scientific leader, or technician, your adoption of safety as a priority and behavior is key.

1. EVERYONE IS PERSONALLY RESPONSIBLE FOR ENSURING SAFE OPERATIONS.

- As a research staff member or as a guest researcher, you are accountable for safety. Your organization has safety professionals available to support you—use them.
- You should know the hazards that your work activities create better than anyone else. If you don't, ask questions until you do.
- Human error is inevitable, but you can reduce its likelihood and consequences.
- Anyone can stop work, and you are expected to use that authority when there is uncertainty about the safe conduct of work.
- Safety requirements and processes are there to protect you, your co-workers, the facility, and the environment. Working around those requirements and processes is not acceptable and may cause an accident, injury, or delay to mission goals.

2. LEADERS VALUE THE SAFETY LEGACY THEY CREATE IN THEIR DISCIPLINE.

- Leaders exhibit behaviors that set the standard for safety.
- Being in research areas and engaging staff is the best way to understand whether your staff are prepared to work safely; coach, mentor, and reinforce expectations about safety during such engagements.
- Expectations for safe performance are communicated often and in many forums.
- Science leaders strive to keep safety at the forefront by being conscious of the complexity of the research, the preparedness of their staff, and the pressure to perform.

3. STAFF RAISE SAFETY CONCERNS BECAUSE TRUST PERMEATES THE ORGANIZATION.

- You can't fix what you don't understand; staff are encouraged to raise concerns and report problems.
- Science leaders create an environment of inquisitiveness as the norm to counteract the tendency of students, postdoctoral fellows, and junior staff to view uncertainty as a sign of professional weakness.
- Anyone can respectfully challenge unsafe behavior regardless of his or her position in the organization; these challenges should be accepted graciously as an opportunity to improve.

Bottom Line: stop yourself or others when unsure.

4. CUTTING-EDGE SCIENCE REQUIRES CUTTING-EDGE SAFETY.

- A conservative posture is assumed when the impact of hazards is uncertain.
- Safety is viewed as integral to the research product and not simply as compliance.
- Opportunities to research improvements in hazard controls are encouraged.
- Safety-related information is included in research records and publications.

5. A QUESTIONING ATTITUDE IS CULTIVATED.

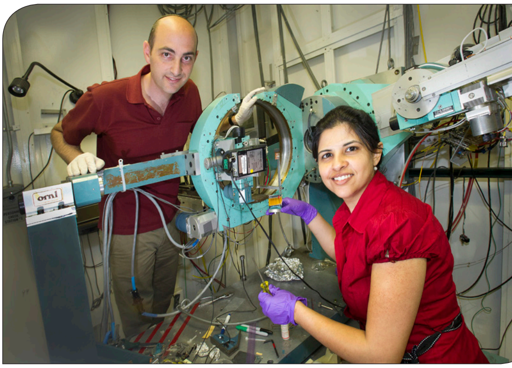
- In the face of uncertainty, researchers do not proceed with work until potential impacts have been evaluated and controls are in place to mitigate them.
- Anomalies are thoroughly investigated and mitigated.
- Opposing views are encouraged and used to advance everyone's understanding. Differing opinions are welcomed and respected, but debate doesn't paralyze sound decision making.

6. LEARNING NEVER STOPS.

- Every experiment, event, or project provides opportunities to improve safety.
- You need to know your issues better than anyone else; self-reflect and self-assess.
- Mistakes are treated as opportunities to learn.
- When challenged by someone else, view it as a chance to get better.
- Safety techniques and lessons learned are routine topics in research discussions.

7. HAZARDS ARE IDENTIFIED AND EVALUATED FOR EVERY TASK, EVERY TIME.

- Research staff are expected to understand the hazards associated with their work, the controls necessary to do the work safely, and the rationale behind the selection of the controls used.



- Procedures and safety components are constantly reevaluated to ensure that they still provide the protection assumed.
- If "work-arounds" are unavoidable, plan and implement changes accordingly.
- Peer involvement is encouraged; it helps to avoid blind spots to new risks.
- Perform research within the boundaries established during safety reviews—be aware of "scope creep."

8. A HEALTHY RESPECT IS MAINTAINED FOR WHAT CAN GO WRONG.

- Avoid complacency; routine tasks can result in serious injuries or operational upsets.
- Time pressure is a setup for mistakes; it is openly acknowledged when present, and attention to safety is heightened during those times.
- Small failures and mistakes are seen as clues to more consequential failures, and thus are highlighted and shared.
- External reviews and management engagement are viewed as opportunities to challenge assumptions and reinforce what is right.
- First-time operations are never conducted without thorough discussion of contingencies.

CASE STUDIES: A CLOSER LOOK

In addition to assessing job-site conditions, systems, and procedures, it is equally important to understand the role of human behavior in events resulting in errors or the unexpected.

These Case Studies show work activity can frequently be divided into three kinds of behavior: Skill-based, Rule-based, and Knowledge-based.

- Skill-based behaviors are used for tasks carried out almost "automatically" (e.g., operating an automobile, playing an instrument, using computer-mediated controls, etc.).
  - Common error traps: distraction, repetitive or habitual tasks.
- Rule-based errors usually occur during problem solving when a wrong rule is chosen ("failure to follow procedures").
  - Common error traps: Misperceiving a situation, over-confidence, procedure unclear.
- Knowledge-based behaviors involve complex problem-solving, and are used when a problem is incomplete or inaccurate; user benefits from collaboration with others to aid in decision-making and problem-solving process.
  - Common error traps: Trying to solve complex problems alone, without the feedback of others; utilizing "mental models" or assumptions that may be incorrect or inaccurate.

Why is it important to understand the different "types" of behavior? Because the behaviors are subject to different types of error. It makes it easier to identify the conditions that led to the error. And, as a result, corrective actions will be more effective.

What are some steps you can take to prevent such errors from occurring? Ask yourself the following before carrying out tasks:

- What can go wrong?
- What measures or controls are in place to prevent that from happening?
- Consider which of the most important controls depend on human actions or behavior. Where might an error or omission impair the effectiveness of an important control?
- Error precursors are conditions that increase the chances of an error during the performance of a specific task by a particular individual. Are there precursors that, if reduced or eliminated, would make the controls more likely to be effective?

Case Study #1: NSLS-II Linac Missteering Event

During commissioning of the National Synchrotron Light Source II Linac particle accelerator, an operator conducted beam loading studies using 100 million electron volt (MeV) beam energy with dipole set at maximum current. This combination caused the beam to bend four times more than designed, miss a shadow shield, and hit the wall between the Linac and Booster wall.

This missteering resulted in elevated radiation levels in a radiation-monitored and controlled area within the Booster enclosure. Fortunately, no one was injured and no significant radiation exposure was identified.

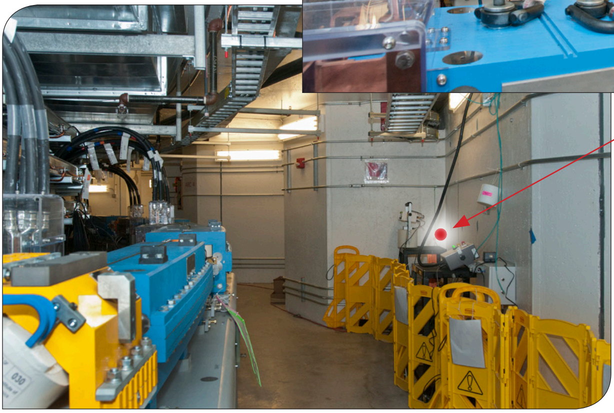
An ensuing investigation determined that the operator exceeded the level of dipole magnet current needed to bend a 100 MeV beam.

More root causes include the following:

- Operators assumed the adequacy of the shielding.
- Operator did not follow established procedures.
- Less than adequate verification by line management of implementation of procedures, safety review process, Control Room equipment, or chain of command.
- Duties of the Control Room Supervisor were not assumed by a specific individual (unclear responsibility).
- The appropriateness of shield design assumptions for operating conditions during commissioning, studies, and abnormal conditions was not onsidered.

This event reinforced the need for training to include walkdowns of procedures, examination of operator's knowledge, and defining consistent and clear roles and responsibilities.

While this event revealed systemic and procedural vulnerabilities, it also reinforced the importance of not relying on the perception of safety without first ensuring the reality of safety.



Simulation of 1700 millirem/hour spot on Booster wall

Case Study #2: Piranha Etch Container Over-Pressurization

A waste container in a satellite accumulation area containing piranha etch (sulfuric acid and hydrogen peroxide) suddenly exploded. The top of the container shattered and some solution sprayed on a user in that part of the lab. Fortunately the user was wearing a Tyvek suit, and had no direct exposure to the skin.

An ensuing investigation determined that a different user had added some waste to the bottle that contained the piranha etch. The user then added an organic solution containing isopropal alcohol (IPA), which is known to react violently with piranha etch.

Some of the lessons learned from this event included the following:

- Segregate different types of waste into acid-only, base-only, and organic-only accumulation areas.
- Use poly-coated waste bottles with vented caps for the piranha etch.
- Check compatibility of materials before storing and using.
- Pay attention to details.
- Understand the hazards and impacts of all materials before usage.
- Label bottles correctly.

Case Study #3: Vacuum Chamber

During a standard operation, a visiting graduate student was venting an ultra-high vacuum chamber when the vacuum system overpressurized, causing a four-inch glass port to burst.

A piece of the glass port was projected approximately 10 feet into an adjacent room entry door and damaged the glass window of that door.

An ensuing analysis of the event determined that the following factors contributed to this event:

- Operator deviated from the typical practice of venting.
- Less than adequate overpressure protection.
- No co-notification.
- Not covered in training.
- No prescribed technique in the written procedures; and no safety approval form.

These elements can be summarized as inadequacies in the operator's questioning attitude, engineering controls, oversight, training, procedures, and hazard analysis.

KEY ROLES IN SAFELY CONDUCTING RESEARCH

Because hazards associated with research can change with little or no warning, Brookhaven Lab employs a layered defense strategy to ensure the safety of staff and facilities. This strategy relies on three layers, or a defense in depth, for the safe conduct of research.

LAYER 1: RESEARCH STAFF

Research staff performing laboratory experiments have the best understanding of the work they are performing. As a result, researchers should have the greatest knowledge of hazards associated with the work, and they are best positioned to understand both the unknowns and the potential energies involved in experiments. Their competence, expertise, and attention to experimental conditions form the first layer of defense.

Research staff are encouraged to use subject matter experts, peers, and support staff to delve into areas where their personal knowledge could be lacking.

LAYER 2: SPACE MANAGERS, INSTRUMENT SCIENTISTS, AND SUPPORT STAFF IN KEY ROLES

At the Lab, the second layer of defense is provided by individuals who become space managers and instrument scientists.

- Brookhaven assigns space managers to most laboratory spaces or high-bay areas in which research is conducted. The space manager maintains cognizance of all work being done in this space, any hazards that could be introduced, and collective or cumulative hazards associated with multiple laboratories that could challenge a facility's safety systems.
- Instrument scientists support the operation of scientific instruments or test stands at user facilities and participate in the research. Many user facilities are equipped with unique instruments and experimental capabilities, so instrument scientists play a critical role in ensuring safe and effective operation of these facilities. The instrument scientist is tasked with assisting users with experiment setup, data collection, data reduction and analysis, and safe operation of a particular instrument or test stand.
- Support staff and Environment, Safety & Health (ES&H) professionals are critical resources available to add knowledge and ideas when planning and executing work.

The expert knowledge of space managers and instrument scientists and their dedication to ensuring safe operation of laboratories and user facilities form the second layer of defense. To be effective, the space managers and instrument scientists must understand the work being conducted in their assigned spaces.

LAYER 3: MANAGEMENT

Brookhaven Lab managers provide the third layer of defense. We expect our first-line managers to be knowledgeable about the work being conducted by their staff, the competence of the staff executing the work, and the effectiveness of the assigned space managers or instrument scientists in performing their roles. The only way of detecting failures in either or both of the first two layers of defense is management presence in the field and technical expertise. Management awareness, gained from active engagement with staff performing research and with space managers and instrument scientists, forms the third layer of defense.

WORKING IN A SAFE AND ENVIRONMENTALLY SOUND MANNER

Although it is important to maintain a strong safety culture and to understand the layered defense strategy, that alone isn't enough. Ultimately, specific tasks at the working level must be executed. In today's complex world, there is a plethora of laws, regulations, standards, and controls that must be integrated into daily work activities. Brookhaven Lab has a system for capturing these inputs and distilling them into a set of operating procedures.

This section outlines a simple concept that forms the foundation for all of our procedures and processes, regardless of group. In addition, in times of uncertainty, this concept can be a useful tool in framing one's thinking about what to do next. This concept, known as "integrated safety management," has five core functions and is very consistent with the scientific method:

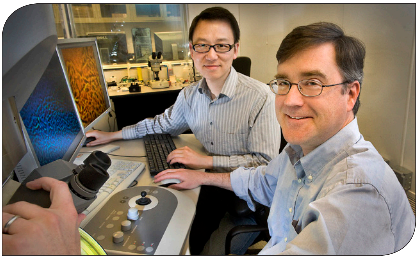
1. **Define the Work and Its Hazards.**
   Translate the work objectives into defined work activities that will meet those objectives and identify expectations for the performance of that work.

2. **Analyze the Hazards.**
   Identify and analyze the hazards, as well as safeguards and security issues associated with the planned work. This includes potential effects on workers, the public, and the environment.

3. **Develop and Implement Hazards Controls.**
   Identify the applicable standards and requirements that address the identified hazards and security issues, establish appropriate work controls to prevent and mitigate those hazards, implement those controls, and allocate resources to ensure that the controls are performed.

4. **Perform Work Within Controls.**
   Confirm readiness and perform the work safely in accordance with the established work controls.

5. **Provide Feedback and Continuous Improvement.**
   Assess and provide feedback on the adequacy of controls and continually improve the programs and processes that form integrated safety management.



PRINCIPLES FOR A STRONG SAFETY CULTURE

1. Everyone is personally responsible for ensuring safe operations.
2. Leaders value the safety legacy they create in their discipline.
3. Staff raise safety concerns because trust permeates the organization.
4. Cutting-edge science requires cutting-edge safety.
5. A questioning attitude is cultivated.
6. Learning never stops.
7. Hazards are identified and evaluated for every task, every time.
8. A healthy respect is maintained for what can go wrong.

NOTES

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