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**FUNDAMENTALS OF SAFETY FOR EXPERIMENTAL  
PROCESSING, HANDLING, AND STORAGE OF  
HIGH-ENERGY MATERIALS**

by  
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**ABSTRACT.** This document presents safety fundamentals relevant to operations with almost all materials capable of sudden release of chemical energy and chemical products that may be harmful or dangerous. These fundamentals are intended primarily as training topics and as guides for evaluating safety programs in the fields of explosives, propellants, pyrotechnics, and the like. While the fundamentals were developed as training aids in a research and development organization, it is believed that they are applicable to almost any operation with dangerous materials.

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**China Lake, California  
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## PREFACE

Research and development organizations, such as the U. S. Naval Ordnance Test Station, working on new propellants, high explosives, pyrotechnics, and other high-energy materials, have attempted to abide by safety rules and safety guidelines developed primarily for production organizations. While this has worked reasonably well in the past, there is concern about the adequacy of current safety guides for the present and future. Rules developed for production tend to fit well known materials and well established practices, but they cannot be expected to deal adequately with all problems in new areas of work.

We have entered into a period of rapid changes where the materials being worked on are considerably different and some are more hazardous than the materials worked on in the past. Therefore, it is believed that some changes are needed in the approach to safety particularly in research and development organizations.

Research and development organizations need guidelines that are flexible and that allow for safety decisions to be made as close as possible to the point of greatest information on new high-energy materials. In the final analysis, it is necessary to depend on the persons working with new materials to analyze their safety problem and to develop safe procedures for which there may be no precedents.

It is proposed that more emphasis be given to the training of individuals, especially chemists, engineers, and other technical and supervisory personnel, working with or supervising work on high-energy materials. It has been observed that conventional training in the rules of safety leaves some people with the attitude that rules are arbitrary and that one is compelled to follow them whether or not they make sense. Therefore, an outlook is developed that causes some people to oppose rather than to support well established rules and practices. The supplementary training that may help form more favorable attitudes is background training enabling people to understand that most safety policies and rules have a reasonable and sound basis. It is believed that individuals who have training in fundamentals will be more willing to accept the rules that are relevant because application of fundamentals would lead to about the same answers. It is also believed that individuals trained in fundamentals are better prepared to formulate sound guidelines for performing experimental work on new hazardous materials. In new areas of work, it is necessary to formulate some safety procedures where there is no precedent; otherwise progress is not possible on a reasonable basis that is acceptable to research and development personnel.

This document is intended primarily as a training aid for giving the kind of background necessary for the conditions mentioned above.

The type of training suggested is a program where each fundamental is discussed by small groups. It is suggested that each person be encouraged to challenge any statement and to present his own interpretation in groups large enough for varying viewpoints but small enough so that each person can effectively participate.

K. S. S.

### PRINCIPLES OF SAFETY FOR EXPLOSIVES

1. Take time to think, plan, and review.
2. Learn and use the experience of others.
3. Assume the worst with the unknown.
4. Minimize hazards and exposure to hazards.
5. Be concerned about the safety of others.

### SAFETY REMINDERS

Of mistakes and cures, learn the past.  
Think and plan, but not too fast.  
Something new, take double care.  
With our lives, we do no dare.  
Instead, we listen, heed the wise  
Minimize, minimize, minimize.

### ACKNOWLEDGMENT

These fundamentals of safety have been reviewed by so many people at the Naval Ordnance Test Station and elsewhere that it is impossible to list them individually. The guidelines have been reviewed by members of the Station's Safety Division staff, by the Propulsion Development Department Safety Group, by members of the Process Development Division, the Explosives and Pyrotechnics Division, the Propellants Division, and the Test and Evaluation Division. The fundamentals have been further reviewed by Dr. P. A. Longwell, California Institute of Technology, Pasadena, and formerly head of the Explosives Department, NOTS. Mr. Paul A. Donaldson, Safety Engineer, and Cecil Hunter, Safety Specialist, Propulsion Development Department, deserve special mention for their close cooperation, careful review, and interest shown in this document.

## INTRODUCTION

The objectives of a good safety program for work with high-energy materials are

1. To minimize hazards to personnel and prevent loss of lives
2. To prevent accidental fires or detonations
3. To minimize possible loss of equipment and buildings
4. To reduce accidents typically occurring in almost any laboratory or operation

The following statements are general guidelines that are relevant to work on almost every material that is capable of sudden release of chemical energy and chemical products in sufficient amounts to be harmful or dangerous.

These guidelines are an organized set of fundamentals of safety on which there is general agreement, among experienced technical, safety, and supervisory people, that the fundamentals are an applicable and necessary part of an explosive safety program. These fundamentals avoid stating exactly how an organization is to perform its responsibilities, but they do attempt to point out what the responsibilities are and to offer general suggestions of the important factors to be considered in hazardous work with high-energy materials. The fundamentals by themselves are just a starting point; they must be put to work and given concrete meaning through thought, discussion, and training sessions. Safety in any situation calls for knowledge of the characteristics of the materials being worked on, knowledge of the behavior and characteristics of equipment and its possible interactions with high-energy materials, knowledge of the characteristics of people as they are, and knowledge of how to design and maintain facilities and equipment for safety.

These safety fundamentals are intended as guides to aid in reviewing instructions and rules for specific applications and as discussion topics for training personnel connected with work on high-energy materials. They were prepared for use by research and development groups working on high-energy materials in amounts ranging from a few grams to full-scale pilot-plant quantities.

The phrase "high-energy materials" and the word "explosives" are used here to cover the broad field of propellants, high explosives, pyrotechnics, and primary and initiating explosives.

## GENERAL FUNDAMENTALS

1. Accidents with explosives are caused by energy concentrations, such as sparks, friction, impact, flame, hot objects, chemical reaction, radiation, excessive pressure, and electrostatic discharge. Energy concentrations anywhere near initiating levels must be kept away from explosives except when it is desired to ignite or detonate the explosive.
2. The initiation of explosives is subject to probability considerations. With a low level of stimulus, the probability of initiation can be small; with a high energy concentration, the probability of initiation will be much larger but still not certain. The probabilities at the extremes cannot be determined with accuracy from a small number of tests. Therefore, in order to keep the probability of initiation low, it is good practice to treat explosives as gently and as carefully as possible.
3. Probability is a consideration in virtually all accidents. The probability of a serious accident may never be reduced to zero, but the probability of an adverse incident can be kept very low by working to find ways to eliminate causes of accidents and by providing a safe environment.
4. A series of safety devices or steps may be employed to greatly increase the safety of an operation or of a weapon system that uses explosives. Unless there is an adequate review process for ensuring that all parts of the safing system are maintained and used, there is a tendency for the safety of the system to deteriorate.
5. When specific knowledge is lacking on the characteristics of an explosive, the worst characteristics that might affect safety must be assumed.
6. Explosives that are new to an individual or group working with them must be regarded as extremely dangerous until their characteristics are well known and the individual or group has become skilled in practices that minimize processing and handling hazards.
7. Human errors and human failings must be allowed for. Even the best man may occasionally forget, fail to understand, act without thinking, go ahead without adequate knowledge, or become upset.
8. Relaxation of safety regulations affecting personnel should be based on proof that present requirements are more stringent than necessary. Conversely, if it is suspected that existing safety measures may not be adequate, steps must be taken immediately to provide

added precautions even though the evidence is not conclusive. Procedures for changing regulations must be known by everyone concerned.

#### PERSONNEL TRAINING AND PROTECTION

9. Important elements of safety are the formation of good habits; a calm, mature environment; and training based on previous experience in the whole explosive field.

10. Supervisors of explosive operations must have adequate training and knowledge to maintain safety of operations.

11. A man performing an explosive operation without direct supervision must have sufficient training and knowledge to maintain safety of his operation.

12. Persons working with explosives must have favorable attitudes toward safety and must be emotionally stable.

13. For persons working with explosives or observing explosive operations, provide protection for their eyes, protection against fire or intense radiant heat, means for automatically discharging static electricity from their bodies, and means for keeping their bodies and personal clothing free from contamination.

14. Means must be provided for safeguarding personnel from toxic materials, fumes, or other harmful effects. With very toxic materials, there may be need for protecting people considerable distances away who may or may not be involved in the work.

15. Provide showers, eye washers, and other first-aid devices, which are necessary immediate aids in preventing further injury, in locations that are quickly and easily accessible.

16. Personnel working with toxic materials must be given periodic medical examinations.

17. Adequate tools and help for lifting, for performing operations, and for emergency assistance should be available.

18. Visitors unfamiliar with explosive operations or the explosive facility must be escorted by a responsible person who knows what is going on and what the safety precautions are.

## PLANNING AND PREPARATION

19. Data on properties and characteristics of new explosives to be processed in larger than minimum laboratory amounts should be reviewed by a qualified group before introduction of the explosive into a process. These data and recommendations of the committee must be available to the processing group before beginning work.

20. Compatibility of different explosives should be established before combining them as part of a design, for storage, or for scrap disposal.

21. Having more than one explosive in a processing building or bay at the same time must be carefully considered for hazards and done only for good reason.

22. General operating guidelines should be written for all new operations to ensure that careful thought and careful review have been exercised before the start of potentially hazardous work. The general operating guidelines may permit flexibility where justified, but they must be reviewed by one or more qualified, experienced persons.

23. Keep up-to-date charts and instructions in the operating building. They can serve as ready references, as reminders of procedures to be followed, and explanations of the essential features of equipment.

24. Time must be allowed—even at the expense of deadlines and schedules—for adequate thought, planning, and preparation of hazardous operations.

25. Within limits of reasonability and practicability, the safest method for processing or working on high-energy materials should be used.

26. Any explosive operation performed with personnel exposed should be of such a nature that there is no detonation hazard, and with ample opportunity to escape unhurt in case of fire. Usually, operations in closed vessels will be performed remotely.

## RESPONSIBILITIES AND CONTROLS

27. Supervisors are responsible for the safety of operations and the men they supervise. The safety-engineering staff is responsible for advising the line organization on safety and is responsible for helping the organization maintain high standards of safety.

28. Whoever recognizes a hazardous situation is responsible for taking steps to have the condition corrected.

29. Scrap or waste disposal is a hazardous operation. The scientist or engineer who originates a new formulation is obligated to assist in specifying disposal conditions and procedures.

30. Most careful consideration must be given to setting processing limits such as maximum temperatures, pressures, rates of machining, rates of mixing, and rates of extrusion.

31. Containers of explosives and explosive ingredients should be clearly labeled at all times as to their content and nature of hazard. When possible, label the explosive directly.

32. Explosive-processing or storage areas should be posted with warnings to advise of precautions to be taken and how to obtain guidance.

#### MINIMIZING HAZARDS

33. The number of individuals exposed to hazards should be kept to a minimum consistent with operational requirements and safety.

34. Always work with, and in the presence of, the least amount of explosive needed for the operation.

35. Get as much useful data on as small a scale as possible. It is much easier to protect individuals and minimize losses with laboratory-scale work than with full-scale work.

36. Check new equipment and new procedures with inert materials whenever possible.

37. Cleanliness and orderliness help to prevent initiation or the spread of a fire or detonation.

38. Operations should be conducted at all times with a view toward minimizing the effects of an accidental fire, detonation, or any other hazard.

39. Only the immediately needed portable tools and equipment should be retained in a processing room.

## TRANSPORTATION, SHIPPING, AND STORAGE

40. With few exceptions, containers should be used for transporting and storing explosives. These containers should provide delay of ignition from fire, should attenuate shock energy, and should protect against contamination and physical damage.

41. When explosives are transported, precautions must be taken to protect persons and property on or near the roadway. Precautions must be taken to reduce the probability of an accident and to minimize the effects of a possible transportation accident.

42. Shipping explosives to individuals or activities should be performed by a group or individuals familiar with pertinent regulations governing packaging, shipping, and handling in transit.

43. Before sending explosives to other activities, it should be established that that activity is qualified to receive and handle the explosive. The receiver should be fully informed in writing of the characteristics of any new or nonstandard explosive.

44. New or experimental explosives whose stability and compatibility with other materials have not been thoroughly established should be stored in small quantities under conditions where possible ignition will cause limited damage. These explosives must never be stored with quantities of other explosives whose ignition could create a hazard.

45. A periodic review of high-energy materials in storage must be made to ensure against storage of these materials for longer than their safe life. Records of all materials in storage must be kept where they are not likely to be destroyed.

## FACILITIES AND EQUIPMENT

46. The design of new facilities, new equipment, and tools should receive the same careful safety review as do new explosives. Designers should remove the human factor from hazards by making protection as permanent and as automatic as possible.

47. All automatic safety devices, such as fire-fighting systems, interlocks, and warning signals should be checked at predetermined intervals or more frequently.

48. Schedules of preventive maintenance should be set up for all equipment used in explosive operations where failure to institute and

conduct such a program can lead to processing hazards.

49. Equipment taken to a shop for repair or adjustment must be freed from explosives by a suitable decontamination process. Shop personnel should be warned of added precautions to be taken during further disassembly.

50. All explosives must be removed from a processing room when it is turned over to a maintenance group for repair or adjustment of equipment. Equipment that may be contaminated with explosives must be cleaned so that repairs or adjustments can be made safely. Maintenance personnel should be given complete information on conditions that might affect their safety.

51. Although every reasonable effort has been made to decontaminate a facility or equipment, anyone performing maintenance or repair work on the equipment should proceed with caution.

#### REPORTING ACCIDENTS

52. The discernible facts associated with any accidental deflagration or explosion must be reported completely and accurately so that others doing similar work may be warned and so that the best corrective action may be taken to prevent similar accidents.

53. Minor incidents, which in themselves do little or no harm, frequently give warnings of unsuspected hazards. These incidents should be widely reported and their significance given thorough consideration.

54. Complete records of operating conditions should be kept. When accidents occur, the records are an important aid in determining the cause and in preventing future adverse incidents. Critical temperatures, pressures, speeds, power consumed by motors, etc., should be recorded continuously when possible.

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