To what extent does this man's safety depend on current decisions and procedures, and to what extent on the design of the physical facilities? Here is . . .

A Hard Look at Safety in High-Pressure Research

E. L. CLARK, *Consulting Engineer*

Research involving high pressure, high temperature and flammable materials poses a safety problem, some phases of which have received considerable attention lately. The design of facilities to house such research has been discussed in several recent articles,[1,2,3] and also in the new edition of "Laboratory Planning."[4] However, there are other phases that have not been given their due, thereby prompting this brief discussion.

There is a tremendous variety of protective facilities, as well as absence thereof, among laboratories engaged in similar research. One author reports: "Some laboratories use no protection other than the factor of safety designed into the equipment. Other research organizations install protective barricading and safety features for all pressure applications."[5]

Even papers describing these protective facilities indicate major variations in their extent. Barricade walls range from a half-inch of steel plate to 36 in. of reinforced concrete. The light-weight relieving or venting walls for such barricaded cells vary from 1 to 5 sq. ft. per 100 cu. ft. of cell volume. Ventilation systems provide from 10 to 60 air changes per hour and differ widely as to how positively in-and-out air flow is maintained. There is almost no agreement among various experimenters as to methods of protecting the high-pressure piping that conducts gas and liquid reactants to and from these barricaded areas.

These wide differences raise important and intensely practical questions. Is the user of minimal protection incurring an unpardonable risk? Is the laboratory that has been designed for the maximum explosive hazard an unwarranted expenditure of capital funds? Conducting an experiment in such a laboratory is more difficult and costly; is this added cost justified? Or will the clever user of fewer protective devices permit lower-cost operation of research facilities without undue hazard?

Finally, how does one assess the protective needs for a pilot plant or an industrial plant from the design and operation of laboratory experiments? Should the same complete and total enclosure be provided?

Having been involved in research and development at high pressures for many years, I realize the difficulties in finding simple answers for these questions. As a consultant, I have had to recommend how much protection is needed, and the personal responsibility involved in this task results in a great deal of soul-searching. Here are some thoughts that have evolved from this critical-evaluation process:

Facilities and Equipment Are Not Enough

Safety in research and development under hazardous conditions depends entirely on the personnel directly involved. No matter how carefully one designs the facilities and controls the atmosphere, the operators make the final decisions.

To make sure these decisions are sound, some system of review and evaluation must be provided. Each experiment or series of experiments must be examined by a competent group with a variety of both engineering and scientific disciplines. The review must consider the equipment to be used, its condition, the experimental program and any necessary protective devices or operating procedures. While the evaluation may be on an informal basis, approval of the experiment and the conditions under which it is to be made must be clearly put forth in writing.

Unfortunately, the present trend in high-pressure laboratory construction appears to be this: first determine the most hazardous combination of materials in the largest reactor available to the research group, and then design a series of experimental cells each identically able to withstand complete failure of such a reactor. As a result, the experimenter with the usual small reactor finds himself surrounded by barricades and operating requirements that are so unsuited to his work that safety precautions lose any meaning and soon are regarded as interferences to be circumvented.

The most hazardous situation should be realized and provisions made for it, but facilities should also be available for lower hazard experiments, to permit most efficient operation. Uniformity of design seems to have an irresistible appeal that negates the more reasonable, though more difficult, approach of designing for a multiplicity of situations so that each might be handled most conveniently.

Preventing the Accident

Most of the literature tends to stress the last line of defense—preventing harm after the accident—

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rather than the first line, preventing the accidents themselves. More needs to be said and done about the latter.

Accident prevention begins with the design, maintenance and testing of the equipment used to contain, transfer and store high-pressure fluids.

Fortunately experimenters no longer have to build their own equipment. It can be purchased for most requirements, suitably designed in accordance with well-established codes. However, it must be constantly checked to ensure its safety. Even standard items such as high-pressure tubing should be critically examined and pressure-tested before use in any system.

Each piece of equipment should be cleaned and preferably polished after each experiment, to avoid concealment of damage or minor corrosion that could be the starting point of a serious and dramatic failure. Periodic micrometer measurements must be made to reveal any dimensional change. For high-temperature work, a definite time limit for usable life should be established. Equipment that has shown deformation or corrosion must be scrapped without delay.

These seem to be obvious and simple precautions, yet they are so often completely neglected. Autoclaves are often coated with dirt and grease, threads and sealing surfaces are often deformed, stretched bolts are not uncommon, and tubing connections are sometimes overstressed to the point where the tubing has been extruded into the fluid passage and sealed it. An inspection of a laboratory's equipment will often result in the scrapping of as many as six or eight autoclaves due to deformed components.

Equally important as the equipment is the understanding of the experiment itself. Do the operating requirements fit the design criteria for the equipment? What happens if temperature or pressure get out of hand because of control failure? How much energy is involved, and can the available relieving devices handle it?

Since most reactions are conducted with the hope of obtaining a recoverable product, these questions are as pertinent to the conduct of the research as to safety. The information is usually available; all that is needed is group effort to evaluate it.

Instrumentation systems and relieving devices form an important second line of defense against accident. They maintain the operating variables at predetermined levels, and act to prevent design limitations from being exceeded.

Proper temperature control requires considerable thought, since the wall of the reactor, as well as the reaction mixture within, must be protected against heat. For some exothermic reactions, emergency cooling is a must; but at the same time, thermal shock to pressure components must be avoided. These multiple and conflicting constraints require careful evaluation and design.

Relieving devices that exhaust flammable materials require proper venting and protection against ignition, even at low pressures.

Finally, all this instrumentation must be maintained and checked periodically.

In complex, continuous pilot plants, even more responsibility falls on the operators. Valves and controls must usually be manipulated by hand. There are always interconnections between plant sections designed for different pressures and temperatures. Fluids at high pressure and high temperatures must be transferred and sampled. At these various points of transfer, most accidents take place.

Similar problems exist even in barricaded simple systems. Gases are manifolded and conveyed to the high-pressure equipment within the barricaded cell. Improper valve manipulation can still result in hazards that bypass the protective walls. In fact, the complexity of manifolded gas systems becomes of itself a serious hazard and has been the indirect cause of several fatal accidents.

Where More Emphasis Should Fall

There is no escape. The primary factor in achieving safety remains a well-trained staff—one with adequate supervision to organize the knowledge of each individual and to blend it into group action so that each experiment can be evaluated and performed in a proper manner. There is no substitute for constant checking and rechecking of research requirements, operating procedures, equipment condition and availability, and maintenance practices.

A great contribution to safety could be made by more detailed discussion of these techniques in the current literature. Such measures are vastly more important than the design of isolation cells and barricades.

References

1. Knap, J. E., Kyle, H. E., *Chem. Eng. Progr.*, 58, No. 3, pp. 48-53 (1962).
2. Stenberg, J., Coffey, E. G., *Chem. Eng.*, Nov. 26, 1962, pp. 115-18.
3. Rebenstorf, M. A., *Ind. Eng. Chem.*, 53, No. 1, pp. 40A-42A (1961).
4. Lewis, H. F., "Laboratory Planning for Chemistry and Chemical Engineering." Reinhold. New York (1962).
5. See (1), pp. 239-56.

Meet the Author

E. L. CLARK, *a consulting engineer for the chemical, coal and nuclear industries, is headquartered in Pittsburgh. A graduate of Northeastern University, his experience includes service with the Commonwealth of Massachusetts, Cities Service, the U. S. Bureau of Mines, and Israel Mining and Industries. He has taught and lectured in chemical engineering at the University of Pittsburgh and Catholic University.*

Key Concepts for This Article

For indexing details, see Chem. Eng., Jan. 7, 1963, p. 73 (Reprint No. 222). Words in bold are role indicators; numbers correspond to AIChE system.

Active (8) Protecting

Passive (9) Laboratories

Means/Methods (10) Training, Analysis

Independent Variable (6) Pressure, high

Dependent Variable (7) Safety, Hazards

Inspection, Maintenance, Design