UNIQUE FEATURES OF AN R&D WORK ENVIRONMENT

AND RESEARCH SCIENTISTS AND ENGINEERS

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> "Not only is good management of research the critical difference between a thriving research organization and an average one, but research is the most difficult to manage of all functional activities" (Lamontagne Report, 1972, Vol. 2. referenced in Vol. 6, Ch. 10, p. 8 of the 1994 Report of the Auditor General of Canada)

Thomas E. Clarke, M.Sc., M.B.A.

Stargate Consultants Limited
1687 Centennary Drive
Nanaimo, B.C., V9X 1A3
(250) 755-3066

http://www.tomeclarke.ca

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Senator Maurice Lamontagne during his extensive review of science policy in Canada identified three reasons or factors why managing research is different from managing other human activities:

- the uncertainty of outcome of research;
- the difficulty of measuring the results or impacts of research when each research task is unique; and
- the differences in the expectations, values, attitudes and motivation of scientists and engineers from those of other employees; [i.e. the people element].

To this list can be added at least two more major factors: the rapid rate of change of the scientific knowledge base, and the unique organizational characteristics of a creative and productive R&D-based institution which differs from the more traditional characteristics seen in most non science-based government departments.

This review of the uniqueness of the R&D work environment and R&D personnel will elaborate on these five factors and show why managing R&D projects and personnel is generally more difficult than managing other organizational functions.

UNCERTAINTY ASSOCIATED WITH SCIENTIFIC ACTIVITIES

> "R&D, by its very nature, is an activity that is aimed at generating new knowledge, testing hypotheses about how matters in the physical or social world act and react, and in general, providing know-how which can be used to create or improve activities or systems in that part of our life to which they pertain. (Salasin and Hattery, 1977, p.5)

A major distinguishing feature of R&D that differentiates it from other functions in an organization is the level of uncertainty associated with it. R&D is characterized not only by uncertainty in terms of project duration, or budget, but also by the nature of the results. This is especially so at the research end of the R&D spectrum, which is usually regarded as the stage from basic scientific research through to experimental development.

A fully competent scientist may tackle a research project, and conduct it in a totally acceptable manner, and still not obtain the output required to answer the scientific question or solve the problem being addressed. In most organizations this would be considered a failure, and reflect badly on the worker. In a well managed R&D organization, the results would be viewed as valuable in that a line of research has been shown to be unproductive, and another approach must be made. The researcher would not be blamed for this “failure”.

In another situation, totally unexpected results might be obtained which may lead to even greater benefits. Is it a failure that the original objectives were not met? Technically, yes, but only a bureaucratic mind or “bean counter” would insist on calling it a failure. 3M's glue that would not permanently stick to anything was clearly a technical failure at one level, but a huge success at another given the widespread use of "Post-It" notes in all their many manifestations.

Uncertainty associated with scientific activities can also take the form of “by-products” of the research process that the observant scientist must recognize. As we all know, penicillin was not a planned discovery, but the result of Alexander Fleming noting something unusual in a petri dish.

As noted above, the uncertainty associated with R&D projects makes it much more difficult for managers to plan and budget. Research activities may take longer to produce results, and may need more resources that originally planned. This does not allow for the traditional annual budget cycles found in most government departments. Multi-year funding must be in place so that the research momentum is kept constant.

Most other professionals, such as medical doctors and lawyers, usually deal with an existing knowledge base (e.g. well understood diseases or prior case law), or known technology, this is not the case for research scientists or engineers. They are either developing a new understanding of a natural phenomenon, developing new analytical techniques, or solving a problem for which there is no known solution. In some cases, they must throw out what they think they know, and work in totally unknown territory. No other professional occupation faces the situation of pushing back the frontiers of science or engineering. "***To go where no one has gone befor****e*".

DIFFICULTY OF ASSESSING THE CONTRIBUTION OR IMPACT OF THE RESEARCH RESULTS

The output of research is knowledge and it is difficult to predict in advance, with any accuracy, the quality, quantity or usefulness of the knowledge that will be generated from any given research project. Yet accountants, finance officers, bureaucrats and politicians like to be able to show quantitative evidence that the resources invested in research have tangible results or impacts, usually within the time frame of their budget or evaluation period, or their term of office.

Senator Lamontagne stated in his review of Canadian science policy that "even when the results can be measured, the delay between the successful conclusion of a research project and the impact may be so great, that it is hard to use the knowledge of the results as a basis for planning for the future".

In many instances, the impact of one line of research must await developments in other areas of science or technology before their impact or application can be seen.

The impact or applications of laser technology, for example, languished for years before practical applications were developed. No one could have predicted such widespread uses from a substitution for record player needles to optical surgery.

On more than one occasion have Nobel Prizes in science been awarded years after the initial scientific discovery, because at the time the value or importance of the discovery to the field was underestimated.

When trying to measure R&D productivity and output, stronger emphasis should be placed on non-financial performance indicators such as value creation, utility to the customer, market share changes, ability to maintain technological leadership in core business categories and ability to implement new technology when needed to meet competition (Wolff, 1991).

Another difficulty facing R&D managers is to conduct the annual performance appraisal of scientific staff in a fair and accurate manner. Assessing the contribution of a scientist's output to a field, or the eventual impact that contribution will have in the future can be especially challenging. In some cases, a scientist's manager may be ill-equipped to evaluate the scientist's performance because of a lack of an in-depth knowledge of the scientific field of the scientist being evaluated.

RAPID ADVANCEMENT OF SCIENTIFIC OR TECHNICAL KNOWLEDGE

In no other area of human endeavour is change more dominant than in the areas of science and technology. In almost no other profession is the pace of change as rapid. Medical procedures change relatively slowly, changes in management practices and theory can be measured in years, changes in law can take decades. In contrast, it has been estimated that the half-life of initial engineering education is less than five years.

Technological obsolescence is a constant fear of scientists and engineers because it is very easy to fall behind. An assignment that takes a scientist away from his or her work for six months, may, depending on the field, force the scientist to have to study the field anew for a year just to catch up with colleagues. Continuous learning throughout the lifetime of working scientists and engineers is a must if they are to stay at the forefront of their discipline and contribute to it.

Technological obsolescence also applies to equipment and analytical procedures. Out-of-date equipment or techniques limit the ability of the researchers to be involved in "cutting edge" research and also the services a laboratory can offer to its internal or external clients

Thus R&D managers and scientific organizations must operate in such a way as to assist their scientific and engineering staff avoid obsolescence. Actions such as assignment of projects that demand the acquisition of new skills and knowledge, and liberal policies on attendance at professional meetings and conferences to meet with their national and international colleagues to learn of the latest advances are extremely important if the organization wants an R&D laboratory with vitality. Conference attendance cannot be considered a luxury. Some organizations such as Exxon in the U.S. go as far as having joint degree programs with local universities and encourage their staff to obtain advanced degrees.

Failure to avoid technological obsolescence in either people or equipment will result in inadequate, or overly expensive solutions to problems, problems avoided and not solved, and a general reduction in the organization's ability to fulfill its mandate or to survive. Thus avoiding technological obsolescence in the face of rapidly evolving science and technology is another unique characteristic of the R&D work environment

RESEARCH CAN NOT BE STOPPED AND RE-STARTED EASILY

One of the important consequences of the rapid change in the scientific knowledge base is that research projects that are of an inherently long-term nature cannot be stopped and then quickly restarted like a production line. Scientists and engineers will not sit around waiting for a green light to re-start a project. They will, in order to maintain their scientific expertise go on to other projects or employers, thus making them unavailable for the original project.

An additional problem is that it takes time to build an effective research team. Once broken apart, it may take six months to a year to bring it back to the functioning level it was at before the breakup. The passage of time may force the members of the team to play catch-up, if their field of activity has moved ahead in areas they were not presently working in, but are of importance to the team activity. The original objectives of the team might have to be modified in the light of advancements that have taken place since the team's break up.

DIFFERENCES IN EXPECTATIONS, VALUES, ATTITUDES AND MOTIVATION OF SCIENTISTS AND ENGINEERS

Research scientists and engineers while sharing many attributes with highly trained people in other professions, have some characteristics that are more associated with them, than with other professionals.

Orientation Toward Things Not People

In general, people who go in for science or engineering are oriented more towards things or natural phenomena than people. Many are characterized as having a poor grasp of social skills, and do not make friends easily. They are more comfortable working with things that they can objectively measure and control (Badawy, 1983). In addition, many scientists, more than engineers, are introverts preferring the company of a few friends or acquaintances rather than being surrounded by strangers at a party.

One result of this orientation is the reluctance among many research scientists and engineers to take on managerial responsibility. Unlike many other professionals, scientists and engineers do not seek out promotion to the ranks of management as this would force them to interact with people to a greater degree and detract from their focus on their scientific profession. They simply would not get any satisfaction out of a management position. In a survey of scientists and engineers in the Canadian federal government conducted several years ago, to determine their views on becoming a supervisor, one respondent when asked whether he would like to be a supervisor said, "***hell no, I would rather drive a cab***". This author has also noted the difficulties some government laboratories have in encouraging competent scientific staff to move into managerial positions.

Orientation Toward Profession Not Employer

Research scientists and to a lesser extent engineers care more about how their colleagues around the world think about their work than their immediate supervisor. Scientists or engineers with what is called a "cosmopolitan" orientation:

- are low on loyalty to their employing organization;
- are high on commitment to advancing knowledge in their professional field; and
- look for rewards from their peers in their professional community.

Badawy (1971) in a study of role orientations of scientists concluded that the goal orientation of scientists was towards:

- advancement of knowledge for its own sake;
- establishing a reputation through publishing;
- having research achievements that will bring professional recognition; and

- advancing and moving ahead as specialists in their field.

This orientation may be the result of the socialization process that research scientists and engineers are subject to while attending university and obtaining advance degrees.

Other professionals, including some scientists and engineers, are more likely to have a more "local" orientation to their work that is described as:

- being very loyal to their employing organization; and
- having a low commitment to advancing knowledge in their professional field; and
- looking for rewards from their employer.

Other Expectations and Values

> "Because professionals invest more time and energy in educational preparation for their work than do most other employees, they bring unique, higher and more specific expectations to work" (Miller, 1988).

Miller (1988) outlines some generalized organizational and work-values usually held by professionals:

- professionals feel that they have a moral and ethical right not to follow the direction of management when it goes against their principles and values;
- being critical of management is a professional responsibility - and often fun;
- individualism is desirable, perhaps even one of the rights of the professional;
- the goal of good science for the scientist - or of a powerful effective program for the programmer - is often more important than and transcends organizational goals in the eyes of the professional; and
- when professionals apply personal knowledge and expertise in a creative way, this usually builds a strong emotional bond (ownership) with the work output. This can be good because it supports a drive for excellence, and/or bad because it often means the professional resents the organization's need for a project end and the passing of the output to another phase.

Bench Researchers Insist that their Immediate Managers Have a Scientific or Technical Background

There is a strong expectation among scientists and engineers "at the bench" that their immediate R&D managers will, themselves, have a scientific or engineering background. The myth of "a manager is a manager is a manager" falls apart very quickly in an R&D environment. The manager is expected to be able to provide substantive advice, and act as a sounding board for technical ideas or proposals. This cannot be done by someone who does not have scientific or technical training in the scientific or technical field under study.

Many studies have noted that an R&D manager's initial credibility comes from their credibility as a contributing scientist or engineer, and then later, hopefully, as an effective manager.

Motivating and Rewarding Scientists and Engineers is Different

> "Managers motivate their scientists and engineers by the work environment they create" (Koning, Jr., 1993)

Scientists and engineers, perhaps more than other professionals are highly motivated when they are allowed to satisfy their psychological needs for achievement, recognition, professional growth, and working on challenging, interesting projects. Even in times of economic and job uncertainty, the opportunity to do challenging, interesting work and to gain recognition are the most powerful motivators of scientists (Bucher and Reece, 1972).

In a review of the R&D management literature on reward and recognition systems for creative scientists and engineers, Clarke, 1996 found that the literature tends to emphasize intrinsic rewards over direct financial incentives. Research scientists and engineers generally respond more positively to intrinsic forms of reward and recognition such as:

- praise and feedback from colleagues, both within their organization and without;
- freedom to develop their own ideas (autonomy);
- being assigned work of significance and importance;
- having the freedom to select, within broad parameters, their research projects;
- being assigned challenging, interesting projects; and

- allowing the scientists and engineers to participate in decision-making that affects them and their work.

More traditional forms of reward and recognition such as salary increases, stock options, financial bonuses, or promotion into management are not as effective with scientists and engineers, as long as they consider their base pay to be fair and satisfactory.

In summary, scientists and engineers with a more cosmopolitan orientation want the opportunity to work on challenging projects that are adequately funded and that will result in some meaningful output that will be recognized and praised by their peers.

CHARACTERISTICS ASSOCIATED WITH SCIENCE-BASED ORGANIZATIONS

Organizations that rely on the output of creative research scientists or engineers for their survival have different characteristics than those organizations who rely on other attributes to meet their organizational objectives or mandate.

Participative Managerial Style Encouraged

> R&D should not be treated in the same manner as on-going repetitive operations... Procedures that are applicable to production or widespread application are not ordinarily properly applicable to R&D" (Salasin and Hattery, 1977, p. 5).

In reviews of the literature concerned with the management of R&D personnel, the need for a science-based organization to promote a participative style of management is a dominant theme. An autocratic approach to management is just not effective when an organization requires both creativity and productivity. Martell and Carroll (1995) point out that traditional human resources management practices (HRM) may not work in environments that stress technological innovation and managers face a special challenge in identifying the HRM practices that most effectively support innovation.

Protestations to the contrary, most organizations are not looking for creative output from their employees. They want employees that can follow instructions and operate within a very narrow band of decision-making authority.

The sharing of decision-making authority is a key element of the participative style. In more traditional organizations, people at the senior levels of the management hierarchy have both the power and knowledge to make effective decisions. In knowledge based organizations, the power to make decisions may still be at the top, but the ability to make effective decisions concerned with the knowledge base of the organization lies at the bottom of the hierarchy, with the bench scientists and engineers. Thus in order to make effective decisions, those with the power must consult and get the input of those with the knowledge to ensure that the decision is the right one.

Another factor that contributes to the unique characteristics of an R&D-based organization is the inability of R&D managers to stay current and at the leading edge in many scientific or technical fields at once. An R&D manager may be supervising a group of scientists or engineers who operate in different fields than the one in which the manager trained. They are the experts. In addition, time pressures on R&D managers may limit their ability to even stay current in their own field. The net effect is that the R&D managers do not know as much as their employees about what should be done in the progress of a research project and how best to do it. They must consult with their staff if the organization is to meet its objectives. Even in the case of work conducted by a technologist, the technologist may be the best person to decide on the physical lay out of an experiment.

Long-term vs. Short-term Planning Horizons

A distinguishing feature of an effectively managed R&D organization is their taking a long-term view of their research activities. Unfortunately many private sector firms in the U. S. and Canada have succumbed to the disease of "short-termitus".

In industrial organizations, managers, especially those with no technical background, often fail to appreciate that in R&D, there can be a long time between investment of resources, including human resources, and tangible results in the form of products or processes that contribute to the company's bottom line. This time frame, especially on the research end of the R&D spectrum, is often well beyond the typical five-year planning cycle of most organizations and usually beyond the "annual budget" time frame. Research managers in government laboratories with mandates to support sustainable growth creation and economic growth or improved quality of life, probably have greater problems in measuring the impacts of research.

One of the major problems in the decline of U.S. businesses in the late 1970s has been attributed to the failure of American managers to keep their companies technologically competitive over the long term (Hayes and Abernathy, 1980). Management that measures both company and managerial performance using only short-term financial measurements create an environment "in which no one feels he or she can afford a failure or even a momentary dip in the bottom line". Yet research, by its very nature, means that some projects will "fail", or may take a long time to produce the hoped-for results. Managers who rely on objective, quantifiable criteria to measure performance cannot relate to the uncertainties of research. The pre-ponderance of financial analysts and accountants in company boardrooms resulted in a reduction in funding for long term research and a concentration on short term work that was less risky, less innovative, and that would produce results quickly. A similar emphasis on the short-term is still seen today. An emphasis not adopted by our competitor, Japan.

Other studies (including Baldwin 1991, NSB Committee 1991, Heininger 1988, Steele 1988) have pointed out that financial considerations such as the use of discounted cash flow techniques and cost-benefit analyses to select projects, and demands for short-term return on investment have contributed to the decline in technology leadership in the United States.

R&D managers have to be aggressive in trying to get corporate management to look at R&D as a long term investment in the viability of the organization and encourage the CEO to establish the research budget outside the time frame of the regular budget control process (Leet 1991).

Delayed Age of Joining the Work Force Shortens the “Window of Creativity”

Unlike many professional disciplines, research scientists usually require training up to the Ph.D. level, and research engineers to at least the Masters level. This results in them joining the work force at a much later age than most employees. In general, scientists reach their creative peak between 28 and 40 years of age. After that, they may remain very productive, but not have the same creative spark that they had earlier. Thus scientific organizations have a "ten to twelve year window" within which to encourage and elicit creative work from their scientists and research engineers. In most organizations, creativity is not called for, and experience over the years is of more importance to their success.

Retention of the Best and Brightest Researchers is More Critical

Retention of professional employees is of vital importance to science-based organizations. It may have taken years for a scientist or engineer to acquire sufficient understanding of his or her specialty to be of creative and productive value to their employer. If they leave, the productive, creative capacity of the firm will be lowered immediately. It may not be possible to replace that person in a timely manner to avoid a whole research program being closed down. Even if a replacement can be quickly found, it may take months before the person is able to achieve the same level of performance as the person they are replacing.

While few people are irreplaceable in the long term, an organization may pay a high price if a key, well-respected, knowledgeable researcher suddenly resigns. The price can be measured in terms of lost research momentum, considerable financial costs of finding a suitable replacement that may involve searching the world-wide scientific community, and the cost in terms of lowered organizational reputation if it is seen as not being able to retain its best and brightest. This last cost could prevent the organization from being able to hire the needed replacement even when identified.

Lower Level R&D Managers Are Still Scientific Contributors

Another feature of the R&D environment which is different from many other professional activities, is the fact that at the lower levels of R&D management, the managers work side-by-side with their subordinates on research projects in their field of expertise. They not only manage the R&D project but also actively take part in the execution of the project.

In most other professional occupations, a move into management means dropping their professional activities and supervising the work of others. They do not "get their hands dirty" with the actual day-to-day work, except in emergencies.

Dual Promotion Ladders

Another unique feature of science or engineering based organizations is the existence of the "dual promotion" ladder. [In some organizations there are more that two promotion paths.]

As noted earlier, scientists are not generally anxious to climb the traditional corporate management ladder. This poses a problem for organizations wanting to reward scientists for excellent performance. To overcome this difficulty, many progressive R&D based organizations have established a second promotional ladder (some have a third ladder specifically for engineers) so that scientists or research engineers can be "promoted" and rewarded or recognized by movement up this technical or scientific ladder. These scientific ladders have rungs comparable to the rungs on the management ladder but do not involve the person having to take on additional managerial duties. Each step or rung on the technical ladder has its own title such senior research scientist, or principal research scientist, etc. and the salary and perquisites associated with the step are the same or comparable to the equivalent step on the managerial ladder. It is common for scientists at the higher levels of the technical ladder to also wield considerable influence over the research direction of the organization.

The existence of a dual or multi-path promotion ladder also avoids putting pressure on productive scientists or engineers to leave research in order to "get ahead" in the organization in terms of higher salaries or organizational power. In many cases, when scientists move to the managerial ladder just to get more financial compensation, the organization loses a productive, highly motivated scientist and gains an unfulfilled, mediocre manager.

In almost no other organizational structure does dual promotion ladders play such an vital role in maintaining the creativity and productivity of the organization. There are, in fact, several possible alternate career paths for scientists or engineers besides staying at the “bench” or going into R&D management: there is S&T policy development, health, safety or environmental regulatory/standards activities or R&D business development.

SUMMARY

The dedication of research scientists and engineers in pushing back the frontiers of science and converting knowledge into practical applications is a hallmark of this professional community.

R&D personnel and the R&D work environment have many features that are either unique, or although shared with other professionals and their work environments, are of greater importance to the effective operation of an organization.

Among these features or characteristics are:

- the rapid pace of change of the R&D knowledge base;
- the considerable uncertainty associated with the outcome of R&D activities;
- the orientation of many scientific professionals towards working with things rather than people;
- reluctance by many researchers to take on managerial responsibilities;
- orientation of many researchers toward their profession not their present employer;
- researchers having a value system which emphasizes independence, freedom and autonomy to make decisions concerning their work;
- a strong need to experience achievement, gain recognition from their peers, have opportunities for professional growth and to work on challenging, interesting projects;
- an insistence that their immediate supervisors have credibility as scientists or engineers;
- a lack of interest in traditional avenues of managerial promotion and reward;
- the difficulty in evaluating and recognizing valuable outputs of research when they occur;
- the need for long-term planning horizons;
- the relatively older age of the scientists and engineers when they enter the work force and the short window of opportunity in which they are creative;

- the damaging effect that prematurely losing a highly creative researcher can have on the organization's ability to meet its objectives;

- the requirement of a working environment in which bench research personnel must be consulted on the direction and conduct of research projects in order to arrive at effective decision; and

- the need for a "dual promotion" ladder to reward scientists and engineers in a manner designed to increase their motivation to be creative and productive and to avoid losing them to a career path which does not use their abilities to the fullest or provide them with adequate job satisfaction.

The management of the technological innovation process and R&D personnel has been the subject of study for the past 50 years (Clarke and Reavley, 2001). In all this work, no one has argued that R&D can be managed or supported in exactly the same manner as any other organizational activity. The special features of R&D management and the R&D work environment are clearly recognized. Only those science-based organizations that acknowledge these differences and modify their management approach accordingly have any long-term future.

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