APPENDIX - Questionnaire Sent to all ICF4 Delegates

Two panel discussions have been organized at ICF4 under the general heading *Fracture and Society*. The first of these is scheduled for Wednesday 22 June, 1977 and is designed to provide a basis for the development of clear educational objectives with respect to *Fracture* as an Engineering subject. It is expected that the discussion will be very lively and several speakers have been lined up. If you wish to contribute to discussion on this topic, please so indicate below. It would also be valuable if all participants would complete and return the remainder of this short questionnaire.

1. Do you wish to contribute to or participate in the discussion on Fracture Education and Society? Contribute Yes____ No____
   Participate Yes____ No____
2. Do you teach at a post-secondary institution (university, technical institute, etc.? If so please give the name of the institutions, and the highest level of qualifications offered (e.g. Ph.D.).________
3. Please give the name of the department or academic unit in which you work, and the highest qualification it is possible to obtain in your own department.________
4. Are graduate courses on Fracture or Failure Analysis specifically offered in your department or another department? Please give details.________
5. Is the subject of fracture an officially designated part of your undergraduate curriculum (e.g., do you have a course entitled fracture, or is fracture a specified part of another course)? If so, please give details________
6. Is the subject of fracture part of the core (i.e. mandatory) curriculum of the undergraduate engineering programme (if you have one)? Yes ___ No ___
   Please give details.________
7. Is the topic of fracture taught in your institution in any special or unusual way - e.g. by means of a "case study" approach, through the use of project work, etc.? If so, please give details.________
8. What place should courses on fracture have in undergraduate curricula for Engineers?________
9. Please add any other comments on this topic - overleaf.

Return to Professor D.M.R. Taplin, Department of Mechanical Engineering, University of Waterloo, Waterloo, Ontario, Canada, N2L 3G1.

FRACTURE AND SOCIETY

D.M.R. Taplin

Two Plenary Panel Discussions were organized at ICF4 under the general heading *Fracture and Society*. These were conducted from approximately 14.30 - 17.00 hours in the Humanities Theatre of the University of Waterloo on the Wednesday and Friday afternoons of the Conference (June 22nd and 24th, 1977). The Discussions were open to the general public and were widely reported upon in the Canadian Press. There was also a good deal of effective television coverage of the Conference, including these Panels.

The object of these panels was to explore and integrate our thinking as experts in fracture and delegates to ICF4 with the wider purpose of the society in which we all live on this planet, Earth. Specifically, the overall aim was to provide a formal framework within which we could examine the broader implications of our technologically based fracture research - be they sociological, philosophical (ethical, moral, aesthetic), educational, political, economic - to perhaps bring us down to Earth from our "lofty" mathematical and "hidden" microscopic studies. For, surely, it is those of us who are educated in the problems of fracture who must ensure that intelligent social and political decisions are arrived at in our areas of competence. Much is spoken of the need to educate the general public in science and technology but a more crucial issue in education is the education of we engineers and scientists and our students in the practical and philosophical facts of social and political life and decision-making.

The two other major innovations in the topics addressed at ICF4 relate to this innovation. They are firstly, an emphasis on the *control of fracture in large-scale engineering structures* - Risk Analysis (Tetelman), Ships and Tankers (Burns), Nuclear Reactors (Nichols), Railways (McClintock), Pipelines (Hahn), Aircraft (Nemec) - clearly such technological structures are, along with the fracture of the Earth itself, the most pressing concerns of society today in considering fracture problems. But the overriding innovation at ICF4, perhaps, was to focus upon an *integrated* approach to fracture. This quite clearly included these panels here being introduced but it also included the aim of integrating the micromechanistic and mechanics approaches both through commissioning broad papers, such as those by Ashby (Maps) and Knott (Alloys) and the judicious juxtaposition of papers from the different disciplines. Furthermore, as Max Williams is often quick to point out, Fracture is an interdisciplinary topic. Perhaps it can best be approached as a *phenomenon* which has many consequences and implications and which needs the application of many disciplines for its understanding and control - including those outside science and technology.

The Conferences in the present series are, indeed, the *Olympics of Fracture*. We must therefore surely endeavour to encompass the study of it in all its aspects - and yet produce a vigorous, integrated theme, philosophy and science. Our purpose at ICF4 was to encompass all nations and all aspects - but, I hope, forward-looking, *critically* and with the application of high standards. Not all things to all people but, at least, a significant landmark and some new departures.

Accordingly, these Panels on *Fracture and Society* represent just a beginning. What follows in this Volume is an edited transcript of the taped record of the two Panels. This written record goes somewhat further than the actual discussions themselves - it is essentially the "book" of the "play" - and, I believe, several aspects of the topic addressed are revealed more clearly in this written transcript. It is surely revealed as a topic worthy of considerable attention - for the collaboration of researchers from several disciplines and a responsibility for ICF and ICF5 to continue.

The first Panel, on June 22nd, 1977, focussed upon *Fracture, Education and Society* and directly followed in the Programme, Dr. Reid's presentation on the Teaching of Fracture. The meeting was turned over to the co-chairman for this session, Professor Ronald W. Armstrong. Dr. Armstrong was at that time with the United States National Science Foundation as a Programme Director in the Science Education Branch. His permanent post is in the College of Engineering at the University of Maryland. The panellists were drawn in the main from prominent engineering educationalists both in Canada and elsewhere, with some wider representation to add a little spice. The full list of panellists is recorded below with their affiliations. Two particular papers were examined as background information - the paper by Reid et al and the Cottrell interview - along with the results of a survey on education. The idea for this survey derived from discussions with Professor Alan Tetelman and it was conducted by Dr. Knapper and myself.

The second Panel on June 24th, 1977, directly followed Professor Bruce Bilby's broad survey of Fracture. Bilby is such an eloquent speaker and penetrating mind that this proved to be, as many expected, perhaps the major single technical highlight of the Conference. Even though, by this time, delegates were themselves somewhat fatigued for, apart from the long and full technical sessions, the evening before this final day was the night of the Conference Banquet and Cabaret. The team of Bruce Bilby, Roy Nichols and John Knott proved themselves to be great cabaret performers, indeed rivalling our main Cabaret star, Dinah Christie. Roy Nichols' poetry, Bruce Bilby's apologia to the J-integral and the Duke of Wellington and John Knott's purple bailiwicks will be long remembered - long after we forget science, perhaps.

This final session of the Conference was conducted by Dr. R. W. Nichols. Apart from being President of ICF and Chairman of the International Council on Pressure Vessel Technology, Dr. Nichols is an Engineer, Manager and Designer concerned directly with perhaps the most crucial and certainly most politically sensitive industry - Nuclear Power Technology. Once again, two pre-published papers were available as a starting point for discussion - Sir Alan's interview and the paper by Max Saltsman, the Member of Parliament for Waterloo-Cambridge. Max Saltsman M.P. is well known in Canada for penetrating political analysis and debate and he has been the parliamentary representative for this constituency for many years - as a member of the New Democratic Party. He is also a Professor in the Faculty of Engineering at Waterloo, teaching courses in Management Science. The panellists were selected to cover a broad front of the interface with the public at large and their names are recorded below with their affiliations.

Naturally, the names of many eminent and well-qualified people are not listed on these panels. For example, Dr. Alan Tetelman contributed to the thinking behind both panels and Professor Mike Ashby unavoidably had to

leave early - many others contributed from the floor and via informal discussion on questions raised. One scientist and engineer whom we should here record as a crucial contributor to our discipline is the late Dr. A. A. Griffith FRS. Griffith is surely the father of the science of fracture mechanics and in his honour we have named the unit of fracture toughness the *Griffith*, where 1 Gr = $1 \mathrm{MPam}^{\frac{1}{2}}$. This should prove to be a useful standard designation amongst the community and it may well achieve formal recognition as an SI supplementary unit. The major part of Griffith's working life was not spent on fracture mechanics. This was a consequence of an unfortunate accident during his experiments on glass. Armstrong (1) records the fact that Griffith's assistant caused a fire by leaving the glass-melting torch on overnight. The work was subsequently scrutinized and the Committee of Scrutiny decided the research was not worthwhile. Thus Griffith turned to other matters, and developments in the science of strength and fracture were halted for a period. As Mrs June George (2) pointed out in an interesting letter about her father, he worked mainly on the Jet Engine. Mrs George's letter is worth quoting as it provides a useful basis for discussion on the topics we now address:

"Sir, Your readers, when trying to decide about the arguments for and against Concorde, might be interested in the story of my father, Dr A A Griffith. He was an aeronautical engineer concerned in most of his working life with the development of the jet engine.

In the mid 1930s, convinced that there would be another war, my father, then working at the Royal Aircraft Establishment in Farnborough, tried to get money from the government to develop the jet engine. I remember, as a child of five or six years, the excitement in my family, and his anger and disappointment when he returned from London having had his request refused. According to the government there would not be another war.

In the early 1950s my father had another idea. By this time he was working for Rolls-Royce, where he could get money to develop his projects. The new idea was for a supersonic airliner which would dramatically reduce flying times between cities. Again the family shone in reflected glory and hoped that this time he would make his fortune.

This time he gave up the project himself, having decided that the disadvantages, particularly those of noise, far outweighed the advantage of increased speed. He went on to develop the "Flying Bedstead", the first vertical take-off machine with a jet engine. He was always interested in the idea of developing this commercially, but again was very concerned about the problem of noise.

My father predicted that the supersonic airliner would be developed at some time in the future at enormous expense and mainly for its prestige value.

Towards the end of his life he became more and more concerned with environmental problems. He believed that if noise reduction had been also of commercial value then it would have happened much sooner and that it was technically very possible.

Perhaps the lesson to be learnt from his advanced thinking is that we should listen carefully to such men, for they do not always shout the loudest. There are also implications in this story for the education of future scientists; that they should be concerned with the human problems *associated with their inventions. My father had an arts education before he became a scientist.*

Yours sincerely,
June George

Clearly much debate on this overall topic will continue under the auspices of ICF and elsewhere. Hopefully the start made here will be developed further at ICF5.

REFERENCES

(1) ARMSTRONG, F.W., The Aero Engine and its Progress - Fifty Years after Griffith, J. Roy. Aero Soc. December 1976, 499-520.

(2) GEORGE, J., Letter to the Editor, The Times, January 24, 1976.

PANELS - FRACTURE AND SOCIETY

Chairman : D.M.R. Taplin

1. FRACTURE, EDUCATION AND SOCIETY

Chairman :	R. W. Armstrong	National Science Foundation, U.S.A.
	J. D. Embury	McMaster University, Canada
	D. Francois	Université de technologie de Compiègne, Fran
	R. W. Hertzberg	Lehigh University, U.S.A.
	E. Hornbogen	Ruhr-Universität, Bochum, West Germany
	C. K. Knapper	University of Waterloo, Canada
	J. F. Knott	University of Cambridge, England
	H. Liebowitz	George Washington University, U.S.A.
	A. J. McEvily	University of Connecticut, U.S.A.
	C. N. Reid	The Open University, England
	A.R.C. Westwood	Martin-Marietta Laboratories, U.S.A.
	T. Yokobori	Tohoku University, Japan

2. FRACTURE, POLITICS AND SOCIETY

Chairman :	R. W. Nichols	U.K.A.E.A., England
	B. L. Averbach	M.I.T., U.S.A.
	B. A. Bilby	University of Sheffield, England
	G. T. Hahn	Battelle Laboratories, U.S.A.
	J. F. Knott*	University of Cambridge, England
	D. Mills	Ontario Hydro, Canada
	M. Saltsman	House of Commons, Canada
	T. Yokobori	Tohoku University, Japan

**Chairman from 16.00 hours*

FRACTURE AND SOCIETY - PART 1

Edited Transcript of the First Panel Discussion on

FRACTURE, EDUCATION AND SOCIETY

Armstrong : The schedule for the conduct of the meeting is as follows. First, Dr. Knapper will tell us about the questionnaires on the teaching of fracture that the participants at ICF4 have returned. Second, Dr. Weaver will show a film relating to Dr. Reid's plenary lecture showing us more about the Open University Course *Materials under Stress*. Then, we will turn to the panellists and, beginning with Professor Embury, each panellist will give a short presentation on the topic we address. Following this, we will open the meeting to further discussion, possibly from the panellists themselves, but preferably from members of the audience.

Knapper : I will talk only briefly about the results of the survey since this is recorded separately. I am a psychologist and my job title here at Waterloo is "Teaching Resource Person". Dr. Taplin invited me to collaborate with him in this enquiry into the place of Fracture in Education, as an educationalist as such and I make no claim whatsoever to any expertise in either engineering or fracture. Fracture is quite clearly something that people should be educated about. This has educational implications not only for those involved directly in fracture research and the teaching of fracture, but also for society as a whole, which should know rather more about potential problems that can arise. This is particularly true when these problems require decisions of a political nature. Experts in this field have a very special responsibility, not only in educating students, but in educating students to be able to communicate with the public at large.

About 80 responses were received to the 400 questionnaires sent out by Professor Taplin. It may be assumed that these are not a wholly reliable indication of the teaching processes going on around the World in the 60 institutions represented, but presumably they do represent the responses of those who are most interested, and it is a good psychological precept that people who respond to questionnaires are the people who have a definite point of view.

Let me extract just a few of the findings. Everybody of course agreed that fracture was a very important subject for people to know about and presumably most of those who responded were actively involved in teaching this subject. Nonetheless the number of formal courses, particularly at the undergraduate level, for the teaching of fracture, was rather small. Less than a third of those responding mentioned a formal course. We were more interested, however, in reports of innovative teaching. The innovative method usually boiled down to a case study or project approach, perhaps along the lines that Dr. Reid and his colleagues have written about.

It should be noted that the proportion of reported innovations is relatively small in relation to the number of institutions that we surveyed and of course we have no good indication as to how successful they were. But there are examples there and several detailed descriptions : these are summarized in a short report.

I would like now to mention the contributions by Dr. Reid and his colleagues from the Open University and the interview with Sir Alan Cottrell. It does seem to me that there are certain themes which run through both these presentations. One is a dissatisfaction with the teaching of fracture and, in fact, you could take it beyond fracture to the teaching of engineering as a whole, in the standard discipline-oriented research way that is characteristic of traditional universities. Instead these presentations are arguing for a much more practical approach to understand fractures, an approach which is rooted much more firmly in real-life situations. There are a number of reasons why this is the case and is true for the Open University for instance. This stems particularly from the type of clientele that they have - very different from the sort of students that many of us would find at more traditional universities. In the case of Sir Alan Cottrell this feeling seems to emanate from his experience outside of universities dealing with real world problems. But I feel quite strongly that this dissatisfaction is appropriate for a topic like fracture. I say this is a "topic" although Professor Taplin calls it a "phenomenon" rather than a "discipline". Thus, fracture does seem to be a rather central topic in this regard because it does not particularly lend itself to teaching in the normal "discipline-bound" ways. You could read about this discipline-bound approach much more eloquently in Sir Alan's interview, where he says, "look, we do not want to produce any more researchers, we have got enough of them anyway - it is just not good enough to train graduate students who are going to be training other graduate students, and so on."

I give fracture as an example of an instance where it does not emanate directly from a discipline in the same sense as physics and where at the same time, people need to know about fracture in order to solve very immediate and worthwhile crucial problems. So you have those twin concerns. How do you do this? That really is the point. That is what presumably some of our panellists and I hope many more of our audience are going to address themselves to today. One approach is the approach you will see demonstrated and it is a case study or project approach used at the Open University. Another approach which I talked about at length in the written version of our paper is the attempt at universities like Waterloo to involve the students in a large measure of co-operative education. I will not talk about either of these efforts but will just end by raising a number of issues that are psychological more than anything else and which perhaps the other panellists might keep in mind when they are talking about training or educating people in the subject of fracture. If there is one point above any, that I would mention as a psychologist, it is the notion of *transfer of training* or *transfer of learning*. This is the basic underlying assumption of all education and that is that what you learn in one situation is applicable in another situation and this is something which I think as university teachers we tend to forget. There are many points which emanate from this idea of transfer of training. Let me just say the psychologists find that transfer of training is not something you can blindly assume will happen. It only happens in very specific situations. Particularly it requires a fairly close match between the learning situation and the situation in which you are to apply that knowledge. Secondly, related to the notion of *transfer of training* is the whole question of what particular skills you, as engineers, will want to teach

under the topic of fracture to the students who pass through your hands. The point here is to bear in mind that the very nature of what they are going to be doing is likely to change even more radically in their career span than it did in yours. Various educators have called for a quite new approach to teaching which, instead of teaching a body of skills and information, teaches one single skill, perhaps, the ultimate one, and that is the ability to learn how to acquire information or to learn how to learn.

Armstrong : As Professor Knapper has mentioned the interview with Sir Alan Cottrell, this may be an appropriate moment to make a few remarks of my own relating to the educational aspects of the Interview.

The first remark is concerned with the point, mentioned again, which was mentioned in the Cottrell interview to the effect that everyone is concerned, even from a very early age, with why things break. In fact, there is an instructive comparison to be made in this regard between fracture technology and space technology. The thesis is that the everyday experiences of a person with common fractures in respect of fracture technology are somewhat analogous with the counterpart everyday experiences of a person, say, with common flying objects relative to space technology. For both subjects, the principles are largely the same in everyday experience and in these significant engineering accomplishments. The interesting consideration is that an understanding of space technology involves observations on the largest scale imaginable whereas understanding fracture involves observations in the opposite direction on the microscale. The problem of extrapolating either way - for most people - makes each subject a bit difficult.

The second remark is a reminder of the pioneering emphasis given by Orowan to the effect of fracture being a model- or mechanism-sensitive phenomenon. This observation is fundamentally important to differentiating between physics and engineering educations in many places in the World even today. In this perspective, there is reasonable educational difficulty involved in connecting the physics of fracture, with its model understanding which is imperative, and engineering considerations of fracture, extending themselves from abstract applied mathematics for purposely poorly defined continua to empirical analyses of service failures.

The third remark is concerned with the fact that fracture is a many-material-parameter subject - and this, too, adds special difficulties for the educational process. Even with the few experimental quantities which are determined, often with difficulty, in fracture mechanics experiments, it is important to understand that these quantities must encompass, at least, all of those parameters which are involved in understanding the strength properties of crack-free materials. This result is a consequence of the theoretical requirement that plastic flow must always be initiated in some limited sense for fracture to occur because of the growth of a single crack or a number of them.

Now I would like to move on to Dr. Graham Weaver of the Open University, who, rather than Dr. Reid, will introduce the OU film.

Weaver : The title for the whole of this discussion, *Fracture, Education and Society*, is clearly much wider than just talking about the sort of teaching one can do with television. It is surely important to produce an understanding among the general public of the issues which can be treated by fracture mechanics and, insofar as Open University television programmes are available to the general public because they are broadcast on the ordinary television channels in Britain, perhaps we are making a start in this regard.

The course on failure is designed to take about 200 hours of student study. Most of this time is spent studying the written work. There are only about 7 hours of television available so it is a scarce resource. We have to make sure that we use it with some care. The extracts we have to show you constitute about a 20-minute sample. The selection is a number of short extracts with which we hope to illustrate how we use television to teach. I should like to say a few words at various places in the middle of the film about what is next to come. You will probably notice some sort of a story line and just in case you do not I will tell you about it.

The first extract deals with designing against failure, without any reference to the presence of cracks or defects at all. It concerns a man-powered aircraft wing. Then we go on to talk about cracks being introduced into a welded structure during its manufacture. Actually this extract is a sequence about welding and then weld testing. The welding operation introduces cracks into the structure but you are not sure where they are. You need to detect them and so there is a sequence about non-destructive testing. Then some of the later sections talk about fracture mechanics and defects actually growing in service. So the sequence is in fairly logical order in terms of the subjects which are presented. I suppose it is no surprise that the presentation roughly corresponds to the order in which the subjects are dealt with in the written part of the course. But that is not the rationale for this selection. As I say, I want to show you how we use television as a medium for teaching. Our written work can give students contact with problems via all sorts of examples which they can try to work out for themselves with direct instruction on theory and its application. There are several things that written work cannot do. It is very difficult through the Open University system to give practical experience. The only practical experience we can give to our students, at least in this course, is with a small home experiment kit which some of you might have seen in the publications room in the other building. So one of the things we would like to do with television is to demonstrate the use of laboratory equipment and the kinds of experiments which it is necessary to do in order to establish evidence for the sorts of theories which are being put forward or in order to establish evidence for taking action in an industrial context. This reinforces learning if you like contact with practical methods. In this limited way, we can put the student in contact with practical applications.

Many of our films serve the purpose of actually taking the students out into industry on location. In the two instances that I have examples of in the film we are talking about fracture mechanics. They are applications of fracture mechanics, in one way or another, or examples of situations where fracture mechanics can be applied. Another thing which we can do is to give students contact with experts in the appropriate fields. I think residential students at universities are often spoiled for this. All the staff are experts in that most of the staff have active research interests, and it is fairly natural that the student receives a good deal of motivation and encouragement from seeing where intelligent study can lead him. But our students, working at home, part-time, trying to hold down a job as well, do not have anything like those opportunities, so television is one way in which we can bring the expert and his opinions and his professional apparatus in front of the student. Well, those are three principle areas that we try to give the student, and they are dealt with in the first three extracts which I shall show you. The remaining parts of the film are just short snatches which actually reinforce these first three items but also show you some of the television tricks of the trade.

The first extract is an example of practical work. It is a demonstration done in a laboratory; actually, the laboratory is the television studio. All the apparatus was taken there and the person who is presenting it is one of our authors from the course team. In one way it is quite a lavish experiment. The students at this time in the course have been studying beam theory and have been following a step by step design of the wing for a man-powered aircraft. This is a situation which was carefully selected because both weight and efficiency of use of materials are important. A man-powered aircraft only has a 300 watt power source which is rather small compared with mechanically-powered aircraft. During this extract you will hear two references which might puzzle you. One is OUMPA (this is merely the acronym for "Open University man-powered aircraft") from which you should not deduce that we have built a man-powered aircraft. We have gone so far as to build a section of the wings of one of these designs that the student is being led through and the programme shows this design being tested. There is also a reference in the extract to "broadcast notes" which I feel I should clarify. Most of our television programmes have associated with them some short written notes which can serve several purposes. Often they are no more than a resumé of the content of the programme which really acts as an aide-memoir to students after they have seen the programme, even a long time after they have seen the programme, because one of the disadvantages of television is that it is a very transient medium. Once you have seen the programme it is all over and done with and there is not much opportunity with the limited Open University schedules of seeing it again. Then, again, the broadcast notes can contain questions for the student to try to answer things based on the lessons of the programme and so he can test the extent to which he has understood it. In this particular programme the "broadcast notes" also contain data which the student needs in front of him actually to use during the time he is watching the programme.

Can I now have the first clip of film, please? It runs about four minutes and there is a blank where I want the projectionist to stop.

FILM (Sound-track transcribed in italics)

We have seen the tests of individual materials and we must now test a section of OUMPA's spar design, the balsa and spruce main spar. I have set it up here in the studio as a simply supported beam, supported here and at the other end, with a load applied by a hydraulic jack in the centre. I am reading force via a pressure gauge directly in kilonewtons. The displacement in centimetres is registered on this scale here. You can see from your broadcast notes that we have a required stiffness of 0.24 meganewtons per metre for this structure. So if I allow a centimetre deflection of the spar, this should give me 2.4 kilonewtons deflection on the displacement scale. If I achieve that I will have predicted OUMPA's main-spar stiffness adequately. Now we are testing this spar as a simply supported beam and this does not precisely represent the conditions of a spar beam in flight because there it would be cantilevered. We are in fact going to have a higher shear force in the present test than we would normally expect. For the design of OUMPA's main spar, a 5,200 newtonmetres bending moment will occur at the centre of the beam when the force on the scale reads roughly 7 1/2 kilonewtons. So, let's begin the test. Ian, can you start pumping? I will call out when we have a centimetre deflection ..... Now! Thus we have just about achieved the required load. This is a pretty successful prediction of bending stiffness and I think we can be pretty proud of that; however the theme of the course is "failure" and we ought to fail this beam now to see whether we can learn anything from *this particular design. So, Ian, can you carry on with the pumping? We are building up the force ..... I am getting some funny noises too. It is starting to crackle but taking more load. There she goes! Now you can see, in fact, if you observe here, that local shear has caused failure of this beam and we pulled out part of the spar from the glued surfaces. So we have not failed at what is something like over 5 kilonewtons. We have not failed the spruce or the balsa but we failed the glued joint. This would lead us to conclude that we ought to reconsider our beam design to have a somewhat larger area between the glued surfaces. However, the shear as I said before in this type of test is quite high and so I think that this is in general a pretty good design for OUMPA's main spar.*

Weaver : Well, that beam cost about $500.00, so we only had one of them. I think it says something for the quality of the presenter that the failure was unrehearsed and he was able to make pertinent comments on it even though it did not fail in quite the way it was expected to. The next excerpt is on location at a pressure vessel works. The main point of this excerpt is the industrial location. You will note that some of the film has the commentary dubbed on to it because it is a noisy factory and it would be rather tiring if all the commentary was backed up with factory noise. However, part of the commentary is deliberately spoken against the factory noise. It is part of our purpose to give an idea of the atmosphere of the place.

FILM

The manual-welding process is used in this company generally for welding nozzles to shells or internal attachments. The circumferential seams and longitudinal seams of the pressure vessels are generally done by automatic processes. In one process the idea is to feed a continuous coil of wire into the electrode over the work piece. Granulated flux is fed round the wire and the arc is struck underneath, melting some of the granules to form a protective blanket. Unmelted granules can be recovered with a kind of vacuum cleaner for further use. The fused slag breaks away easily after the weld pool is solidified and gives a smooth even surface to the metal, reducing the possibility of slag entrapment, which is a big danger with manual welding. With this, the submerged arc process as it is called, very large volumes of welding material can be deposited without stopping, by simply keeping the workpiece rotating. But how can checks be made on weld quality? Sample welds are taken for mechanical testing and sections can be etched in the laboratory so that the grain structure of the welded material can be examined.

Here is a close-up of an etched section of a multi-run submerged arc weld. What does it show? First there is a difference in structure between the weld and the parent metal on either side. The columnar crystals reveal the successive weld pools which are all well-fused in this case with no obvious slag entrapment or porosity. The darkly etched narrow zones immediately surrounding the weld deposit are the heat affected zones of the parent metal. Compare the structure with this next one, which is a section of nozzle, that is the vertical member, manually welded to a thicker horizontal shell. Again you can see the individual weld pools but notice that the root run of the weld on the right-hand side is not as well fused as the later welded zones. This zone could be the starting point for cracks to be initiated. So something has to be done about this. Notice also on the outermost welds that there are depressions between the weld pools and the horizontal surface of the parent metal. These could also act as stress raisers. But neither of these defects is left unattended.

After the nozzle welding is complete, the outsides of the welds are painstakingly dressed to produce a smooth contour and thus, leave the surface free from stress raisers. For the smaller diameter root welds a similar operation of grinding the irregularities can be carried out. But what about the problem of the larger nozzle to shell welds? These parts are only tack-welded in position. They are about to be welded and we know that the first weld run, the root run, is not likely to give such good fusion with the parent metals as the later ones, and this is where there are likely to be faults. The engineers can take care of this provided that it is realized at the design stage. We can account for it by leaving surplus metal on the inside of the nozzle. We use this to form the root run and, later, when the welding is finished, we machine away all of the metal which is surplus, at the same time taking along with it the faults involved in the root run.

Weaver : In the next extract we shall again be out on location, this time at Hartlepool on the North Sea Coast where an oil production platform is being built. This sequence starts with an explanation of a practical non-destructive testing method and, then, we meet an expert who in this case is the chief engineer on that site for the non-destructive testing sub-contractors. He explains some of the difficulties of the job through a recorded interview. "A" in the following is Mr. K. A. Reynolds, a major author of the course - unfortunately, he could only be present at ICF4 on film.

FILM

A : The job is still some months away from completion but already you can see the size of this enormous structure which is being built. Parts are being brought in by sea, whereas others are being built on site and assembled to make the platform. You must remember that the model is only of the jacket. This which we are looking at is about half complete and on top of that is going to go the superstructure. You can see that the large cylinders at floor level are about half their final length and already the K-frames are being erected. From this you can gain an impression of the size of the thing. That particular fabrication is about half-way between the top and bottom of the platform. There is going to be over 35,000 tons of steel used in manufacturing this structure. It is being joined together by welding with something like 40 miles of welds being involved. In a few months' time it will be complete and it will be taken out into the North Sea where it will finally take up its position. Just imagine the problems of inspecting all of those welds, because when once it leaves this basin there is no hope of being able to get to it and remake any faulty work.

How does one radiograph welds in a structure like this? Access is so varied and generally difficult that an X-ray tube with its associated power source is just not feasible. So a portable radioactive isotope source is used, emitting gamma rays. This is mounted on a capsule which includes suitable shielding and is taken to the job in order to make the exposure. Film is laid over the area of the weld to be examined. As many of the sections to be welded are tubular, it is convenient to place the gamma ray source at the centre of the tube which sometimes necessitates drilling a hole and positioning the isotope at the centre. This allows the whole seam to be photographed at one exposure. The isotope is fed into position through this cable from its storage box. The hole in the tube will have to be welded up again afterwards, of course.

B : That is a 36 inch diameter joint, 5/8" wall thickness and it is a panoramic technique. The exposure conditions would be about 80 curie minutes. If we use a 10-curie isotope we would be using an eight-minute exposure.

A : Panoramic photographs allow us to look at the whole weld at one shot.

What other types of technique could you use?

B : Well, there are single shot techniques where you only want to look at a specific piece of the weld and if you cannot get access to the inside of the joint you can do what is known as a double wall single image technique where you put the isotope on the outside of the joint and the film on the outside of the joint also but at the opposite side. You then penetrate two walls and look at the images of only one weld.

A : Is this a typical situation or is this an easy one?

B : This one is relatively simple for this type of work. It is only about 30 feet up in the air. It is well-scaffolded from ground level. The difficult ones are when you start going up into the 200 feet level. Again scaffolding is there, but access is quite difficult at 200 feet.

A : What are you actually looking for in this examination?

B : We are looking for defects in the weld and, basically by using gamma radiography, we shall be looking for volume type defects, that is slag, porosity and inclusions of any nature, and we are not really in a position to be critically examining for cracking. But the reason that we do this by gamma radiography rather than, say, ultrasonics, which may be more useful for detecting cracks and crack-like defects, is that past experience of structural welding of this nature has led us to believe that cracking is a relatively rare occurrence and volume defects are the major problems.

Weaver : The rest of the film consists of several much shorter extracts than those we have seen. These show mostly our teaching technique in the studio, and some of the television techniques. Have a look at the one called colour separation overlay, which is a fancy name for the ability to add and subtract features from a diagram as you go along.

FILM

I think we should now go back and have another look at the grids on the deformed cube, to see again this transition from plane strain at the centre to plane stress at the outside. In the centre we have no deformation in the Z direction (this is the plane strain region), but as we come out through the specimen we start to find a deformation taking place in the Z direction, until right out at the surface, where the specimen is free to contract, we have changed over to the plane stress region. So far we have been looking at deformations, but we are more interested in stress distributions. We have a contour map here, a stress contour map, which shows the shear stress distribution which runs along the crack front. This is actually an envelope of maximum shear stress. If we look along the direction of the crack front, the shear stress distribution takes the shape of two lobes which radiate from the crack tip. You will become quite familiar with this shape when you carry out the home experiments in photoelasticity.

Weaver : Now I would like to show you how a television camera can get really close into an experiment. These next two examples are taken from a programme which closely supports the students' initial learning of linear elastic fracture mechanics.

FILM

As with any load displacement curve, the area under the line represents the amount of energy stored in the specimen. If this were a simple material test we could transpose the load and displacement into stress and strain and take the slope of the line as the elastic modulus of the material. But remember, this specimen has got a crack in it, and its behaviour is a consequence of both the material it is made from and its geometry. And it is more convenient to take the displacement per unit load and this term is referred to as the "compliance" of the specimen. If I repeat the test but this time use a specimen with a longer crack in it, I again get a straight line but it is somewhat shallower. There is less energy stored in this specimen for the same displacement. And it has got a higher compliance. If I look at the shaded area, this represents the difference in energy between the specimen with the short crack in it and the one with a long crack. If you consider what has happened, if the crack has grown from a length of a_1 to a_2 with no increase in displacement, you can see that the energy released by the crack growing is represented by this area that is shaded. By carrying out a series of tests on specimens with varying crack lengths we get a family of straight lines and from this we can generate a plot of compliance against crack length. Here we have compliance plotted on the vertical axis and crack length on the horizontal and you can see from this line that the compliance increases with increasing crack length.

Weaver : I like the way that the dynamic picture of the load displacement curve suddenly becomes a teaching graphic. The next one is similar. It shows the load displacement curve again, but in a different way. It is a split screen with the sample and the load displacement curve on view simultaneously. You will see a white marker too, to indicate the position of the crack tip. You will see the toughness specimen actually fracture in this one.

FILM

Once more a plot of load against displacement and as the load increases the stress intensity at the end of the crack is increasing.

Weaver : The next excerpt is another example of going to an expert and using his professional equipment. When we wanted to explain fatigue testing we contacted Dr. Clive Richards of the C.E.G.B. to do the talking for us.

FILM

Now let's start a test and see the load cycling. As the load or stress cycles, the K value varies from a minimum to a maximum value. It is this difference, ΔK, that we are interested in in fatigue crack growth. The quantity, ΔK, is really the counterpart of stress amplitude in S-N endurance testing. Remember that K_{max} cannot exceed K_{IC}, otherwise the specimen will fracture suddenly. Now, how do we measure fatigue crack *growth rate in the laboratory? Well, we can use any of the types of tests normally used in the evaluation of fracture toughness. In this case we have this particular type of specimen on the machine. Usually we do tests in which the stress amplitude remains fairly constant throughout. But as the crack length increases the alternating stress intensity increases and so, too, does the fatigue crack propagation rate. We need to count the number of cycles as we reach successive crack lengths. In this particular case, we are doing it visually using scribed markings on the surface of the specimen, placed 1mm apart. The fatigue crack is moving fairly slowly but if we waited five minutes, the crack would have moved like this ...*

Weaver : Finally a short example of animation.

FILM

Well, when we have a fatigue crack we are in a situation in which we can control both the rate of breaking of the oxide film and the rate of supply of the environment to the crack tip. Each time we apply a tensile cycle we are going to break the oxide film, so we are going to give the opportunity for environmental crack growth to occur. But, in addition, every time we open the crack it will suck in fresh environment and every time we close it we squeeze it out. So, in every opening cycle, we have a fresh amount of aggressive environment which is ready to really attack the exposed metal at the surface. And then, when it is used up, we close the crack and flush it out. So let's just have a look at an animation that will show this in detail. We have another crack, this time in a passivated metal : in other words the metal surface is covered with a thin film of metal oxide. As we apply tensile load, dislocations move along their slip planes and produce a slip step near the crack tip. The oxide film ruptures. The dissolution and passivation processes compete with each other at the crack tip producing a characteristic crater. A dissolution takes place in this confined region, it gradually uses up all of the corrosive strength in the solution, which will gradually get weaker. The liquid will possibly become sufficiently weak to prevent further dissolution. Reversing the loading and applying a compressive load, closes up the crack, expels the stale solution and amalgamates the crater into the crack itself. Reversing the load again opens up the crack, sucks in fresh solution and the process repeats itself. At each stress application we get a dissolution-aided increment in crack length.

Weaver : In conclusion, I think the only sadness that we have about television is that in spite of the fact that it is broadcast on the general services, and anybody can see it, the one thing we want to do is to *stop* broadcasting it on general service, because the limiting factor is the amount of transmission time available to us. The day we can have a videotaped casette in every student's home as easily as we can now have a sound recording tape in every student's home, is the day when I think television teaching will really come to the Open University.

Armstrong : For the second part of our panel discussion we would like to have short presentations, of the order of three minutes or so, by those individual panellists who wish to do so. We will begin with Professor Embury of McMaster University.

Embury : I really want to say some things which may appear rather the statements of a heretic. One of the things which strikes me about education in regard to fracture is that we should look very carefully at those who are going to actually consume this education. One has to look very

carefully at the idea of whether education is complete in a three-year process or a four-year process or whatever we normally think about. It seems to me that one of the vital educational functions, in fact, for the engineering community, may be to require a very different approach than the one that we generally take for standard undergraduate or graduate students. Now with that type of audience in mind, I would like to make some comments on the information which we have received so far in the Conference as it relates to education. Let us consider concepts such as Professor Ashby's mapping approach. I think (and this is not meant to be a critical comment) that there is very little which is new in that approach in the sense of new physics. There is not obviously any new information there. The thing which is really startling is the way in which you can condense information. You can condense a great deal of engineering experience and you can distil this with the added knowledge of good constitutive equations and models. That seems to me one direction in which educators could go.

This raises, of course, the question of academic disciplines. One could perhaps say as a heretic that there might be really two branches of engineering in the future - a kind of systems engineering and materials engineering. The subject of fracture is very much at the interface of these two disciplines. Another point I would like to raise is the idea of the consumption of information specific to the fracture field. Very few of the presentations that I have heard so far have dealt in any sense with the statistical nature of fracture. There was a very important point raised this morning which concerns the kind of bases on which you approach the whole question of yield criteria and fracture criteria. The other area which strikes me as being one of great interest, and this is a point of Canadian nationalism, is the area of rock mechanics. It seems to me that there is a geological interface which is certainly of long term value of which we have heard virtually nothing.

The final point I would like to raise is concerned with the whole question of case studies. Most of the information that we think about in case studies is really a simple transmittal of information, a change of environment if you like. There is something else in the case studies system which is worth exploring : this is the use of case studies to encourage group study. It is a very valuable way of putting together civil, mechanical and metallurgical engineers and asking them jointly to solve a problem. This is often the case in design and it is a thing which we really use to a very limited extent. There is a need to force final year students, graduate students and others into the process of synthesizing their knowledge. I think that is one of the things which comes through very forcibly in a meeting such as this. There is a real need for educators to force students into this process of synthesis.

My last statement, as a heretic, is that really I think the function of universities is not to tell students what professors know, but what they do not know. Professor McClintock raised a very important point this morning concerning the almost biblical nature of the educative process. You really have to force the student, both to this interface of synthesis and, to the point, particularly at the graduate student level, where he will ask questions about the real basis of his education. Are the criteria which you give him, the premises on which arguments are based, really complete? It is in many cases really the premises of the argument which you have to attack rather than the conclusions.

Armstrong : That will certainly help to promote strong audience participation, I think. Let us move on to Dr. Knott. Let me say, too, as far as the panellists are concerned, that this 3-minute stretch is only for your opening important comments. You certainly will have another chance to enter the discussion as we go along.

Knott : As a point of information, I think that any comments that I make ought to be seen in the context of the typical British educational system, in which the University period consists of three years of undergraduate training, often rather specialized by American standards, followed in some cases by three years of research training for a Ph.D. degree. There is also a limited number of Master's courses which are taught on a one-year basis, or perhaps done by a mixture of teaching and research in two years. Speaking very generally, in undergraduate engineering courses, the vast majority of engineers leaves after three years' undergraduate training to go out into industry, and does not stay on to do research. A number of metallurgy courses and materials courses are also taught on a science basis : for example, as Professor Ashby noted in his Monday morning lecture, he is teaching in the Cambridge University Engineering Department; I am in the Faculty of Physics and Chemistry. Again, of the people we have in the final year, about 30% go into research training and the rest go into industry. I think we must separate perhaps our thoughts, in the British context, about the undergraduate training for general industrial graduates as compared with the much more limited field of research training.

As one of the interviewers of Sir Alan Cottrell, I would like to draw your attention to three points made in the interview with him which pertain to education. The first one of these is made with regard to undergraduate courses and, particularly, the teaching of materials to engineering students and, in the reciprocal sense, the teaching of smatterings of engineering to the materials students. Here, I think, there is a point which is perhaps just a British one, but I suspect is not; that is, that very often such reciprocal teaching is done as service courses to other departments and very often it is regarded as a chore to be taken on by one of the least senior of the lecturers. This often does not create a very good impression in the other department. There are exceptions, where senior people make it a point of interest and honour : for example, I know that Professor Smith at Manchester is very keen on the teaching of materials to engineers. The second point Sir Alan Cottrell makes is on case study approaches, which he generally endorses, but I think that Professor Knapper has greatly overemphasized Cottrell's dissatisfaction with traditional methods of teaching. If you look at the words that he used, he was by no means advocating that we should throw overboard traditional methods in teaching and go on to case study approaches, although he recognized their value, particularly in the process of developing the interest of people. The third point that Sir Alan makes is a very general one on the nature of research training, particularly of university research, and I believe that he has very, very clear distinctions in his own mind between what is pure science and what is engineering. He does feel that, in the fracture field, as Dr. Scully mentioned this morning, there are some real problems still to be solved as a pure science, such as stress corrosion and some of the fatigue problems. That, in the view of Sir Alan I am sure, can be done only through the traditional research training methods.

As a personal view, I think I must overwhelmingly support Professor Embury on what it is necessary to teach engineers. In the British context, they are going out into industry at the end of their undergraduate training. They may go into design or they may go into general management. Thinking only of mechanical and civil engineers, to make consideration a bit easier, we do want obviously to teach them something about materials, so that they

do not make really silly mistakes right from the outset. They are conventionally taught all their general considerations of design, plastic collapse, buckling stability and things of that nature, and we do want to bring home to them the importance of failures. The failures should include not just fracture mechanics but the whole concept of why things tend to fail, for material, environmental, or mechanical reasons. This, of course, requires a very complicated combination of knowing something of the mechanics of stress analysis, knowing something about fracture mechanism, and knowing quite a lot about non-destructive testing as well. I think one of the points made on the film was that the X-ray or the isotope technique being used to do the non-destructive testing was quite good at picking up volume defects such as slag entrapment; not very good for cracks, where ultrasonics should be used. Engineers, even in management, should have some awareness of the problems of defects and of the ability of techniques to detect or not to detect them.

I think, in summary, the most interesting paper with an educational aspect, apart from the one on "teaching methods" that is in this Conference, is the one by Professor Tetelman. He presents an overall philosophy of trying, through a combination of statistics and engineering modelling, to quantify past experience on structures and trying to predict failures or the chance of failures in real engineering situations. I think, for two reasons, we want to look at this effort; we want to look at it as a framework on which to hang all these other things when we are teaching undergraduates, and, on the other hand, I think we want to use that sort of analysis to examine our own educative methods and the substance of what we teach. We want to examine, in fact, the percentage return on the investment we put into our undergraduates.

Hertzberg : There are a few things that I would like to comment on with regard to what I have been doing at Lehigh University. Before I do that I would like to call everyone's attention to the fact that The Metallurgical Society (TMS) of AIME is going to be conducting a seminar at their meeting in Chicago this October which relates to this subject. There will be a Mechanical Metallurgy Committee-sponsored day-length seminar on teaching graduate mechanical metallurgy courses involving a series of 7 or 8 talks dealing with the kinds of material that should be introduced into such courses in universities. I am not sure whether that is going to be published in any form or whether it will simply appear as an abstract in the Journal of Metals (JOM).

I think that the idea of a fracture course at University has to be considered in the context of other relative courses being taught and, perhaps more specifically, with regard to the department in which one is going to try to teach such material. With regard to the metallurgy department that I am a member of, one tries to seek a balance between the mechanical properties of solids, the physical properties of solids, and the chemical properties of solids. Thus you are always fighting to create a balance for the student so as to give him or her a perspective as to the relative importance of these various disciplines within the general field of materials. On that basis I have serious doubts as to whether a course solely devoted to the subject of fracture is appropriate within an undergraduate curriculum. On the other hand, I feel that a course that deals with mechanical behaviour of solids including fracture *is* appropriate. About ten years ago, our department decided to completely overhaul our undergraduate curriculum and in so doing, a course was introduced for the first time dealing with the subject of "mechanical behaviour of solids".

I would say about 40-45% of the course was devoted to the subject of "deformation of solids" and here we were dealing with tensile testing, some elements of dislocation theory, the deformation of crystalline solids, slip and twinning behaviour in crystalline solids, a discussion of high temperature behaviour, creep behaviour, creep deformation, and, then, a section on the deformation of polymeric solids. In this last section, we introduced some elements of visco-elasticity. The other half of that course deals with the subject of "fracture" and here the primary emphasis is with regard to fracture mechanics and the role of fracture mechanics in the study of static and dynamic fracture processes.

In addition, the mechanical behaviour aspect of our curriculum includes a separate course in metal forming, which, together with the course on mechanical behaviour, is a required course in our department. A separate course in dislocation theory is offered as an optional course. There are graduate courses, as well, that deal with the subject of mechanical behaviour. The course that I am involved with deals with fracture mechanics concepts at a more advanced level, but here again, the treatment is more from the metallurgical standpoint than the continuum standpoint. Thus, my emphasis is not that of deriving stress intensity factors and talking about some of the continuum aspects, though I do present this material in a more physical sense. Rather, I focus on the material aspects, and the more continuum aspects are handled in the mechanics department with other courses in fracture mechanics that are taught there, with appropriate personnel. There is a new course that I am going to be attemping this fall which brings to mind the question of case histories. I will be bringing in a considerable body of knowledge on failure analysis and, in addition, introducing a new concept of product liability. This will involve some of the legal aspects and legal implications of failure in structures : we hope to bring in some lawyers to assist in the teaching of this part of the course.

Armstrong: Our next speaker can also give us information from the very important perspective of a university Dean, so I introduce to you Dean Liebowitz.

Liebowitz : I have been asked by the chairman to comment on the offerings of fracture courses at George Washington University and to mention some of the problems in implementing fracture mechanics courses in a School (Faculty). At first, I will interpret fracture in its broader sense and not just fracture mechanics. At the undergraduate level we have five courses being offered, including materials science, introduction to mechanics of solids, materials engineering, mechanics or materials laboratory, finite element methods and structural mechanics. All students in the engineering school are required to take the first four courses and the fifth could possibly be taken as an elective. None of the five is totally oriented to the field of fracture. At the graduate level, however, fourteen courses are offered which are directly involved with fracture and, at least, an additional 20 courses are related to the field. Examples of the ones specifically in fracture are : failure and reliability, analysis of engineering structures, fracture mechanics, fatigue and failure of materials, finite element methods, structure of materials, introduction to continuum mechanics. Examples of some of the 20 related courses include : environmental effects in materials, theory of elasticity, physical ceramics, design of metal structures, automated design of complex structures, nuclear reactor engineering, transformations in materials, deformation of material, composites, and others. If we were to interpret fracture to embrace only fracture mechanics, then we would reduce the number of full courses at the undergraduate level from five to zero and, at the graduate

level, from 14 courses to six. At both the undergraduate and graduate levels there are courses which contain particular aspects of fracture mechanics. Certainly there is a need for greater curricular emphasis on this important field. We have to differentiate between the different departments and curricula in a School or College of Engineering. By this I mean that there are certain curricula which require fracture mechanics more than others. For example, aeronautical, mechanical and ocean engineering require more of a knowledge of fracture mechanics than electrical, chemical and possibly civil engineering programmes. The highest priority problems in aeronautics are fatigue and fracture. Certainly an aeronautical engineer being trained today in such a field should have a good awareness and working knowledge of fatigue and fracture in wings, engines, fuselages and landing gears.

At the undergraduate level it is important not only to offer fracture mechanics programmes, whether in complete courses or piggy-back on present ongoing courses, but also to include such information in the last year of design projects. As you appreciate, there are a number of problems associated with implementing new courses in fracture mechanics into a curriculum, which I would summarize thus : 1) many schools in the United States are trying to maintain present course offerings at a constant level, or to reduce their number; 2) faculty will try to maintain their own pet courses; 3) there is a need to educate and train faculty for teaching design, elasticity, plasticity, and finite element courses so as to expand, re-orient and integrate their present courses to include fracture considerations; 4) faculty must be convinced that fracture has been growing in importance and requires a more substantial presence in up-to-date curricula; 5) Chairmen and Deans must be persuaded to support such an effort; 6) a course in fracture mechanics must be composed which is not too superficial to be meaningful, even at the undergraduate level; 7) the support of knowledgeable people in industry and government who are faced with fracture problems in their structures should be obtained; 8) work on engineering accreditation groups will be necessary in order to appreciate and acquire the correct curricular emphasis to be given to fracture mechanics (this would particularly pertain to the United States and Canada); 9) some agreement on what constitutes a good programme in fracture mechanics must be reached.

Since there is no single proven methodology accepted by us in the field, I would think, on the broad level we are considering here, that there would be a difficulty in recommending a particular programme for a student to pursue. I would recommend a very broad background involving physics, mathematics, continuum mechanics, computer mathematics and, also, including materials sciences. Problems in the establishment of a new course can be approached with some optimism, because similar problems were experienced not too long ago with the integration of computer courses into modern engineering curricula. Because of the newness of this field, most of the knowledgeable people in the computer field were young and had little seniority on university faculties. However, we were able to overcome the formidable obstacles and consequently arrived at a satisfactory situation in many universities. We did this with other programmes as well, and I have no doubt that it will also be accomplished soon for fracture mechanics. I am concerned about a remark made previously that we have enough researchers and that we should train instead people more practically oriented. While I feel some additional effort should be made on the latter, I certainly do not feel we have enough proven researchers to meet our needs.

Francois : What I am going to say must be seen against the background of the traditional French education, which is very much centred on theoretical aspects. Mathematics has high prestige in our educational system and this includes secondary school, where the entire selection of young people for engineering and science is done through mathematics. Thus, when these people arrive at University, they anticipate more and more mathematics, which is indeed the case. When we want to train engineers we are faced with the problem that they see no relation between this theoretical background and the reality of things : the way materials behave and larger structures behave. It is very difficult to give the proper practical basis to our courses. Students feel that they are receiving a low grade education if we attempt that. There is also reaction from mathematics teachers, who would like theory and not practice. This is the problem that we face.

First, I will describe the content of the five year training period of engineers. Two periods of six months are spent in industry. In these periods, the students are faced with really practical situations and this is very successful. Some students have carried out excellent projects in industry. They have learned a lot and have also been of considerable help. We are also trying, of course, to introduce as much practical teaching as possible into the curriculum. The difficulty here lies in the amount of money and equipment available, which is never enough for the needs of the teachers. I have tried to overcome this problem in the teaching of first year undergraduate students by employing very simple experiments to give them a feeling for practical failure problems. The approach has some similarity to the things we have seen in the film. The students are asked to build, using only a sheet of cardboard and some glue, a small bridge, which is then loaded until it breaks. They do this as a group project, and once they have seen the way it breaks they do it again a few days later. Then all the results are analyzed with the help of their teachers. We also arrange to have engineers come in to demonstrate what is really done in industry. The way that bridges are built is described so the students see the connections between the practical observations they have made in the labs and the industrial reality.

As far as fracture is concerned, there is no specific course. It is introduced in mechanical engineering, where there is a course on mechanical properties of materials. It is only later, in graduate studies, that there is a specific course on fracture mechanics. We think the teaching of fracture and failure more generally is very important, because of the inter-disciplinary approach it requires. You have to appreciate the relation between the internal structure, i.e., the microscopic structure and events, and the macroscopic behaviour of a structure. I think it is very important that students realize that a few dislocations moving somewhere can cause a crack to start and that crack can make a bridge or some other big structure fail.

Yokobori : I will talk about the fracture course in our Department at Tohoku University. It may be felt that it is better to avoid teaching students subjects which are too specialized in undergraduate courses. This may be true in some circumstances. On the other hand, in the light of the importance of fracture problems in engineering applications, we start to teach undergraduate students about fracture in a course called Fractology, by emphasizing three special considerations. The first is the understanding of the fundamentals and methodologies of fracture by an inter-disciplinary approach. The features of this approach are outlined as follows :

1) Atomistic approach, say, in terms of dislocation theory.
2) Microstructural approach, say, in terms of larger scale features, such as grain size, non-metallic inclusion parameters, etc. A fractographical approach is also included based on morphology.
3) Continuum mechanical approach, say, so-called fracture mechanics.
4) Mathematical theory approach.
5) Stochastic theory approach.
6) Approach based on thermodynamics and statistical mechanics, such as reaction rate process theory, nucleation, etc.
7) Environmental approach including chemical effects.
8) Material testing approach.
9) Design aspects approach.

Based on the many approaches mentioned above, and on the other hand, by using systems analysis, new methodologies are being explored such as :

10) Combined micro- and macro-fracture mechanics, including the interaction of cracks and dislocations.
11) Kinetic theory approach, combined micro- and macro-aspects.
12) Stochastic theory approach, combined micro- and macro-variables.

... and so on.

The second special consideration is based upon developing the science of comparative fracture. This is a science analogous to comparative anatomy, comparative literature, comparative philology or comparative psychology. Brittle fracture, fatigue fracture, creep fracture, other fracture modes and yielding behaviour are compared in a range of materials. Differences in behaviour of cracked and uncracked specimens are also considered. It should be noted that fracture mechanics concerns only cracked specimens, whereas dislocation mechanics concerns mainly uncracked specimens.

The third special consideration in the "Fractology" course is the treatment of fracture and related problems in liquids and gases as well as in solids.

That summarizes the subject of "Fractology", for which the standard teaching text is my book, "Methodologies and Fundamentals of Fracture of Matter and Solids" (Iwanami Shoten).

Westwood : I would like to make a few remarks from rather a different point of view from most of the other members of the panel. I speak as an industrial scientist and manager : the person who is concerned with hiring the products of Universities. We are concerned in industry not only with the consequences of fracture, but also with its important positive applications. I would certainly want any mechanical or materials engineer that I might hire to have been exposed to some courses on fracture for three reasons. The first, fracture is a phenomenon which can work either for you or against you; second, fracture is an issue which must be considered in relation to cost and also to safety; and third, fracture must be considered in connection with industrial productivity. It seems to me vital that any practical engineering course on fracture should deal with these three aspects.

I feel that the first aspect relating to the mechanisms and phenomenology, is probably well taught, but the other two are either less well-covered or hardly dealt with at all. In connection with the teaching of phenomenology, I certainly strongly support the Open University's view that their study of real examples of failed components, fractographic analysis and such is an extremely useful educational technique. I feel this is true both in terms of adding substance to the theories and in preparation for one of the most likely uses of the knowledge that the student will acquire in the University. As Sir Alan Cottrell has said, "It is amazing how far you can get with a little practice in diagnosis." This fact of life, of course, has long been the secret of success for most medical doctors and perhaps also for practising engineers, as indicated by Dr. Tetelman. Nowadays, we have quite sophisticated techniques for fracture studies. I urge that training in the use of scanning electronmicroscopy and Auger analysis be considered an automatic part of courses because these are certainly techniques which you find widely applied in industry. It is also important for students to realise that it is on extremely rare occasions that we find a situation in industry where we are concerned with a single crystal being deformed in uniaxial tension. More often we have, of course, a polycrystalline, multiphase, multi-component system subjected to a variety of stress modes. It is generally in contact with some other metal and, therefore, there is a potentially active electro-chemical situation arising. Its protective paint film is invariably scratched and it is probably exposed to some complex environment which, it seems to me, invariably contains some totally unexpected aggressive species such as chloride ions, sulphide ions, copper ions.

In our laboratory, which serves a quite diversified company, we are concerned with everything extending from low grade technology, such as blasting technology, intermediate technology, such as the extraction of aluminium and its production, and high grade technology, such as putting a Viking Lander on Mars or building a satellite. I think eight out of any ten times that our materials engineers are called out to investigate a problem concerned with component performance or a failure, it turns out that the problem is related to corrosion, stress corrosion, or corrosion fatigue. Very rarely is the problem concerned with strength or fracture toughness. It seems to me, then, that any course on fracture for engineers must contain an adequate consideration of environmental factors.

This brings me to the second aspect of what I think the course on fracture should contain. This has to do with the prevention and control of fracture. The keys to prevention and control are proper design of the component and appropriate material selection with respect to the environment to which it will be exposed. The third aspect is the use of protection of some sort by inhibitors, surface films, or control of the chemistry. This is another area which, I think, is not yet being adequately handled in most university courses on fracture. Design is usually well-covered and a design problem rarely is encountered in industry. Material selection is a much weaker area, and we frequently find a failure that has come about because of improper materials selection. I think it is crucial that our engineers think like engineers about fracture and analyze it in terms of a systems approach. The components of the system are the structure, the state of stress, and the environment. I think if you neglect any one of these three components it will probably be to your detriment.

Finally, I would like to turn to the application of fracture processes. This is a subject close to my own heart and, I think, largely neglected by scientists and teachers at present. Fracture is sometimes a beneficial process, although the usual concept of fracture is that expressed by Sir Alan Cottrell. He said that "fracture is a very attractive subject because of big engineering failures and that sort of thing". I think this is the common concept which sometimes leads us astray in this field. In my view it is the little fractures that are more often of account, and by little fractures I mean the small and usually not well-controlled fractures which are used in such industrial processes as blasting, comminution,

grinding, drilling, machining and polishing. Here fracture is a critically useful industrial phenomenon. However, we spend most of our time attempting to prevent it. "How important is it?" you might ask, when we want it to occur. In the United States, for example, we spend about 5% of the Gross National Product each year, which in 1975 amounted to 75-billion dollars, in fracturing things. This is done by drilling holes in mountains for rapid transit systems, or by machining, grinding, polishing and other industrial processes. I wonder how many scientists here have thought about fracture in the context of machining, grinding, or blasting processes. We also spend a lot of time being concerned with the fact that active or corrosive environments enhance the risk of fracture. In this case, we give our attention to the possibility of facilitating fracture when that is the desired end by the use of those very active environments that engineers otherwise spend most of their time designing against. I hope that the teachers of fracture who are here will begin to think about this different view of fracture in what I have called applied fracture and perhaps tailor their courses differently. To cite a few examples of applied fracture involving Soviet tests as well, people in this field are showing that you can drill stainless steel, for example, 8 to 10 times faster by using certain liquid-metal environments, or you can drill titanium and certain steels four or five times faster by using an oleic acid environment. Now we do not know the reason for these effects but we do know that they occur. You can increase life by factors of four to five with the use of appropriate liquid environments. You could go on with numerous examples but very few of these are understood at all and in very rare cases have any of the sytems been optimized. My point in this regard is that there is need for consideration of the constructive use of fracture instead of thinking that it is always a detrimental phenomenon. This would be a useful concept to get across to students. If it should happen I would think of this as a means of improving productivity and so maintaining or even improving upon our standard of life.

McEvily : It seems to me that somebody has done a fairly good job of acquainting society with the subject of fracture, during the past 25 years. Recently, there was an unfortunate accident at the top of the Pan Am Building in New York City, involving a helicopter, and people were killed. To my surprise, I noted that the headline of the Daily News the next day said in bold letters, "Metal Fatigue Causes Crash", which seems indicative of a certain awareness in the world at large. As a consequence of this development, as well as of developments in product liability, and its attendant publicity, students are becoming more aware of fracture. They realize that, in fact, it can be a career unto itself, as evidenced by Alan Tetelman's group, Failure Analysis Associates, and they appreciate that prevention of fracture is a societal need in which they can become involved. I have noted this development in the 10 years I have been at the University of Connecticut.

In this ten year period, the University has offered a course entitled, "The Metallurgy and Mechanics of Fracture". It has been a course which has always drawn students from a variety of departmental backgrounds : civil engineering and mechanical engineering, as well as metallurgy. In offering the course even at the graduate level, the subject becomes somewhat simplified. The students have available to them a number of texts. I might mention the text co-authored by Alan Tetelman and myself. More recently, we have available texts by David Broek, by John Knott and by Richard Hertzberg. At the undergraduate level we are still relying very much on a broad treatment of the subject of mechanical metallurgy. I use the text by George Dieter, which is now in its second edition. We are fortunate in the sense that our department is a relatively new department at the University, and we did not have to dislodge some other course to make room for teaching fracture, and we could put fracture in right at the beginning. We have also done some other things, particularly at the undergraduate level which have been designed to inform non-engineering students about this subject. We have a course taught by Professor Gallagan entitled, "Technology in Modern Society". The objective of this is to bring up some of the concerns about nuclear reactors, to explain what the problems might be, to acquaint students with the engineering approach to solution of such problems and to consider fracture of such structures as a matter of topical concern. The subject of material selection was also mentioned. We have recently offered such a course. It was a very popular course, taken by a variety of engineers in their fourth year where they could have the satisfaction of seeing the application of the principles which they have been taught in other courses. The course, which relates very closely, I think, to the Open University approach, seemed to be a very popular and worthwhile venture.

Another new area, which is being explored by Professor Greene, whose interest is in corrosion, is the video-taping of standardized experimental techniques. This is a very valuable teaching aid, particularly at the graduate level. There are certain routine but exacting techniques involved in electro-chemistry, which can be carried out properly by a graduate student and taped and so made available to his successors. I do not know whether ASTM has been involved in this sort of activity or not. It would seem to be a very worthwhile thing to have the procedures involved in, say, the specification of fracture mechanics testing, i.e. E399, presented on video-tape so that people could understand better what these procedures are.

Another interesting feature of fracture to me is that it is a very dynamic field in contrast to some of our other graduate programmes. I think of the classical subjects, such as thermodynamics, as being rather static : one might even use class notes of some years ago in teaching such a course, even at the graduate level. In our curriculum the information is relatively new : this is evident from this particular meeting. The concepts are still under development, which makes it a very exciting field. It is important for the teachers of this course to be well-versed in the field in order to do a good job. The other rewarding aspect, my final point, is that the demand, at least from our department, for graduates with backgrounds in fracture is as high as in any other area. This seems to reflect a strong need for this type of training as far as industry and other universities are concerned.

Hornbogen : My remarks refer to the West German situation. We have no formal course on fracture in West Germany, and there is no textbook. Most Germans in the fracture field tend to regard themselves as experts. Three groups can be distinguished : those who are doing creative work in fracture; those who know the state of the art and design and apply it successfully; and, those who work without adequate knowledge. In order to improve this situation, in a country like ours, I think we should first concentrate our teaching efforts at the graduate level, by setting up schools and courses which will serve somewhat the requirements which Dr. Westwood mentioned. There is a need to set standards for what a fracture expert should have as his educational background. This could be done, perhaps, on the basis of results from the two or three competing graduate schools which would train these experts.

A second point of concern is the degree to which undergraduate engineers should be trained in this field. Here we are in conflict with the tendency

to reduce, rather than increase, the number of courses. One possibility I can see is to include fracture and failure in a course given for the different types of engineer just before graduation in their third or fourth year. A course which also deals with material selection and dimensioning of parts is important. In this type of course, also, I think we could include failure analysis and some information about understanding fracture. Otherwise, I do not see much hope of including a special course on fracture in the field of engineering. There is a problem because fracture must compete with two other fields, wear and corrosion, in importance and in popularity. I think if we are to consider fracture as a field, we have to consider wear and corrosion equally, as they seem correspondingly important for society.

Armstrong : Now we should turn to the floor. We will first try to run through all those who might wish to contribute and then come back to ask the panellists for their responses.

R. Eisenstadt, Union College : In light of current events in flight liability, flight safety and malpractice insurance for engineers, what is the absolute minimum information we should supply for undergraduates or for feedback courses in this regard? I cannot see how fracture courses can be offered to undergraduates without some level of minimum information being given, in order to alleviate some of the major problems that we are having.

F.A. McClintock, M.I.T. : I wonder if we are not putting this matter somewhat backwards with respect to education. Perhaps we should look at the product, namely, a design engineer working at his board, a project engineer, or a failure analyst, and ask what he will need to know in order to solve a particular problem on fracture. This is likely to be a good deal more than fracture alone, and it is also likely to be more than he learned when he was an undergraduate or graduate student. How do we make a living body of information available so that people can draw from it the specific answers that they need, and put this information to work? If we could design such a structure of information and learn how to modify it other than by the use of short courses, by conferences, and by all the things we have now, including books, then perhaps we could turn this process around and start teaching our graduate students and our undergraduates to use that body of information. This would give them a little practice in digging into it here and there. Now it seems to me that perhaps this EMMSE project for Educational Modules for Materials Science and Engineering at Penn State falls into this category. I would like to hear what people's comments are about the success of that project, and whether it fills this sort of need. My own feeling is that it is a little too polished. It is too hard to prepare things in the beautiful detail that we have seen here from the Open University and from EMMSE. Nevertheless, perhaps these indicate the right ways to go.

V. Weiss, Syracuse University : I would like to reinforce points made by Professor McClintock and Dr. Westwood. It is clear to many educators that an undergraduate Fracture course is not very likely in the near future. It is also clear that no engineer involved in design, mechanical engineering, civil engineering or aerospace engineering should be able to graduate without knowing something about fracture. It is equally clear that the phenomenon of fracture or failure is a part of metallurgy, a part of materials if you are in ceramics, a part of mechanics in terms of stress analysis, and a part of design. Thus it is necessary that this topic be taught as a part of these courses. I feel that the problem that we address in meeting the industrial or market requirements, whatever you will, is that we are in the position of having to capture the interest of people who will teach these courses in fracture. Now the reverse would clearly be true if I were to teach a course in mechanics of materials or a related area. I cannot see how I would teach it without involving fracture in an important way. However, if somebody who has not been as close to fracture as all of us have been, were teaching this course, it might be hard to include fracture. There is a textbook on mechanical behaviour of materials that is used in some undergraduate schools which does not even include a chapter on fatigue. I think correction of deficiencies of this sort is of high priority in our effort to improve the education of undergraduates. It is important, too, that they get a multi-disciplinary approach.

Armstrong : Do you want to respond directly to that, Dr. Westwood?

Westwood : I have a brief comment on what might be done to prepare undergraduates for coping with practical problems in industry. This is based on our experience in industry of being called out to look at numerous failures in the field. I have observed that people with doctorates, plus perhaps fifteen years' experience and numerous published papers, invariably use Metals Handbook at times like this. It is remarkable how the wealth of information in that book has contributed to solving so many practical problems. I feel that it would be very useful if engineers would learn to use books like this. It may be that parts of their courses should involve questions for which they would simply have to go to the book to find a solution, just as most people in industry have, in fact, been doing. In this way they would learn the trade.

D. Felbeck, University of Michigan : There is really so much to say on all that has been brought up that I hardly know where to start. A word to Deans, Associate Deans and Chairmen : if you want fracture taught, you have to start by hiring people who know something about fracture. Older staff tend to be cutters, polishers and etchers, whose only concept of failure analysis is looking for inclusions and porosity. It is unrealistic to try to teach them anything about fractography and fracture mechanics; much less expect them to teach students. I think that would be a disaster.

We have drawn several departments into the operation of teaching fracture at the University of Michigan. We now have a graduate course in fracture mechanics that is taught in the aeronautical engineering department. We have a senior level graduate course in failure analysis which involves case studies and involves practical experience on real-life, real-time, failure analysis in industries in the Detroit-Ann Arbor area. These students are able to use an SEM as a tool in their failure analysis. Lastly, we teach fracture mechanics for about two weeks in our sophomore-junior level course, the latter stages of this course being on mechanical behaviour of materials. The tragedy is that there are people in some other departments, for example, engineering mechanics, who teach a thing called "strength of materials", but never talk about cracks and, also, that in my own department there are people who teach an engineering design course but never mention fracture mechanics. They teach design according to the old standards based only on yield stress. They talk about fatigue only in terms of Goodman and related diagrams. They do not go any further than that. We are now graduating engineers whose only contact with fracture mechanics has come in a materials course rather than in a design course. I think that at this time of rapid change the people who are teaching these courses are perhaps too old to do it, because they do not intend to learn any fracture mechanics themselves. At our university, and possibly at many of the universities represented here, one of the saddest features is the low hiring rate of the last five years and probably the future ten years. I see no way of improving and enlarging the teaching of fracture when the

staff is in general approaching retirement and knows less and less about the subject, of course, with a few notable exceptions. It is quite significant that there is virtually nobody coming into the Universities. To reiterate, I think that the word must be carried to the Deans and Administrators of the Universities. They are in need of some of the young men in this room, perhaps, to come in and teach more about fracture. They are the ones who know most of what is going on in this subject area and could do the most effective job.

J.R. Rice, Brown University : I have some philosophical differences with some of the recommendation we have heard. In fact, I am a little concerned that one can detect an almost "trade school" mentality in some of what is being proposed as education for engineers. By that I mean an emphasis on rather highly specialized techniques, which are almost sure to be outdated, probably not very long after our graduates leave us. I feel that the best way to teach Fracture is indeed to continue to demand, as I hope we are all doing now, that our students have the most fundamental, rigorous and demanding exposure that we can give them to things like the science of materials and the mechanics of solids. Of course, in presenting courses like that we must mention the fundamentals of the subject of fracture, but mainly we want to train people who can think, who can look at ideas and evaluate exactly where their boundaries of knowledge are. We hope they can figure out what they do not know and can plan a route to get the additional information and answers they need. I think it might also be worthwhile to reflect a moment on those who have made really seminal contributions to this field, both at a fundamental scientific level and by pointing the way to really innovative engineering applications, and ask whether the production of seminal thinkers in the future would be best served by a technique oriented education or one which continues to put the emphasis on the fundamental engineering and physical sciences that underly fracture mechanics.

J.A. Alic, Wichita State University : I would like to offer a partial reply to that by repeating some of the earlier remarks. I have always felt that the seminal thinkers in any field get that way without much help from those of us in teaching. I think what we need to do in teaching fracture is to reach the practitioners. There is no doubt that, in Wichita, where I teach, fracture mechanics in the aircraft industry is at the more or less routine day-to-day level. The students who are graduating from Wichita State University and from many other Universities in the country will be doing fracture work in future. I agree that there is not a place for a fracture course in the undergraduate curriculum. I think our curricula are far too fragmented already and I support very strongly the incorporation of fracture topics into design courses, mechanics courses, materials courses and so on. I have been heartened to see that most of the more recent materials science and engineering textbooks do include material on fracture mechanics. It is unfortunate that the design texts do not, but I think that will inevitably happen. I think what we need to do is to get the word to our colleagues. The people we have to convince are not in this room, unfortunately. We are all specialists to some extent and it is the rest of the engineering community and teaching community that needs to hear our message.

I think also that there is a place in the materials testing laboratory for experiments that deal with fracture mechanics, particularly with the use of feedback controlled testing machines. There has been a phenomenal growth in the use of that sort of equipment in industry. I have brought a slide that illustrates this. The slide shows the exponential increase in the use of servo-controlled testing equipment over the last ten to twelve years.

I do not think it makes very much difference what kinds of experiments we do in the laboratory at the Universities, but it does matter that we use modern equipment. I think we need to begin to do that for the very good reason that there is no doubt that our graduates will be using such equipment for many kinds of applications in the future.

M.W.T. Spencer, Alberta Gas Trunk Line : I am one of the objects of this discussion : I am an ex-student. The Universities tend to feel that the teaching process ends at graduation. After that, communications between industry and University are relatively poor. They may occur on a consulting basis, but that is not very educational. The education of an engineer or of other persons who are working in industry is taken over then by other institutions such as the ASM. I believe there should be a continuing input from the University in updating industrial people in the current developments of their particular fields. It seems that most people who are here agree that there is not room in the undergraduate curriculum to include a fracture course independent of other courses. That is probably true, but when a person goes into industry there should be some attempt made in one way or another to keep the lines of communication open so that that person can get hold of the necessary expertise or the information that would help him to develop this particular expertise. I agree that if we attempt to give engineering courses on specific topics at the undergraduate level we are going to lose some of the essential fundamentals. I think that is the rule of the University now and it should be maintained. There may not be room during this time to give the person that specialist training. That has to be done afterwards, and thus it is very important to maintain effective channels of communication.

Armstrong : I propose now to take some responses from our panellists.

Knott : First, I would point out that, in Britain, fracture is being taught in materials departments and engineering departments at the undergraduate level. I think it is important that fracture be an accepted topic in an engineering department in the sense that it is thought of as part of the proper engineering teaching. I also think it is proper that materials be treated in the same way. I see these as rather similar products. It may be difficult if Fracture gets into a course, but is thought of as not being "real" Engineering. I think it is much better that it should go into the design and structural engineering parts of the course. This can be done as part of a general failures appreciation course through case studies or through formal teaching. It is very much a question of balance and selection and here I would take some issue, I think, with Professor Rice. Of course we want rigour and challenge and excitement in our undergraduate courses, but we can get carried away at the undergraduate level with over-sophistication in what we teach them. I think that what we really ought to work towards on this particular topic is what Sir Alan Cottrell referred to as the "science of materials in service".

Hertzberg : I have some comments related to the question that Professor Eisenstadt raised and to some other points that have been made. I definitely feel that the idea of product liability should be, at least, introduced in the undergraduate curriculum. This could be done either in a course that deals with fracture topics or in a course that deals with engineering professionalism. This is where the student is exposed to what it means to be an engineer and is made aware of the career opportunities which are available. Some schools have this, including Lehigh, where our department is concerned with this. I think that perhaps one of the most profound things that a student can become acquainted with is the concept of strict liability, where no one has to be negligent. All you have to do in this regard is to establish the fact that a structure contained a defect and that someone was hurt as a result of the defect. I think the student really learns something from such considerations.

With regard to a comment that Professor McEvily made, one could also use video tapes for *in situ* experiments involving electron microscopy, particularly, with regard to fractography. I have been working along these lines and I think it is very useful to bring the instruments into the classroom.

Regarding Professor Rice's remarks about fundamental versus applied concepts, I think one has to recognize the fact that the Universities provide a service, and one must therefore consider the market that seeks such service. In the future, there is going to be a demographic redistribution of the available student body. Many projections that the Deans are well aware of show that there will be fewer students going to college and, thus, the student body that one will have to attract will be increasingly a student body derived from industry. We will, therefore, have to design our courses to be more responsive to the needs of industry and that will involve some emphasis towards the more practical things.

Liebowitz : Regarding the comment concerning curriculum content and the fundamental aspects/practical aspects balance, I would be very concerned about any master plan to be used by all Colleges and Universities. Each College and University has a certain resource. It has its own specific objectives, whether it is a state or a private institution. I think it would lead to a problem if we trained all engineers to be of the same fabric. I think mixture and diversity in engineering education is very very important. I would hesitate to see any one curriculum being followed throughout. Now, concerning the question raised by Mr. Spencer on lines of communication between Universities and students upon graduation : there are some countries which have been very active in the field of continuing engineering education. I think that is one of the many ways that the University can be in touch with former students. I think there was a very interesting point raised by Professor Francois on our panel concerning the importance of work experience. Certainly those institutions that have co-operative education arrangements can look to ways in which fracture experience could be gained by their students.

Reid : I want to say that I certainly agree strongly with Mr. Spencer about the fuller involvement of Universities in what we in Britain call "post-experience education". I think, certainly, speaking of British Universities, we could do much more than we do now in this area. It is really the exception rather than the rule that Universities are active locally in this area. There is no limit, I think, to what can be achieved here and, certainly, from my own point of view, I think the ultimate future of the Open University, perhaps, lies very largely in this direction. We have no guarantee that the current very gratifying flux of students will keep coming through our gates at the same rate. Indeed, there are some plausible reasons why we might eventually come to teach our way out of business, as people's ambitions become satisfied. That is an imponderable point, but it certainly is a possibility that the undergraduate education, which at present takes up the majority of our energies, may decline in relative importance, and yet, in the post-experience area, as I say, there is no limit. I think we will probably develop in that area over the years, although certainly our brief from the government at the moment is to give absolute priority to the undergraduates. This will apply only as long as the undergraduates are there.

Things are happening already on a modest scale. For instance, some of my colleagues in the Energy Research Group at the Open University are at present planning a short correspondence course that will be launched nationally quite soon, called "Energy in the Home". This will have quite modest educational objectives and it will be concerned really with helping people to understand the physics of heating and lighting homes, so that they can do something about saving money and saving energy in the process. There is no reason why another such example in the future could not be the presentation of fracture mechanics to those who graduated and underwent their training before that was a recognized kind of analysis.

Westwood : One of the things that I have found difficulty in learning to live with as I have made the transition from an active scientist to a full-time manager is my own increasing ignorance. You get used to being an expert and suddenly you find you are ignorant in just about every area you are supposed to be involved in, but yet you have responsibility for problems in specific areas where you are totally ignorant. What I am really saying is that you cannot know everything in the same sense that a teacher cannot teach everything either. How can this be compensated for? The answer is to have some awareness of phenomena, and some awareness of issues, but not to know exactly all there is to know about any of them, simply to know that they exist. In other words, I think that it is important that an engineer knows about such things as fatigue, creep and wear but he does not have to know all the details involving the mechanisms of those things.

Secondly, it is important to be able to follow on from knowing that these things exist to being able to do something about them when a problem arises. The principal way to do this is to learn to seek help. You have to learn to ask questions and you have to learn to draw on the resources available. I find in industry that engineers simply do not do this. They do not read the engineering literature. One of our staff, many years ago, did an analysis of how many times the engineers ever went to the library or ever asked for textbooks, and it was remarkably low considering the incredible problems which arise every day. Perhaps this indicates that more must be done to teach our students to go to the appropriate literature and handbooks and to make use, too, of the research laboratories and the University professors. The students must not be afraid to ask questions. It is rather important that we know what we do know well, but it is also important that we recognize what we do not know, and perhaps do not need to know, because there are very probably people who do know, and, therefore, we must learn to question them.

Knapper : I certainly endorse the last comment. I do, however, think that the skills that have to be taught are much broader than the discussion this afternoon has suggested to me and will no doubt be brought out in the second Panel on the overall political ramifications of fracture including the social, moral and ethical considerations. The engineer of the future or the materials scientist of the future will be expected by society to consider all these, and that is a real challenge for the educator.

Armstrong : I am sorry that we have run out of time. I surely feel that I have learned a great deal from the discussion, from the panellists, and from the active participation of the audience. I certainly want to thank the audience for their attention and constructive comments and, on behalf of the audience, I want to thank the panellists for all their effort. I suggest that we close with a round of thanks for the panellists.

Taplin : Thank you, Dr. Armstrong, for your very constructive Chairmanship. The second Panel on Friday afternoon will address the wider public issues in Fracture Problems and is entitled *Fracture, Politics and Society*.

FRACTURE AND SOCIETY - PART 2

Edited Transcript of the Second Panel Discussion on

FRACTURE, POLITICS AND SOCIETY

Nichols : This afternoon's panel discussion is on *Fracture, Politics and Society*. It is perhaps appropriate that this comes at the end of the Conference, if only because we would otherwise have spent the whole week talking on this single topic. We have a varied and enthusiastic panel set up here, as you can see, but I hope that we will have a fair amount of audience participation. To encourage this participation, I intend to open the floor to general discussion after each panel speaker, and only when the steam has gone out of that part, will we move onto another panellist, who will, I hope, move us onto a different topic. Unfortunately, because there is only one plane a day to Manchester I have to leave before four o'clock. If you see me get up and sneak off it is not because I have disagreed completely with the panel, and I apologize in advance for having to leave you. So, to make the most of my time I will spend no more of it on introductions. You will notice that I have not said anything relevant to the topic, and the reason is that, having read Max Saltsman's paper in Volume 4 , I was left with precious little that I wanted to say, since he had said it all for me. So, since Max is one of this panel's bigger guns, I will fire that gun off first, and make a start.

Saltsman : I was a little worried when you started saying "Fire Max Saltsman", there is an election in the offing and we get sensitive about these things. The main theme of this meeting, of course, is purely technological, but it is a sign of our times that the proceedings should include consideration of theme in political, social and educational terms. Politics and public opinion (I want to say something about public opinion shortly) now play a major role in deciding the level of support that can be given to technology, and while this may be somewhat unpalatable to research engineers and scientists, it is not wholly unreasonable that he or she who pays the piper should call the tune. At any rate, for better or worse, that is the reality of politics. I think another important reality of present day politics is that public opinion is everything. There are no big levers in government that can be pressed, that you can pull down and say, "I have reached the right people and they are going to make the decision". I have never seen politics and the political system so sensitive to what the public thinks.

To the extent that I have any advice at all to give to scientists it is simply this, that you must present your case to the public rather than to the politicians, with a reasonable assurance that, if you make your case to the public, and that is not always easy to do, the politician will respond to that, because there is a kind of running scared of public opinion that exists in Canadian politics. I should say that I am not an elitist about public opinion. I think it is quite intelligent, or at least that part of public opinion that is capable of being shifted away from traditional loyalties. It is not venal, it is I think just confused. It is confused by the conflicting claims that are made by the experts of our times. Thus, I think it entirely proper that I should address this question in my capacity as a politician, and it is not my purpose to be political in an absolute sense, but, rather, to try to give you a politician's view on technology in general and fracture in particular.

Professor Saltsman then presented his paper on Political and Social Decision Making in Relation to Fracture, Failure, Risk Analysis and Safe Design, which is included in this volume.

Nichols : This gives us a good start to the discussions. I would like to just pick on a couple of points which could be run together. Right at the beginning you made reference to the fact that, whilst you had admiration for the public, the public can be confused, or think itself confused, either through lack of information or from too much information. It wonders whether it can trust the politicians or the media; when it comes to the scientists, the public often gets contradictory stories. One of the points that I would like to hear a little discussion on is this question of how the public can judge whether the scientist that is speaking is indeed qualified to speak on that topic. I am afraid that often scientists offer profound statements outside their own particular field of expertise : how is the public to know that? This leads to the second point, your very interesting suggestion that we might consider having a technical court. I am rather wondering whether the same sort of thing would happen there. It would probably be impossible to have a single technical court which could deal separately and competently with all forms of expertise. Someone will have to answer the same question : How relevant are the people in the technical court to the particular problems that they are tackling?

Questioner : The usual procedure, once a court has been established, is that a member of the legal profession, typically a judge, is appointed to run that court. His selection undergoes some sort of scrutiny and his competence is widely accepted. The usual procedure is then to ask the judge to select from a panel who should sit in the Court. That at least solves the selection side of the problem. The selection of competent people does not then have to go through a long *ad hoc* procedure every time, as discussed in the interview with Sir Alan Cottrell.

Saltsman : That then raises the problem of whether judges trained in the law are appropriate people to make technical judgements. It is interesting to see what has happened in society. I think in all societies it is the case that new kinds of courts that are not called courts have arisen : for example Labour Relations Boards and National Energy Boards.

Nichols : They might even be called professional institutions. Very many of these now operate as courts in some cases.

Saltsman : Often they operate together, in situations where the normal legal training is not required to supervise the court, but rather the technical training in order to make judgements. For instance, recently, in Quebec, a judge refused to hear a labour case because he said the court was not competent to hear a labour case, even though it was standing before the court. Standing is important, and you can always get standing in another court if you disagree with technical decisions.

Averbach : A few courts have been established on quite technical grounds. There is, for example, a water court in Sweden which deals, on a very technical basis, with the distribution of rights to bodies of water, and use of water. Some of the considerations are political, of course, but the courts are quite separate from the normal legal system. We have regulatory bodies with specialized judges, but I think that the Swedish experience is quite unique in this respect.

Saltsman : So they have taken riparian rights out of the legal system and turned them over to special courts.

Averbach : Yes, and they have existed for quite some time.

Hahn : In the United States the National Academy of Sciences and the National Academy of Engineering mount committees which make technical evaluations : for example, in the case of Freon used in aerosols and its effect on the environment.

However, I think the problem in these situations is that there is a sudden public controversy, and an informed and trusted opinion is needed right then and there, whereas these committees take two years to come up with a report and a collective opinion. Meanwhile, people pass judgement who perhaps are not qualified to speak, and I see this question of time scales as a real problem. Public opinion would like to be served very quickly, but the scientific process takes a long time.

Questioner : I have a question that is really very central to what the Chairman had to say about how to establish credibility, in other words, whom does the public believe? This is terribly important if we talk about nuclear energy. On the one hand you have a group of scientists who say, "Do not move in that direction at all"; you have another group of scientists who say, "There is no harm, we have everything under control". Whom does the ordinary layman, and a politician is to some extent that kind of a layman, believe? We have a very good organization in Canada : the Science Council of Canada, although they tend to be rather circumspect, perhaps a little less today than formerly. Even with such a body in existence, how does a scientific community agree amongst itself on what it should put before the public and whom the public should accept as authoritative. This may be a tentative authoritativeness, able only to say : "Up until this moment this is the state of scientific knowledge."

Questioner : I see a problem in the tendency for the public to ask for absolute truth. As Max Saltsman commented, the general public has a different time scale from people in science. We cannot produce answers immediately, as the public requires. Thus opinions are often taken as being absolute truths, whereas, in fact, many are highly arguable : argument being one of the bases of our profession.

Nichols : Certainly people may read more into statements than is meant by the speaker. I think the classic case of this is the man that goes along to his physician and then comes away and analyses virtually every sentence, and reads into it more than was intended, and, in all probability, his physician was speaking off the top of his head, giving an instant opinion. I think we should now turn to another topic, and I am going to call on Dr. John Knott to talk about his interview with Sir Alan Cottrell.

Knott : Before I do so, I might point out, apropos of the earlier discussion on the membership of technical courts, that it is technically quite possible at the University of Cambridge to read two years' engineering followed by one year of law and become acceptable both to lawyers and to the professional engineering institutions.

The aim was initially to try to get Sir Alan Cottrell to come and address the meeting, as being a person who has spent a lot of time in high level scientific research, and more recently has been very much involved in government decisions on scientific matters. Unfortunately for the Conference, he has become Vice-Chancellor Elect of the University and is unable to come at this time, and presents his apologies. I am going to pick out some of the points which I think need to be mentioned, although some may not be particularly relevant to the broader theme. The interview itself was very loosely structured. We started with a list of questions which had been provided by various people and these were in no particular order, so that the logical connections between various parts of the interview are perhaps not as good as they would be had we had three or four recording sessions, but we touched on a large number of points.

The first thing that we were concerned with was his views on the science of fracture. Here, with the exception of some remaining interest in the surface energy of iron in fracture processes, Sir Alan tends to regard the *basic science* of low temperature fracture as more or less complete, whereas he still feels that there is a lot of work to be done in understanding fatigue, stress corrosion and interactions of various sorts. Sir Alan, of course, is a man whose science is of a rather broad nature. He likes to treat materials as fairly simple continua and it may be that there are details in low temperature fracture, particularly where embrittlement is involved, where his overall judgement may not be correct. But the point behind this, I think, is one of the support of university research, particularly in Britain. He says that, for the more complicated problems of fatigue and stress corrosion, "I think the only way that you can make progress with that sort of problem is to have a healthy university research environment and let people get around pretty freely to exchange ideas." So that what he is saying there is that there is a need still for some fundamental research in universities to try to understand some of the more complicated problems. That is one point on the science.

The second one is on the application of scientific knowledge to engineering design. His view here is that, with one or two notable exceptions, our application of scientific knowledge to design is not all that good. There are some major exceptions : the plastic design theory (initiated by Sir John Baker) and fracture mechanics (due to George Irwin) - a concept that he thinks is of considerable value is "leak before break". He is, I think, not as enthusiastic as I expected on the philosophy of probabilistic design and things of that nature. I was also rather disappointed that he had nothing to add in the way of examples of areas into which effort could be usefully put to improve the translation of scientific concepts into design. I think there may be lots of fields which one might regard as being semi-empirical still - where we are using data from e.g. SN-curves in fatigue - where perhaps one may say there are still things where the science can aid in engineering design. Cottrell is less strong on these points than I envisaged.

The third point is the teaching of engineers about fracture and materials. This was covered in Wednesday's discussion and I do not intend to bring it up any further except to mention the point that he makes about the materials men being brought in at the engineering design stage. The factor that he emphasizes is that the materials man has not found it

really attractive to make a career in helping the engineer to design things because, "I think the materials man has known that he would always be only an assistant in that kind of work. He would never become the Chief Designer and he would never become the head of the firm. It does not prove such an attractive avenue for materials people as some of the other careers." That is perhaps a point to bear in mind. Towards the end of his interview there is specific discussion on the areas into which research effort should be put : whether one in fact should be dealing with fracture toughness and fracture mechanics or whether the stress analysis or non-destructive testing sides are the areas where we would get the most benefit from directing our research.

I think that the point that will be of most interest to the present audience is his view generally on the avoidance of failures. This is in two parts, one of them being on duty : whose duty is it to ensure that things are done properly and that safety standards are maintained? Does one use inspectorates, the institutions or professional bodies? What should be done about design codes and what is the responsibility of large companies in maintaining their own safety standards? Some points were made on the use of materials and on the rather large number of fairly similar materials that we use and whether it would not be better to try to rationalize this by concentrating on specific materials and learning a lot about them. I think there will be most interest in Sir Alan Cottrell's views on nuclear pressure vessels and on alternative forms of energy supply and the safety of these in current use. This follows his comments on the *leak before break* concept and the importance of this and the way in which he felt that this was a protecting feature which the light water reactor did not have. He had commented in letters to *The Times* and elsewhere that the situation was such that it was necessary to be ultra-critically careful in terms of inspection and quality. Sir Alan says, "I think that the specifications that the Americans have set for their water reactor pressure vessels are extremely rigorous, there is no doubt about that. If human frailty is able to achieve that degree of rigour in practice then they will be all right. But you must always have a question mark against human frailty and this is the thing that worries me, whereas with the pressure tube kind of reactor, again you have to be just as good as you can be against human frailty. Nevertheless, if you are let down by human frailty then you have got a natural back-up, the *leak before break*. That is where the difference is, and I still feel strongly about that point."

We followed with a somewhat more searching set of questions as follows : "Do you think, because of the emotive word *nuclear*, that more attention is given to your commentary on the nuclear reactor case, than is given in the equally worrying ecological case of having large pipelines running hundreds of miles across the bottom of the North Sea with large amounts of oil running through them, where a split could again be equally disastrous?" Sir Alan replied : "I think so, yes. My own position on that specific reactor problem does not reflect any sort of general position that I have about nuclear power. In general I feel that politicians and the general public are being taken for something of a ride by the environmentalist lobby which has been going very hard against nuclear energy. I feel that this is an extremely unfortunate development because the only assured new major source of energy for the world in thirty years' time or so is nuclear energy. And to turn one's back on that without very very good reasons, could, I think, be a disastrous step for mankind. I think that the fossil fuel position, certainly in the Western World, is really alarming. It is much worse than it is said to be in the newspapers.

We in Britain are locally in a good position for oil since the North Sea will give us what we need for the next twenty or possibly forty years. But if you go outside Britain then the position is really alarming and we may already have left it too late. The only way out of this situation is the nuclear one. I think that the environmentalists have served the Western World badly with their overdone campaign against nuclear energy."

The next point that we put was whether in fact a double standard is applied in the assessment of risk, in that we are asking the nuclear people to fulfil criteria of safety which are much more stringent than for equally worrying problems such as pipelines. Sir Alan makes a very good point : "This is true, and it is true of other things. A highly dangerous source of energy is hydroelectricity. You have the big dams and if a big dam bursts it could not only take out enormous acreages of ground but could drown large numbers of people. On the whole a big dam bursts about once a year and these as incidents are large scale, even by the standards of the worst imagined nuclear reactor incident." I have quoted these parts because I think they are most pertinent and of specific interest to the present session. I am sorry that you have had to receive these views by proxy, but I hope I have been able to convey Cottrell's points fairly.

Nichols : I happen to know that Jim Justice from Trans Canada Pipelines is here, and I wonder if he has any views on the treatment he receives relative to the nuclear people in this respect.

J.T. Justice, Trans Canada Pipelines : I know very little about the nuclear regulations. I feel that we get a considerable amount of regulation, and in most cases I think it is very fair and just regulation. I understand that nuclear regulations are much tougher, but I think that Dr. Mills is probably far more qualified to answer the question than I.

Nichols : You do not feel as though the public ignores any risks in your pipelines?

Justice : No, I do not think so.

Nichols : Dr. Mills, would you like to say anything about either big dams or nuclear?

Mills : I have a few remarks on nuclear issues prepared, and this seems an appropriate moment to make them. When I looked at the title of this discussion, I made a note of my own as to what it might be. My title was "Fracture, Ontario Hydro and Society", and I seem to have that right with two fracture experts, then Ontario Hydro, and Max Saltsman representing society on my right. There are certainly many in Ontario who would find Ontario Hydro synonymous with politics. Ontario Hydro's interest in fracture is shown readily in its concerns with major plant. From the very first conception of a plant design Ontario Hydro seeks to ensure four things:

1) Safety of the public.
2) Safety of operating personnel.
3) Avoidance of economic loss due to plant shutdown and repair.
4) Enhanced reliability due to fracture resistant design.

I would like to comment briefly on each of these topics with examples (illustrated by slides).

My first topic is public safety, and we, in particular, as proponents of nuclear power, have been very sensitive to the need to assure the public

that our plants are safe. In the Canadian CANDU reactor system we employ 5 boundaries between the public and the nuclear heat source. Firstly, we clad our nuclear fuel in an alloy designed specifically for that purpose. Secondly, we contain the primary coolant of that fuel in a pressure boundary which is subject to rigorous quality control during construction and which receives regular periodic in service inspection. Thirdly, we contain that primary pressure boundary inside a thick concrete reactor building. Fourthly, should this reactor building ever become slightly above atmospheric pressure, it is automatically connected to a vacuum building maintained at low pressure and containing a dousing system to condense steam. And fifthly, we build an exclusion fence around the plant such that no one at the fence receives radiation doses higher than he or she would receive from natural sources. Thus our philosophy is to put as many boundaries as is economically possible between the public and the nuclear heat source.

Regarding the safety of our operating personnel, we cannot expect them to do their job in anything but a safe working environment. And there are now very specific regulations in Ontario which lay the onus for plant safety on the employer. This slide shows 2.44m sections of Schedule 20, 340L stainless steel pipes which were hydraulically pressure tested to failure for our heavy water plant operations to determine their burst pressures and fracture mode. A stress raiser was present along the longitudinal seam in these pipes. In one case an internal surface flaw was introduced using a milling cutter. These experiments showed that the pipes can tolerate large plastic deformation and that final failure is controlled by plastic instability. The burst pressures were also predicted using a plastic instability analysis to be well above anything that they might see during abnormal operation.

Our third concern is economic loss, and the next slide shows a fractured forged 'T' from a small boiler pressure equalizing line at our Pickering station. The pipes running into the 'T' are about 10mm diameter. The fracture of that 'T' resulted in a forced outage of 36 hours, resulting in a replacement energy cost of $75,000. The downgrading of the heavy water caused a further direct loss of $80,000. That fracture was thought to be caused by a combination of stress corrosion cracking and fatigue from tube vibration.

Our final concern is enhanced reliability, and we are engaged in an extensive programme of testing the fracture properties of pressure boundary materials and both nuclear and conventional thermal heat transport systems. The ASME Boiler & Pressure Vessel In-service Inspection Code, Section XI, states that : components with flaws exceeding the normal allowable standard may be considered acceptable for continued service if a fracture mechanics analysis performed in accordance with the recommended procedures of that section shows that the structural integrity of the component is not impaired. An extensive fracture mechanics data base is required to perform these analyses. We therefore have an experimental programme in progress to determine fracture properties of primary and secondary pressure boundary materials.

As with any large electrical utility, in operation there are always failures of components, and we do have many interesting case histories, although this panel is certainly not the forum for discussing these in detail. Let me conclude by saying that Ontario Hydro, as, I hope, a responsive crown corporation, with significant influences on the economy and technology of this province, has as one of its objectives the desire to ensure that in the operation of its major plant there is safety for the public, safety for the operating personnel, avoidance of economic loss and enhanced reliability.

Nichols : I would like to ask you a question which, I think, relates both to your comments and to a point in Sir Alan Cottrell's interview; that is the comment about the difficulty of communications, of getting the information across. This is an area in which I have learned something over the past 6-9 months. Criticism of the nuclear power industry has at times reached such a pitch that it appears to be something that the public just does not want anymore. We are reaching a stage when virtually every person in my laboratory is encouraged to go out and talk about nuclear power. We all are presented with facts outside our own area of special expertise in a way that might interest the general public, and to enable us to answer questions that might come up in formal and informal discussions. Everyone is encouraged to talk over the garden fence, in the pubs, in the clubs, and as I told you last night, to actually go out to the Women's Institute, the schools and so forth. We have come to the conclusion that we must try to get our message across; we believe now that not only is it our duty to make nuclear reactors safe, but also it is our duty to convince the public that we are so doing. I do not know whether many of you have done this sort of thing. I believe that scientists as a whole tend not to regard it as part of their duty to talk to the public, and perhaps this is a problem to be faced, we will talk amongst ourselves but not to the public. Therefore, I wonder if you have any organization in Ontario Hydro for getting this message, on your attention to safety, across to the public. In other words safety must not only be done. It must be believed to be done.

Mills : There are two things that Ontario Hydro does. First, it provides a technical information service at its main head office where any member of the public can go to examine research reports and safety reports, which are submitted to our regulative authority. In fact, any document in the company, unless it is to do with a commercial contract, is open to the public. However, in the last two years there has been a Royal Commission sitting in Ontario and its duty has been to examine what Ontario Hydro should be doing in terms of electric power planning over the next ten to fifteen years. This Commission has received submissions from the general public, from environmentalists, from the many concern groups who have the general label 'anti-nuclear', and from Ontario Hydro itself, which is trying to make a case for an expanded or continued nuclear power programme. In order to understand Ontario Hydro's case on nuclear power we should consider what it costs Ontario Hydro to make 1 kilowatt hour of power. It costs us about five thousandths of a dollar to make a kilowatt hour with hydraulic power, and there is very little left in Ontario now. It costs us at Pickering approximately 9 thousandths of a dollar to generate a kilowatt hour. On our best coal-fired station it costs us about eighteen thousandths of a dollar to generate a kilowatt hour. At an oil fired station it costs us 28 thousandths of a dollar to generate a kilowatt hour. Thus, any movement that we are directed to make towards greater use of fossil fuel, as a large utility, is going to have severe impact on electric power costs in the future. This is a major concern as Ontario's economic base is its relatively cheap electric power, and, if that base is destroyed, there are going to be severe economic consequences, not only for Ontario, but also perhaps for the whole of Canada.

Nichols : We should not allow this to turn into the nuclear debate itself, but thank you for giving us those examples and indicating how your public

relations is handled.

E. Von Bezold, University of Waterloo : I have a question on the matter of public education. Mr. Saltsman pointed out that in this country the decisions made by politicians are rather sensitive to public opinion, and in some respects I would agree with him. My concern is with the facts which are available to the public in formulating its opinions : how can the intelligent lay person obtain the information to enable him to assess properly, for example, the options in allocating resources for research or the choice of nuclear reactors? Can scientific workers be relied upon to act in the public interest and bring controversial questions to public attention? Will the public receive all the facts?

Averbach : The point which you raise is central to our discussion here. That is, how do we go about assuring the public that it is hearing something which is impartial? For example, we have just heard somebody from Ontario Hydro and somebody from the U.K. Atomic Energy Commission. Each may be impartial, but their affiliations are such that there will be some suspicion of self interest. On the other hand, if we hear someone from the Ralph Nader Office, he is also labelled with a certain tag, which all may not accept as impartial. This categorization is an extremely difficult thing to avoid. Until we establish some kind of arms length approach to these technical problems, which we can make understandable to the public, we will not really ever come to grips with this situation. We will simply argue ourselves to the point where the decision is made, willy-nilly, by some political body which has made an assessment on some quite different grounds.

Saltsman : I have a serious comment on establishing credibility : how we should go out to the public and explain out position. I think the first thing that is involved is to develop a better mental attitude towards the public. This applies to politicians, the media, and I think to scientists as well. There is a tendency to think of the public as children. Nobody is going to say : "We think the public is a bunch of 12-year olds." but very often in private conversations or little asides this is the kind of impression you get. There is a feeling that they are not really going to understand what we have got to say and really we know better than they know. I think you have to purge your mind. I, as a politician, have tried to do this, and I think, in fact, that I have been reasonably successful as a politician, because I have done that. It is certainly true that there are 12-year olds out there, adult 12-year olds, but there are many intelligent people as well. Those people are important and can be addressed in a very straightforward way. You do not have to tell them : "There is nothing to worry about on this issue." You can say to them : "There are certain benefits and there are certain problems. We do not know everything about these problems, and there is some risk involved". The people will understand that. They do not understand it when you simply say that there is nothing to worry about regarding a problem that is highly technical. That immediately loses you credibility. People are prepared to accept certain risks. They accept a risk when they drive a motor car, they accept a risk the minute they start to live in society. That is not the only answer of course, but to start with I think you have to develop a certain mental attitude, or at least come to the conclusion that there is a sophisticated, intelligent public that can be addressed.

A.N. Sherbourne, University of Waterloo : I would like to make one point. That is to say that not all the 12-year olds are to be found in the public domain. Many of them are in universities and other organizations which should know better.

Nichols : We are all 12-year olds with regard to some subjects, are we not?

N.I. Adams, Nuclear Installations Inspectorate, London : First I should state that what I am going to say reflects my own opinion and should be in no way interpreted as a part of the policy of the Nuclear Licensing Authority of the United Kingdom. I have, in the past two years, whilst working in London, been intimately concerned with the U.K. assessment of the light water reactor system. I am also intimately concerned with assessment of the Steam Generating Heavy Water Reactor, and I would like to make a few remarks which stem from John Knott's interview with Sir Alan Cottrell and perhaps go on to mention public opinion. To sketch the relevant background, Sir Alan Cottrell was the Government Chief Scientific Advisor, and in 1974 a decision was made in the form of a government white paper that the next U.K. power system would be the home grown SGHWR. Sir Alan stated that he did not believe that it could be shown that a pressurized water reactor pressure vessel could be convincingly shown as safe for its entire lifetime. I have since concluded that that was his instinctive decision as a metallurgist with a great deal of experience. I believe he was right, at the time, in making that judgement, and I think that judgement was supported by the outcome of the Marshall report, which Dr. Nichols, in fact, helped to write. This report took something of the order of 2½ years to produce and concluded that, with quite a considerable number of improvements to U.S. Technology, it should be possible to have a pressure vessel that would be safe at the start of life. It further concluded that, given a great deal of in-service inspection, and provided that this can be shown to detect defects, the vessel should be safe during its working life, and that, I believe, vindicated Sir Alan's views expressed in 1974.

Sir Alan has, however, written to *The Times* more recently and expressed further views which show that on some other matters, whatever his feeling, he has got part of the technical story incorrect, and is making judgements on the basis of an incorrect interpretation of the real situation. This leads me to wonder whether we can really communicate effectively with the public at large. If eminent scientists cannot really get to grips with technical issues that are outside their own particular scientific sphere, can we really expect the public, without any scientific understanding at all, really to come to grips with the technical issues? I would agree with Mr. Saltsman that we can put across the major issues - the benefits and the problems - but I do not think that we can expect them to come to terms with the real technical issues. I think it is difficult enough for those of us who have to try to do it as part of our livelihood.

Mills : I would like to come back on this business of public acceptability. Perhaps we in Ontario Hydro have really suffered very little with regard to the nuclear issue as compared to many of the large private utilities in the U.S.A. We have made some attempt to increase public awareness of nuclear power. When the Pickering construction was half complete, and we had two reactor units operating as a nuclear island, the entire station was thrown open to any member of Ontario Hydro and his family. They toured the whole station including the turbine hole and the reactors under construction, the only exception being the nuclear island, to avoid any danger of contamination. I feel that this has probably done more to show that we have a reasonable system, which is put

together with care, than anything Ontario Hydro could ever do in print or by publicity. I think this philosophy of showing the public should be carried out more. If it is shown inside the system, while it is still possible, I think it is much more acceptable to them.

Nichols : I would like to take the matter of communications one stage further. I believe, Dr. Hahn, that you have a few points on this in relation to the difficulty of one man speaking to another if they have different backgrounds. I will take a point from the floor first though.

Dr. C.F. Old, AERE, Harwell, U.K. : I would like to offer a piece of information which surprised me when I first read it and which is particularly germane to the points which Prof. Averbach and Dr. Adams raised. A survey was done, the results of which were published in " New Society" and recently also in the House Journal of the UKAEA. Although it addressed the topic of nuclear power, in fact it dealt on a much more fundamental basis with the credibility of engineers which Prof. Averbach mentioned. A question was asked of the total sample, which was over a thousand people spread throughout the population : "Whom would you believe if you were reassured as to the safety of a nuclear installation?" I remember the figures roughly and something like 3 to 5% percent of the sample said that they would actually believe the news media. Around 5 to 7% said that they would believe politicians. Approximately 17 - 20% would believe the manufacturers of the installation and something in excess of 60% would believe the qualified engineers and scientists in the field concerned. This surprised me, and suggested that our standing may not be as low as we might suppose.

Nichols : It might also suggest that the public is, as we have said, a very wise public.

Would you like to go ahead Dr. Hahn?

(At this point Dr. Nichols left the meeting and Dr. Knott took the chair.)

Hahn : I wonder if it may pay to examine for a moment why there are differences of opinion. I think that in some cases these are honest differences of interpretation, but there are other cases, I think, where the differences of opinion derive from differences in the interests of the parties involved. I think that, in this general problem of science and politics, we are dealing with many sub-cultures which have really quite different interests, quite different values, quite different jargons, we have already mentioned different time scales, and quite different scientific IQ's, by which I mean the ability to discriminate between two different scientific arguments.

I would take the public to be one sub-culture, and industry, technology, management and invested capital together form another. It seems to me that the basic interests of the public and of industry, say, are not quite the same. I think industry is looking for a guaranteed return on investment whereas the public is looking for the highest guaranteed quality of life, and there are differences. Industry must protect its competitive position. The public does not have this particular interest. I see science and research and development as being another sub-culture, and I think that within specialized fields people can have the scientific IQ to enable them to talk with one another. Outside these fields dialogue is very difficult, and I do not know that a great deal can be done about that. Government, the regulatory boards and agencies, and the standards associations constitute a further culture with somewhat different interests. I think that the Government interest in the last few decades has been primarily in terms of supporting the economy and preventing unemployment, and while they talk about safety and environment, when employment and the economy are threatened, these other things lose importance, to some extent with public approval.

Thus, it seems to me that there are some basic differences and conflicts of interest : if, for example, you present the different cultures with the proposition that you would like to make, say, a pressure vessel more fracture resistant, you will receive a range of responses. The science and research and development culture would say : "Yes, that is a great idea", and they would present a bill for millions of dollars. (The world wide investment in fracture mechanics, for example, must be at least 100-million dollars, so that there is a tremendous amount of money involved in technology, in science and in changing things.) The public would say : "Yes, but please do not pass on the cost to us or raise taxes". Industry might say : "No, it would hurt our sales and our competitive position", and I think that is a perfectly valid viewpoint. Government may take the position : "We see both sides, so let us move slowly, or let us do nothing at all." This exemplifies the fundamental conflicts of interest, which, I think, stand in the way of more rapid solutions to some of our problems.

It seems to me that it is first of all a task for the political system to reconcile these cultures and to try to bring them together, and I see several necessary elements in this process. A possible solution must be found that is not totally destructive of existing investments, be they emotional or capital. Leadership will be needed, and it is not clear whence the best leadership can come - science, industry or government - and frequently a lot of money will be required which may be a stumbling block. Regarding possible innovations, at our private research institute we have found that one mechanism for bringing together money to solve research problems is to try to develop industrial associations, either formal or informal, to bring many companies with a common problem together, so that each may provide some funding and make it possible to tackle certain problems. In the past, some of these associations have not been legal, for antitrust reasons. This is a situation where other interests and political considerations stand in the way of pooling research money. Certainly a phenomenon of the last three decades has been the tremendous growth of government involvement in and support of research.

Another solution that I would like to raise in connection with failures and safety is the possibility that industry and government might consider purchasing hardware, aeroplanes or nuclear plants, not for delivery on a certain date and then to be taken over, but for the whole lifetime. You would purchase the ability to generate electricity, say, for 20 years, and then if there were an outage, if the plant were to fail, the vendor would have to come in and bear the expenses; consequently he would have the incentive to worry about these things more, and perhaps spend more on research and development. I think there is a difficulty there, in that Government, at least in the United States, restricts the way the cost of power is carried over to the consumer, and this makes extra expenditure more difficult. It would cost more to buy a plant on that basis initially, and with the cost of capital, and the way these costs are passed on, it is difficult, for reasons which are not too clear to me, for the utilities to operate in this way. I think the government is moving in that direction in, for example, the purchase of aeroplanes,

where it buys a unit on the clear understanding that it last for the expected lifetime, and here again, perhaps changes of laws are needed to facilitate different ways of doing business.

Knott : I think that you have highlighted two problems there, one being that of communication and the other the weighing together of conflicts of interest. Sir Alan Cottrell, speaking from the British viewpoint, clearly passes the buck to the Ministers for balancing all these various factors. Here is where the communications problem can enter, because the Minister himself, the decision maker, may have to become familiar with the technical arguments. Sir Alan says that he does not. He has to trust his advisors and they have to put it into language that he can understand. That is in terms like : "If you build it this way, there is a real chance of the thing breaking; that way, the chance no longer exists." The British system then, appears to be the technical advisor going to the Minister and the Minister weighing a technical argument, together with all the other public arguments. Perhaps I could ask Mr. Saltsman how it is done in Canada? Then perhaps one of you gentlemen will tell us about the American method of decision making.

Saltsman : I think that it is one of the great mysteries of Canadian politics, exactly how people arrive at these decisions. I think mostly by accident. I think one of the severe restrictions on public policy in this country is that nobody has sat down and tried to formulate long term plans in a conscious way, and we tend to live on crisis politics, simply responding to crises as they arise. I think, in that sense, North American experience has been considerably different from European experience, and mostly because we could allow ourselves the luxury not to plan. The resources seemed to be so vast, that we could squander, we could be wasteful, we could move from crisis to crisis, without really being in any serious trouble. When the decision was taken it was usually by government. We do have a strong form of government. Decision is usually taken by the executive, again in response to public opinion, and usually after the establishment of a Royal Commission to tell the government what they wanted to hear in the first place, but did not have the courage to say themselves.

I want, if I may be permitted this indulgence here, to talk about leasing, or rather the letting arrangement that Dr. Hahn mentioned. We do not have that problem, and, at the risk of preaching to our American cousins, I would point out that that is because the utilities are under public ownership in Canada. We are the boss and the user and everything else at the same time, and the kind of a conflict you describe does not arise. You also raised something else that was extremely interesting to me, in asking where the leadership comes from. It can come from any source, but I think one of the most effective examples of leadership in our time has been not an *either or*, in other words the politician or the scientist, but rather what we saw in the early years of the Kennedy regime in the United States. Here was a very articulate politician, whose credibility was, I think, bolstered very very considerably by the fact that he had surrounded himself with well-known and highly regarded academics. I think, getting back to what you were saying about public opinion polls, you will find the same thing about academics generally, that, while people may make a target of academics, whenever a political scientist polls the public to find out how people feel about professors and how credible professors are, they usually come out with a high degree of credibility. The cartoonists may have a field day depicting the eggheads advising the politicians, but, in fact, experience has shown that that combination of a sensitive politician with expertise from the intellectual and the university communities is really the kind of leadership that the public will respect.

Knott : This is done then, by setting up a Royal Commission that has these people on it and acts as a single scientific advisor?

Saltsman : Yes, this is true in Canada because of the different political system, and I think it is true in Britain too, as ours is very much like the British system. In America, of course, the executive can directly take upon itself advisors. They do not have to stay within the legislative process in order to pick advisors, they can select expertise from outside. In our system, that is a little more difficult to do, and whenever it has been attempted, all kinds of terrible things have happened, as with Walter Gordon's budget a few years ago. Therefore, we tend to use Royal Commissions, Select Committees, and we tend to pick generally very good people. Two of the references I had today were of such groups.

Averbach : We do not have Royal Commissions but we do have Congressional Committees which serve quite the same functions. It is interesting to note that, until very recently, Congressional Committees had no scientific staff at all to advise them. Scientific and technical questions were frequently not answered or turned over to the National Academy of Science for advice. I have testified before some of these Congressional Committees and I am mystified as to how a decision is ever reached. A wide range of opinions is usually presented, with some very technical, and others not technical at all. Someone in the backroom eventually sorts it all out, and a report is eventually published. This is a situation where we have failed to help the public to understand the problem, or to help our Congress and our Executive to arrive at procedures to assist them in scientific matters.

N.A. Sinclair, IBM, U.S.A. : First a point on leasing, the possibility of which you mentioned. IBM, as you may know, do lease their equipment, and, largely because of that, they have set up a whole division to handle product assurance, one aspect of its activities being the use of physical models to predict lifetime.

Before going to IBM I was a nuclear specialist, and I engaged in many debates about nuclear power with people that worked in the development of it as scientists. I saw the fallibility of inspection techniques, where the system may easily break down because of the human element. It has been known that, when the lunch whistle blew, an inspector has wiped off the magnetic particle inspection indications and gone to lunch. In other words we get back to human frailty. In teaching these inspectors I dismissed three students for cheating because I upheld a puritan standard that said cheats are not allowed in the inspection team. However, that had to be reconciled with the general liberalism of the organisation. The plant psychologist of this nuclear agency for which I worked said that we could not do that; everyone cheats because he is motivated to succeed. Thus we have contradicting values in that the drive for success may induce the neglect of an obvious crack in a weld, regardless of the rigour of the inspection techniques or the qualifications of the inspectors. Therefore, it becomes a matter of probability as to whether failure of a plant or a nuclear incident occurs.

Turning to political issues, I write to Jimmy Carter and ask what explanation he has ready for the inevitable nuclear accident. I think this

thought must be in our minds throughout the nuclear safety debate. The former chief of the Atomic Energy Agency made a statement to the effect that the public should be prepared for the eventual nuclear accident. There is another point of view that says that no politician is willing to accept a probability of failure; I find these somewhat irreconcilable. The question of the public, which thinks in absolute terms, being able to comprehend the concept of the probability of failure must also be addressed. Is the general level of education such that the public is able to think as a scientist does, in terms of probability of failure?

I would like to make another comment on the nuclear debate. I saw a television programme in the States on the nuclear question in which the anti-nuclears put forward their fifteen best points, and the pro-nuclears theirs. There was no point of contact between the groups, and I found that format extremely destructive, and I feel that we should pay attention to this point when we consider such questions. A more positive approach may be found in Futures magazine, or in social modelling techniques, where statistical concepts such as decision theory can be used in an attempt to weight and evaluate all the factors involved and their cross interactions. It seems to me that the credibility of engineers is a very tenuous quality. I have knowledge of more than one occasion when an engineer has been threatened with being released or fired if he should speak up against the best interests of corporate policy. Public awareness of this situation will inevitably undermine the credibility of the scientist and engineer.

Knott : I will just hold this point for a moment, before we look at whether it is possible to educate the general public to accepting a failure probability. Dr. Reid, do you want to say something first?

Reid : It may be exactly the same point, but I feel that one of the by-products of failures is that they provide a tremendous stimulus to either re-design or re-invest, and it is important to capitalize on this. Yet, as Mr. Saltsman pointed out, there is an opposing tendency, and that is the quite spontaneous tendency to extreme confidentiality, a shyness about discussing these things, and it is here that very big, often fatal failures, are important, because they force the disclosure of information and there often has to be a public court of inquiry. This, in turn, publishes a full report, which is normally available to the public, al-although even that has its problems, as we saw in Britain within the last couple of years over the big chemical factory explosion at Flixborough. There was a court of inquiry, but there was certainly a hint in the media after this court of inquiry reported that full justice perhaps had not been done. Really it was a somewhat inconclusive matter, and certainly some people had gone away from the inquiry feeling that their advice had not been taken into account. The question I would like to pose is : What is the optimum way to run a court of inquiry? There is a lot of international experience here and there may be people present who have some experience of serving on these courts of inquiry. What is the best way to let all the experts have their say, and then, when the experts tend to neutralize one another, what do you do about it? Do you have a jury system, and if so what kind of a jury? These are the questions to which I would like to draw some response.

Knott : That gives us another question to answer now.

Old : I do not want to offer an answer to Dr. Reid's question, but I would like to raise a point related directly to what he said. It often seems to me that there is a scale factor in the interaction of fracture or failure politics and society. He mentioned the accident at Flixborough, which provoked an enormous inquiry. It must have used up an enormous amount of time and resources. There is a point which I am not clear about, and which I would like to put to Mr. Saltsman as a politician, because he can perhaps give an explanation. *Which?*, the consumer magazine in the U.K., quoted that there were something like 26 people killed last year by the failure of electric blankets. I cannot understand why failures which cost lives at a steady slow rate attract no attention whatsoever, whereas the single isolated incident, for example Flixborough or the aeroplane accident in Tenerife, will attract an enormous amount of attention. Can you perhaps help me to understand why the one is politically acceptable and the other is not.

Knott : I think, therefore, that we have three points. One is whether you think that the general public can be educated into realizing that engineers, when they design things, may have a failure probability; perhaps a one in ten to the tenth power chance of failing. The second point is the technical one of general information on how a court of inquiry should be run, and the third is why it is that the small scale accidents, that occur all the time, receive far less publicity than the very big catastrophic events. Perhaps you would like to take the public reaction one first of all Mr. Saltsman.

Saltsman : Whenever you are faced with this kind of a problem, ask yourself how you would put it in a headline, if you were an editor. For instance, I see no difficulty in producing an eyecatching headline for the electric blanket story. Therefore, I feel that, if you get electrocuted in bed, that is news, and not only that, you can possibly sue somebody for a lot of money, and I come to the conclusion that the consumer magazine does not know what it is talking about. If what the magazine said could be supported by fact, it would have made a great story and would indeed have received publicity.

Old : That is actually a statistic.

Saltsman : Statistics are curious things. It is a question of how they are obtained and what kind of information is used. It may be their statistic, but it does not mean that it is a valid statistic or a provable statistic. As a scientist, you immediately assume that because it is a statistic and somebody said it, it is true. I am a politician. I do not make that kind of decision. It is a verifiable statistic, but I would like to see how it was determined.

Old : They count the number of bodies!

Saltsman : You know a person could have died for all kinds of other reasons.

Averbach : I think the point is that there is an individual remedy, and it does not mean that the victim has no recourse. The accidents like this do not create an outcry in that they occur over a long period. When a disaster occurs which involves a lot of people, it gets a lot of attention and is subject to official inquiry. I think both types of event do receive attention, but in different ways.

Knott : To come back to the point on snappy headlines, I suppose a headline which said : "Engineers Expect There to be a Chance of Failure in

such and such a Reactor", would attract the public interest.

Saltsman : "Engineers Expect.." does not show up as a headline. "Engineer Charges Failure of Nuclear Reactor", "Engineer Warns of Dire Consequences", is the required form of words : "may be", "perhaps", "on the other hand", "later", do not get into headlines.

Knott : On the concept of deliberate design for a chance of failure, do you think the public will accept that or not?

Saltsman : Yes, I think so. At the risk of being considered naive by harping on this, I think that if people are basically honest in what they say, or at least are perceived to be honest, because it is pretty hard to test honesty, then they will be listened to. Let me give you an example of what is happening here in Canada. At the moment we have what is supposed to be rather a scandal with our police. The minister is accused of almost abetting a break in. He rose in the House and straightforwardly stated the facts, although some of the facts were somewhat damaging to him and the opposition tried to make a great issue. This ended the affair because he appeared to be honest. I think Nixon would have been forgiven if he had publicly admitted his involvement in Watergate. The classic example is the Profumo case in Great Britain. John Profumo had to leave the House, not because of his liason with a beautiful girl, or because her reputation was somewhat questionable, but because he lied to the House of Commons when he was asked about it. There are certainly risks attached to being honest : you know that when you are honest, everybody is going to attack you as much as possible, but you can be sure that this will only last so long. But, if you are not honest, you will be hounded indefinitely until finally the truth is dragged out. This is a terrible situation. Thus, I think that, even with science as with politics, if you lay all the facts on the table, the good and the bad, and it is perceived that you have, that is probably the best policy.

Mills : I would like to add a comment on public acceptability. I ask you to picture a steel box with four wheels, containing up to 20 gallons of very very inflammable liquid and a battery and a means to produce sparks. I pump the inflammable fluid into a cylinder, compress it with air, and spark it. Now, if anyone were to ask you to sit inside that steel box, your first reaction would be : "No, I would be crazy." Yet General Motors sell hundreds of thousands of these steel boxes every year, and because they have been around for a long time, they are acceptable to the public. I think that, once nuclear reactors have been around for about 75 years, they will achieve the same public acceptability. Further, if you consider acceptable design lives, the public buys something from General Motors which probably has a design life of about 1,500 hours. For any sort of nuclear installation or major generating facility the minimum design life is 100,000 hours. I think that public acceptability is really a conditioning process dependent upon how long these things have been around. There are too many people who still remember nuclear meltdown of an American test reactor.

Questioner : This is a general background comment. During the course of the Conference, I have noticed that, quite often, the one thing that does not come out, and it has been commented on, is the understanding of probability and risk. We should understand this better than the majority of the public and we do not. It shows up in our work. We draw a straight line through a series of points and half the audience will say : "Yes, a straight line". This, I think, carries over to public acceptability also. I like the analogy of the steel box and the flammable substance. The probability of being injured in it is tremendously high, but the public is fairly aware of the risk that they are taking. However, when we put a number on the risk of a nuclear reactor or an oil pipeline or a gas pipeline, failing, the number really does not mean anything to them, or to us, because we really have no reference with which to compare it. Thus, one aspect of public acceptability, when it comes to fracture, say, is simply an inability on the part of most of us to understand what risk and probability really is.

Knott : I think that there is a slight problem, particularly in Britain, that the only really large number attached to chance is something like the chance of winning the football pools, where a large number of people bet and one wins. Unfortunately, there is always the feeling that "yes, it is a very large number, but someone is going to win", and if that sort of thinking carries across to failures, then there is always the thought that the number is very large but one is going to break. I think it might be a real task to get across large numbers in a really comprehensible way.

Saltsman : An interesting thought occurred to me as you were speaking, that you might be able to write a political formula for acceptability and it would read something like this : "Acceptability = familiarity + alternatives". Familiarity is an important thing, and we live with all kinds of dangers. I was thinking of, say, a loaded jumbo jet flying over a major city and the destruction that would be caused if that jet crashed, and I was thinking of alternatives. We have fossil fuels, and we have gas and oil and, while their prices do not reach the point which is unacceptable, as long as you have those alternatives, people will not want to take the risks associated with nuclear energy. As those alternatives start to run out, or become increasingly expensive, then the whole formula changes. The figures in the formula get changed and you are in a different position. I want to say something else about the question raised about the risk of the people who operate the system. There is an advantage, I think, to some of the publicly owned facilities in terms of risk, for this reason. I think that it brings together a different breed of people, the bureaucracy. There are many things wrong with a bureaucrat. You can be very critical about his lack of imagination and all the rest of it, but as Weber once wrote about the bureaucrat, he is honest, he is generally reliable and the lack of imagination turns out to be an asset. He is not climbing all the time, as he might be doing in private industry work, he is getting ahead differently. I think that this is probably one of the arguments for public ownership of some of these chancy and dicey things, because in fact you need that habit of mind, that bureaucratic attention to little tiny details, and to making sure that everything gets checked off and all appears on your report.

Knott : I think at this stage I would like to ask Professor Yokobori to give a short description of the implications of the failure of a Japanese oil tank.

Yokobori : The fracture of a very large oil tank occurred in Japan in 1974. The tank had an inner diameter of about 52m, and height of 23.7m. Some of the audience will know of this accident. It involved spillage from the fractured part of the tank of 7,500-9,500 kiloliters of heavy oil into an inland sea. This caused great damage to the fishing industry of the two prefectures on the coast of the inland sea. I was a member of the government inspection committee. At the conclusion of its inspection,

several possible causes of the failure were suggested by the Committee. One was the digging out of part of the foundations when constructing a staircase along the side of the tank, which led to local subsidence. Another was that compacting was not properly carried out in view of the state of the ground on which the tank was built. In addition, some of the Committee considered some defects in welding the side plate and the bottom plate. The crack initiation path was traced back with some difficulty, as the surface of the fractured part was so heavily covered by a layer of oxidized scale or rust. When we removed these oxidized layers, we found a characteristic intergranular fracture surface. Naturally, we could not observe the exact fracture surface, but only the surface exposed after removal of the oxide film.

As can be seen from this example, a large scale fracture accident throws up problems requiring an inter-engineering, interdisciplinary approach and must be considered in terms of the interaction between engineering, economy and politics. I feel that not only design engineers but all other engineers and even the public should be educated in, at least, the fundamentals of fracture. On the other hand, a standing investigation system for such a large scale fracture accident may be necessary in order to ensure the correct interdisciplinary basis.

Knott : Before the session comes to a close, I would like to ask Professor Averbach to make general comments on the field, and particularly perhaps if he could say something about American Courts of Inquiry that might help Dr. Reid on his question earlier.

Averbach : The American Court of Inquiry is a traditional system, in that the matter is usually settled in a court of law. The operation of these courts is interesting in that no witness is allowed to give an opinion except an expert witness. As a result there are expert witnesses for both sides with each stating impartial opinions. A decision is eventually reached by a judge or a jury on the basis of a lay interpretation of what has been presented by the experts. Perhaps we can develop a system whereby we have special engineering courts presided over by masters who might have some technical competence and be able to call in impartial experts to advise the court.

Knott : I think that is taking responsibility, which is a good thing. I can understand the people's feelings over the particular incidents of the Flixborough report, because there there was an awful lot of work done, and the conclusion was basically that it was a patched-up job by a non-qualified engineer which led to the failure. Does anybody have burning points from the audience?

G.L. Dunlop, Chalmers University, Sweden : Dr. Mills disappointed me somewhat, because it seems that he is trying to form an acceptability in the eyes of the public; taking people on a tour of a power plant and showing them that the walls of a pressure vessel are very thick is very impressive, because who can imagine that several inches of steel can be broken by a reasonable sized force. I think we really have to do as Mr. Saltsman suggests : we have to lay all the cards on the table and be completely honest. This is exemplified by my own experience in Sweden, where there is a very large political debate concerning nuclear power generation. I work in an institute where there is a very large group of nuclear physicists, many of whom are anti-nuclear power. That is rather surprising, but it occurs because they know very little about engineering, and it is thus very important for engineers to put all the cards on the table.

Mills : We do, in fact, before any construction starts, put all the cards on the table regarding our nuclear plant by presenting a safety report to a government agency, the Atomic Energy Control Board. This is usually a report of considerable magnitude, which details all the design calculations, all the risk factors, which are put into that plant. That presentation to the Board is not necessarily a public affair, I am not too sure if and when the public is involved, but that government agency is the regulatory body for Canada. We cannot proceed with a plant constructional design before we get their approval. The purpose of the plant tours was to avoid the sort of confrontation which the U.S. Utilities have experienced with very virulent groups who want to stop nuclear power development at any cost. By trying to inform some of the public, we can perhaps turn away some of these fears.

Dunlop : I do not doubt that the plants as designed are reasonably safe, but I think that it is not just the government or a decision making body which has to be convinced of this. The public must also be convinced, and we must, therefore, in a straightforward way, make then understand the design principles and the engineering principles behind the construction. It is not sufficient to detail all the information in very thick volumes, but, we have a duty to make it much clearer, and more easily accessible to the public.

Knott : We are back to the communications problem again.

D.F. Watt, University of Windsor : I hate to see us go away congratulating ourselves on our credibility on the basis of the poll to which Dr. Old has referred. I noticed that in the list of people whom you would believe there was no category that said "none of the above". I think that if we had rephrased the questions to read : "What is the probability that this person would mislead you if his personal interests were involved?" a rather different result, and perhaps a better reflection of public opinion would have been obtained.

Questioner : I would like to reinforce Dr. Dunlop's comment that laying the books open for public scrutiny is not good enough. We have to take the information to the public, as otherwise only interest groups, frequently of preconceived opinions, will go and get it. We have to help the public to form an opinion because it has to make the decision.

Mills : The activities of a group in Ontario called the "Electronic & Electrical Manufacturers' Association" may be relevant here. Over recent months they have been putting very small ads into the business section of *The Globe and Mail* which say "When oil and gas run out, what about electricity?" and other ads to the effect that electricity is vital to the economy and is vital to various parts of the public. Recently, in the electric power hearings, that group has been accused of putting forward its point of view to the detriment of the credibility of the anti-nuclear or the anti-electrical society people, and they have objected to these tiny ads. I think that again we find ourselves in the middle. If we go out and advertise, and try to sell our product on a wide basis we are criticised, and similarly if we say nothing. It seems to be the fate of the utilities to be whipping boys for both the public and sometimes politicians.

Knott : I must now bring discussion to a close. I cannot really try to

sum up such a wide ranging conversation in any brief statement. Points have, I think, been well made, on various topics. Some possible roles for ICF are emerging from some of these discussions. That is presumably a matter for the Executive to consider. Before we finish I will ask Mr. Saltsman if he wants to say anything else.

Saltsman : Not really, except to say that I have enjoyed the discussion, I have appreciated the invitation, and I found a lot of what you had to say very helpful.

Knott : I suggest that we close with a round of thanks to the panellists, after which Professor Taplin will take the Chair for the final closing of the Conference.

Taplin : Let me record my own appreciation to the co-chairmen of these two panels on *Fracture and Society* - Ron Armstrong, Roy Nichols and John Knott - to the members of both panels and to the other participants in this venture. I have spent my time during these discussions in the control box, with the Conference Secretary, Dr. Richard Smith. As you know, the entire discussion of the two panels has been taped - using two separate systems to allow for any failures or erasures - and we shall transcribe and edit the entire discussion for publication in the Pergamon Edition of the Proceedings. I can say now that the taping was successful and I believe we can look forward to an interesting written document. Let me also say how very pleased and honoured we have all been here at Waterloo to host this Conference. It has been hard work - and I would like to mention just two of the many people who have been particularly unstinting in their efforts - Dr. Richard Smith, Conference Secretary, and Professor Roy Pick, Registration Chairman. It has also been a totally fulfilling and realizing experience and now that the Conference is over I wish to record my appreciation to all the various participants of ICF4 for permitting this to occur. Many friendships have been made and renewed here in Waterloo and we look forward to their continuance and further renewal in the next four years.

Before turning over to Professor Ben Averbach, President of ICF 1973-77, Dr. van Elst and Professor Francois would like to say something.

van Elst : I would like to make an announcement, principally to my ICFEA (ICF - European Association) Colleagues. I take great pleasure in announcing that a European Group on Fracture was founded here on the Waterloo campus last Thursday. As Chairman of this European Group on Fracture, Professor Kerkhof of the Institute of Mechanics of Solids at Freiburg, Germany was elected, as Secretary Dr. Brughofen of Delft University in the Netherlands. The objectives of this Group are very similar to those of ICF, but on a more modest continental, rather than global, scale. The Group will apply to ICF for membership, demonstrating its affiliation to ICF, with whom it seeks further co-operation and will consult in relevant matters. The European Council members will all receive a letter of invitation to their country to join the European Group on Fracture.

The Group's initial activites will involve the organization of advanced courses on fracture mechanics given by invited lecturers and the organization of colloquia or symposia on fracture, papers for which will be solicited among European research workers. It is envisaged that these will take place at least annually, and care will be taken to avoid overlap with other ICF activities or any other fracture meetings. I might remind you that the seminar organized in Italy, October 1975, and the 1st European Colloquium on Fracture in France in November 1976 were both great successes, that of the latter demonstrating the talents of Professor Francois for organizing such meetings. A second seminar with the theme *"Elastoplastic Fracture Mechanics"* is planned for the early Spring or the late Autumn of 1978, and a second European Colloquium on Fracture will take place at Imperial College in London in September 1978. The Congress is happy to see this integration of European efforts in the study of fracture at ICF4. It feels that it will certainly promote progress and dissemination of information and will stimulate research on fracture. I am sure you all will share the European feelings of content with this development.

Taplin : Now may I ask Professor Dominique Francois, Chairman of ICF5, France, 1981 to say a few words.

Francois : I feel it a great honour that the Executive of ICF has decided that the next ICF Conference should be held in France. I want to tell you that you will all be welcome in our country, and that we expect you all to come and to bring your friends to ICF5.

Averbach : At 9:00 o'clock last Monday morning we started - 5:00 o'clock on Friday afternoon we have finished. During the period we have talked about almost everything including politics and we have even spawned at least one new society. We have had a marvellous time here at Waterloo and I would like to close by thanking the Canadian Organizing Committee which has done a tremendous job in arranging and running this Conference. I would like to suggest that we give them all a standing ovation. Good-bye and good luck!

Taplin : ICF4 stands adjourned.

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