

## **Papers by Laurence Draper**

### **a) Pages 2 - 5**

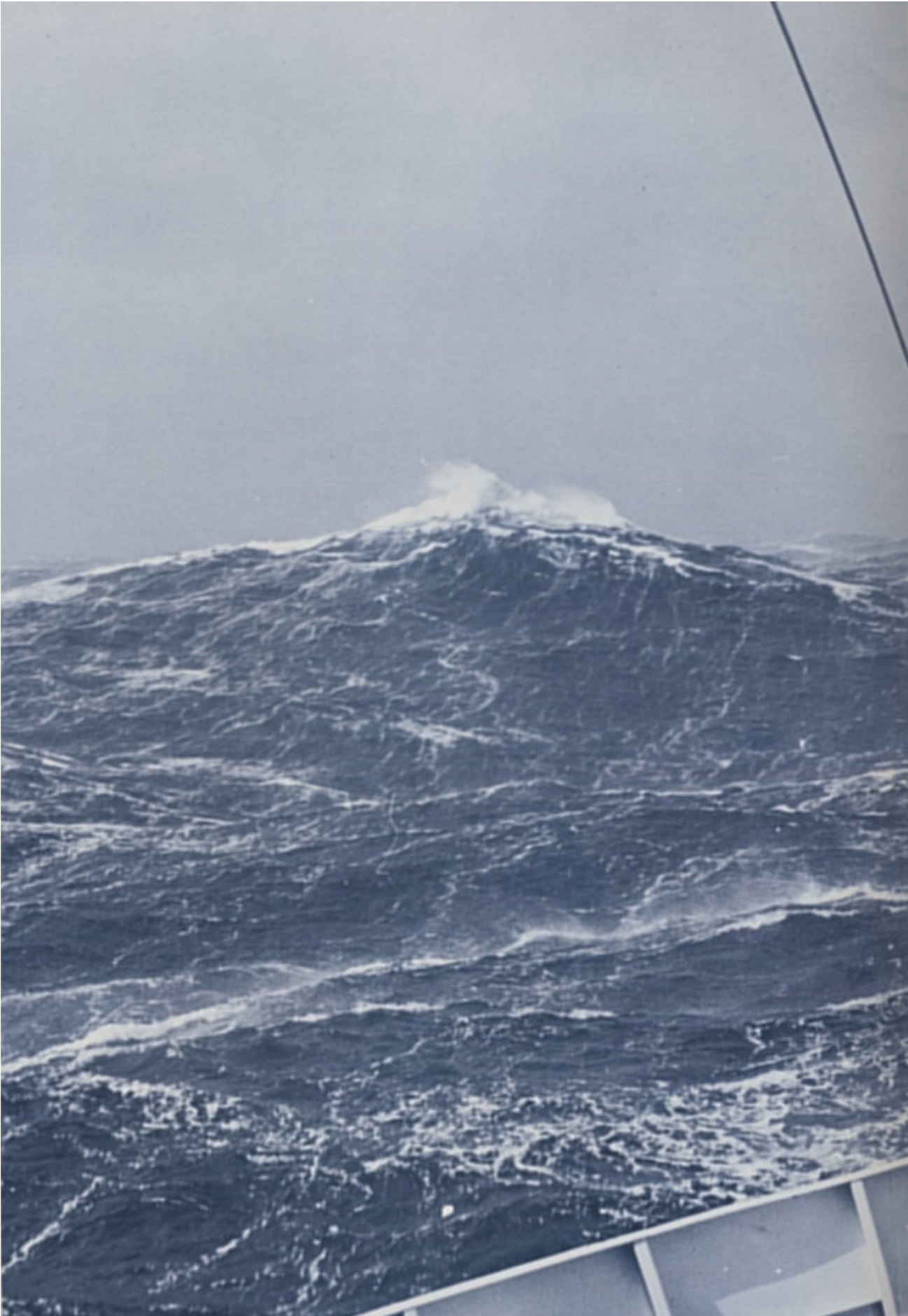
#### **'Freak' Ocean Waves**

**Oceanus (X:4), July 1964**

### **b) Pages 6 - 10**

#### **Severe Wave Conditions at Sea**

**Jnal of the Inst. of Navigation (24:3),  
July 1971**



# 'Freak' Ocean Waves

*Exceptionally high waves are not curious and unexplained quirks of Nature. Their occurrence can be calculated with an acceptable degree of precision.*

By L. DRAPER

STORIES abound of monstrous waves; every sailor has his tale of how a great wave arose from nowhere and hit his ship leaving a trail of damaged lifeboats and shattered crockery. Estimates of the heights of the highest waves which can be encountered at sea vary widely. Cornish reported a freak wave 70 feet from crest to trough seen in the North Pacific in 1921, and waves of 80 feet and possibly higher in the North Atlantic in 1923. More recently, in 1956, Captain Grant of the cargo vessel 'Junior' reported a wave estimated to be 100 feet high about 100 miles off Cape Hatteras. There must be many more reports of similar waves in the history of the seas. As early as 1826 Captain Dumont d'Urville, a French scientist and naval officer in command of an expedition, reported encountering waves 80 to 100 feet high. The poor fellow was openly ridiculed for making such an outrageous report, even though three of his colleagues supported his esti-

mate. Perhaps the most famous reliable report was that of the wave encountered by U.S.S. 'Ramapo' in the North Pacific in 1933; that wave was estimated to be 112 feet high, a monster indeed.

Although such events happen only rarely, this does not mean that their likelihood of occurrence is not predictable. There are two aspects of this problem. One concerns what happens on a sea when a large number of wave components each with its own period and height, are traveling along together at slightly different, but constant, speeds. As the components continually get into and out of step with each other they produce the groups of high waves followed by brief intervals of relatively quiet water which are characteristic of all sea waves. Every now and then, just by chance, it so happens that a large number of these components get into step at the same place and an exceptionally high wave ensues. The life of such a wave is



## Waves

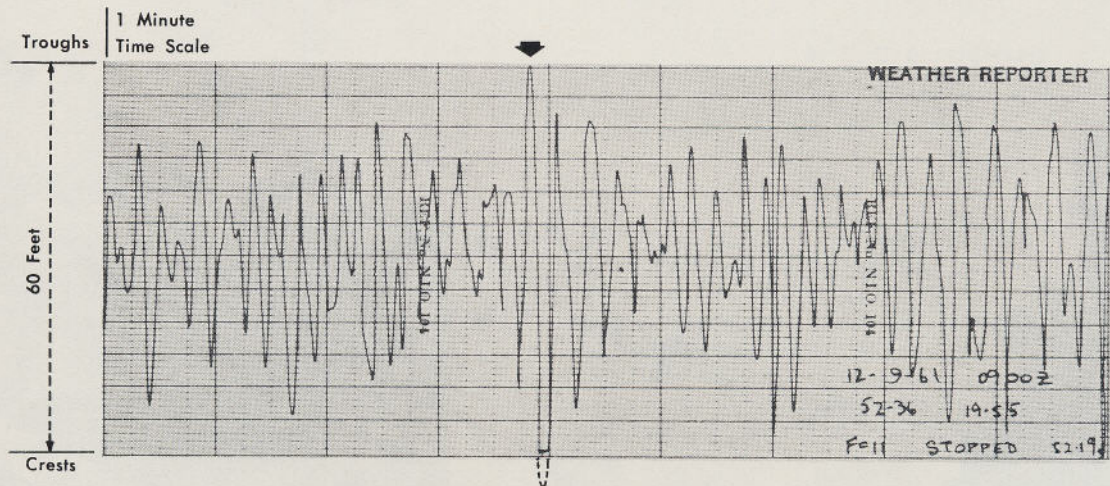
only a transient one, being not much more than a minute or two. Because each wave component is traveling at its own characteristic speed, the faster ones will escape from the others and the monster wave will die just as surely as it was born. The energy it contains belongs to its component wave trains, which still exist and travel on, taking their energy with them. Somewhere else in the storm at some other time some other wave trains will, again just by chance, coincide and produce another large wave which will have its brief moment of glory before disappearing forever into the random jumble of the sea. Although we are never likely to be able to predict just where and when an exceptionally high wave will appear, because the instrumentation problems involved are immense, the probability of occurrence of any such wave is finite and can be predicted; its calculation has the apparently contradictory title of Statistics of a Stationary Random Process. Using this theory, it has been shown that whilst one wave in 23 is over twice the height of the average wave, and one in 1,175 is over three times the average height only one in over 300,000 exceeds four times the average height.

The second aspect of the problem, also concerned with the prediction of the occurrence of exceptional waves, has a different basis. The probability of occurrence of unusual events such as severe storms, heavy rainfall, or hot summers, can be predicted by the Statistics of Rare Events. This technique has been used extensively by meteorologists in the study of natural phenomena and has proved to be a useful tool. The probability of occurrence of storms of any severity can therefore be calculated. From a series of recordings of wave conditions over a period of time such as a year, it is possible to estimate how often waves of any given size will occur by using these two methods. The longer the time over which the recordings have been made the more reliable will be the prediction.

**MR. DRAPER** is a physicist who, since 1953, has worked mainly on ocean waves at the National Institute of Oceanography in Great Britain.

It is only about thirteen years since it became possible to measure waves in the open sea from a ship with acceptable accuracy, and so provide a check on whether or not the stories of monstrous waves were to be believed. One of the British Ocean Weather Ships, operating in all weathers in the North Atlantic, has carried such a shipborne wave recorder for twelve years. As the ship is on station for about two-thirds of the time, the National Institute of Oceanography now has a long series of wave records which were taken for fifteen minutes every three hours. At first the scale of the instrument could record waves 50 feet high from crest to trough, but very soon it was found that waves higher than this were not uncommon and the scale was increased to 60 feet. This proved to be adequate for about nine years, but on September 12, 1961, 'Weather Reporter' lay close to the track of the dying hurricane Betsy, and as she made her routine recording at 0900 hours the pen dipped and touched the lower edge of the chart and then rose rapidly and "hit the stops" at the top — a wave over 60 feet high. A crest was fitted to this wave and it is estimated that the true height of the wave was not less than 67 feet from crest to trough. The period of this wave was 15 seconds, which meant that the weather ship was lifted over 60 feet in  $7\frac{1}{2}$  seconds and then dropped almost as far in the succeeding  $7\frac{1}{2}$  seconds! The probability that we actually recorded the highest wave which hit the vessel is fairly small, because the instrument is operated for only about 8% of the time. Using the first method described above one can compute that the highest wave which was felt by the weather ship during that storm was probably about 80 feet from crest to trough. At the present time the wave which 'Weather Reporter' measured is the highest one which





has ever been recorded by an instrument — conservatively estimated to be 67 feet from crest to trough.

Because the proportional area of an ocean which is occupied by vessels is incredibly small, it follows that only a minute proportion of the exceptional waves which must occur each year in an area such as the North Atlantic are ever noticed by man. It therefore seems reasonable to suppose that with only one vessel equipped with a wave recorder regularly at sea in the North Atlantic, the chance that our 67 foot wave is the highest which ever occurred is small indeed. We must by no means claim that the report from the 'Ramapo' was exaggerated.

Although one is inevitably surprised when an exceptional wave appears to rise from an apparently ordinary rough sea, and everyone who sees or feels it labels it as a freak, it is fair to say that no miracle is being witnessed; the chance of this occurring does seem to obey well established physical laws, so that the probability of occurrence of a wave of any specified height, or the probable height of the highest wave which will occur in any specified length of time, can be calculated with an acceptable degree of precision. After all, the latter problem is raised by every good engineer who hopes to build a structure in the sea, and oceanographers are expected to provide the answer!

## Severe Wave Conditions at Sea

Laurence Draper

1. INTRODUCTION. Perhaps the most surprising thing about sea waves is that they come in a vast range of shapes and sizes. The casual observer on a ship in waters not exposed to an ocean, for example the southern North Sea, may rightly think that the waves he can see have all been generated

by the same wind blowing over some particular stretch of water for a fixed length of time. It then seems almost logical to deduce that all the waves ought to be of the same height, length and shape. Unfortunately this is not the case, the energy of sea waves is locked in wave components spread over a wide range of wave periods, each of which travels at a speed dictated by its period. Considering the very simple case of a sea with only two wave components, when a crest of one component overtakes the other, a higher wave will ensue. As a result of this process, high waves come in groups; during the time in which the components gradually get into phase the wave height builds up giving a train of waves of increasing height, which then decreases as the faster component travels away, until when they are out of phase the sea is temporarily fairly calm. This is the reason why it is commonly said that every seventh wave is the highest, although whether it is every fourth or every fourteenth depends on the relative speeds of the components.

2. THE HEIGHT OF WAVES. In the sea there are not two components but an infinite number, and their continual interplay makes it difficult to ascribe meaningful numbers to wave height. However, there is one parameter, named significant wave height, and defined as the average height of the highest one-third of all the waves, which is a useful one to have. It is a meaningful parameter to the theoreticians, and it has the additional virtue that on average it is very close to the value which an experienced seaman would give if asked to estimate the wave height. It has been shown by both theory and measurement that if the sea is watched for the duration of about 60 waves, typically about 10 minutes, the height of the highest wave which appears is about 1.60 times the significant height and if the sea is watched for 3 hours the height of the highest individual wave will be about twice that of the significant height. The same theory, due largely to Cartwright and Longuet-Higgins, tells us that whilst one wave in 23 is twice the height of the average wave, one in 1175 exceeds it by three times and only one wave in over 300,000 exceeds four times the average height (300,000 waves is equivalent to about once a month at sea). It is perhaps important to stress that this refers to the average height, which is about 0.63 times the significant height.

These improbable events are, of course, very rarely experienced, and almost never recorded by an instrument. However, there is in existence one record (Fig. 1), taken by the Commissioners of Irish Lights with a Shipborne Wave Recorder on *Daunt* light-vessel off Cork, showing a wave 4.1 times the average height. According to theory, this is likely to occur only once in about 700,000 waves, or one record in about 10,000. The actual height of this wave was about 42 feet, at a time when the significant height was 16.5 feet.

An important characteristic of individual waves is their lack of longevity; once again, it is simply because the really big wave is the result of a chance superposition of many components overtaking each other at one point in space and time. Before long, perhaps two or three wave

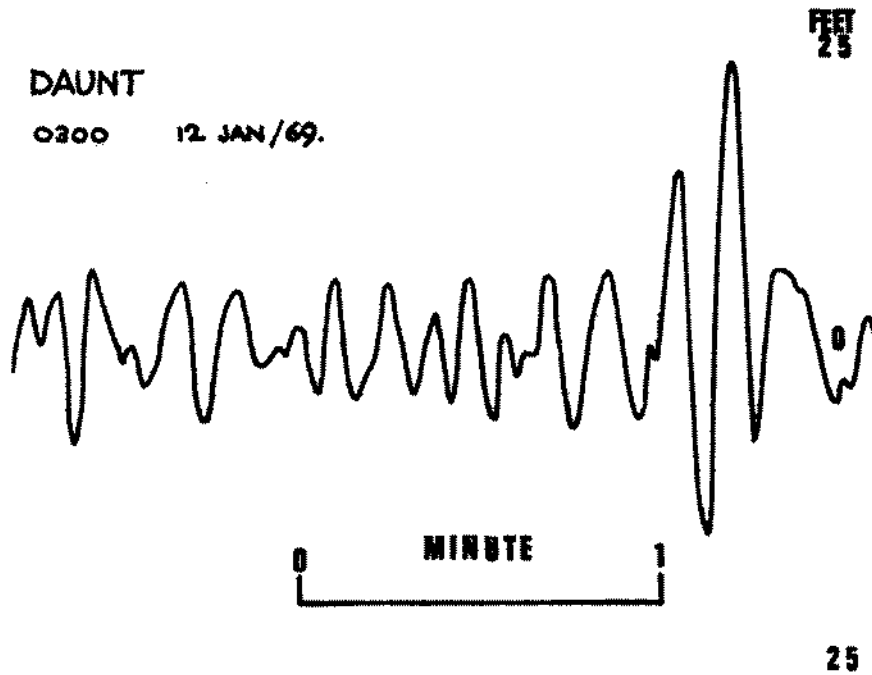


FIG. 1. Wave recorder trace taken on light-vessel *Daunt* off Cork

periods and over a distance of less than a mile, the height of any large individual wave has decreased and it is no longer distinguishable from any other wave.

It might be of interest to mention some of the large storm waves which have been reported. In 1826 Captain Dumont D'Urville, a French scientist and naval officer in command of an expedition, reported meeting waves 80 to 100 feet high, but he and three colleagues who supported him were openly ridiculed. There is an interesting report by Captain (later Admiral) Robert Fitz-Roy in the *Narrative of the Surveying Voyages of H.M.S. Adventure and Beagle, 1826-36*, London, 1839, Appendix to vol. II, p. 297.

'In H.M.S. *Thetis*, during an unusually heavy gale of wind in the Atlantic, not far from the Bay of Biscay, while between two waves, her storm try-sails were totally becalmed, the crest of each wave being above the level of the centre of her main-yard, when she was upright between the two seas. Her main-yard was sixty feet from the water-line. I was standing near her taffrail, holding by a rope. I never saw such seas before, and have never seen any equal to them since, either off Cape Horn or the Cape of Good Hope.'

This is an objective and unemotional report by an experienced sailor, and if there were several waves higher than 60 feet then the highest of all would have been appreciably higher than this. The 112 foot wave experienced by the U.S.S. *Ramapo* in the North Pacific in 1933 still seems



to be the highest reliably observed wave. In the last few years perhaps the highest claimed is the 90–100 foot wave which hit a drilling rig off Vancouver Island about 3 years ago. There is a Russian stereophotograph of the Antarctic sea surface in which the vertical distance between the highest and lowest points appears to be 82 feet, although if these two points are not on the line of travel of the wave energy it may not necessarily be justified to refer to this as a wave height.

An interesting point is that there is just as much likelihood of an unusual trough occurring as there is of an unusual crest, but of course these are not as likely to be seen unless an unfortunate vessel happens to fall into one. Nevertheless, such things have been experienced, for example, the report by the Master of the *Edinburgh Castle*, Commodore W. S. Byles, R.D., that in 1964 his vessel 'charged, as it were, into a hole in the ocean at an angle of 30° or more'. This report prompted Commander I. R. Johnston, R.N. (retd.), to recount his startling experience in the cruiser *Birmingham* during the Second World War when his vessel fell into a similar hole. The interesting thing is that, to the author's knowledge, such holes have only been reported off South Africa; there seems to be no obvious explanation for such a geographical preference, as these phenomena ought to occur at any place if waves are present.

3. HIGH WAVES IN BRITISH WATERS. Out in north-eastern parts of the open North Atlantic, the highest wave likely to be experienced each year at any location will be about 70 or 80 feet in height, and even a few miles off Land's End there will probably be a wave of over 50 feet in height almost every year. In the north-eastern Irish Sea, the eastern end of the English Channel and the southern North Sea, the highest wave each year at any open-water point is likely to be in excess of 30 feet.

As one goes northwards in the North Sea, extreme wave conditions become more severe. Structures such as those which are being operated by the hydro-carbon companies are designed to survive, for example, the 50-year wave. At places where waves have been recorded, such as Smith's Knoll, this can be estimated in two ways. One is to extrapolate the measured wave data, and this yielded an estimate of 56 feet as the height of the highest wave occurring in 50 years. The second method is to use the estimates of extreme wind speeds made by H. C. Shellard of the Meteorological Office and to apply these to a wave forecasting technique, and if one does this with the National Institute of Oceanography's technique, one ends with a figure of 53 feet as the height of the highest wave likely to be exceeded once in 50 years. The apparent agreement is better than one can expect if one considers the errors at play in both methods. In the extreme north of the North Sea conditions are approaching those of the North Atlantic. In its first winter, 1969/70, a Shipborne Wave Recorder on the Norwegian rescue and weather ship *Famita*, 160 miles east of Peterhead, recorded a wave 61 feet high, and the estimated height of the highest wave in the storm was 76 feet. More recently, in the storm of 18–21 October 1970, during which time the wind was mainly from

between west and north, the highest waves seemed to have been reported from the more easterly areas of the sea, and there were several visual observations of waves of over 70 feet in height, although the highest wave actually recorded by *Famita* in the storm was only 51 feet high.

Over the last quarter century the understanding of sea waves has improved tremendously, theory has helped us understand the processes and factors at play, and measurements have enabled us to determine with a fair degree of accuracy the sizes of the waves. It is of interest that far from ridiculing the old sailors' stories about enormous waves, modern research has confirmed that such monsters can occur, and that wave heights can exceed by an appreciable amount the maximum values which have been accepted in responsible circles.

4. ACKNOWLEDGMENT. I am indebted to Miss Margaret Deacon for bringing to my attention the report of Captain Fitz-Roy.

#### REFERENCE

Byles, W. S. (1965). The one from nowhere, *British and Commonwealth Review*, Feb. (This article is quoted in *The Marine Observer*, 35, 210, October 1965, together with the comments from Commander I. R. Johnston, R.N. (retd.).)