THIRD QUARTERLY PROGRESS REPORT
PRODUCTION ENGINEERING MEASURE

CR-(XM-45)/U
QUARTZ CRYSTAL UNITS

HIGH SHOCK AND VIBRATION
RESISTANT, LOW FREQUENCY

DA-36-039-SC-86719

Period Covered By Report:

1 December 1962 through 28 February 1963

Placed By:

U.S. ARMY ELECTRONICS MATERIEL AGENCY

225 South 18th Street

PHILADELPHIA 3, PENNSYLVANIA

Contractor:

BLILEY ELECTRIC COMPANY

ERIE, PENNSYLVANIA

Unclassified Report

PRODUCTION ENGINEERING MEASURE

QUARTZ CRYSTAL UNITS
CR-(XM-45)/U
(High Shock and Vibration Resistant, Low Frequency)

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Objective of the Study:

To accomplish the Production Engineering Measure (PEM) objectives which are listed by Signal Corps Industrial Preparedness Procurement Requirements No. 15 (SCIPPR #15) as they apply to quartz crystal units type CR-(XM-45)/U, governed by Signal Corps Technical Requirement SCS-121.

Signal Corps Contract Number: DA-36-039-SC-86719
Order Number: 19041-PP-62-81-81

Applicable Signal Corps Specifications:
1. Units: SCS-121
2. Project: SCIPPR #15

Report Prepared By:

J.M. Wolfskill
A.R. Krespan
/Robert Mouck

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ABSTRACT:

The CR-(XM-45)/U crystal units are to be similar to standard CR-42A/U units except that the new units must withstand much more severe vibration and must also hold much tighter frequency stability over the +70°C to +80°C operating temperature range (OTR.) This report presents evaluation data from the second group of experimental units prepared for this project.

The units of this second group did not meet the specified capacitance requirements and they did not hold the required frequency stability over the OTR. Despite these deficiencies, they gave indications that the new experimental design -- which uses special, double-rotated X cut resonators mounted in Bliley's ceramic-frame holders -- can be refined to meet the CR-(XM-45)/U requirements, provided an increase of 3.5 uuf is made in the specified capacitance values.

Attention is now concentrated on improving the temperature characteristics of the new resonators. Increases in the second rotation angle have made no significant changes in peaking points but there are indications that improved drift over the OTR can be obtained by proper placement of the support wires on the crystals. Investigations into this, as well as into the effects of various combinations of plate dimensions have already been started.

PURPOSE:

The purpose of this project is to accomplish the objectives of Signal Corps Industrial Preparedness Procurement Requirements No. 15, (SCIPPR # 15), as they relate to ruggedized low frequency quartz crystal units type CR-(XM-45)/U.

The purpose of this report is to record the progress which has been made during the third quarterly interval of the project. This includes the time from December 1, 1962 through February 28, 1963.

NARRATIVE AND DATA:

The CR-(XM-45)/U crystal units with which this project is concerned are in the 90 kc to 200 kc frequency range. They use HC-13/U holders, operate over the +70°C to +80°C temperature range, and are similar to standard CR-42A/U units with only two major exceptions:

1. The CR-(XM-45)/U units must withstand up to 2000 cps vibration at 15g acceleration, while the standard CR-42A/U units are required to withstand only up to 55 pcs at the low acceleration produced by 0.015" amplitude excursion.

2. The CR-(XM-45)/U units are required to hold frequency stability of at least 1 part in 10^6 per degree over the +70°C to +80°C operating temperature range, while the standard CR-42A/U's are required to hold only ±0.002% stability over this same range.

These new requirements are so far beyond those of the standard units that neither the crystal mounting arrangement nor the conventional +5°X-cut resonators of the standard CR-42A/U's could be adapted for use in the new units. Therefore, despite their apparent similarity to the CR-42A/U units, the new CR-(XM-45)/U units must be distinctly different in internal design and construction.

The two basic areas in which new developments are required are, of course, the mounting arrangement and the crystal resonators. Not only must each of these be capable of meeting the stringent new demands but also, in combination, they have to achieve the same performance capabilities which were set up to govern the standard, non-ruggedized units. In short, the new CR-(XM-45)/U units are required to do everything the standard units do plus also providing greatly-improved ability to withstand severe vibrational disturbances and providing better temperature-frequency stability.

It was known that a mounting arrangement which could serve the new units would have to provide symmetry and freedom from structural resonances during vibration and it was decided to adapt Bliley's unique ceramic-frame mounting arrangement to the CR-(XM-45)/U units. This mounting system utilizes a rigid, rectangular ceramic frame, which completely encircles the edges of the crystal resonator, as the main support structure. "Harp" support wires extend completely across the open faces of the frame, parallel to the major face surfaces of the resonator, and are attached at both ends to the encircling frame. The resonator is supported in the conventional manner by headed wires which are soldered to fired silver spots on the quartz. These headed wires then cross the "harp" wires at right angles, and are attached by solder balls which also serve as terminations to control the crystal wires at the proper resonant lengths.

Previous reports in this series have traced the initial adaptation of this ceramic-frame mounting arrangement to the CR-(XM-45)/U units. The ceramic-frame arrangement was originally devised and developed for higher frequency units which use square, CT- and DT-cut resonators and adaptation to the lower frequency CR-(XM-45)/U units involved changes to accommodate the long, rectangular resonators which must be used. Provisions also had to be made for the two sets of headed wires which are used to mount the longer, heavier resonators since the original design had provisions for only a single set of centrally-located wires.

In addition to the general adaptation of the mounting to this new use, there are several details which must be worked for each individual frequency. These details, which have considerable influence on the performance of the finished unit, cannot be worked out until the exact resonator which is to be used for each frequency is known. These details include the following:

1. The optimum diameter for the headed wires which support the crystal.
2. The proper amount of solder with which the headed wires will be attached to the fired-silver spots on the quartz.
3. The most satisfactory length for the support wires.
4. The size of the "solder ball" termination which controls the length of the support wires.
5. The diameter of the "harp" wires.
6. The size and positioning of the fired-silver spots.

The details of the mounting cannot, obviously, be worked out until after the selection of crystal resonators has been made. For this reason all experimental units are inevitably handicapped in performance, both in vibration as well as drift stability, and only the final, developmental models can hope to achieve optimum performance. In addition, once the initial adaptation of the mounting arrangement was done, attention had to be turned to the search for suitable crystal resonators.

The search for crystal resonators which could serve the CR-(XM-45)/U has also been traced in the earlier reports in this series. After it had been confirmed that +5°X crystals, such as are used on standard CR-42A/U's, cannot be made to peak closely enough to the +75°C reference temperature to meet the CR-(XM-45)/U requirement, attention was turned to investigation of possible alternate crystals: wide-plate NT cuts, a variety of single-rotation X cuts, and several combinations of double-rotation NT cuts.

No promising resonator-type was found, since almost all of the experimental resonators had both too-high capacity and too-low activity. For a time it was believed that significant increases would have to be made in the CR-(XM-45)/U capacitance and resistance limits if the drift stability was to be met. Finally, at the suggestion of Mr. R. A. Sykes of Bell Telephone Laboratories, investigation was made of double-rotated X-cut resonators which use orientation and dimensions similar to wide-plate NT crystals, but which use full electrode areas to excite length-extension modes (similar to +5°X crystals) rather than the divided electrodes which excite length-width modes on conventional NT resonators.

These experimental X-cut resonators provided good activity with reasonable capacitance levels; they were our first indication that the CR-(XM-45)/U requirements might be accomplished.

A group of engineering sample units was made, with the intent of locating basic information from which derivation of designs using the new resonators could begin. Since these units were a pioneering effort they were not, of course, fully refined and therefore they were not expected to meet the CR-(XM-45)/U requirements.

Process Information Sheets (PISN) which listed the details of the designs used on the second-group experimental units were presented in the Second Report of this series. Evaluation data for the units which used these designs are presented in this report, starting on page 14. These data, together with the known deficiencies of the second-group units, have lead to certain conclusions concerning the CR-(XM-45)/U requirements and have also lead to the location of certain problem areas in which extensive development work is still necessary.

First, the capacitance values of all the second-group units are too high, in terms of the original requirements (which demand that the new, ruggedized units meet the same stringent capacity levels as the standard, non-ruggedized units.) A major portion of the higher capacitance in these units comes from the ceramic-frame holders, which have at least double the capacity of the standard holder arrangements. (Attempts to reduce the capacity values of the ceramic-frame holders have not been successful.) In addition to the holder capacitance, however, some further allowance must be made so that the experimental X-cut crystals can be made to achieve optimum activity.

Review of the second-group experimental units lead to the conclusion that while the regular CR-42A/U capacitance-formula requirement could not be applied directly to the CR-(XM-45)/U units, it could be adapted to them simply by increasing the constant factor on the formula from the 1.2 value used for the standard units to 4.7, an increase of only 3.5 uuf. It is believed that relaxation of the original capacitance formula-requirement is necessary if the ruggedized units are to be practical. The following tabulation shows our proposed changes:

ORIGINAL CAPACITANCE FORMULA

Frequency (kc)	Capacitance (pf)
90 to 170 kc	$\frac{450}{f} + 1.2$, ±15%
170 to 200 kc	$\frac{322}{f} + 1.2$, ±15%

PROPOSED CAPACITANCE FORMULA

Frequency (kc)	Capacitance (pf)
90 to 170 kc	$\frac{450}{f} + 4.7$, ±15%
170 to 200 kc	$\frac{322}{f} + 4.7$, ±15%

This proposed change is being processed by means of a Technical Action Request. As far as can be determined at this time, it is the only change in the original requirements which will be necessary, making a slight increase in capacitance the only performance penalty imposed by the ruggedization.

Review of the data on the second-group experimental units also shows that the activity levels of most of these units were uniformly high -- well within the requirements -- and that only those units in the 120 kc group exceeded the 4500 ohm maximum resistance value. The poor activity of the units in the 120 kc group has been traced directly to the length-width ratio which resulted from the plate dimensions which were chosen for these resonators. It is believed that a slight change in the dimensions of the quartz plate, slightly increasing the ratio value, will eliminate this problem. (Experimental units which will check out this belief are now nearly ready for evaluation.)

The following tabulation summarizes the length-width dimensions and the ratio values for the second-group units:

ORIGINAL LENGTH-WIDTH RATIOS
(experimental double-rotated X-cut resonators)

frequency	width	length	ratio
90 kc	0.244"	1.2600"	5.16
120 kc	0.244"	1.2600"	3.86
150 kc	0.244"	0.9430"	3.08
170 kc	0.244"	0.7540"	2.73
200 kc	0.244"	0.5655"	2.32

REVISED LENGTH-WIDTH RATIOS
(only the 120 kc dimensions were changed)

frequency	width	length	ratio
120 kc	0.200"	0.9525"	4.76

In addition to the other deficiencies, none of the second group units met the stability requirements over the +70°C to

+80°C operating temperature range. This was to be expected, of course, since none of the resonators in these units had proper orientation (there were no guides for selection of orientation) and none of the plates was properly mounted for optimum performance. (The lack of proper mounting details also resulted in less uniformity than would ordinarily be expected.)

It was decided to start the investigations of improving the +70°C to +80°C drift performances of our experimental X-cut crystals by shifting orientations: specifically, by changing the second rotation angle slightly. The following tabulation lists the orientations which were used on the second-group crystals:

ORIENTATION
(second-group experimental units)

frequency (kc)	rotation symbol	orientation		
		phi	theta	psi
90	XYTWL	+8° ± 30'	±58° ± 30'	0° ± 30'
120	XYTWL	+8° ± 30'	±58° ± 30'	0° ± 30'
150	XYTWL	+8° ± 30'	±58° ± 30'	0° ± 30'
170	XYTWL	+8° ± 30'	±57° ± 30'	0° ± 30'
200	XYTWL	+8° ± 30'	±56° ± 30'	0° ± 30'

The +70°C to +75°C and the +75°C to +80°C drift performances of the second-group experimental units is shown by the data summary sheets which start on page 14. The majority of the units (except those at 200 kc) have steadily negative drift over both portions of the temperature range, indicating that the resonators peaked too far below the +75°C reference temperature. It was concluded that the second-rotation orientation angle of the resonators must be increased in an attempt to obtain higher peaking points, but it was expected that significant increases in this angle could lead to lower activity so that units would have excessive resistance levels.

Experimental units were prepared with resonators on which the second-rotation angle had been increased to 60°. There were no significant changes in either drift or activity, so further shifts were made, to 62° and then to 64°. There were some increases in the resistance values of these increased-angle resonators, indicating that activity did decrease as the rotation increased. However, even the ±8°, ± 64° double-rotation resonators were able to meet the CR-(XM-45)/U resistance requirements when full use was made of the higher capacitance values permitted by the revised formula.

No detailed investigation was made of these increased-angle resonators after it became apparent that drift performance could not be significantly changed by shifts in the orientation. Instead, attention was turned to investigation of the results obtainable by various combinations of mounting arrangement details. Evaluation was made of such things as variations in the size and placement of the fired-silver spots on the resonator plates, various sizes and lengths of headed wires, variations in the amount of solder with which the headed wires are attached to the fired-silver spots, and variations in the plate dimensions of the resonators themselves.

Of these, only the changes in the positioning of the support wire attachment seem to hold any great promise of improving drift performance, although the investigation of changes in plate dimensions has not yet been completed. (It should be noted that the reason for the positive-drift performance of the 200 kc units of the second experimental group was that the resonators were mounted on a single set of headed wires, while all the other units were mounted on double sets; use of a centrally-positioned mounting point results in a peaking temperature near +90°C in contrast to the below 70°C peaking points of the dual-support crystals.)

The other factors in the mounting do, of course, affect the drift patterns of the finished units. However, they primarily contribute to uniformity and to other performance traits rather than to the drift over such a short temperature range. In particular, proper mounting is necessary to obtain optimum performance in the severe vibration tests. It may be difficult to combine the particular mounting arrangement which is desirable for optimum drift performance with the arrangement which is desirable for optimum vibration performance. For this reason, investigation of other possible methods of obtaining better frequency stability over the +70°C to +80°C temperature range will be continued even while the new positions for the support wires are being worked out.

90 kc

EVALUATION OF SECOND ENGINEERING TEST SAMPLES IN TERMS OF THE CR-(XM-45)/U SPECIFICATION

Specified tolerances for 90 kc units:

1. Calibration: ± 1.8 cps of nominal at +75°C
2. Resistance: 4,500 ohms maximum with 32 uuf load
3. Capacitance: 7.1 uuf maximum
4. Drift: +70°C to +75°C: ± 5 ppm
   +75°C to +80°C: ± 5 ppm
5. Shock: frequency change: ± 5 ppm maximum
   Vibration: resistance change: ± 15% maximum

Measurements made on second-group 90 kc sample units:

Unit No	Freq. (+75°C)	Resist. (ohms)	Shunt Capac.	Drift +70°C to +75°C	Drift +75°C to +80°C
# 6	89.9995 kc	3,100	10.49 uuf	-7.7 ppm	-8.8 ppm
# 7	89.9988 kc	2,700	10.40 uuf	-8.8 ppm	-8.8 ppm
# 8	89.9989 kc	2,800	10.20 uuf	-10.0 ppm	-8.8 ppm
# 9	89.9992 kc	2,800	10.41 uuf	-11.1 ppm	-8.8 ppm
#10	89.9994 kc	2,800	10.22 uuf	-10.0 ppm	-10.0 ppm

Shock and vibration performances of second-group 90 kc sample units:

Unit No.	Shock freq. change	Shock resist. change	Vibration freq. change	Vibration resist. change
# 6	-1.1 ppm	-0.6%	+2.2 ppm	+0.4%
# 7	0	0	+3.3 ppm	0
# 8	-1.1 ppm	-2.1%	+1.1 ppm	0
# 9	-1.1 ppm	0	+2.2 ppm	0
#10	0	0	+1.1 ppm	0

CR-(XM-45)/U

120 kc

EVALUATION OF SECOND ENGINEERING TEST SAMPLES
IN TERMS OF THE CR-(XM-45)/U SPECIFICATION

Specified tolerances for 120 kc units:

1. Calibration: ± 2.4 cps of nominal at +75°C.
2. Resistance: 4,500 ohms maximum with 32 uuf load
3. Capacitance: 5.7 uuf maximum
4. Drift: +70°C to +75°C: ± 5 ppm
   +75°C to +80°C: ± 5 ppm
5. Shock: frequency change: ± 5 ppm maximum
   Vibration: resistance change: ± 15% maximum

Measurements made on second-group 120 kc sample units:

Unit No	Freq. (+75°C)	Resist. (ohms)	Shunt Capac.	Drift +70°C to +75°C	Drift +75°C to +80°C
# 6	120.0022 kc	4,700	8.49 uuf	-5.0 ppm	-7.5 ppm
# 7	120.0005 kc	6,000	8.58 uuf	-6.6 ppm	-10.8 ppm
# 8	120.0016 kc	6,600	8.48 uuf	-10.0 ppm	-18.3 ppm
# 9	120.0003 kc	6,200	8.52 uuf	-8.3 ppm	-14.1 ppm
#10	120.0059 kc	7,700	8.44 uuf	-17.5 ppm	-14.1 ppm

Shock and vibration performances of second-group 120 kc sample units:

Unit No.	Shock freq. change	Shock resist. change	Vibration freq. change	Vibration resist. change
# 6	+1.6 ppm	0	-2.5 ppm	-1.3%
# 7	+2.5 ppm	0	+5.0 ppm	-3.2%
# 8	0	0	+3.3 ppm	0
# 9	+1.6 ppm	0	+4.1 ppm	0
#10	+4.1 ppm	0	-5.0 ppm	-2.2%

CR-(XM-45)/U

150 kc

EVALUATION OF SECOND ENGINEERING TEST SAMPLES IN TERMS OF THE CR-(XM-45)/U SPECIFICATION

Specified tolerances for 150 kc units:

1. Calibration: ± 3.0 cps of nominal at +75°C
2. Resistance: 4,500 ohms maximum with 32 uuf load
3. Capacitance: 4.8 uuf maximum
4. Drift: +70°C to +75°C: ± 5 ppm
   +75°C to +80°C: ± 5 ppm
5. Shock: frequency change: ± 5 ppm maximum
   Vibration: resistance change: ± 15% maximum

Measurements made on second-group 150 kc sample units:

Unit No	Freq. (+75°C)	Resist. (ohms)	Shunt Capac.	Drift +70°C to +75°C	Drift +75°C to +80°C
# 6	150.0022 kc	6,100	7.23 uuf	-6.6 ppm	-9.3 ppm
# 7	150.0006 kc	4,000	7.11 uuf	+1.3 ppm	-0.6 ppm
# 8	150.0017 kc	3,300	7.10 uuf	+1.3 ppm	-2.0 ppm
# 9	150.0024 kc	3,200	7.10 uuf	+1.3 ppm	-1.3 ppm
#10	150.0008 kc	5,200	7.12 uuf	-7.3 ppm	-12.0 ppm

Shock and vibration performances of second-group 150 kc sample units:

Unit No.	Shock freq. change	Shock resist. change	Vibration freq. change	Vibration resist. change
# 6	-0.6 ppm	0	+1.3 ppm	0
# 7	0	0	-3.3 ppm	0
# 8	0	0	-0.1 ppm	0
# 9	0	0	+0.1 ppm	0
#10	-2.6 ppm	-0.8%	-0.1 ppm	0

170 kc

EVALUATION OF SECOND ENGINEERING TEST SAMPLES IN TERMS OF THE CR-(XM-45)/U SPECIFICATION

Specified tolerances for 170 kc units:

1. Calibration: ±3.4 cps of nominal at +75°C
2. Resistance: 5,000 ohms maximum with 32 uuf load
3. Capacitance: 3.5 uuf maximum
4. Drift: +70°C to +75°C: ± 5 ppm
   +75°C to +80°C: ± 5 ppm
5. Shock: frequency change: ± 5 ppm maximum
   Vibration: resistance change: ± 15% maximum

Measurements made on second-group 170 kc sample units:

Unit No	Freq. (+75°C)	Resist. (ohms)	Shunt Capac.	Drift +70°C to +75°C	Drift +75°C to +80°C
# 6	170.0028 kc	3,750	6.98 uuf	-1.2 ppm	-3.5 ppm
# 7	170.0037 kc	3,800	6.69 uuf	-7.0 ppm	-10.5 ppm
# 8	169.9991 kc	3,400	6.58 uuf	-1.2 ppm	-2.9 ppm
# 9	169.9989 kc	3,500	6.71 uuf	-4.7 ppm	-6.4 ppm
#10	170.0021 kc	3,800	6.80 uuf	-0.5 ppm	-4.1 ppm

Shock and vibration performances of second-group 170 kc sample units:

Unit No.	Shock freq. change	Shock resist. change	Vibration freq. change	Vibration resist. change
# 6	+0.6 ppm	0	+4.7 ppm	0
# 7	+4.7 ppm	-0.8%	+3.1 ppm	-2.0%
# 8	+4.7 ppm	-1.1%	+1.7 ppm	-1.4%
# 9	+3.5 ppm	0	+3.8 ppm	-1.3%
#10	+2.9 ppm	0	+2.4 ppm	0

200 kc

EVALUATION OF SECOND ENGINEERING TEST SAMPLES IN TERMS OF THE CR-(XM-45)/U SPECIFICATION

Specified tolerances for 200 kc units:

1. Calibration: ±4.0 cps of nominal at +75°C
2. Resistance: 5,000 ohms maximum with 32 uuf load
3. Capacitance: 3.1 uuf maximum
4. Drift: +70°C to +75°C: ± 5 ppm
   +75°C to +80°C: ± 5 ppm
5. Shock: frequency change: ± 5 ppm maximum
   Vibration: resistance change: ± 15% maximum

Measurements made on second-group 200 kc sample units:

Unit No.	Freq. (+75°C)	Resist. (ohms)	Shunt Capac.	Drift +70°C to +75°C	Drift +75°C to +80°C
# 6	200.0040 kc	3,200	5.41 uuf	+11.5 ppm	+12.0 ppm
# 7	200.0034 kc	3,200	5.31 uuf	+11.5 ppm	+12.0 ppm
# 8	200.0008 kc	3,200	5.39 uuf	+20 ppm	+15.0 ppm
# 9	199.9997 kc	3,600	5.42 uuf	+19.5 ppm	+16.0 ppm
#10	200.0004 kc	2,700	5.38 uuf	+18.5 ppm	+15.0 ppm

Shock and vibration performances of second-group 200 kc sample units:

Unit No.	Shock freq. change	Shock resist. change	Vibration freq. change	Vibration resist. change
# 6	+2.5 ppm	0	-2.0 ppm	0
# 7	+2.0 ppm	0	-1.5 ppm	0
# 8	+4.0 ppm	0	+3.0 ppm	-2.0%
# 9	+4.0 ppm	0	+1.5 ppm	-1.5%
#10	+3.1 ppm	0	0	0

CONCLUSIONS:

Despite their deficiencies, the second-group experimental units are considered to have served their purpose well: they have provided a firm base from which the further development of the designs can proceed. It is believed that the CR-(XM-45)/U requirements can be met by refinements of the present designs.

The major problem at the present time is in obtaining proper control of peaking points so that the required frequency stability can be obtained over the +70°C to +80°C operating temperature range. Although control by means of proper placement of the supporting wires seems to hold promise, it is not yet certain that it is a complete solution. Further investigations are necessary and much development will be needed.

Even if the control by placement of the headed wires proves to be practical, difficulties are anticipated in combining that mounting arrangement which provides the best drift performance with that which produces the best vibration performance. It is to be expected that this difficulty will be reflected in the next (third) group of experimental units and that full compliance with the requirements may not be obtained until later in the project.

CONFERENCES:

1. Mr. Edward Mason of USAEMA and Mr Marvin Bernstein of USAERDA visited Bliley on January 14, 1963. This project was reviewed and the problems were discussed. No specific conclusions were reached.

PROGRAM FOR NEXT INTERVAL:

The program for the next interval includes the development, fabrication, testing, and submission of the third group of experimental units. While the third-group units will still be developmental models -- it is not expected that they will meet all parts of the CR-(XM-45)/U specification -- they should incorporate all of the basic features of the final designs and should, therefore, deviate from the requirements only in minor details.

The testing and evaluation of the third-group units will provide the information which will permit finalization of the designs for use in the fourth group (final group) of experimental units. It is hoped that evaluation of the third group of units will be completed in time so that data can be included in the next report.

IDENTIFICATION OF TECHNICIANS:
(Key technical personnel only)

1. The technicians assigned to this project were identified in the First Report.

2. The approximate number of man hours expended on this project during the second period were as follows:

   A. R. Krespan (Radio Engineer) . . . . (36)
   J. J. Cicero (Laboratory Assistant). . (112)
   J. P. Ciano (Laboratory Assistant) . . (140)
   Production Personnel . . . . (45)

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