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A COMPARISON OF DETERMINISTIC AND PROBABILISTIC RESERVE ESTIMATES

by

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ABSTRACT

A comparison of deterministic and probabilistic methods for estimating oil reserves has been made. Recently, the Society of Petroleum Engineers proposed changes in the definition of reserves from the currently used deterministic method to a probabilistic method. The proposed probabilistic method would require three levels of reserve estimates with different levels of confidence. The three levels of confidence would be P_{90}, P_{50}, and P_{10} where the P_{90} level would be called "Proved", P_{50} would be called "Proved plus Probable", and P_{10} would be called "Proved plus Probable plus Possible". There should be a 90% probability (confidence) that the actual reserves are greater than the P_{90} value. Likewise there should be a 10% probability that the actual reserves are greater than the P_{10} value.

To make the comparison, a comprehensive data set was prepared for a reserve study on a real reservoir. This real data was given to practicing engineers. The study was given in phases starting with volumetric data and continuing through the production decline phase of the wells. Both deterministic and probabilistic reserve estimates were made by each evaluator at sequential points in time.

A comparison of the results shows that most evaluators used their deterministic estimate of reserves as a basis for their probabilistic estimates. These evaluators did poorly in estimating P_{90} values when the hyperbolic exponent "b" was low (near zero). The same evaluators did poorly in estimating the P_{10} values when the decline exponent "b" was high. Most evaluators have more difficulty in estimating P_{10} values compared to estimating P_{90} values. In comparing individual evaluators, there was considerable variability in deterministic, P_{90}, P_{50}, and P_{10} estimates. The most variability was in the P_{10} values.

TABLE OF CONTENTS

LIST OF FIGURES viii

LIST OF TABLES xx

ACKNOWLEDGEMENTS xxii

1.0 Introduction to Probabilistic and Deterministic Reserve Estimates 1

1.1 Purpose of Study 1

1.2 Reserve Definition Background 3

2.0 Literature Survey 9

2.1 Procedure for Literature Survey 9

2.2 Results of Literature Survey 9

3.0 Project Background 29

3.1 Introduction 29

3.2 Well/Field Criteria and Selection 30

3.3 Study Design 40

3.3.1 Phase I 41

3.3.2 Phase II 52

3.3.3 Phase III 52

3.3.4 Phase IV 53

3.4 Study Participants 53

3.5 Study Distribution 55

3.6 Study Well's Ultimate Reserves 56

4.0 Study Procedure 60

4.1 Collection of Data 60

4.2 Processing of Data 63

5.0 Discussion of Results 68

5.1 Introduction 68

5.2 Capen Quiz 68

5.3 Reserve Estimates 70

5.3.1 ERR/ARR Plots 84

5.3.2 Standard Deviation Plots 86

5.3.3 Quartile Plots 89

5.4 Evaluation of P_{90} and P_{10} estimates 96

5.5 Hyperbolic b value determination 100

5.6 P90 and P10 Score versus Capen Quiz Results . 103

6.0 Validity of Study 118

7.0 Conclusions 120

RECOMMENDATIONS 122

NOMENCLATURE 123

REFERENCES CITED 124

APPENDIX A ERR and Standard Deviation plots for all wells and the Company Total 126

APPENDIX B Quartile plots for all wells and Company Total 150

APPENDIX C Cutler # 1-A, Individual Evaluator ERR/ARR Plots for P_{90}, P_{50}, P_{10}, and Deterministic Estimates 172

APPENDIX D Dahlinger # 1, Individual Evaluator ERR/ARR Plots for P_{90}, P_{50}, P_{10} and Deterministic Estimates 184

APPENDIX E Erger # 1, Individual Evaluator ERR/ARR Plots for P_{90}, P_{50}, P_{10} and Deterministic Estimates 196

APPENDIX F Kallsen # 2, Individual Evaluator ERR/ARR Plots for P_{90}, P_{50}, P_{10} and Deterministic Estimates 208

APPENDIX G Reasoner # 1, Individual Evaluator ERR/ARR Plots for P_{90}, P_{50}, P_{10} and Deterministic Estimates 220

APPENDIX H Company Total, Individual Evaluator ERR/ARR Plots for P_{90}, P_{50}, P_{10} and Deterministic Estimates 232

LIST OF FIGURES

		PAGE
Figure 1	Schematic presentation of the range of estimated ultimate recovery values throughout the life of a producing property. From Arps (1956)	25
Figure 2	General location of Bugle Field, Adams Cnty, Colorado. Arrow marks the field.	31
Figure 3	Detail location of Bugle field, Adams County, Colorado.	32
Figure 4	Cutler # 1-A production history, with phase cutoff dates.	34
Figure 5	Dahlinger # 1 production history, with phase cutoff dates.	35
Figure 6	Erger # 1 production history, with phase cutoff dates.	36
Figure 7	Kallsen # 2 production history, with phase cutoff dates	37
Figure 8	Reasoner # 1 production history, with phase cutoff dates.	38
Figure 9	Diagram of the order statistics in an ordered distribution	65
Figure 10	Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Cutler # 1-A	85
Figure 11	Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Cutler # 1-A. Y axis in MBO	87

Figure 12 Standard Deviations of P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Cutler # 1-A 88

Figure 13 Standard Deviation for P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Dahlinger # 1. Y axis in MBO 90

Figure 14 Quartile plot of Deterministic Estimates for the Cutler # 1-A 91

Figure 15 Quartile Plot of P90 Estimates for the Cutler # 1-A 92

Figure 16 Quartile Plot of P50 Estimates for the Cutler # 1-A 94

Figure 17 Quartile Plot of P10 Estimates for the Cutler # 1-A 95

Figure 18 Individual Evaluators P_{10} % correct versus P_{90} % Correct 97

Figure 19 % P_{10} Correct versus % P_{90} Correct by Well 99

Figure 20 Cutler # 1-A Type-Curve Best Fit, b = 0.8 104

Figure 21 Dahlinger # 1 Type-Curve Best Fit, b = 0.6 105

Figure 22 Erger # 1 Type-Curve Best Fit, b = 0.7 106

Figure 23 Kallsen # 2 Type-Curve Best Fit, b = 0.2 107

Figure 24 Reasoner # 1 Type-Curve Best Fit, b = 0.0 108

Figure 25 Best Fit b Value versus % P_{10} Correct for each Well 109

Figure 26 Best Fit b Value versus % P_{90} Correct for each Well 110

Figure 27 Individual Evaluators P_{90} % Correct versus Capen Quiz Score 111

Figure 28 Individual Evaluators P_{10} % Correct versus Capen Quiz Score 112

Figure 29 Probability paper showing the procedure for P_{10} revision based on Capen quiz score 114

Figure 30 Revised P10 % Correct vs Capen 115

Figure A-1 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Cutler # 1-A 127

Figure A-2 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Dahlinger # 1 128

Figure A-3 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Erger # 1 129

Figure A-4 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Kallsen # 2 130

Figure A-5 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Reasoner # 1 131

Figure A-6 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Company Total 132

Figure A-7 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Cutler # 1-A. Y axis in MBO 133

Figure A-8 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Dahlinger # 1. Y axis in MBO 134

Figure A-9 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Erger # 1. Y axis in MBO 135

Figure A-10 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Kallsen # 2. Y axis in MBO . . . 136

Figure A-11 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Reasoner # 1. Y axis in MBO 137

Figure A-12 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Company Total. Y axis in MBO 138

Figure A-13 Standard Deviations of P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Cutler # 1-A 139

Figure A-14 Standard Deviations for P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Dahlinger # 1 140

Figure A-15 Standard Deviations for P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Erger # 1 141

Figure A-16 Standard Deviations of P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Kallsen # 2 142

Figure A-17 Standard Deviations of P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Reasoner # 1 143

Figure A-18 Standard Deviations for P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Company Total 144

Figure A-19 Standard Deviation for P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Dahlinger # 1. Y axis in MBO 145

Figure A-20 Standard Deviation for P_{90}, P_{50}, P_{10} and Deterministic estimate by phase for the Cutler # 1-A. Y axis in MBO. 146

Figure A-21 Standard Deviation for P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Erger # 1. Y axis in MBO. 147

Figure A-22 Standard Deviation for P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Kallsen # 2. Y axis in MBO. 148

Figure A-23 Standard Deviation for P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Reasoner # 1. Y axis in MBO 149

Figure B-1 Quartile plot of Deterministic Estimates for the Cutler # 1-A 151

Figure B-2 Quartile Plot of P_{90} Estimates for the Cutler # 1-A 152

Figure B-3 Quartile Plot of P_{50} Estimates for the Cutler # 1-A 153

Figure B-4 Quartile Plot of P_{10} Estimates for the Cutler # 1-A 154

Figure B-5 Quartile Plots of Deterministic Estimates for the Dahlinger # 1 155

Figure B-6 Quartile Plots of P_{90} Estimates for the Dahlinger #1 156

Figure B-7 Quartile Plots of P_{50} Estimates for the Dahlinger # 1 157

Figure B-8 Quartile Plots of P_{10} Estimates for the Dahlinger # 1 158

Figure B-9 Quartile Plots of Deterministic Estimates for the Erger # 1 159

Figure B-10 Quartile Plot of P_{90} Estimates for the Erger # 1 160

Figure B-11 Quartile Plot of P_{50} Estimates for the Erger #1 161

Figure B-12 Quartile Plots of P_{10} Estimates for the Erger # 1 162

Figure B-13 Quartile Plots of Deterministic Estimates for the Kallsen # 2 163

Figure B-14 Quartile Plots of P_{90} Estimates for the Kallsen # 2 164

Figure B-15 Quartile Plot for P_{50} Estimates for the Kallsen # 2 165

Figure B-16 Quartile Plot of P_{10} Estimates for the Kallsen # 2 166

Figure B-17 Quartile Plot of Deterministic Estimates for the Reasoner # 1 167

Figure B-18 Quartile Plot of P_{90} Estimates for the Reasoner # 1 168

Figure B-19 Quartile Plot of P_{50} Estimates for the Reasoner # 1 169

Figure B-20 Quartile Plot of P_{10} Estimates for the Reasoner # 1 170

Figure B-21 Quartile Plot of Deterministic Estimates for the Company Total 171

Figure C-1 Evaluator # 4, Estimates of Deterministic P_{90}, P_{50}, P_{10} values for the Cutler # 1-A 173

Figure C-2 Evaluator # 5, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A 174

Figure C-3 Evaluator # 9, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A 175

Figure C-4 Evaluator # 14, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A 176

Figure C-5 Evaluator # 16, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A 177

Figure C-6 Evaluator # 18, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A 178

Figure C-7 Evaluator # 19, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A 179

Figure C-8 Evaluator # 20, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A 180

Figure C-9 Evaluator # 21, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A 181

Figure C-10 Evaluator # 27, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A 182

Figure C-11 Evaluator # 31, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A 183

Figure D-1 Evaluator # 4, Estimates of Deterministic P_{90}, P_{50}, P_{10} values for the Dahlinger # 1 185

Figure D-2 Evaluator # 5, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1 186

Figure D-3 Evaluator # 9, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1 187

Figure D-4 Evaluator # 14, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1 188

Figure D-5 Evaluator # 16, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1 189

Figure D-6 Evaluator # 18, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1 190

Figure D-7 Evaluator # 19, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1 191

Figure D-8 Evaluator # 20, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1 192

Figure D-9 Evaluator # 21, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1 193

Figure D-10 Evaluator # 27, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1 194

Figure D-11 Evaluator # 31, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1 195

Figure E-1 Evaluator # 4, Estimates of Deterministic P_{90}, P_{50}, P_{10} values for the Erger # 1 197

Figure E-2 Evaluator # 5, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1 198

Figure E-3 Evaluator # 9, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1 199

Figure E-4 Evaluator # 14, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1 200

Figure E-5 Evaluator # 16, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1 201

Figure E-6 Evaluator # 18, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1 202

Figure E-7 Evaluator # 19, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1 203

Figure E-8 Evaluator # 20, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1 204

Figure E-9 Evaluator # 21, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1 205

Figure E-10 Evaluator # 27, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1 206

Figure E-11 Evaluator # 31, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1 207

Figure F-1 Evaluator # 4, Estimates of Deterministic P_{90}, P_{50}, P_{10} values for the Kallsen # 2 209

Figure F-2 Evaluator # 5, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2 210

Figure F-3 Evaluator # 9, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2 211

Figure F-4 Evaluator # 14, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2 212

Figure F-5 Evaluator # 16, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2 213

Figure F-6 Evaluator # 18, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2 214

Figure F-7 Evaluator # 19, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2 215

Figure F-8 Evaluator # 20, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2 216

Figure F-9 Evaluator # 21, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2 217

Figure F-10 Evaluator # 27, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2 218

Figure F-11 Evaluator # 31, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2 219

Figure G-1 Evaluator # 4, Estimates of Deterministic P_{90}, P_{50}, P_{10} values for the Reasoner # 1 221

Figure G-2 Evaluator # 5, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1 222

Figure G-3 Evaluator # 9, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1 223

Figure G-4 Evaluator # 14, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1 224

Figure G-5 Evaluator # 16, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1 225

Figure G-6 Evaluator # 18, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1 226

Figure G-7 Evaluator # 19, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1 227

Figure G-8 Evaluator # 20, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1 228

Figure G-9 Evaluator # 21, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1 229

Figure G-10 Evaluator # 27, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1 230

Figure G-11 Evaluator # 31, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1 231

Figure H-1 Evaluator # 4, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total 233

Figure H-2 Evaluator # 5, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total 234

Figure H-3 Evaluator # 9, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total 235

Figure H-4 Evaluator # 14, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total 236

Figure H-5 Evaluator # 16, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total 237

Figure H-6 Evaluator # 18, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total 238

Figure H-7 Evaluator # 19, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total 239

Figure H-8 Evaluator # 20, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total 240

Figure H-9 Evaluator # 21, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total 241

Figure H-10 Evaluator # 27, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total 242

Figure H-11 Evaluator # 31, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total 243

LIST OF TABLES

Table 1: USGS Reserve Classification - "McKelvey Box" 5

Table 2: Volumetric Reserve Estimates for both pessimistic and optimistic values. From Petroleum Primer (1982) 21

Table 3: Deterministic Answer Tables Supplied for Study 47

Table 4: Probabilistic Answer Tables for Study . . . 48

Table 5: Capen Quiz 50

Table 6: Capen Quiz Answers 51

Table 7: Estimated Ultimate Production for the Five Study Wells 58

Table 8: Actual Remaining Reserves for each Well by Phase. Based on AUR in Table III . . . 59

Table 9: Personal Information for Study Evaluators 61

Table 10: Capen Quiz Score by each Evaluator 69

Table 11: Estimated Remaining Reserves for Phase I and Phase II for each Evaluator 71

Table 12: Estimated Remaining Reserves for Phase III and Phase IV for each Evaluator 72

Table 13: Estimated Remaining Reserves for Phase I and Phase II for each Evaluator 73

Table 14: Estimated Remaining Reserves for Phase III and Phase IV for each Evaluator 74

Table 15: Estimated Remaining Reserves for Phase I and Phase II for each Evaluator 75

Table 16: Estimated Remaining Reserves for Phase III and Phase IV for each Evaluator 76

Table 17: Estimate Remaining Reserves for Phase I and Phase II for each Evaluator 77

Table 18: Estimated Remaining Reserves for Phase III and Phase IV for each Evaluator 78

Table 19: Estimated Remaining Reserves for Phase I and Phase II for each Evaluator 79

Table 20: Estimated Remaining Reserves for Phase III and Phase IV for each Evaluator 80

Table 21: Estimated Remaining Reserves for Phase I and Phase II for each Evaluator 81

Table 22: Estimated Remaining Reserves for Phase III and Phase IV for each Evaluator . . . 82

Table 23: P_{90} and P_{10} Estimates % Correct by Well . . . 98

Table 24: Computer Matched - Statistical Best Fit b Values for each Well 102

Table 25: P_{10} % correct before and after revision based on Capen score 116

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1.0 Introduction to Probabilistic and Deterministic Reserve Estimates

1.1 Purpose of Study

Recently there has been much discussion regarding the proposed revision of the Society of Petroleum Engineers (SPE) definition of reserves, particularly the definition for proved reserves. The SPE is considering changing the definition, citing it's desire to be more in line with those used worldwide. Currently the SPE defines proved reserves as those that the estimator is "reasonably certain" will be produced. The new definition would eliminate the undefined phrase of "reasonably certain" and replace it with three levels of certainty. The first level is defined as "Proved" or P_{90}. This is the amount of reserves that the estimator is 90 % sure will be produced from the well. The second level is "Proved + Probable" or P_{50}. This is defined as the amount of reserves that the estimator is 50 % sure will be produced. The third level is "Proved + Probable + Possible" or P_{10}. This is defined as the amount of reserves that the estimator is 10 % sure will be produced. The new definition is designed to put confidence levels on an estimator's reserve estimates.

Although there has been much debate regarding the proposed definition changes, to my knowledge, there are no published real data comparisons of the deterministic and probabilistic approaches. The research in this thesis is designed to add some insight into the comparison of the two methods. To accomplish this objective, a "reserve study" was designed using a depleted field so actual reserves were known. This reserve study consisted of real data and was given to practicing engineers. These engineers were asked to estimate the reserves for five wells at several points in time starting with volumetric estimates and continuing into the production decline phase of the wells. Both deterministic and probabilistic reserve estimates were made by each evaluator at each point in time.

Also, at the onset of the reserve study each participant was asked to answer a set of ten general knowledge questions. Instead of a single deterministic answer, each participant was asked to answer each question with a range such that there is an 80 % probability that the correct answer lies inside the stated range. A similar quiz was first published by E.C. Capen (Capen, 1976). The objective of giving the quiz is to make a comparison of the reserve estimator's ability to establish a range for reserve estimates with their ability to range answers for ten general knowledge questions. This comparison is possible since "truth" was known for each well in the reserve study as well as the answers to the general knowledge questions.

The data and results of the reserve estimate study may be organized into four main categories. First, the range of deterministic reserve estimates made by the evaluators are compared to actual well production. Second, the range of probabilistic reserve estimates made by the evaluators are compared to actual well production. Third, the confidence intervals for the probabilistic estimates and the Capen quiz are compared to each other and the target values that the evaluator was supposed to achieve. Fourth, individual well decline characteristics (b values) are compared to individual well's P_{10} and P_{90} score.

1.2 Reserve Definition Background

Currently, most of the systems to classify reserves of minerals are based on the concepts first proposed by the United States Geological Survey (USGS), which is exemplified by what has come to be known as the "McKelvey Box", (Cronquist, 1991) shown in Table 1. This system classifies mineral resources using two attributes: (a) degree of geologic assurance and (b) feasibility of commercial extraction. Although initially proposed to classify "hard" mineral resources, like coal, the concepts embodied in this system have been adopted by the oil and gas industry for the classification of crude oil and natural gas. In this context, reserves are that portion of the resource base which has been discovered and have a high feasibility of commercial extraction. According to the "McKelvey Box" reserves are classified as "Proved", "Probable", and "Possible."

The Society of Petroleum Engineers currently defines reserves in those same three categories - "Proved", "Probable", and "Possible". According to the 1987 definitions, "Proved" is defined as those reserves that;

> " can be estimated with reasonable certainty to be recovered under current economic conditions. Current economic conditions include prices and costs prevailing at the time of the estimate. Proved reserves may be developed or undeveloped." The definition continues with, " The area of a reservoir considered proved includes (1) the area delineated by drilling and defined by the fluid contacts, if any, and (2) the undrilled areas that can be reasonably judged as commercially productive on the basis of available geological and engineering data."

Table 1: USGS Reserve Classification - "McKelvey Box"

	IDENTIFIED (DISCOVERED)			UNDISCOVERED	
	DEMONSTRATED (SAMPLED)			HYPO-THETICAL	SPECULATIVE
	MEASURED	INDICATED	INFERRED		
ECONOMIC	PROVED	PROBABLE	POSSIBLE		
MARGINALLY ECONOMIC	"...now border on being economically producible." McKelvey				
SUB ECONOMIC	"...require substantially higher price...to be economically producible." McKelvey				

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In the same definitions, "Probable" reserves are;

> "less certain than proved reserves and can be estimated with a degree of certainty sufficient to indicate they are more likely to be recovered than not."

Possible reserves are;

> "less certain than probable reserves and can be estimated with a low degree of certainty, insufficient to indicate whether they are more likely to be recovered than not." (Definitions for Oil and Gas Reserves, 1987)

In June of 1990, the SPE Oil and Gas Reserve Committee began reviewing the existing definitions of oil and gas reserves. Their purpose was to determine how these definitions serve professionals in different countries (SPE Considering Changes for Reserves Definitions, 1991). In adopting the current definitions in 1987, the committee wished to achieve their worldwide applicability and approved the Preamble to the definitions, which stated "Achieving a standard terminology to define reserves has been a sought after but elusive goal," and that

> "Adopting the consensus definitions should not significantly alter the established procedures or

> systems within countries or organizations but may require minor modifications to the definitions." (SPE Considering Changes for Reserves Definitions, 1991)

In March of 1991, the board announced proposed changes to the current definitions. A major change would include the quantification of reserve categories by inclusion of confidence levels to express an evaluators confidence in the values. The preamble would state

> "Subsequent worldwide commentary definitely indicated a need for a more quantitative description for each classification of reserves. Various levels of confidence have been added in the accompanying definitions to provide the necessary description." The Preamble would further state, "Confidence levels have been added to the definitions because frequently a better idea is needed of the potential recovery from oil and gas fields than could be given by the imprecise Proved, Probable, and Possible concepts alone." The Preamble continues "These terms on their own reflect increasing uncertainty without the quantification of this uncertainty. The numerical quantification of confidence levels rectifies this situation, and these are stated for Proved, Proved plus Probable, and Proved plus Probable plus Possible. Reserves at the stated confidence levels may be derived by deterministic or probabilistic means." (SPE Considering Changes for Reserves Definitions, 1991)

The proposed changes to the current reserve definitions would, among other things, affect the categories for proved, probable and possible reserves. For "Proved" reserves, there is an 80 to 90 percent confidence level that the actual quantity recovered will be more than the amount estimated and a corresponding 10 to 20 percent confidence level that it will be less. "Proved + Probable" and "Proved + Probable + Possible", would include a 50 percent and a 10 to 20 percent confidence level respectively.

Many countries currently support and use this type of definition and that is the driving force behind these proposed changes. For example, both Austria and the Netherlands define "Proved' as having more than a 90% certainty and "Probable" as having greater than 50% certainty. The United Kingdom, however, used the qualification "virtually certain" to define "Proved" reserves, with "Probable" reserves having greater than 50% certainty. The SPE wishes to support a definition that more closely matches those used worldwide. This wish has stirred up much controversy as to the applicability of the probabilistic definition of reserves in the United States. With this new definition, it can be argued that a well's reserves could now be represented not with one but three reserve estimates. The single proved "reasonably certain" number could be replaced with a low estimate, P_{90}, a high estimate, P_{10}, and an estimate between the two, P_{50}.

2.0 Literature Survey

2.1 Procedure for Literature Survey

The literature survey focused on two subject areas. The first area relates to papers on the topic of reserve estimates through probabilistic or deterministic methods. The second area relates to papers or studies concerning uncertainty in estimating oil and gas reserves.

2.2 Results of Literature Survey

Since the comparison of the deterministic and probabilistic reserves has only recently become an issue, there are only a few published papers on this subject. All of the articles cited in this survey were published after 1988.

In the August 1991 Journal of Petroleum Technology (JPT), R.H. Caldwell and D. Heather discussed deterministic and probabilistic reserve estimates in regards to the proposed reserve definition changes. The article is titled

"How To Evaluate Hard-To-Evaluate Reserves". They agree that current definitions "for the most part work well." However they conclude that for emerging technological plays "where individual well performances are characterized by significant variability of recoveries", current definitions alone are insufficient. They offer case histories of the "statistical plays" in the San Juan Basin coalbed methane and the Austin Chalk horizontal drilling as examples of where the new probabilistic definition would be beneficial. They argue that a deterministic reserve estimate "asymptotically converges on the ultimate reserve figure from a high, low, or middle position on the basis of the validity of the first estimate." They continue with the statement,

> "a probabilistic estimate based on the same data set will converge from the low end of the estimation range and grow toward the ultimate revision by production of lower confidence categories."

They argue that the reserve revision is orderly and smooth and that this is the conceptual difference between a probabilistic and deterministic reserve estimate. They offer the 75% confidence level as the definition for "reasonably certain" in order to link probabilistic and deterministic reserve estimates. They do agree, however that "for properties with an established production history and decline, the conventional deterministic approach is tried, tested, and preferable."

In the August 1991 JPT, L.D. Sipes discusses Caldwell and Heather's paper referenced above. He discusses the use of probabilistic analysis for emerging statistical plays and planning purposes such as large multi-well projects controlled by a single entity or joint venture and for assessing financial risk and rewards for specific ventures. Under these circumstances he agrees with Caldwell and Heather and calls the use of probabilistical analysis "excellent." However, he argues,

> "the use of probability analysis is not an evaluation of reserves but an examination of possibilities.... the right answer as well as all the wrong answers are provided. Take your pick."

Sipes calls allocating the reserves back to a specific well or location "an interesting but seemingly unworkable outcome."

In a paper prepared for the Society of Petroleum Evaluation Engineer's 1991 annual meeting in Durango, Colorado, Chapman Cronquist discusses the worldwide inconsistencies in reserve definitions and the problems in comparing reserves done deterministically and probabilistically. He attempts to answer the question of the degree of variance that can be expected when reserves are estimated using volumetric and decline curve analysis.

For his paper, Cronquist develops a hypothetical model to observe the effects of various types of statistical distributions on the distributions of the calculated reserves. He assumes that a log-normal distribution is a reasonable approximation of the distribution of reserve estimates for a specific prospect and that, with maturity, the variance of the distribution will decrease.

He concludes that there can be a significant difference between reserve estimated by deterministic methods and those using probabilistic methods, depending upon the nature of the actual statistical distribution of the input parameters. He states that the deterministic "best estimate" of reserves may be approximated by the median value of the statistical reserve distribution, with this approximation becoming poorer as the variance increases. He further concludes that,

> "reserves estimated and classified using probabilistic methods, while clearly needed for certain operations cannot be compared directly with those estimated and classified using deterministic methods."

Cronquist is careful to point out that his calculations are hypothetical and that it would be desirable to compile a large enough data base of actual examples to perform a statistically significant analysis.

In the March 1992 JPT, Jacques Hagoort discusses Chapman's paper referenced above. He states that, "The probabilistic method is the more general and superior one. We should use it routinely whenever we are manipulating uncertain data, such as in reserve estimation." He says the deterministic method may be considered a special case of the probabilistic method because it assumes that the variables exhibit symmetrical probability distributions. He discusses two values of the probabilistic approach. One value is that the deterministic method is made more valuable by the error range provided by a probabilistic approach. The second is that probabilistic methods can handle skewed data which may cause the deterministic estimates to be "grossly in error".

In the June 1988 JPT, Forrest Garb discusses the methodologies of estimating reserves for a producing property. The article is titled "Assessing Risk in Estimating Hydrocarbon Reserves and in Evaluating Hydrocarbon-Producing Properties." He identifies two procedures for assessing risk and determining the expected value of the producing property. They are deterministic, which yields one result, and the probabilistic, which yields a distribution of reserves. For the deterministic estimate, he states, we are developing a "most likely case" and are ignoring the fact that it is highly unlikely that this case will actually occur. The probabilistic method, he states, "considers all possible outcomes and then attempts to estimate the most likely one. Use of this theory, however, has meaning only if there are a significant number of happenings in the past to help us estimate the odds for a few events in the future." For his discussion he proposes the 50 percentile or median point for the deterministic estimate while using the total distribution for the probabilistic approach. He concludes that

> "deterministic approaches have been, and continue to be , the most popular, because of lack of understanding of probabilities and the simplicity in performing and understanding a single answer. In large, continuous investment programs, probabilistic procedures offer a better answer by taking into account the 'odds' of the investment and the distribution of results."

In the October 1988 JPT, Frank Martin offers his opinion on Forrest Garbs paper referenced above. He makes several points. First, the Monte Carlo type simulation has no place in property evaluation because necessary data are not gathered and cannot be generated because of the confidential nature of the data. Second, engineers do not have the mathematical intuition to see the relationship between the input and output of such models and will not expend the necessary labor to learn this skill because work is abundant and time is short. Third, the probabilistic description of an essentially deterministic problem is at best moot. "If you are conservative, why not simply be conservative rather than using some perfectly good mathematics rather badly?" He offers some personal experience as to the estimation of reserves. He noted that estimation of remaining reserves never improves and that apparent improvements in the estimates of ultimate recovery are caused by the increasing percentage of metered hydrocarbons in the estimate. He says, "unfortunately, when you buy properties, you are buying remaining recoverable reserves. Produced reserves are already gasoline at this point."

In the August 1988 JPT, Forrest Garb replied to Martin's discussion of his June 1988 JPT article. Garb concludes that his experience with risk analysis is in direct conflict with Martin's position. Garb agrees with Martin that probability analysis should never replace good specific data in an evaluation but within specific applications it proved "quite helpful". He also agrees with Martin's statement that ultimate reserve estimates improve with time, but that remaining reserve estimates do not necessarily do so. Garb disagrees with Martin's assessment that probability is a bad application of good mathematics and that data bases are so proprietary that information is difficult if not impossible to obtain. Finally Garb disagrees with Martin's idea that just because someone does not understand the development or use of such analysis, it should not be studied, written about, and used.

In the April 1990 *JPT*, Helge Haldorsen and Elvind Damsleth discuss stochastic modeling with emphasis on its use when reservoir modeling is done. They describe a reservoir as being intrinsically deterministic. All of it's features are potentially measurable. They offer six major reasons as to why a deterministic reservoir should be defined stochastically. Briefly, they are: (1) incomplete information (2) complex deposition of reservoir building blocks (3) rock property variability (4) unknown relationships between property value and the volume of rock used for averaging (the scale problem) (5) relative abundance of point values of reservoir data, and (6) convenience and speed.

Haldorsen and Damsleth's paper is more of a exploration application than reserve estimating application but in it they do offer a technique to convert uncertainty in rock properties to an uncertainty range for recoverable reserves over a field's life.

In the July 1990 JPT, N.G. Saleri discusses Haldorsen's and Damsleth paper referenced above. He essentially agrees with the main points of their paper but has some qualifications. He questions the time and money that would be necessary to stochastically forecast each scenario for a moderately developed reservoir. He believes that stochastic forecasts may be too time consuming and expensive.

He brings up another interesting point that was found in no other literature. "For many reservoirs," he states, "operation-related uncertainties far outweigh geologic uncertainties." He sights production allocation, metering, and down-hole completion status as examples. In these cases, Saleri believes that stochastic modeling for geologic uncertainties will not enhance the accuracy of the reserve estimate. He advocates a knowledge of probable ranges of all uncertainties in the problem - not just geologic.

The second area for the literature survey involves assessing uncertainty, especially in estimating oil reserves.

In the August 1976 JPT article titled "The Difficulty In Assessing Uncertainty", Ed Capen introduced a short general knowledge quiz designed to test individuals ability to accurately range answers. For the quiz, the individual was to give a high and low answer based on a 90% confidence level for ten questions. If done correctly, the individual should accurately range his answers 9 of 10 times. The average number of correct answers on Capen's quiz was less than 4. This led Capen to the following conclusions. First, a large number of technical people have little idea of what to do when uncertainty crosses their path. Second, that having no good quantitative idea of uncertainty, there is an almost universal tendency for people to understate it. Regardless of what confidence interval they intend to set, they will predict ranges that correspond to 35 - 40% intervals. Thus, they overestimate the precision of their own knowledge and contribute to decisions that later become subject to unwelcome surprises. It appears that the ego satisfaction of "coming close" motivates the evaluators to set excessively narrow ranges. A quiz of this type was included in the study.

In Colorado School of Mines thesis number 3018, "The Effect Of Individual Interpretation On Reserve Estimates And Present Value Economics From Decline Curve Analysis", Scott

Digert developed a study that, among other things, studied the uncertainty in reserve estimates. The study was given to Petroleum Engineering students at the Colorado School of Mines. These students were asked to estimate reserves for four wells using decline curve analysis. The estimates were done at yearly intervals throughout the life of the wells. This study was extensively used as a model for the design of this Probabilistic and Deterministic study. He concluded that the error in the estimates for both ultimate and remaining reserves may be surprisingly large, especially during the early phase of the production. He also concluded that the range of estimates for ultimate recovery tends to converge toward truth with increasing cumulative production, but the estimates of remaining reserves do not.

In a 1982 Petroleum Primer article titled Reservations About Reserve Estimates, Bennett Daviss discusses the difficulties in assessing and the importance given to reserves. He compares valuing an oil company by the amount of reserves in the ground to running a business without knowing exactly how much money you have in the bank. He states, "Estimating the amount of oil in the ground is a science marked by individuality: An optimistic engineer may give your company a glowing report, but a pessimist might not." Roland Blauer, president of Resource International

Inc. consulting firm, offers his opinions throughout the article. He says that an engineers estimates are a result of personal biases which are a result of training, experience and professional expertise. Blauer also observes, that while numbers are crunched with standard engineering techniques, the numbers in those equations are a combination of an individuals "best guess and best wishes." The entire paper echoes those sentiments. Reserve estimates while done professionally, with the best intentions, are rarely correct.

A good example of the amount of difference in a reserve estimate given identical data is discussed in this article. The example shows the assumptions made by a pessimistic and an optimistic engineer. All data chosen by each engineer can be argued to be the correct estimate for that particular unknown.

Table 2 is taken from the reserve estimation example. It shows that given the same reports and the same procedure, the engineer's estimates for recoverable reserves differ by a factor of thirteen. This is a good example as to the individuality of reserve estimates.

As you might expect, these reserve variations can greatly effect a companies projected cash flow. Blauer reports doing an experiment for a client in which he

Table 2: Volumetric Reserve Estimates for both pessimistic and optimistic values. From Petroleum Primer (1982)

	Optimistic	Pessimistic
Drainage Area 160 Acres Spacing	Square (160 acres) 6,969,000 sq ft	Circular (126 acres) 5,473,911 sq ft
Thickness	18 ft	12 ft
Porosity	16 %	10 %
Hydrocarbon Saturation	80 %	50 %
Oil Shrinkage Res Bbl/Bbl	1.1	1.2
Recovery Factor	25 %	10 %
Recoverable Oil	650,000 Bbl	49,000 Bbl

decreased the projected decline for a series of wells by 10%. That is, if a well is declining at 10%, he decreased it to 9%. The result was a virtual doubling of the clients projected discounted cash flow. All of this was done within accepted engineering tolerances.

Also in this article, results of a reserve study done by a unnamed Denver, Colorado petroleum engineering student were shown. The student asked three practicing petroleum engineers to estimate reserves for a Williston Basin well. The reserve estimate results showed a spread of 13 to 1. The estimates ranged from a high of 13 million barrels to a low of 934,00 barrels. The student concluded the report with this warning.

> "Each and every person interested in a reserve report must take the responsibility of learning and understanding the limitations, subjectiveness, and impreciseness inherent in that report. Depending on a reserve report as a true statement of things to come will only lead to financial, business and legal problems for all involved."

In his book Decision Analysis For Petroleum Exploration, Paul Newendorp includes discussions on risking uncertainty in reserve estimation. Newendorp believes that even though risk analysis is tough we cannot afford to ignore it. However, he concedes that there are no "handy-dandy" formulas which yield probability estimates nor is it likely that any will be found.

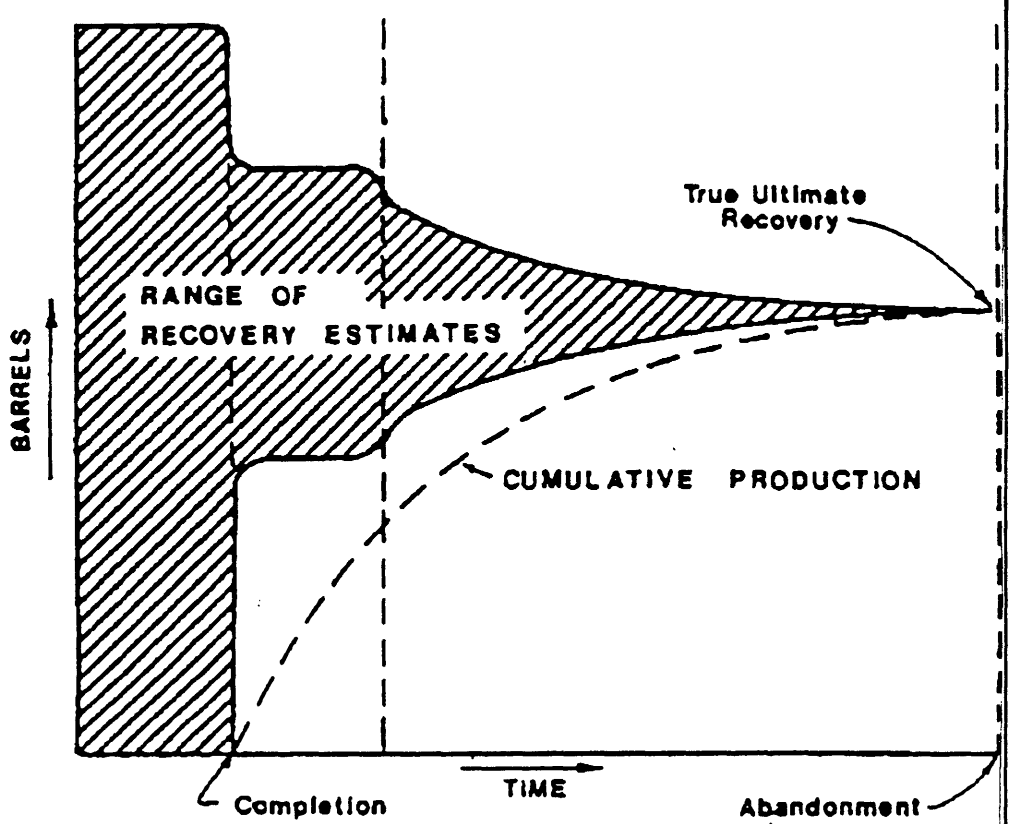
As he states, the principal reason for the lack of a "handy-dandy" equation is that we do not know the factors controlling petroleum reserves. That is, with regard to reserve level probabilities we cannot explicitly describe the process which originally generated the distributions of the accumulation. In petroleum exploration we do not know the basic process controlling the origin, accumulation, migration, and entrapment of the hydrocarbons. He says,

> " Any 'quasi-theoretical' model we develop will only be an approximation to what we think or perceive as the basic process- but we probably will never have an exact probability analog."

He states that subjective probability estimates are a common way of expressing the degree of risk of uncertainty to the uncertain parameters in exploration. He lists several implications of this type of probability. One is that these estimates on based on the individual judgement of the professional and that different evaluators may not reach the same conclusion given the same data. Simply stated, personality plays a major role. Another implication is that the judgements by the evaluator can be sometimes biased by his or hers feelings toward the consequences of the outcome.

In chapter 37 of Frick's Petroleum Production Handbook Volume II, Jan J. Arps discusses the estimation of primary oil and gas reserves. He states that estimating reserves is one of the most important phases of a petroleum engineers job. This is because these reserves often dictate future action. Unfortunately these reserves are needed early in the life of the property when minimal data are available.

Figure 1 is taken from this reference. It illustrates Arps general idea. It shows three periods in the life of an oil property. During the first period, before wells are drilled, estimates are based on analogy and are very general in nature. Period two further defines the limits of the ultimate recovery. This can be done due to the increase of data on that particular property. The third period is referred to as the " decline curve" period. Here, the information contains sufficient amounts of actual performance. This information may be in the form of decline-curve trends, pressure or other long term information. During this period, the limits are further defined toward the ultimate recovery. It should be noted that Arps is talking about ultimate and not remaining reserves. Arps states that it desirable for the estimator to provide a range of reserve estimates for management to



PERIOD	I BARRELS PER ACRE PERIOD	II BARRELS PER ACRE FOOT PERIOD	III DECLINE CURVE PERIOD
TYPE OF DATA	COMPARATIVE DATA	VOLUMETRIC DATA	PERFORMANCE DATA

Figure 1 Schematic presentation of the range of estimated ultimate recovery values throughout the life of a producing property. From Arps (1956)

base a decision, both high and low. If that estimator provides a single answer then a probable error in the estimate should be stated.

Arps believes that the probable error in reserve estimates, done by experienced engineers, declines with an increase in the number of individual wells being estimated. Arps states,

> "Whereas substantial differences between independent estimates made by different estimators for a single property are not uncommon, chances are that the total of such estimates for a large group of properties or an entire company will be surprisingly close."

In an article, published January 1987 in the American Association of Petroleum Geologists Bulletin, titled "Dealing with Risk and Uncertainty in Exploration: How Can We Improve?", Peter Rose examines the impact of risk and uncertainty on mineral exploration and how to deal with it. He believes that if we accurately state the probabilities that effect an outcome, then we can invest wisely. If this approach is followed consistently then long term success will be achieved. He states, "Then we are not gambling- we are playing the odds."

According to Rose, an effective way to express uncertainty is to formulate a range of values, with confidence levels assigned to numbers comprising the range. He refers to Capen's work on uncertainty when discussing potential biases or problems with ranging these values. He also discusses other biases.

One of these is "anchoring." This is when a person makes an estimate from an initial value then makes adjustments until they reach a final answer or range. This, he believes, may limit sufficiently wide ranges being set. A possible solution, he contends, would be to set the upper and lower, then estimate a median or most likely value.

A second bias is "representativeness." This is when estimates are made through mental comparisons with some form of analogy which may not actually be representative of the case.

A third bias is "availability." This is when an individual associates the probability of an event with the ease with which similar circumstances can be brought to mind.

The fourth bias he discusses is "unrecognized limits." This is when an estimator places certain unstated limits on the occurrence of an event, either because of their professional specialty or of what they perceive to be the intent of those requesting the estimate.

The fifth bias he discusses is "motivational bias." This is when the estimator associates some self-interest with their estimations.

Also included as a bias is the widespread notion that over-optimistic estimates are far more undesirable than over-conservative ones. Obviously both estimates can cause problems in the future. In his experience he believes that this type of bias is "most prevalent among highly quantitative, linear thinkers and dedicated technical specialists."

In his book Risk Analysis, Robert Megill supplies a rigorous discussion of risk. Obviously a complete summary of this book would not be suited to a literature survey.

In his book, Megill differentiates between risk and uncertainty. By his reasoning, uncertainty is one of several fundamentals of risk. He states that parameters have an up-side and down-side in addition to a most-probable value. "Your view of a parameter should reflect both the up-side as well as the down-side." He feels, that because of the high, low, and most probable values, the triangular distribution is most popular. This is because it allows the evaluator to "see" each value as a point in the distribution.

3.0 Project Background

3.1 Introduction

A research study has been conducted in which a group of practicing petroleum engineers were asked to estimate remaining reserves for five oil wells. These estimates were to be done according to current SPE definitions for reserves and the new proposed SPE definitions for reserves. These estimates were made for all five wells at four time intervals called Phases I through IV. These Phases represented a five year time span.

The study was given to 29 petroleum engineers. The professionals are both men and women having varying degrees of industry and geographic experience. Some are personal friends, others represent SPEE chapters from Denver, Dallas, Houston, Midland, and Tulsa and are employed by consultants, independents, and major oil companies. All participants remain anonymous and are assigned an evaluator number to be used with all correspondence. Of the 29 that started, 12 finished this study in time to be included in this thesis.

3.2 Well/Field Criteria and Selection

This study focuses on reserves estimates done both deterministically and probabilistically. Therefore, it was critical that the field and wells chosen represented "real world" wells and not fabricated or unusual data. Every attempt was made to avoid "tricky" or unusual data.

The reserve portion of the study was designed with several criteria in mind. A major consideration was to make this study as painless as possible for the participants while at the same time creating a study that when finished would produce meaningful results. With this in mind the reserve estimates were limited to five wells, within the same field where good data are available. Field selection was limited to the state of Colorado and were chosen based on decline characteristics, field information, well information, analogous field information, maturity, and proximity to each other. Only oil wells were considered to avoid gas curtailment problems.

After studying several areas and fields, the Bugle Field, of the Denver - Julesberg basin, T 1S R 66W, in Adams County Colorado was selected (Figures 2 and 3). This field was discovered in 1974 and has produced from 13 wells in the D & J sands of the Lower Cretaceous. The five wells

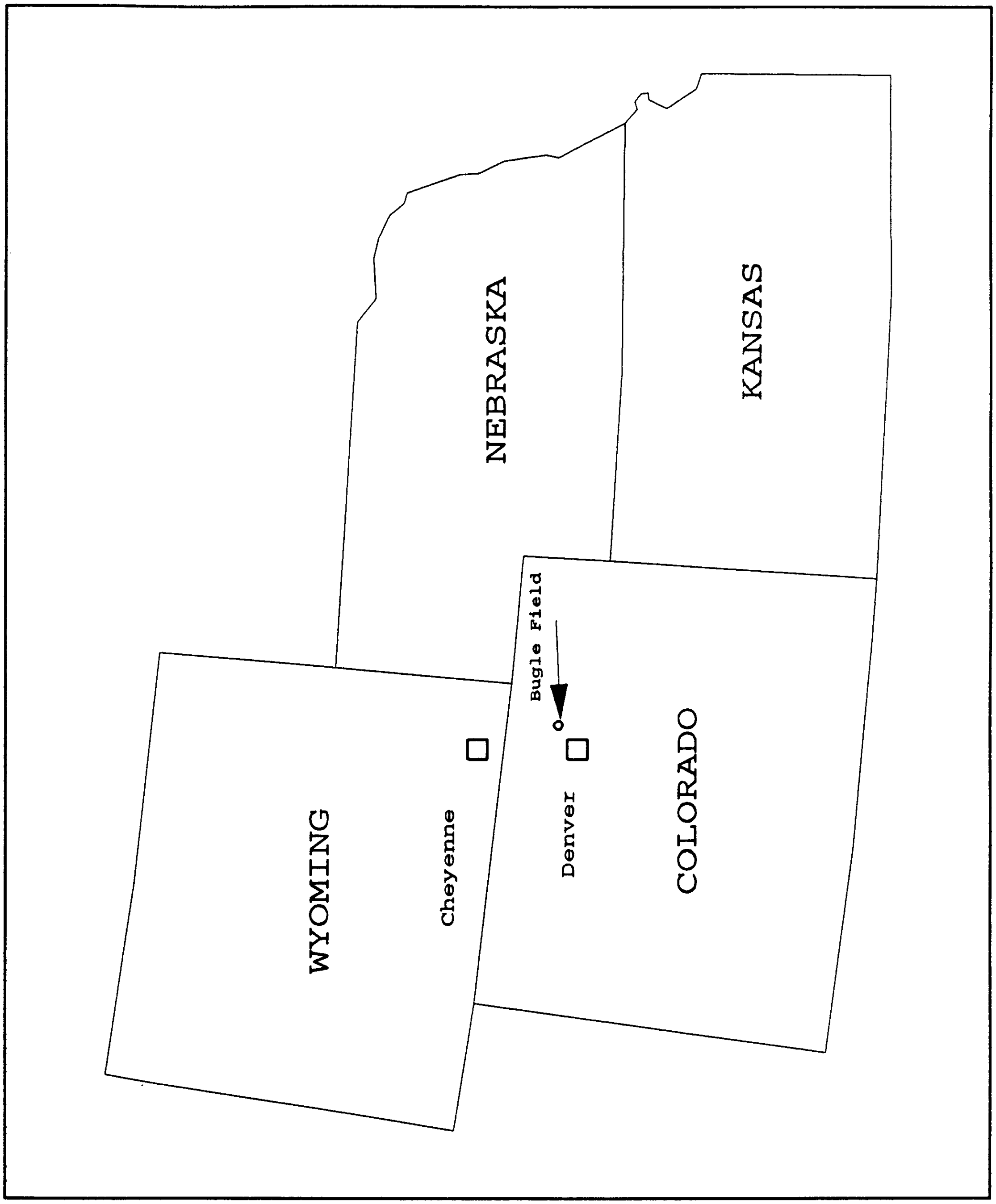


Figure 2 General location of Bugle Field, Adams County, Colorado.

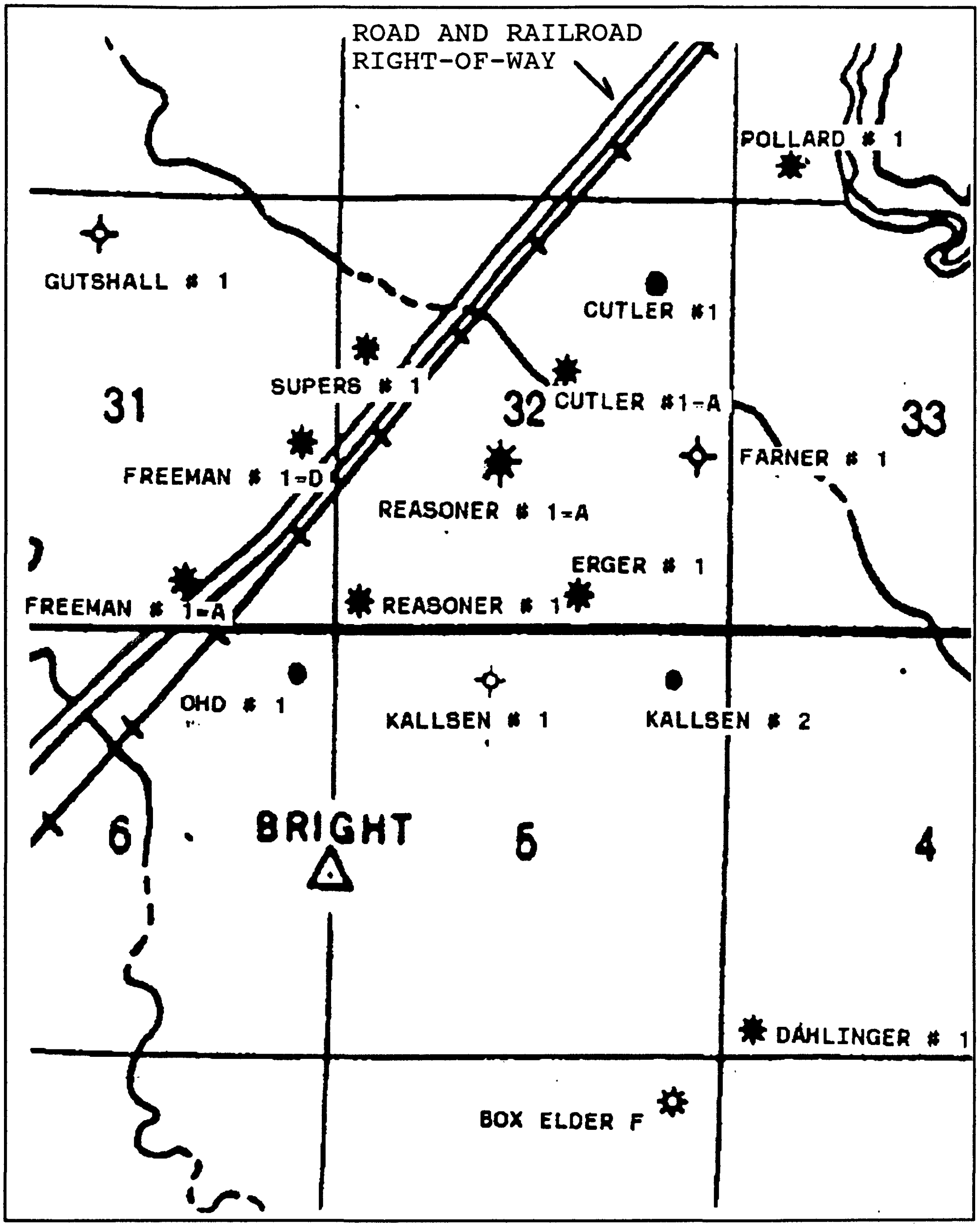


Figure 3: Detail location of Bugle Field,
Adams County, Colorado

chosen from within this field are oil producers and all began producing in either 1974 or 1975 and have reached or are very near the study imposed economic limit of 60 barrels of oil per month (BOPM). The wells chosen are the ;

Cutler # 1-A, Sec 32 T 1S R 66W

Dahlinger # 1, Sec 4 T 2S R 66W

Erger # 1, Sec 32 T 1S R 66W

Kallsen # 2, Sec 5 T 2S R 66W

Reasoner #1-A, Sec 32 T 1S R 66W

Figures 4 - 8 are the individual declines for each well with each Phase of the study marked. Also marked is the study imposed economic limit of 60 BOPM.

Since this field is 18 years old, good information is available in the form of established declines, well information, field studies, and analogous data.

Good decline curve information is essential in this study since all estimates will be compared to an ultimate reserve figure. All five wells exhibit established decline curve characteristics and have been producing for at least 17 years and have either reached or are very near the study

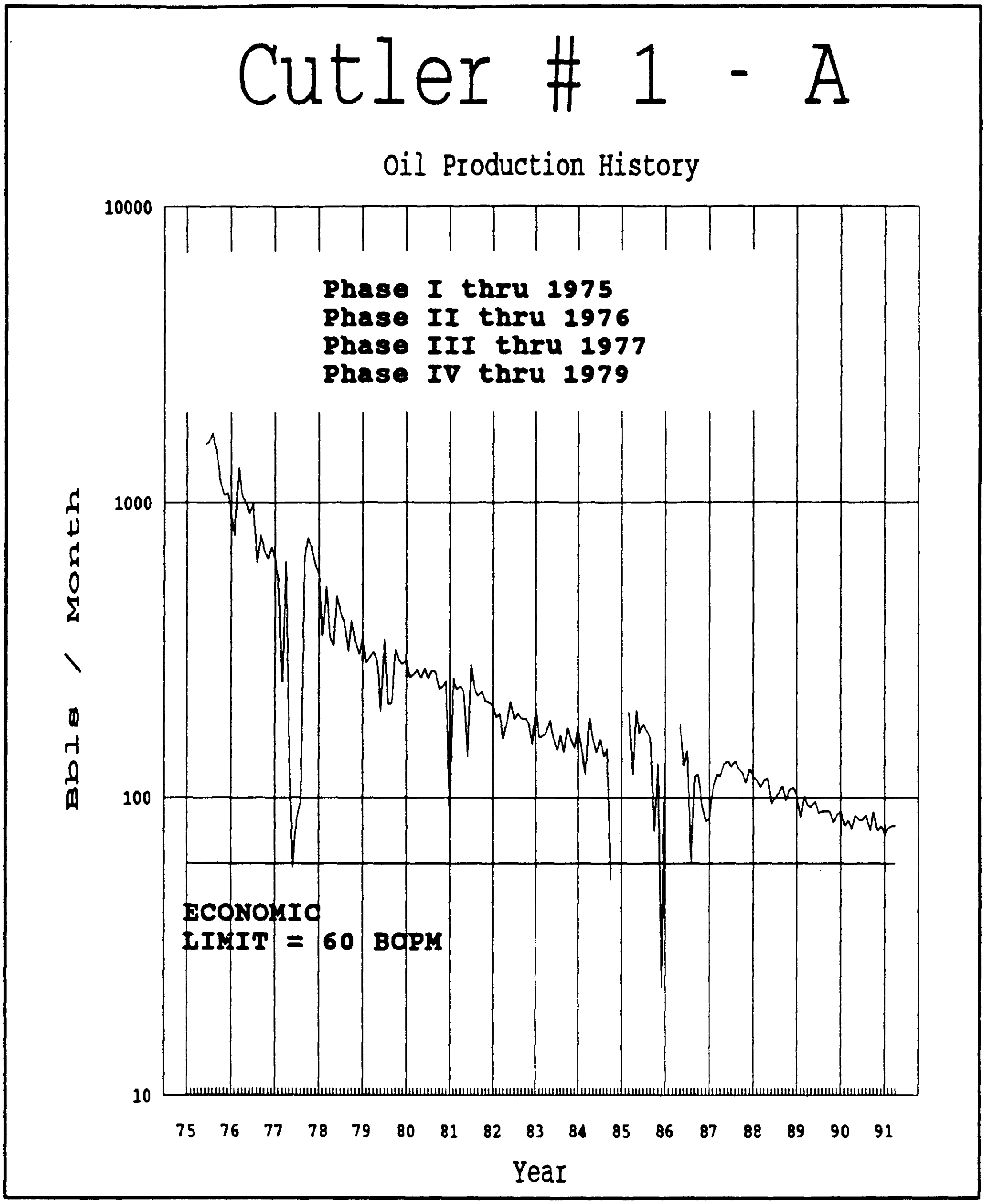


Figure 4 Cutler # 1-A production history, with phase cutoff dates.

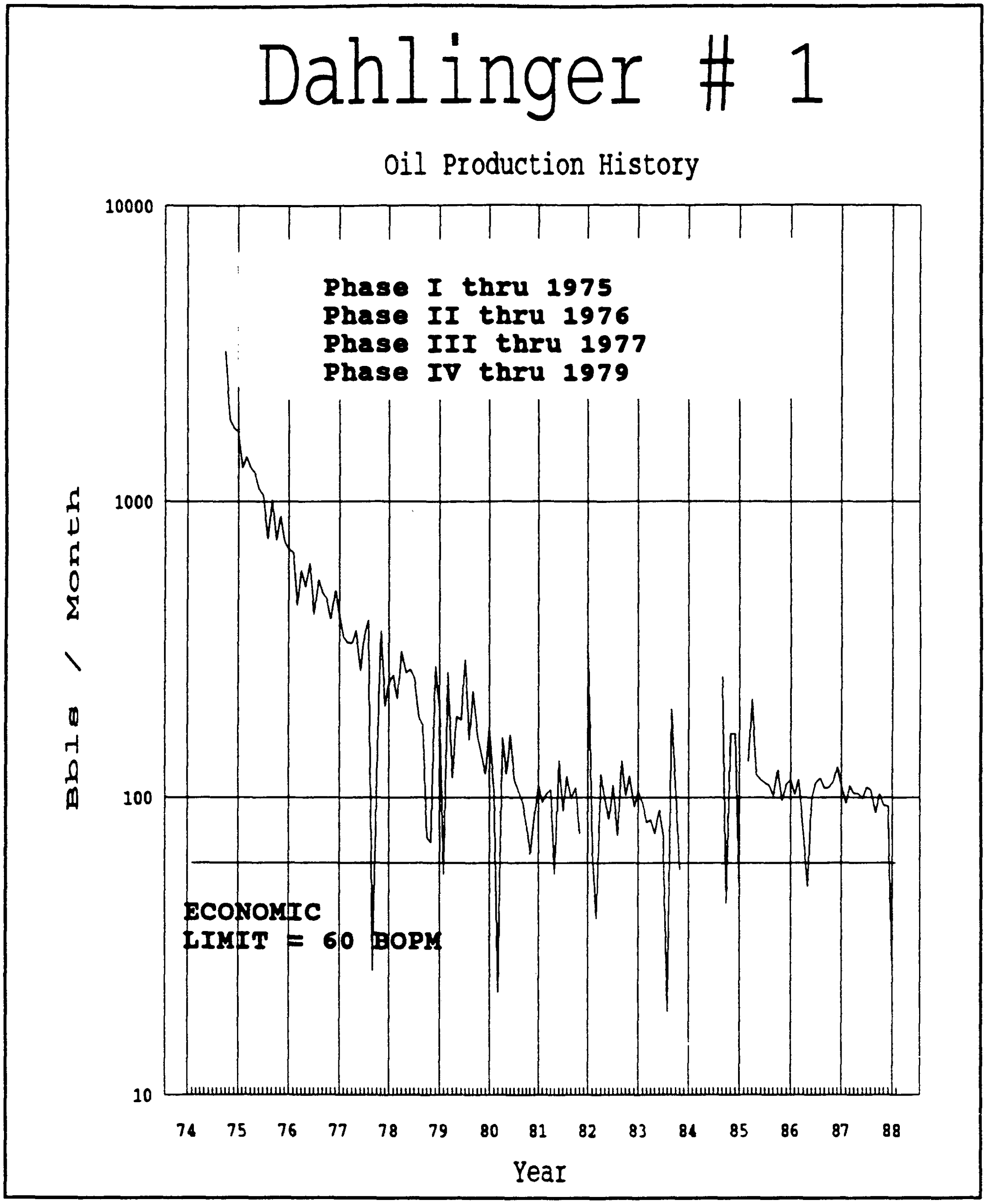


Figure 5 Dahlinger # 1 production history, with phase cutoff dates.

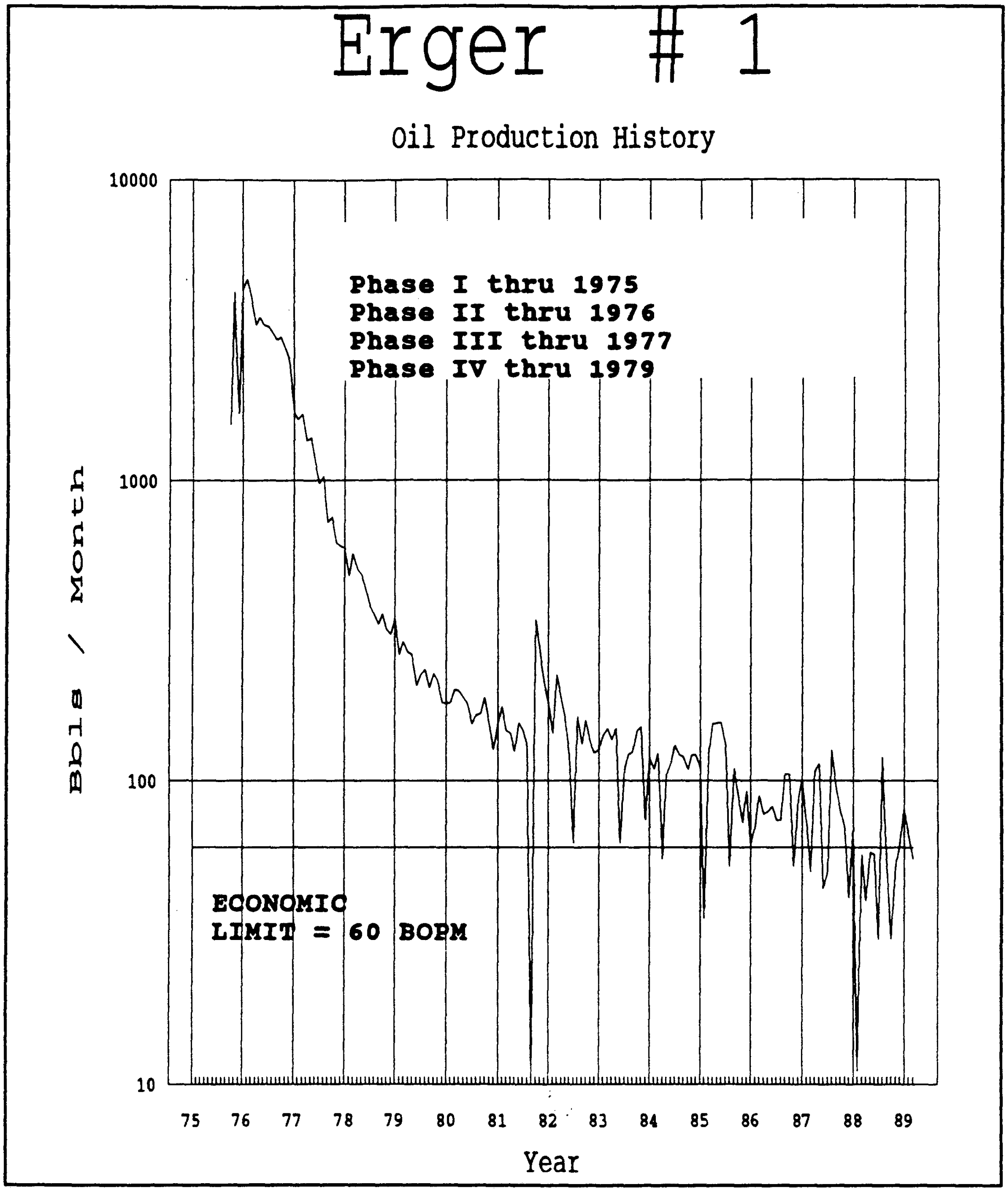


Figure 6 Erger # 1 production history, with phase cutoff dates.

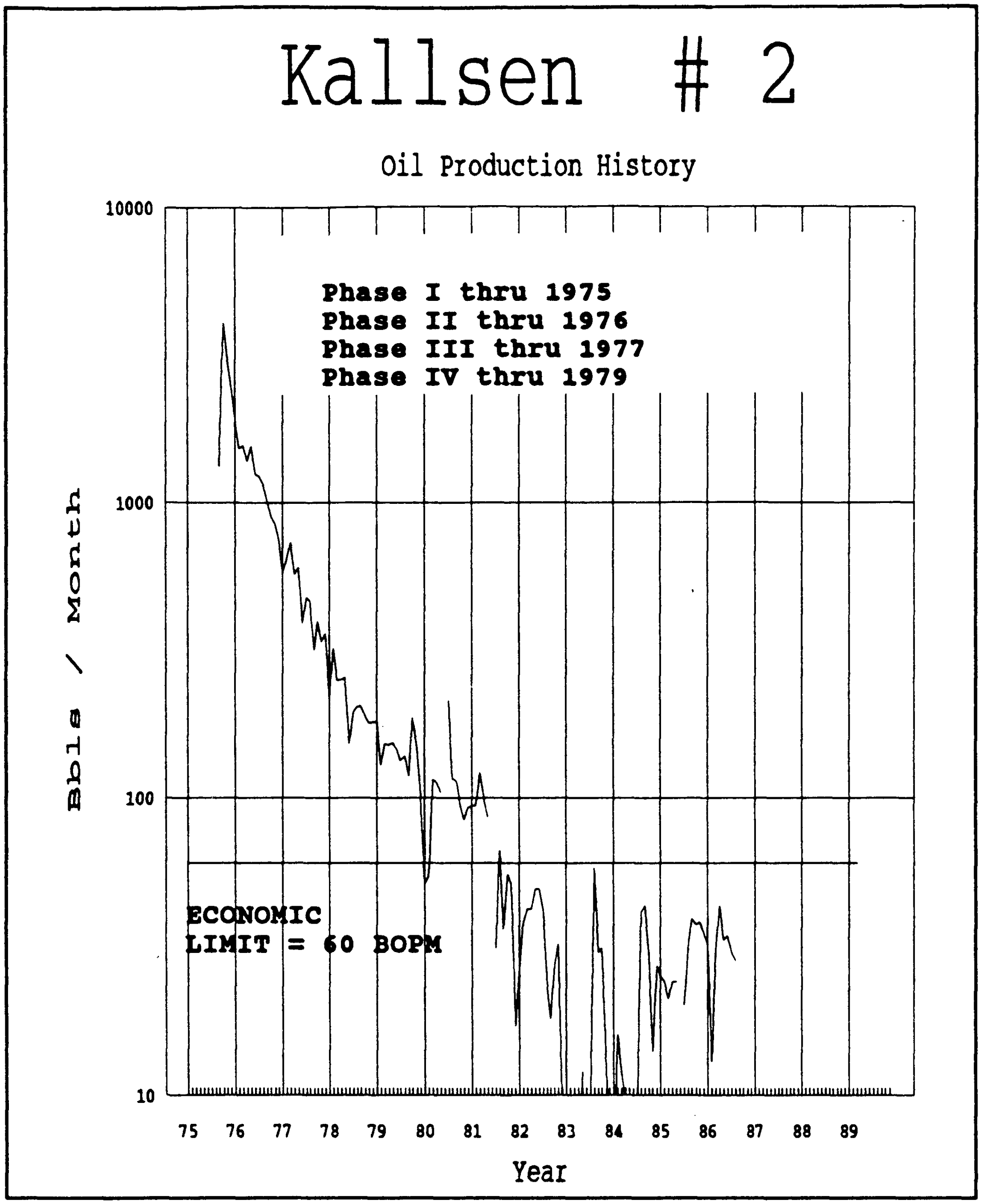


Figure 7 Kallsen # 2 production history, with phase cutoff dates

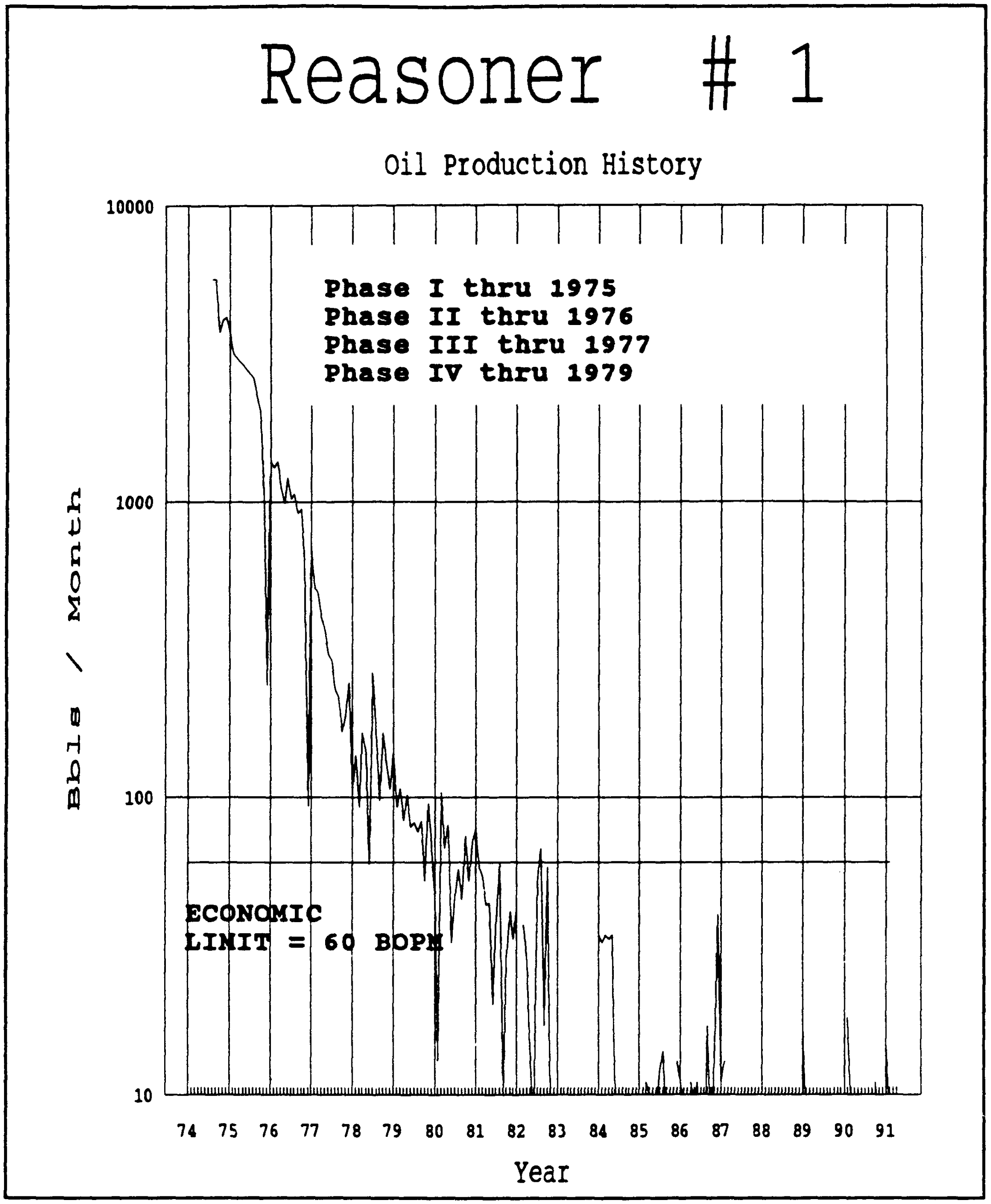


Figure 8 Reasoner # 1 production history, with phase cutoff dates.

imposed economic limit of 60 BOPM. This allows a confident estimate of ultimate reserves.

Although all five wells have "good" production plots, each well exhibits a different decline curve ranging from exponential to hyperbolic. This means that each well should be studied individually rather than combined with a generic field decline curve. No attempt was made to find wells with erratic or otherwise unusual decline characteristics.

Geologic information for the wells is limited to formation tops, producing horizon and individual well logs. Pressure data in the area was either not taken or the results were never made public. According to Petroleum Information (PI) Well Cards it appears that for a majority of the wells pressure data are not available. Information on geologic formation tops and producing interval is public information and was gathered from Petroleum Information (PI) Well Cards. Well logs vary from well to well but always include at least a density and resistivity type log. The one exception to this is the Reasoner #1-AX. This well is a redrill of the Reasoner #1-A, an abandoned well, and was logged with only a density tool.

The field itself has been studied by the Rocky Mountain Association of Geologists and the study has been published. The field study includes isopach and structure maps as well as a detailed discussion of the field. This field study was made available to the participants.

A large number of similar D - J basin producing fields were discovered in the years prior to the Bugle Field discovery. Many of these fields were also studied by the Rocky Mountain Association of Geologists. Therefore, analogous data on producing histories and field studies were made available to the study participants. Individual historical well data, however, is difficult to obtain, since Colorado reports production on a lease basis rather than by well. Therefore, a decline that looks like a single well may in fact represent several wells. This caused many problems in the early, data accumulation portion of this research.

3.3 Study Design

The study has two parts. The major portion of the study focuses on reserve estimation done both probabilistically and deterministically. The second is a ten question quiz similar to the one first introduced by E.C. Capen and designed to test an individuals ability to range answers which he defined as a "confidence interval".

The reserve portion of the study was designed to be given in a series of four phases with each phase updating information from the previous. The information supplied for these phases will be discussed in the following paragraphs. Each phase represents an incremental time interval and was given to each participant on a weekly basis for four weeks. The evaluators were asked to complete the current phase before opening the next phase. Each evaluator was asked to do reserves for all five wells for each phase of the study. The reserves were to conform with the existing and proposed SPE definitions for oil reserves. All attempts were made to give the participants only the information that would have been available for that specific year referenced in that phase and all previous years. Any variation from this will be noted in the following paragraphs.

3.3.1 Phase I

Phase I represents all years through 1975. The field was discovered in 1974. Two of the five wells, the Reasoner # 1-A and the Erger # 1, began production in that year while the remaining three, the Kallsen # 2, Cutler # 1-A and Dahlinger # 1, began a year later in 1975. For Phase I, a structure map, isopach map, Bugle Field study, cumulative field production, individual well production and decline curves, well logs, well information tickets, analogous data and answer tables (to be returned) were made available to the evaluators.

The structure map, isopach map, field study and cumulative field production data were taken from, and with the permission of, the Rocky Mountain Association of Geologists (R.M.A.G.). The actual date of publication of this material was 1982. This is a case were information that was not available in 1975 was made available to the evaluators. It was assumed that the "Company" the evaluators were doing the reserves for would have had this information and made it available to the evaluator. Because of the date of the information, some changes were made to the R.M.A.G. data. Three wells were eliminated from the 1982 published data as they were drilled subsequent to the study's Phase I (12/31/75). They were the Reasoner # 1-Ax, Boxelder # 1-9, Dahlinger # A-1. These wells were all dry holes (the Reasoner # 1-Ax was a redrill of an existing produced and abandoned well) and were assumed not to effect the R.M.A.G. mapping. Any reference to these wells on maps or in the written study was eliminated. In addition, production data or reference to ultimate recovery after 12/31/75 was eliminated from the field study.

Individual well production for the study (company) wells and the offset (non-company) wells were taken from public domain production data. All data represent actual public data and are true to the best of my knowledge. The one exception to this is the Reasoner # 1. Because Colorado reports on a lease basis, this well was reported along with the Reasoner #1-A. This lease reporting causes a problem only in 1974 when both wells were producing. At the end of 1974, the Reasoner #1-A was abandoned and the only well reporting production on that lease was the Reasoner #1. By using records at the Colorado Oil and Gas Commission in Denver, Colorado, the Reasoner # 1-A production data was eliminated from the public domain data to reflect only the Reasoner #1 well. For this study monthly oil, gas, and water production data were made available.

For the convenience of the evaluators, decline curves for all wells were made available. The production data mentioned above was plotted as monthly production oil (Bbl) and gas (Mcf) versus time (months) on semi-log graph paper. These plots were made using the capabilities of the MIDA Advanced Petroleum Software that was made available to the

Colorado School of Mines by Mannon Associates, Inc. This is the same software that was used to predict hyperbolic b value and ultimate recoveries for the study wells.

Well resistivity and density logs for all wells drilled before 12/31/75 in the Bugle Field were made available. Copies of the logs were purchased from Petroleum Information in Denver, Colorado. The entire log was not given to the participants. Instead the log was shortened to show the curves just above and below the producing horizons of the D & J formations. This, it is assumed, did not adversely affect the study while making the logs easier to handle. Since no definite water table can be seen in any of the field logs and for convenience and consistency, Rw estimates were given to all participants. These values were taken from a variety of sources. The first was data from nearby wells as published by The Denver Well Logging Society. The next was from the published R.M.A.G. studies of fields that were drilled prior to 12/31/75 in proximity to the Bugle Field. The final Rw data are commonly used values supplied by Schlumberger Well Services.

Pertinent information about the wells was typed along the side of each well log. This information is taken from the well tickets and is intended to help the participants make better use of the information and their time.

The information tickets are copied Petroleum Information tickets. These tickets are available for all company and offset wells drilled prior to 12/31/75 and contain true information to the best of my knowledge.

Analogous field data comes from data published by the R.M.A.G. The date of the publication is 1982 but the analogy data represents only selected data before 1975. The fields were chosen to represent fields with similar producing horizon(s). Also, mature fields were chosen so that participants could become familiar with an established field decline. For this study it was assumed that any data past 1973 would not have been available for the study. No attempt was made to eliminate pertinent data. The one exception to the 1973 cut-off date is that individual field primary ultimate recoveries according to the 1982 R.M.A.G. publication were supplied. These fields had a very mature decline prior to 1973 and any production since that date was considered negligible to the total production. It is assumed that an ultimate reserve estimate from these type fields would have been available at the time of this study. The average individual well ultimate reserve estimates for analogous fields was supplied only as a convenience and was not to be used as the only tool for the probabilistic estimates. This per well estimate is simply the total number of wells that ever produced in the field divided into the estimated ultimate recovery. Because the state of Colorado reports on a lease basis, individual well data can be very hard to get. These estimates were supplied to eliminate the complaint that the study failed to supply individual well ultimate reserve figures essential for some types of probabilistic evaluations. It was hoped that the individual participants would recognize the difficulty in using historical data when production is reported on a lease basis. These data were accompanied with a warning to the evaluators stating this problem.

The final information supplied to each evaluator was put on a computer disk. This disk contained the same information that was used to generate the decline curves. This was supplied for the convenience of the participants in the event they chose to use a computer type-curve program to evaluate the production declines of the wells.

Answer tables, that were to be returned, were also supplied (Tables 3 and 4). They have columns for reserve estimates and other data used for the estimates as well as room for comments and assumptions. Each table has an evaluator number box that was to be filled in by the individual.

A quiz similar to the one by E.C. Capen (Capen, 1976)

Table 3: Deterministic Answer Tables Supplied for Study

Deterministic Reserve Report
Phase No. II , Production through 12/31/76
Effective Date of the Reserve Report is 1/1/77

		Forecast Parameters as of 1/1/77			
Well No.	ERR MBO	Q_i BOPM	b	D_i 1/yr	Q_{el} BOPM
Cutler # 1-A					60
Erger # 1					60
Reasoner # 1					60
Kallsen # 2					60
Dahlinger # 1					60
Company Total					

Please enter your evaluator number in the box below.
This is critical for study evaluation !

Comments/Assumptions:

Table 4: Probabilistic Answer Tables for Study

Probabilistic Reserve Report
Phase No. II , Production through 12/31/76
Effective Date of the Reserve Report is 1/1/77

Well No.	PROVEN MBO	PROVEN + PROBABLE MBO	PROVEN + PROBABLE + POSSIBLE MBO
Cutler # 1-A			
Erger # 1			
Reasoner # 1			
Kallsen # 2			
Dahlinger # 1			
Company Total*			

*Individual well Proven (P_{90}), Proven plus Probable (P_{50}), Proven plus Probable plus Possible (P_{10}) values are not additive when calculating the company P_{90}, P_{50}, P_{10} values.

Please enter your evaluator number in the box below.
This is critical for study evaluation !

Estimate of time to complete this Phase.

Comments/Assumptions - Please comment on how the company total reserves were determined was also given in Phase I (Table 5). Capen formulated ten general knowledge questions and asked SPE-AIME members to answer these question not with a single answer but with a high and low estimate such that the true answer would lie between the two. In his quiz, Capen asked the participants to range their answer to reflect an 90 % confidence level. That is, range their answers such that they are correct an average of 9 out the 10 times. Since the proposed SPE definitions of reserves would include a confidence level for each category of reserves, a quiz similar to Capen's original quiz was given to each participant. Like Capen's, this quiz uses 10 general knowledge questions that were taken from the World Book Encyclopedia and the World Almanac. Each question is on a different topic and each answer is either a date, distance or height. The answers to the quiz given to the study participants is presented in Table 6. For this quiz, the evaluators are asked to answer with an 80% confidence interval. This reflects the interval between the Probabilistic estimates of P_{10} and P_{90}. This quiz was given to establish their confidence interval for general knowledge topics. This was done not only for data purposes but also to get the participants used to the idea of ranging an estimate to reflect an 80 % confidence interval that they would be using later in the probabilistic

Table 5: Capen Quiz

Capen Quiz

Give a high and low answer (i.e. , range) for the following questions. Use an 80% confidence interval - that is, if you do the quiz perfectly, the correct answer will lie inside your range on eight of the questions and the correct answer will lie outside your range on two questions. This portion of the study will introduce you to the idea of the 80 % confidence interval that will also be used for the probabilistic reserve estimate.

		HIGH	LOW
1.	POPULATION OF THE U.S. IN 1900	________	________
2.	AREA OF THE CONTINENTAL U.S. AND DISTRICT OF COLUMBIA, IN SQ MILES	________	________
3.	MEAN DISTANCE FROM MERCURY TO THE SUN, IN MILES	________	________
4.	YEAR OF SAFETY PIN INVENTION	________	________
5.	HEIGHT OF MT. EVEREST, IN FEET	________	________
6.	LENGTH OF GEORGE WASHINGTON BRIDGE OVER THE HUDSON RIVER, NEW YORK CITY, IN FEET	________	________
7.	LENGTH OF THE COLORADO RIVER, IN MILES	________	________
8.	MILES OF SURFACED ROADS IN THE U.S. IN 1964	________	________
9.	DISTANCE FROM SEATTLE TO ATLANTA ACCORDING TO AAA ROAD ATLAS, IN MILES	________	________
10.	WHAT IS THE AIR DISTANCE FROM SAN FRANCISCO TO HONG KONG, IN MILES	________	________

Table 6: Capen Quiz Answers

1.	75,994,575
2.	3,630,854
3.	36,000,000
4.	1849
5.	29,028
6.	3,500
7.	1,450
8.	2,271,886
9.	2,793
10.	6,904

reserve estimates. The results of this quiz would then be compared to results for the probabilistic reserve estimates.

3.3.2 Phase II

Phase II of the study represents data through 1976 and updates the information in Phase I. During the year represented by Phase II, one well was drilled and subsequently abandoned as a dry hole. This was the Reasoner # 1-Ax - a redrill of an abandoned well. Information supplied for this phase updates all production and includes log information for the Reasoner # 1-Ax.

3.3.3 Phase III

Phase III of the study represents data through 1977 and updates the information in Phase II. During the year represented by Phase III, two wells were drilled and subsequently abandoned as dry holes. These were the Boxelder # 1-9 and the Dahlinger # A-1. Information supplied for this Phase updates production and includes log information for the Boxelder # 1-9 and the Dahlinger # A-1.

3.3.4 Phase IV

Phases IV of the study represents data through 1979 and updates the information in Phase III. Information supplied for this Phase updates all production.

3.4 Study Participants

Once the study had been outlined with goals established, study participants were needed. Participants were selected with the sole criteria being that they are practicing or retired petroleum engineers. No attempt was made to select professionals based on their opinion of the proposed definitions.

Their degree of experience, expertise, or feelings about the proposed changes was not a factor. The main pool of participants were taken from my personal acquaintances in the industry and nationwide chapters of the Society of Petroleum Evaluation Engineers (SPEE).

My personal acquaintances were contacted individually. The study was outlined to them and they were asked if they were willing to participate. Once an individual accepted the invitation, a letter was sent to each, further outlining the study. A total of 14 engineers from this group accepted the invitation to participate in the study.

The SPEE chapters of Denver, Dallas, Houston, Midland, and Tulsa were also asked to participate. The chapters were contacted through a single individual, usually the chapter chairman. After outlining the study to that individual, a letter further outlining the study was then sent to each chapter. That letter was copied and offered to the members at the chapters next meeting. The members then, individually, decided if they wished to take part in the study. The study received good response from the SPEE chapters and a total of 13 SPEE members chose to participate. The majority of the SPEE participants are from the Denver and Tulsa chapters, although Dallas and Houston are represented. In addition to these groups of participants, additional engineers offered their assistance after hearing of the study through current participants.

A total of 29 practicing petroleum engineers offered to take the study. The engineers are both men and women and represent a wide range of companies. Several work for, or own, consulting firms while others work for independents, majors and pipeline companies. Experience levels are also wide ranging with many being professional engineers and, as mentioned before, members of the Society of Petroleum

Evaluation Engineers. Several have been in the industry for over 25 years and have several years experience in the study area of the Denver-Julesberg basin.

3.5 Study Distribution

The study was designed to be mailed to the evaluators in four separate, weekly phases. The study started in mid-February with each participant receiving Phase I of the study. Subsequent phases followed on a weekly basis for the three remaining Phases. The final phase was mailed on March 13. The initial letter spelled out this time schedule and stated that all estimates for all phases should be completed and returned by mid-April. Each additional phase was sent with a label sealing the manila envelope that asked the participants not to open the envelope until all previous phases were completed and returned. This label allowed the weekly mailings of each phase rather than waiting for a returned phase before mailing the next. By mailing weekly it was hoped to keep the participants focused on getting the study completed rather than letting it sit. It was felt that the professionals were honorable enough to not look at a future phase before doing the current one. Besides, since the field is an actual producing field they could have easily accessed a production database to get the actual up-to-date production had they desired.

3.6 Study Well's Ultimate Reserves

Since this study is a comparison of estimated remaining reserves to actual remaining reserves, it was essential that a good, defendable estimate for actual remaining reserves be obtained for each well. As stated, the study imposed an economic limit of 60 BOPM to eliminate any individual variation. Using this economic limit, ultimate reserves were figured for the five study wells. This estimate was done two ways. The method of the estimate depended on the individual well.

The first method is very straightforward. Since two of the wells have already reached the study economic limit, their ultimate reserve number was assumed to be the total amount of production the well had made prior to reaching the study economic limit. Some well's production fluctuated around the economic limit and the point chosen can be disputed. However, since the wells made the majority of their production early in their life, it was seen that any error in picking the economic limit date would not significantly alter the study results.

A second method was used for the three remaining wells. Since they are still producing above the study imposed economic limit, the previously mentioned type curve program was used. For this program, production data was loaded from a floppy disk. The production data was then superimposed on a series of Fetkovich log-log dimensionless curves. The data was then manipulated to a best fit on a given curve. The program was given the study economic limit of 60 BOPM and a ultimate recovery was estimated. As in method number one, the three wells are so close to the economic limit that any error in the type curve matching does not result in a large swing in remaining reserves. In addition, the remaining reserves are small in comparison to the ultimate reserve estimate. The "Results" section of this thesis gives the results and further discusses the type-curve matching.

Table 7 gives the well's current cumulative production and estimated remaining reserves where appropriate.

Table 8 gives the well's actual remaining reserves (ARR) for each phase.

Table 7: Estimated Ultimate Production for the Five Study Wells

Reserve Table for all five study wells			
Well Name	Cumulative Production 4/91 (MBO)	Estimated Remaining Reserves (MBO)	Ultimate Production (MBO)
Cutler # 1-A	52.3	3.8	56.1
Dahlinger # 1	43.8	1.3	45.1
Erger # 1	83.9	0.8	84.7
Kallsen # 2	38.2	0.0	38.2
Reasoner # 1	73.5	0.0	73.5

Table 8: Actual Remaining Reserves for each Well by Phase. Based on AUR in Table III

Actual Remaining Reserves by Phase (MBO)				
Well Name	Phase I	Phase II	Phase III	Phase IV
Cutler # 1-A	46.2	35.8	30.7	21.5
Dahlinger # 1	23.6	17.3	13.8	9.1
Erger # 1	77.3	36.6	23.1	15.0
Kallsen # 2	29.6	12.8	6.6	2.0
Reasoner # 1	20.3	8.3	4.18	1.51

4.0 Study Procedure

4.1 Collection of data

Of the original 29 evaluators who offered to assist in this reserve study, 15 finished at least one Phase while 12 completed all four Phases. This response is understandable since these evaluators were completing this study while doing their full time job. All data that have been analyzed represent only the 12 fully completed studies - no partials. Any other completed studies will be incorporated into the database for future analysis. Table 9 shows the personal information (no names) of the individual evaluators.

In order to collect the data in a concise and consistent manner, the professionals were asked to return Tables 3 and 4 for each Phase of the reserve study. These tables included both the deterministic and probabilistic reserve estimates for each well. Also included were the calculation parameters for the deterministic estimates and their comments on that particular Phase of the study.

After collecting the reserve estimates, a data base of each evaluator's estimated remaining reserves (ERR) values for each well was constructed for each phase, using a Lotus

Table 9: Personal Information for Study Evaluators

Evaluator #	Total Years	Rocky Mountain Years	DJ Basin Years	SPEE Member	Registered PE
1	30	30	30	y	y
4	30	15	5	y	y
5	15	8	0	n	y
9	24	19	15	y	y
14	10	6	0	n	y
16	15	0	0	y	n
18	18	3	0	y	y
19	26	9	2	y	y
20	13	10	0	n	n
21	10	8	8	n	y
27	15	5	3	n	y
31	9	8	8	n	n

123 spreadsheet program. In addition to the wells, a data base was constructed for the "Company" total (all 5 wells combined). Thus six data bases were constructed which included the evaluator's number and ERR estimates for P_{90}, P_{50}, P_{10} and Deterministic categories.

It became evident when rechecking the data, that several evaluators had misunderstood some of the directions for reserve evaluations. A few reported Deterministic reserves on an estimated ultimate reserve (EUR) basis and had then multiplied this value by some percent to obtain the probabilistic values for EUR. Fortunately, these evaluators detailed their estimating process in the comments section of the answer tables and an estimate for ERR for both the deterministic and probabilistic values could be calculated. One evaluator, on occasion, allowed the estimate for the deterministic ERR to fall outside of the probabilistic P_{90} and P_{10} range. This evaluator was contacted and the discrepancy was explained. One evaluator refused to believe that reserves from a producing well could be called anything but "Proved". Therefore, this individual did not accept the "Proved + Probable", P_{50}, and "Proved + Probable + Possible", P_{10}, categories for the probabilistic ERR estimates. This evaluator simply reported these categories as 0 reserves. Because of the skewing effects of this data, this evaluator

(#1) was not used in this study. One evaluator had mistakenly completed Phase IV before Phase III. This obviously would bias his decision in Phase III since he had already "seen" the future. Therefore, this evaluator's Phase III estimates were disallowed and this is the reason that the number of evaluators is one less in this Phase than the other three Phases. This same problem occurred for Phase II. This is the reason Phase II has one less evaluator. Other quirks in the data come from an individuals perception of what P_x is represented by the deterministic "reasonably certain" definition. Some placed the deterministic values at P_{50} while others placed it a P_{90}. Still others placed it anywhere from P_{90} to P_{10}. Since there is no firm definition as to what deterministic "reasonably certain" really means, no attempt to refine or eliminate these data was made.

4.2 Processing of Data

The data were analyzed using the Lotus 123 spreadsheet program.

In an effort to describe the average ERR value for each Phase and well and the distribution of the estimates about that average, the mean and standard deviation of the ERR data were calculated for each well at each Phase. It was discovered that the presence of several very high or very low estimates of the ERR for each well was skewing the mean values and resulting in high standard deviations. Eliminating these outliers was not prudent as they represented valid estimates.

In order to evaluate the distribution without the skewing effect of the outliers, a method employed by Scott Digert in the Colorado School of Mines Thesis number 3018 was used. This method uses the median values and the fourth values as the summary statistics. Here, if the data were sorted in ascending order, the median value would be the center of the data in terms of counting, with the upper and lower fourths splitting each resulting half into quarters. Thus, fifty percent of the data points would lie above the median and fifty percent below. Twenty-five percent of the data points would lie below the lower fourth, and twenty-five percent above the upper fourth. Fifty percent of the data points would lie between the upper and lower fourths. This relationship is illustrated in Figure 9. It should be noted that both the median and the fourth values are resistant to the magnitude of any outlying data, as they are a function only of the relative position of the data points

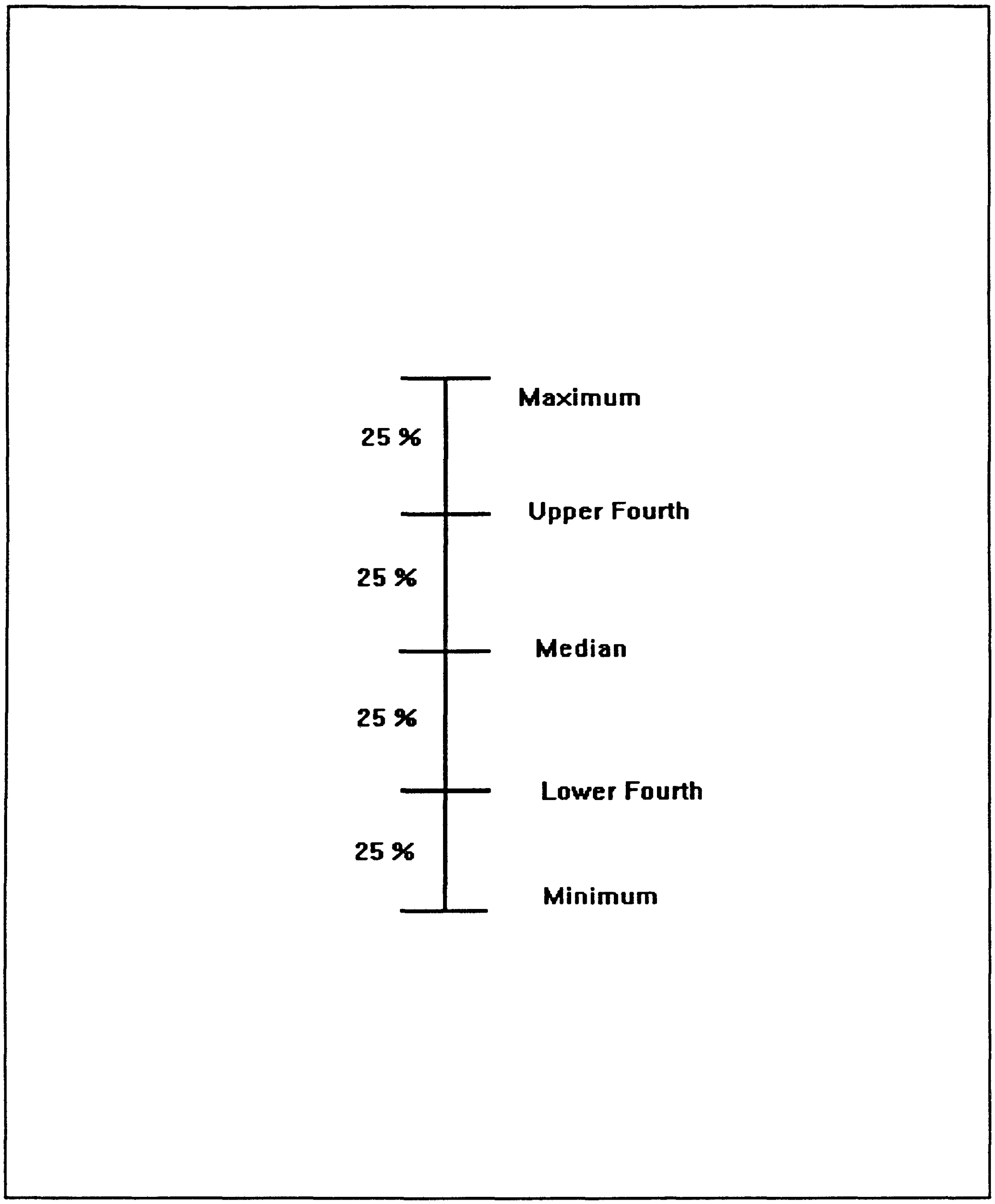


Figure 9 Diagram of the order statistics in an ordered distribution

within the ordered sample. Thus, a high outlier has no more weight than any other data point within the upper twenty-five percent of the sample. The value of the median and fourths would not be changed by a change in the value of the outlier, as long as it remains within its quartile. Such a change would change the value of both the mean and the standard deviation. Due to this resistance to the values of the outliers, the median and fourth-spread (the value of the upper fourth minus the lower fourth) are better indicators of the center of the distribution and its spread than are the mean and the standard deviation.

The point of collecting the evaluator's data is to compare their estimates with the actual performance of the wells. This is done most clearly by calculating the ratio of the estimates to the actual production. As the estimate approaches "truth", this ratio approaches 1. For this study, the comparison is made on the basis of Estimated Remaining Reserves to Actual Remaining Reserves (ERR to ARR).

This comparison of the evaluators distribution with the actual production data requires either the knowledge of "truth" or the best possible estimate. For two wells, the Reasoner # 1 and the Kallsen # 2, the actual production figures are known as the wells are now abandoned. The remaining three wells were estimated from a monthly production of less than 100 BOPM (3 Barrels per day - BOPD). As explained earlier, a type-curve program was used to estimate remaining reserves for these three wells. Since the wells were so close to the study imposed economic limit of 60 BOPM (2 Barrels per day - BOPD) any error in the type-curve match did not result in any meaningful change in the ultimate production figure. This is due to the fact that the vast majority of the reserves were made early in the wells life. Of these three wells, the Dahlinger # 1 was abandoned in 1987 at approximately 3 BOPD. This was done for economic reasons and it was therefore necessary to extrapolate this wells decline to the study economic limit for consistency. Table 8 shows ultimate production broken down by cumulative production and remaining reserves if any.

5.0 Discussion of Results

5.1 Introduction

After all the data were received, it became apparent that it could be manipulated in many of ways. However, it was decided to concentrate on four main areas. First is the results of the Capen quiz. Second is the deterministic and probabilistic reserve estimates and subsequent evaluation for each well and evaluator. The third is the determination of the effect of an individual well's hyperbolic exponent b on the probabilistic reserve estimates. The fourth and final area is comparing an evaluators ability to estimate the probabilistic reserves versus their Capen quiz score.

5.2 Capen Quiz

Table 10 shows the results of the Capen quiz. This table lists the evaluator number and the number of correctly ranged answers out of ten. For this study the average score was slightly less than 5 out of 10. The average score for Capen's original quiz was between 3.5 and 4.0. According to

Table 10: Capen Quiz Score by each Evaluator

Evaluator #	Total Years Experience	Capen Quiz Score
1	30	5
4	30	4
5	15	8
9	24	4
14	10	5
16	15	5
18	18	3
19	26	7
20	13	2
21	x	3
27	x	8
31	9	5

these results, this study's evaluators are above average when ranging answers. These results will be used to analyze the probabilistic estimate results.

5.3 Reserve Estimates

The individual evaluator estimates for ERR are presented in Tables 11 through 22 for the five wells and the company total. It should be noted that of the several methods to estimate the probabilistic reserves, no evaluator chose to use any kind of distributions for use in a statistical type analysis (although several alluded to the possibility of their use). The majority of the evaluators chose to use volumetrics and decline curve analysis for the deterministic estimate then varied this estimate by some function to estimate the probabilistic reserves. In comparing individual evaluators an examination of the data shows a large spread between the minimum and the maximum estimates.

Table 11: Estimated Remaining Reserves for Phase I and Phase II for each Evaluator

Cutler # 1-A

Estimated Remaining Reserves

Eval #	PHASE I MBO ARR = 46.2 MBO				PHASE II MBO ARR = 35.8 MBO			
	Determ	P90	P50	P10	Determ	P90	P50	P10
1	16.3	16.3	x	x	10.7	10.7	x	x
4	13.6	10.0	12.0	15.0	18.5	18.0	21.0	24.0
5	11.7	10	13	16	18.4	13.9	22	30
9	37.68	12.5	35.6	75.4	45.2	7.4	11.4	18.1
14	33.9	33.9	52	81.6	23.2	23.2	48	98.9
16	28.3	28.3	40.6	65.0	22.2	22.2	31.7	54.6
18	16.0	8.0	16.0	39.0	22.9	17.1	26.5	50.2
19	20.6	15.6	28.0	50.9	20.0	15.0	24.5	40.0
20	24.0	13.0	21.5	35.9	16.5	9.3	14.1	21.2
21	10.9	0.75	7.4	14.0	x	x	x	x
27	55.3	31.6	55.3	89.6	36.8	23.0	36.8	56.1
31	45.9	34.5	46.0	57.5	25.6	19.2	25.6	32.0

Table 12: Estimated Remaining Reserves for Phase III and Phase IV for each Evaluator

Cutler # 1-A

Estimated Remaining Reserves

Evaluator #	PHASE III MBO ARR = 30.7 MBO				PHASE IV MBO ARR = 22.5 MBO			
	Deter	P90	P50	P10	Deter	P90	P50	P10
1	8.6	8.6			6.2	6.2		
4					9.4	8	9	10
5	9	6.4	9.5	13	6.4	5.3	8.2	11
9	38.3	5.0	13.1	26.1	25.5	14.2	18.7	24.9
14	16.6	16.6	39	89.1	8.4	8.4	15	26
16	18.8	9.5	23.6	31.8	6.2	6.2	10.0	20.0
18	14.8	12.3	16.4	23.7	4.6	3.8	5.8	10.2
19	14.9	10.1	17.0	29.8	12.2	9.7	15.5	24.4
20	14.2	7.1	12.0	18.1	5.6	4.1	5.3	6.8
21	5.3	0.9	5.1	9.3	13.4	7.0	15.8	24.5
27	30.4	18.2	30.4	49.5	22.3	12.2	22.3	40.1
31	21.6	18.4	21.6	24.8	7.2	7.2	7.9	9.0

Table 13: Estimated Remaining Reserves for Phase I and Phase II for each Evaluator

Dahlinger # 1

Estimated Remaining Reserves

Eval #	PHASE I MBO ARR = 23.6 MBO				PHASE II MBO ARR = 17.3 MBO			
	Deter	P90	P50	P10	Deter	P90	P50	P10
1	9.5	10	x	x	9.2	9.2	x	x
4	31.4	30	35	40	18.9	19	20	21
5	21.5	15	22	29	18.8	13.9	18	21
9	56.1	23.1	55.2	108.8	30.6	7.5	10.3	14.3
14	33.1	33.1	62	112.	16.8	16.8	39	92.5
16	36.8	36.8	49.1	79.8	16.7	16.7	38.2	62.5
18	40	12	22	45	21	18.8	25.1	36.6
19	40.2	28.1	52	100.6	21.9	16.5	26.5	44
20	17.7	8.6	15	26.6	14.6	8.4	11.7	15.9
21	6.7	2.5	7.0	11.3	x	x	x	x
27	45.7	30.5	45.7	66.8	15.8	20.1	31.4	58.1
31	83.7	63	84	105	25.6	19.2	25.6	32

Table 14: Estimated Remaining Reserves for Phase III and Phase IV for each Evaluator

Dahlinger # 1

Estimated Remaining Reserves

Eval #	PHASE III MBO ARR = 13.8 MBO				PHASE IV MBO ARR = 9.1 MBO			
	Determ	P90	P50	P10	Determ	P90	P50	P10
1	5.2	5.2	x	x	4.1	4.1	x	x
4					4.0	4	4.5	4.8
5	7.9	5.6	8.3	11	3.3	2.7	3.8	5
9	10.5	4.8	6.8	10.1	6.9	5.1	5.8	6.8
14	11.8	11.8	15	51.1	7.2	7.2	8	9
16	6.7	2.6	12.7	22.8	3.3	3.3	5	8.5
18	6.4	4.5	6.4	10.2	4.2	3.4	4.2	5.4
19	8.1	5	9	16.2	6.7	5.7	8.7	13.4
20	4	3	3.9	4	1.2	0.7	1	1.4
21	2.9	0.03	7.2	14.4	3.2	0.1	3.6	7.0
27	14.1	8.9	14.1	20.1	9.2	4.8	9.2	14.1
31	7.6	6.5	7.6	8.7	2.8	2.8	3.1	3.5

Table 15: Estimated Remaining Reserves for Phase I and Phase II for each Evaluator

Erger # 1

Estimated Remaining Reserves

Eval #	PHASE I MBO ARR = 77.3 MBO				PHASE II MBO ARR = 36.6 MBO			
	Deter	P90	P50	P10	Deter	P90	P50	P10
1	59.0	59	x	x	54.4	54.4	x	x
4	62.1	50	62	80	61.6	60	100	120
5	21.6	18.8	26	34	55	40.5	50	65
9	68.9	35.1	66.6	118.1	43.2	45.5	53.5	63.4
14	52.4	52.4	86	143.3	94.4	30.5	71	164
16	102.6	102.6	112.6	179.3	81.9	81.9	100.8	117.5
18	16	8	19	48	55	47	50.7	78.7
19	28.7	21.3	37	64.8	109.6	87.1	138	220
20	23.1	11.9	20	34.6	63.5	36.7	55	83.9
21	37.5	36.4	50.0	63.9	x	x	x	x
27	45.3	26.0	45.3	71.0	66.2	33.9	66.2	104
31	93.9	70.5	94	117.5	97.6	73.2	97.6	122

Table 16: Estimated Remaining Reserves for Phase III and Phase IV for each Evaluator

Erger # 1

Estimated Remaining Reserves

Evalu #	PHASE III MBO ARR = 23.1 MBO				PHASE IV MBO ARR = 15.0 MBO			
	Deter	P90	P50	P10	Deter	P90	P50	P10
1	4.8	4.8	x	x	2.6	2.6	x	x
4					5.1	5	5.5	6.0
5	8.1	5.4	9.2	13	3.9	3.3	5.2	6
9	21.7	6.5	11	19.1	9.6	5.7	7.1	9.2
14	19.9	17	29.5	52.6	7	7	9.4	12.9
16	17.5	5.3	32.3	59.2	4	4	7	14
18	10.8	9.3	12.7	18.2	3.1	2.6	3.6	5.4
19	16.1	10.8	18.8	32.2	5.6	4.7	7.2	11.2
20	10.7	5.4	9.2	15.6	3.0	2.1	2.8	3.9
21	33.5	24.4	42.3	60.2	6.3	2.9	8.2	13.5
27	30.1	15	30.1	53.8	8.4	4.5	8.4	13.4
31	21.6	18.3	21.6	24.8	6.3	6.3	6.9	7.9

Table 17: Estimate Remaining Reserves for Phase I and Phase II for each Evaluator

Kallsen # 2

Estimated Remaining Reserves

Evalu #	PHASE I MBO ARR = 29.6 MBO				PHASE II MBO ARR = 12.8 MBO			
	Deter	P90	P50	P10	Deter	P90	P50	P10
1	60	60	x	x	8.0	8.0	x	x
4	53.6	40	49	60	15	15	17	20
5	49	32	50	68	12.8	11.1	15	20
9	68.9	20.5	39.7	81.6	28.3	9.8	14.5	22.3
14	72.1	65.1	110	190	35.7	35.7	74	151.4
16	91.4	91.4	137.4	241.4	23	23	48.8	74.6
18	82	29	51	99	25.9	13.3	21.4	41.4
19	64	43.6	76	136.6	20.3	15.3	24.5	40
20	61	30.3	50	80.5	14	8.9	12.6	17.8
21	13.7	2.4	11.8	21.6	x	x	x	x
27	83.7	53.0	83.7	133.9	36.4	24.3	36.4	59.4
31	93.9	70.5	94	117.5	29.6	22.2	29.6	37

Table 18: Estimated Remaining Reserves for Phase III and Phase IV for each Evaluator

Kallsen # 2

Estimated Remaining Reserves

Eval #	PHASE III MBO ARR = 6.6 MBO				PHASE IV MBO ARR = 2.0 MBO			
	Deter	P90	P50	P10	Deter	P90	P50	P10
1	3.6	3.6	x	x	2.7	2.7	x	x
4					3.4	3.4	4.4	6.0
5	5.2	3.9	5.4	7	2.7	2.2	3.6	5
9	7.3	4.6	6.5	9.5	2.2	1.9	2.0	2.2
14	14.1	14.1	24	41.8	3.3	3.3	4.5	6.3
16	9.8	4.7	18.8	33	2.0	2.0	4.5	10
18	4.7	3.5	5.4	9.1	2.1	1.8	2.3	3.1
19	5.7	4.5	7.2	11.4	8.0	6.9	10.4	16
20	4.3	3.1	4.1	5.3	2.6	1.8	2.4	3.3
21	4.3	2.5	6.7	10.8	2.8	0	4.3	8.6
27	13.8	8.6	13.8	19.3	6.3	3.0	6.3	8.6
31	11.6	9.9	11.6	13.3	3.5	3.5	3.9	4.4

Table 19: Estimated Remaining Reserves for Phase I and Phase II for each Evaluator

Reasoner # 1

Estimated Remaining Reserves

Eval #	PHASE I MBO ARR = 20.3 MBO				PHASE II MBO ARR = 8.3 MBO			
	Deter	P90	P50	P10	Deter	P90	P50	P10
1	26.3	26	x	x	7.0	7.0	x	x
4	48.6	45	48	50	21.1	21	28	35
5	9.4	2.8	8	13	17.4	12.7	17	22
9	53.6	11.1	52.1	117.7	10.1	11.2	13.3	15.7
14	89.3	45.1	140	437	30	30	108	370
16	61.8	61.8	87.8	189.5	29.5	29.5	69.0	100
18	0.8	0.5	1	6	0	0	0	0
19	80.0	64.4	116.0	213.2	36.6	25.7	43.5	73.0
20	22.7	1.3	8.6	56.6	16.2	0.3	2.4	19.4
21	14.6	2.9	11.0	19.3	x	x	x	x
27	7.3	0.9	17.8	51.5	0.9	0.5	12.6	39.2
31	135.1	101.3	135	168.8	51.6	38.7	51.6	64.5

Table 20: Estimated Remaining Reserves for Phase III and Phase IV for each Evaluator

Reasoner # 1

Estimated Remaining Reserves

Eval #	PHASE III MBO ARR = 4.18 MBO				PHASE IV MBO ARR = 1.51 MBO			
	Deter	P90	P50	P10	Deter	P90	P50	P10
1	2.0	2.0	x	x	0.3	0.3	x	x
4					1.6	1.6	1.7	1.8
5	4	2.9	4.4	6	0.8	0.6	1.3	2
9	3.9	2.1	3.1	4.6	0.32	0.31	0.31	0.32
14	2	2	9.3	45	0.5	0.5	1.4	4.0
16	5.7	1.8	10.6	19.4	0.3	0.3	0.8	2.6
18	2.4	1.8	2.8	4.7	0.2	0.1	0.2	0.5
19	3.3	2.8	4.3	6.6	0.9	0.8	1.2	1.8
20	2.6	1.5	2.2	3.1	0.18	0.17	0.19	0.21
21	10.7	5.1	9.8	14.5	0	0	4.3	8.6
27	9.2	5.9	9.2	16.5	1.6	0.78	1.6	3.4
31	5.6	4.76	5.6	6.44	0.38	0.38	0.42	0.47

Table 21: Estimated Remaining Reserves for Phase I and Phase II for each Evaluator

Company Total
All Five Wells Combined

Estimated Remaining Reserves

Eval #	PHASE I MBO ARR = 197.0 MBO				PHASE II MBO ARR = 110.8 MBO			
	Deter	P90	P50	P10	Deter	P90	P50	P10
1	171.1	171	x	x	89.3	89.3	x	x
4	209.3	175	206	245	135.1	133	186	220
5	113.2	86	119	154	122.4	105	136	165
9	285.2	102.3	249.2	501.6	157.5	81.5	103	134
14	280.8	331.2	510	795.3	200	183.3	260	367
16	320.9	x	x	x	173.3	173.3	288.5	409
18	154.8	57.5	109	237	124.8	96.2	123.7	207
19	233.5	173	310	566.1	208.4	160	257	417
20	148.5	58.3	105	189.1	124.8	59.5	100	163
21	64.5	35.2	60.0	97.1	x	x	x	x
27	237.3	142	247.8	412.7	156.2	101.8	183.4	317
31	452.6	339.8	453	566.3	230	173	230	288

Table 22: Estimated Remaining Reserves for Phase III and Phase IV for each Evaluator

Company Total
All Five Wells Combined

Estimated Remaining Reserves

Eval #	PHASE III MBO ARR = 78.4 MBO				PHASE IV MBO ARR = 50.1 MBO			
	Deter	P90	P50	P10	Deter	P90	P50	P10
1	24.2	24.2	x	x	15.9	15.9	x	x
4					23.5	22	25.1	28.6
5	34.2	24.2	36.8	50	17.1	14.1	22.1	29
9	81.7	23.1	40.6	69.3	44.5	27.2	34	43.3
14	64.1	59.2	95	150.8	26.4	34	42	52
16	58.5	x	x	x	15.8	15.8	27.3	55.1
18	39.1	31.4	43.7	65.9	14.2	11.7	16.1	24.6
19	48.1	33.2	56.3	96.2	33.4	27.8	43	66.8
20	35.8	25.7	38.5	57.3	12.6	16	25	30.8
21	58.3	42.1	64.9	87.6	48.3	0.4	32.2	64.0
27	97.5	56.6	97.5	159.2	47.7	25.3	47.7	79.6
31	68	58	68	78.2	20.2	20.2	22.2	25.3

The following graphical comparisons were made for each well and the Company Total:

a) ERR/ARR versus % AUR Produced. Average ERR for Deterministic, P_{90}, P_{50}, P_{10} values. Y axis is normalized (ERR/ARR).

b) ERR versus % AUR Produced. Average ERR for Deterministic, P_{90}, P_{50}, P_{10} values. Y axis is absolute ERR (MBO).

c) Standard Deviation/ARR versus % AUR Produced. Standard Deviations of Deterministic, P_{90}, P_{50}, P_{10} values. Y axis is normalized - representing the standard deviation per barrel of remaining reserves.

d) Standard Deviation versus % AUR Produced. Standard Deviations of Deterministic, P_{90}, P_{50}, P_{10} values. Y axis is absolute ERR (MBO).

e) Deterministic Quartile plots. Plots of the median, upper fourth, and lower fourth deterministic values versus % AUR Produced.

f) P_{90} Quartile plots. Plots of the median, upper fourth, and lower fourth P_{90} values versus % AUR Produced.

g) P_{50} Quartile plots. Plots of the median, upper fourth, and lower fourth P_{50} values versus % AUR Produced.

h) P_{10} Quartile plots. Plots of the median, upper fourth, and lower fourth P_{10} values versus % AUR Produced.

Each % AUR point represents a Phase in the study. Individual evaluator plots for ERR/ARR versus % AUR Produced can be found in Appendices C through H.

An example of each of the graphs is presented in the following pages for the Cutler # 1-A. This well is not a "typical" well but was selected to demonstrate each of the graphs. The graphs for the remaining 4 wells can be found by graph type in Appendices A and B. The Cutler # 1-A is also included in these appendices. Please note that the company plots show only the deterministic values. This is because the majority of the evaluators added individual well P_x values to get a Company P_x. This is not correct and therefore any plots of this data would be useless.

5.3.1 ERR/ARR Plots

Figure 10 is ERR/ARR versus % AUR Produced for the Cutler # 1-A. The line representing ARR/ARR can be used as a baseline. If the data fall on this line then the

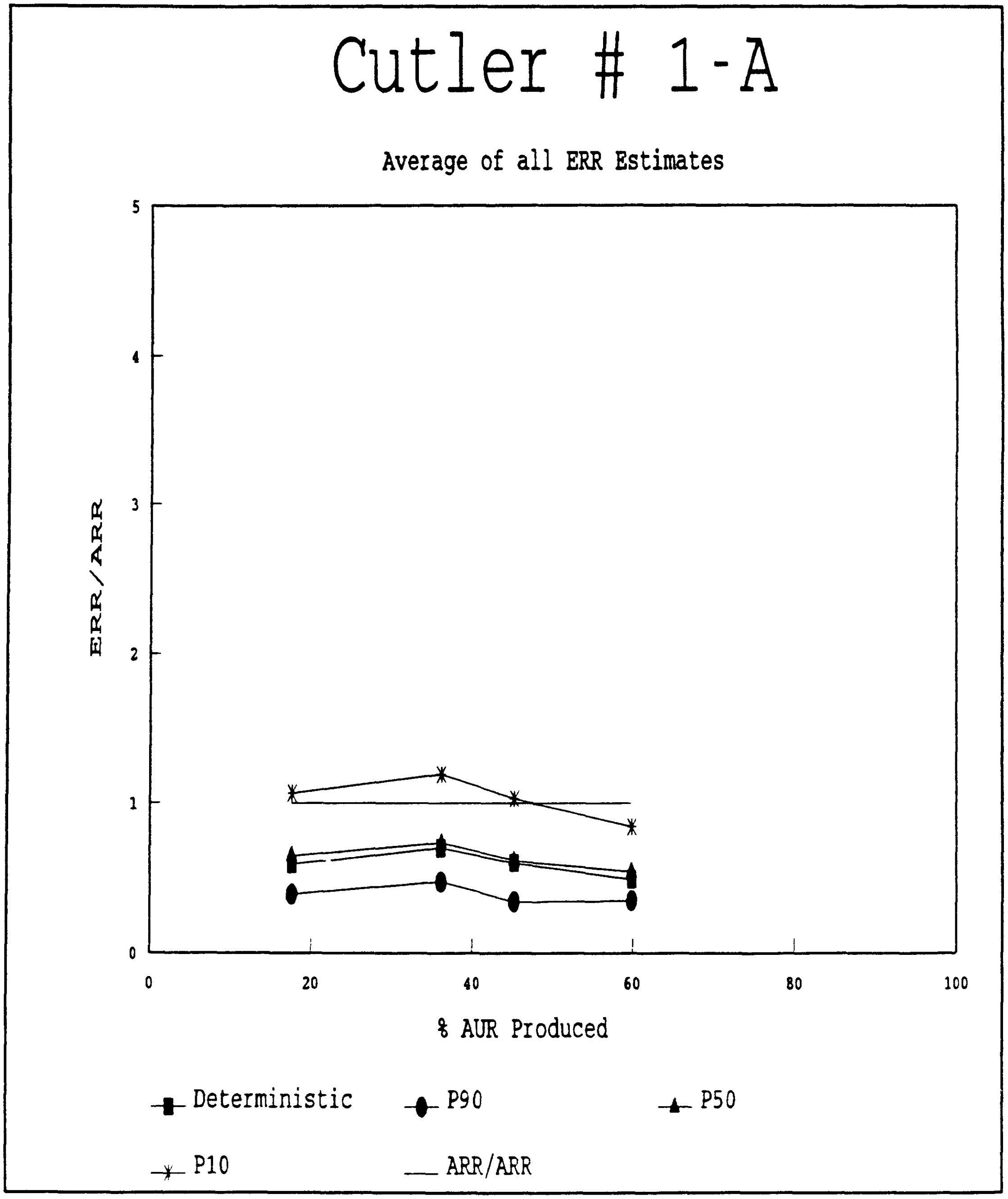


Figure 10 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Cutler # 1-A

estimates closely represent the actual remaining reserves or truth. This figure shows that the range between P_{90} an P_{10} does not narrow with additional production history. In general the average estimates for all reserve categories tended to be below truth. In Appendix A, the Kallsen # 2 average estimates are seen to be above truth and, like the Cutler # 1-A, the range between P_{90} and P_{10} does not narrow.

Figure 11 is ERR versus % AUR Produced for the Cutler # 1-A. This graph uses the same data as in Figure 10 but the Y axis is plotted as absolute ERR in MBO. Actual remaining reserves are represented by the straight line without the marked data points. This plot shows that the range between P_{90} and P_{10} in MBO narrows and that all categories of average estimates follow the actual reserve decline through time.

5.3.2 Standard Deviation Plots

Figure 12 is Standard Deviation/ARR versus % AUR Produced for the Cutler # 1-A. This plot represents the variability per barrel for each category of reserves. This "certainty" ratio gives an indication of how the variability of the estimates changes with respect to the actual

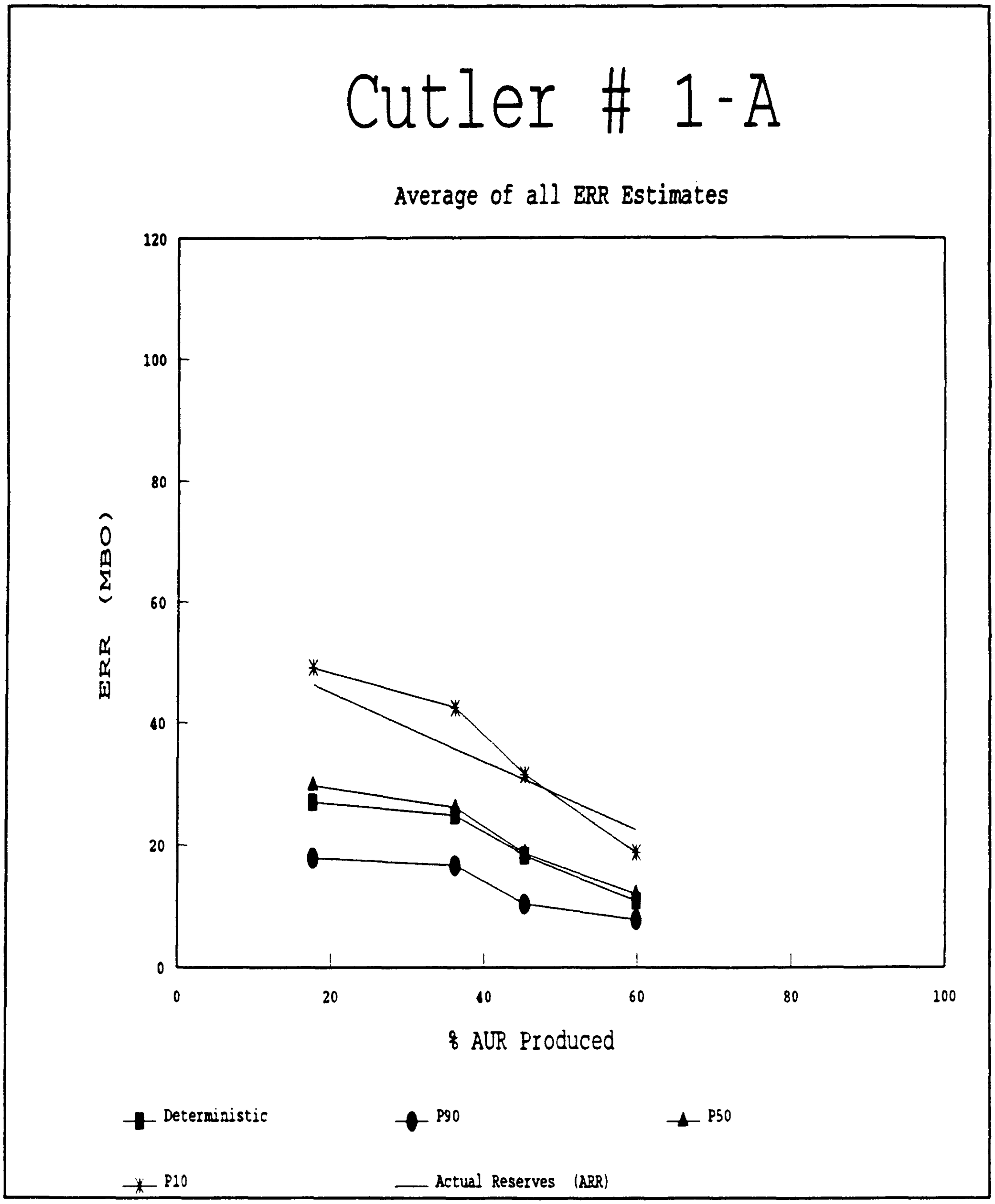


Figure 11 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Cutler # 1-A. Y axis in MBO

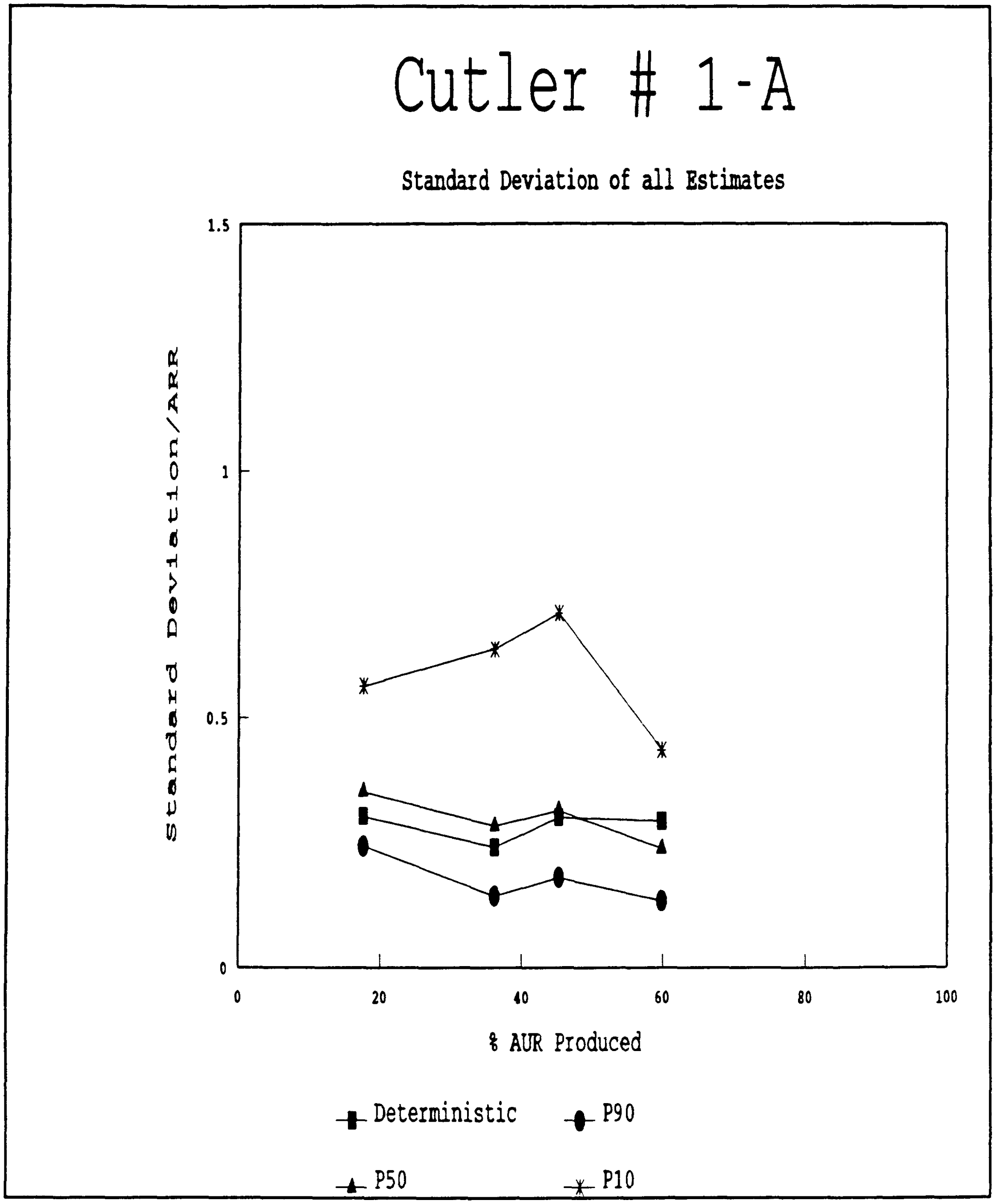


Figure 12 Standard Deviation/ARR of P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Cutler # 1-A

remaining reserves. For this well, the "certainty" ratio does not improve with time. The greatest variability lies with the P_{10} estimates. That is, the evaluators are more in agreement with the other estimates than they are with the P_{10} estimates.

Figure 13 is the Standard Deviation versus % AUR Produced for the Cutler # 1-A. On an MBO basis, the standard deviation decreases with time and the difference between P_{90} and P_{10} decreases.

5.3.3 Quartile Plots

Figure 14 is the Deterministic quartile plot for the Cutler # 1-A. This plot as explained earlier, gives an indication of the range of estimates without the skewing effects of outliers. This plot indicates that the deterministic estimates were generally low.

Figure 15 is the P_{90} quartile plot. Here again, the estimates are below "truth" (as they should be). A comparison of this figure to Figure 14, shows that the ranges for both estimates are nearly identical. This indicates that many evaluators put the P_{90} estimate very near the Deterministic estimate.

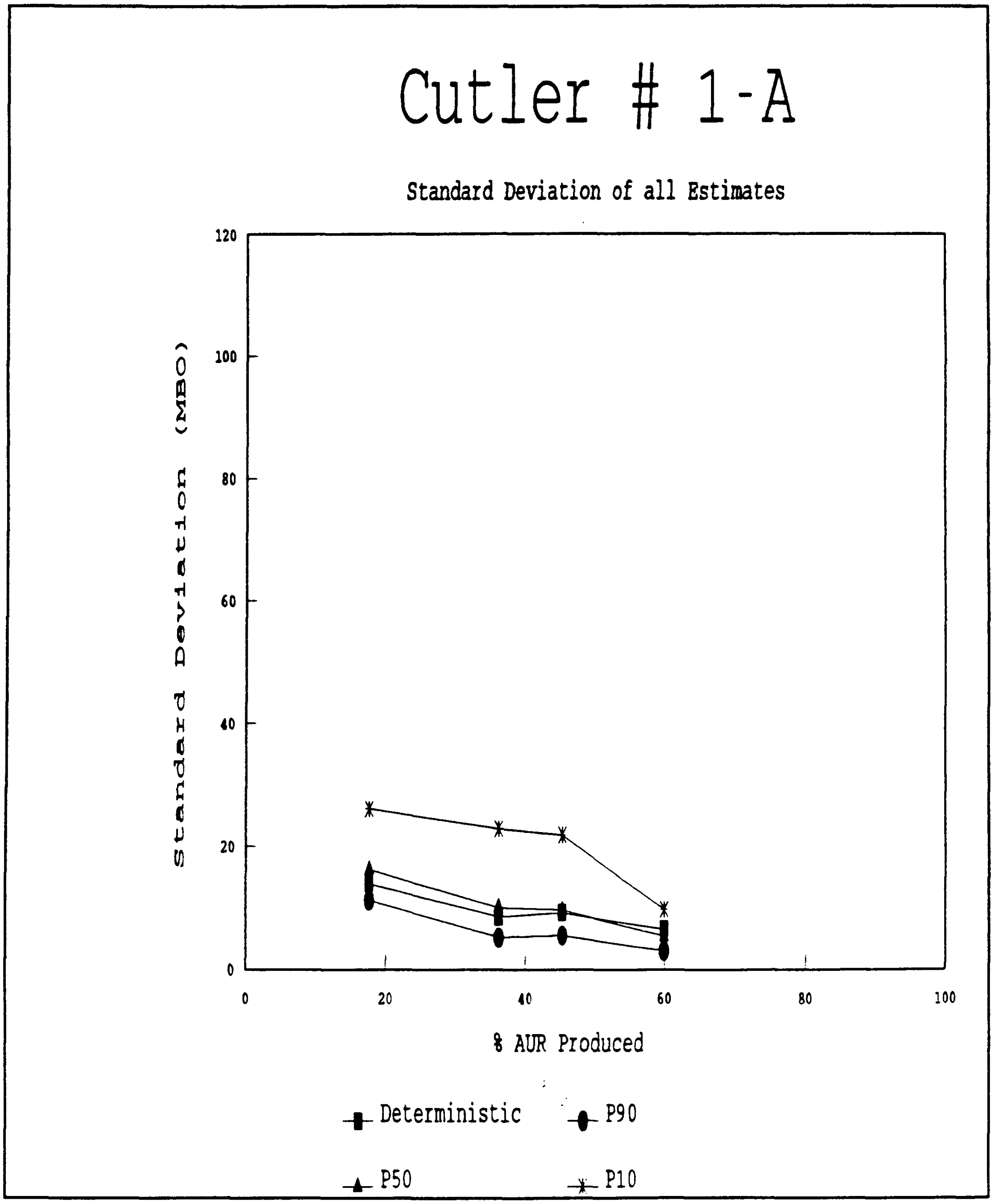


Figure 13 Standard Deviation for P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Dahlinger # 1. Y axis in MBO

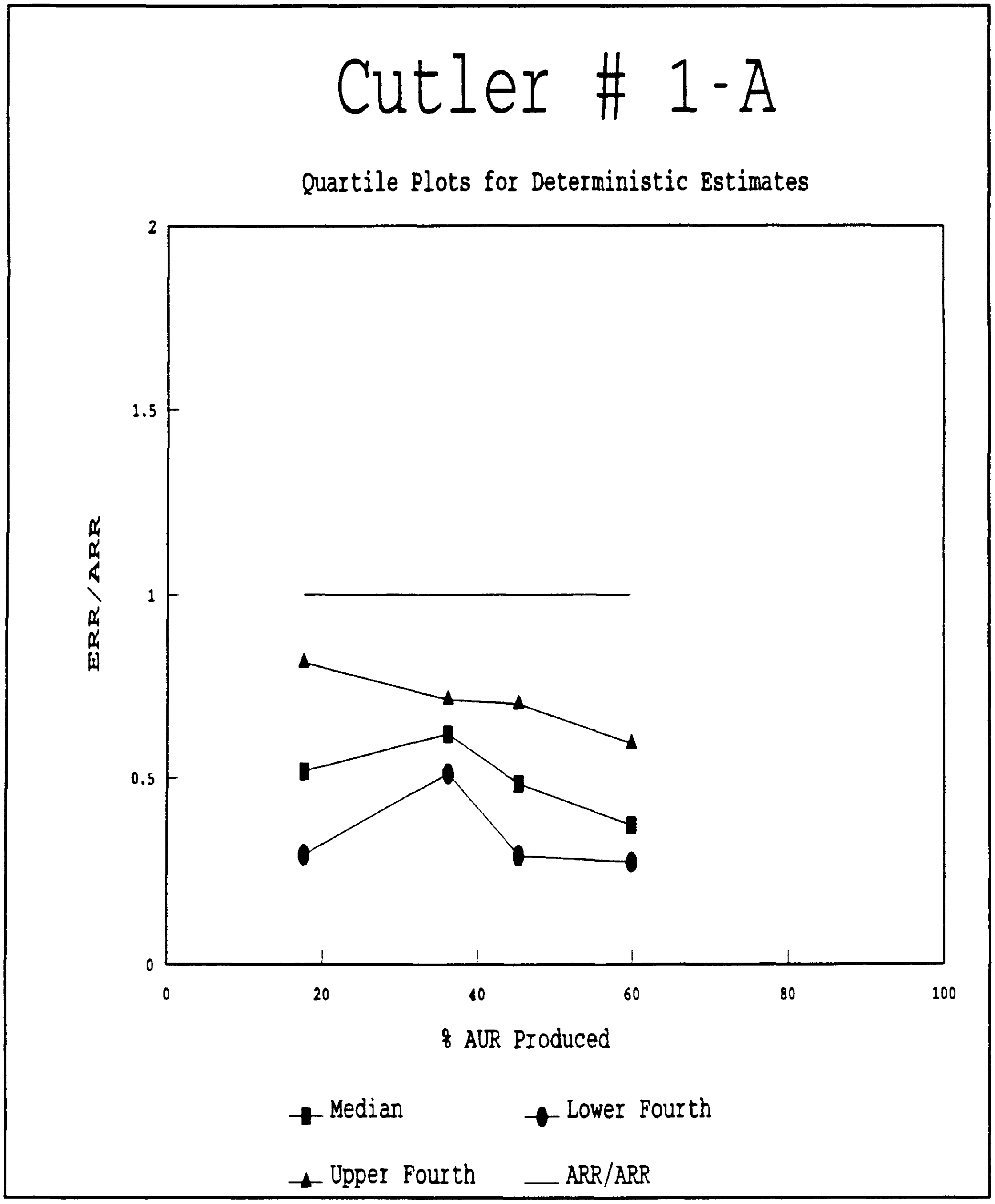


Figure 14 Quartile plot of Deterministic Estimates for the Cutler # 1-A

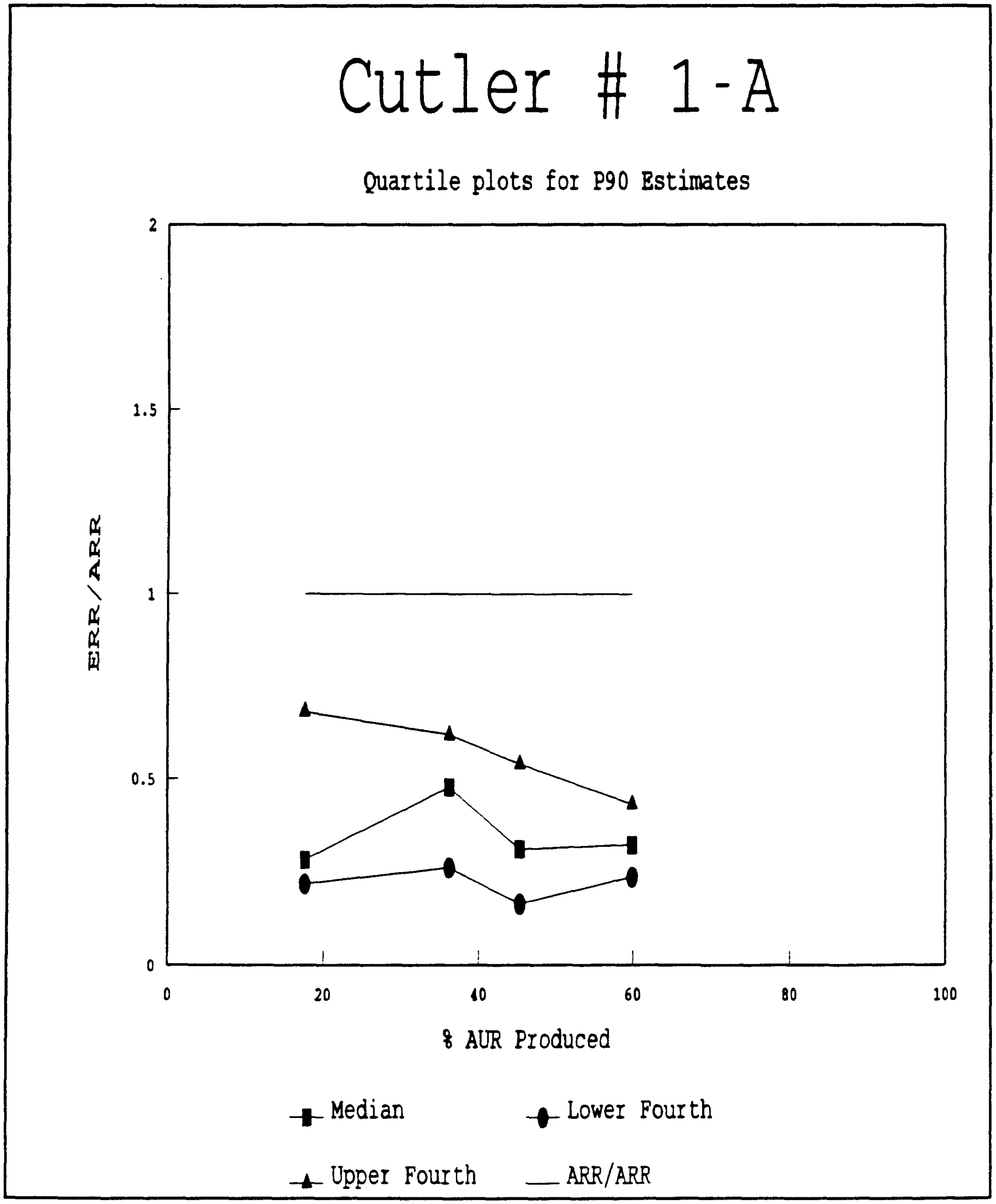


Figure 15 Quartile Plot of P_{90} Estimates for the Cutler # 1-A

Figure 16 is the P_{50} quartile plot. This plot's upper quartile moves closer to truth than the previous two plots. However, the upper and lower quartiles do not bracket "truth" as might be expected. In Phase I, the evaluators are in less agreement with the P_{50} value than they are with the Deterministic and P_{90} estimates.

Figure 17 is the P_{10} quartile plot. The upper and lower quartiles straddle truth. Since P_{10} is the high end estimate, one would expect this plot to be above truth. When comparing the range from upper to lower quartile, it is seen that this estimate has the greatest variation. Also note that the lower quartile falls within the Deterministic, P_{90} and P_{50} quartile ranges.

Again, the Cutler # 1-A is not intended to illustrate an average study well. Instead, it is used to demonstrate the meaning of each of the plots. Plots for each well can be found in Appendices A and B. Individual evaluator plots are in Appendices C through H. The reader is encouraged to review all plots.

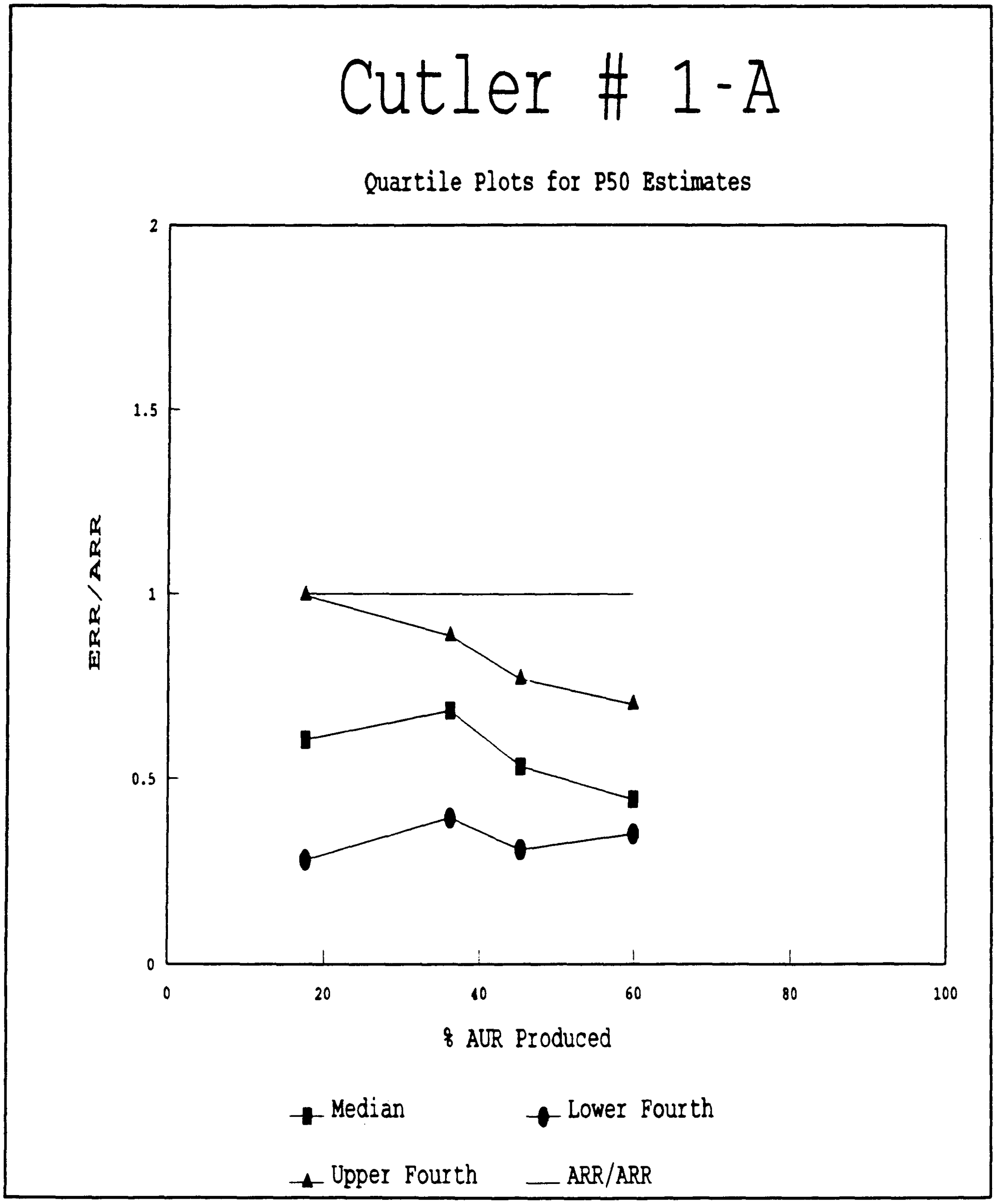


Figure 16 Quartile Plot of P_{50} Estimates for the Cutler # 1-A

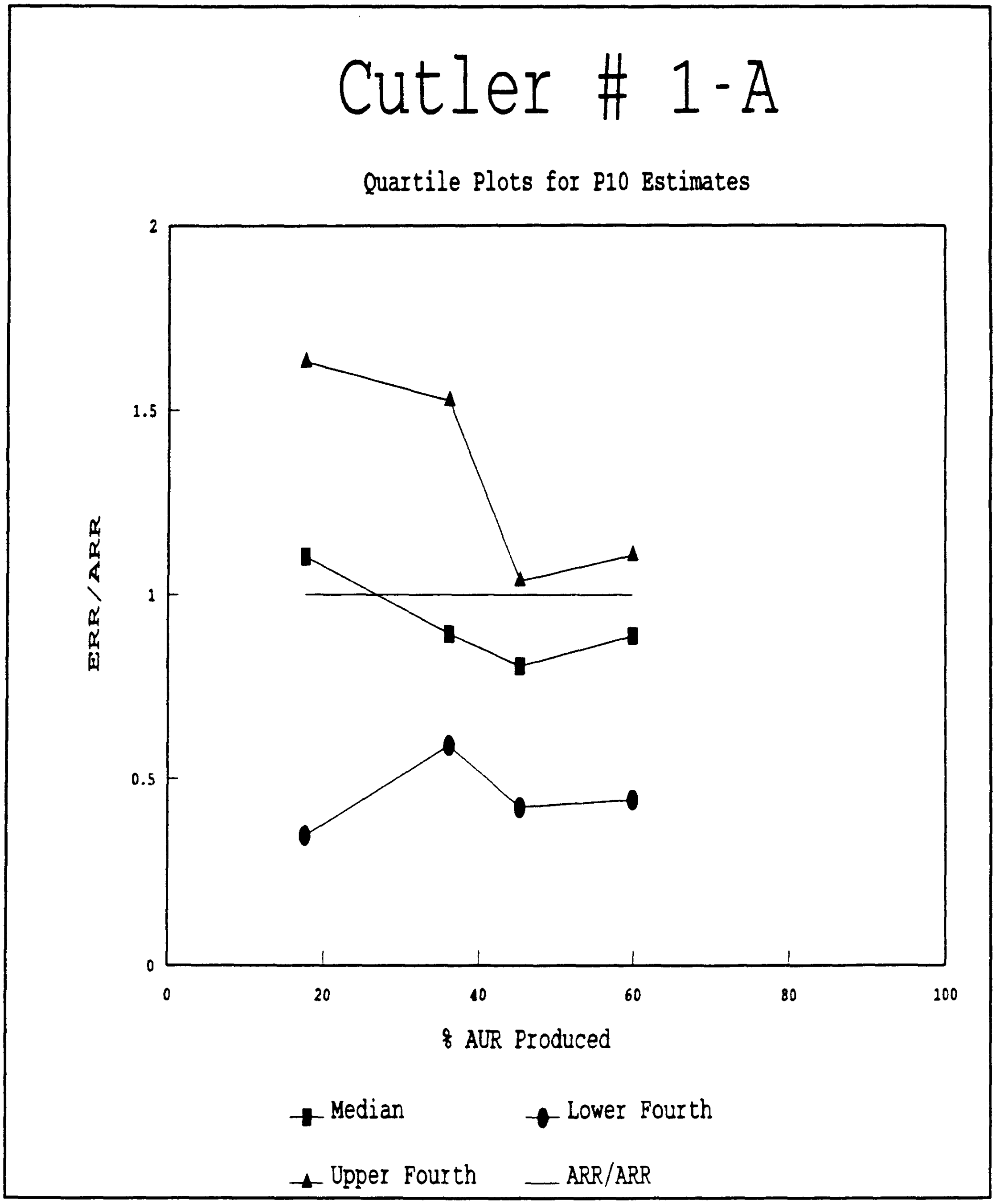


Figure 17 Quartile Plot of P_{10} Estimates for the Cutler # 1-A

5.4 Evaluation of P_{90} and P_{10} estimates

A process of "grading" the evaluators was used to determine how accurately P_{90} and P_{10} are estimated. In order to be completely correct an evaluator's estimate for P_{90} should be less than actual remaining reserves 9 out of 10 times. In order to be completely correct for the P_{10} estimate, an evaluator's estimate for P_{10} must be higher than actual remaining reserves 9 out of 10 times. The "grading" for this study was very simple. A P_{90} estimate was correct if it was less than actual remaining reserves. A P_{10} estimate was correct if it was greater than actual remaining reserves. The percent correct is simply the total number of correct estimates divided by the total number of estimates.

The individual evaluator's "graded" P_{10} versus "graded" P_{90} values is shown in Figure 18. The trend seems to be that if an evaluator is good at estimating P_{90}, then they are not as good at estimating P_{10} and visa-versa.

Table 23 lists the five wells and the percentage of correct P_{90} and P_{10}. When a plot of individual well P_{10} versus P_{90} is made, a trend appears. Figure 19 shows that the wells that appear to be "more" hyperbolic score lower in percent P_{10} correct and higher in

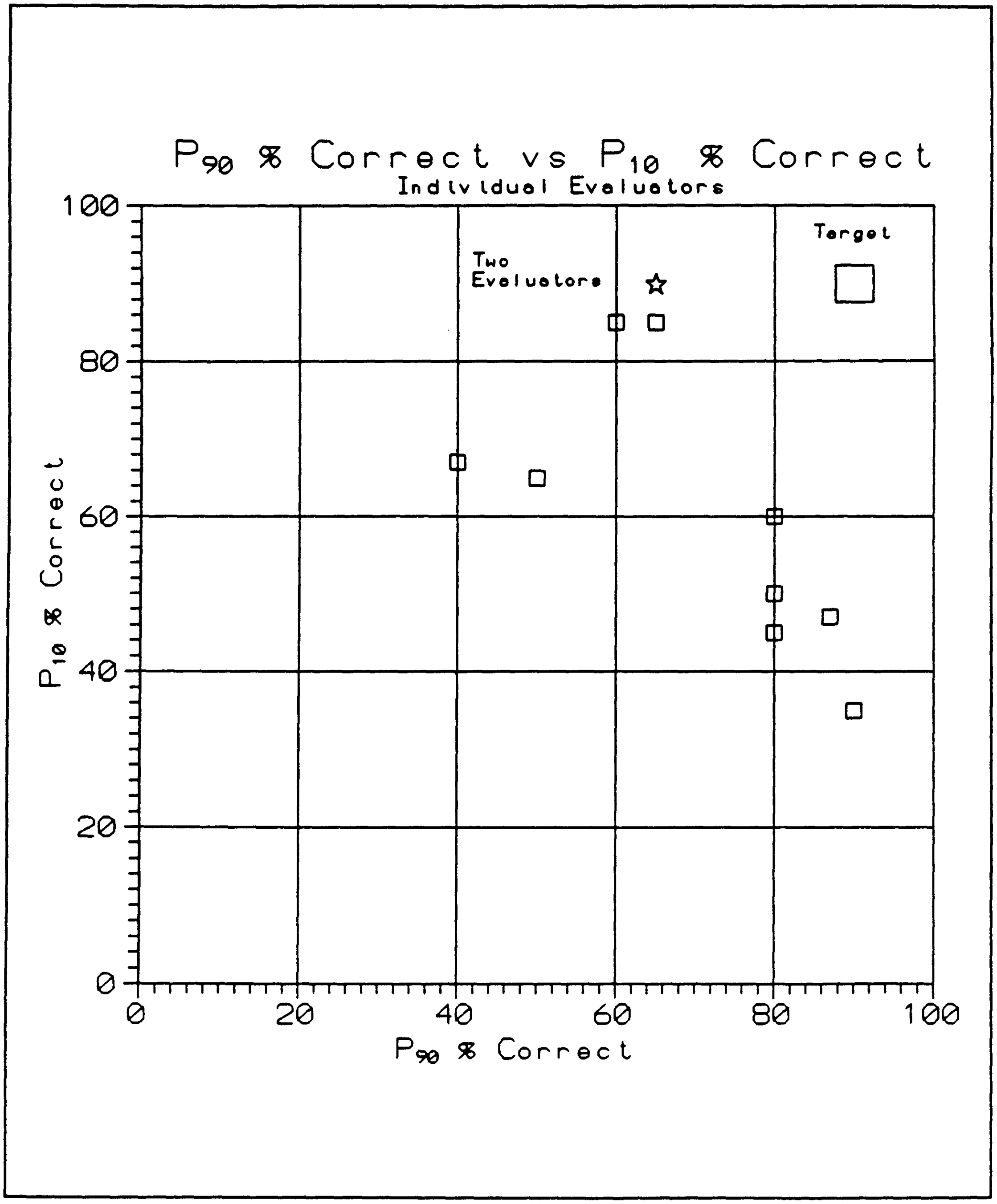


Figure 18 Individual Evaluators P_{10} % correct versus P_{90} % Correct

Table 23: P_{90} and P_{10} Estimates % Correct by Well

% P90 and P10 Correct for each Well		
Well Name	P90 % Correct	P10 % Correct
Cutler #1-A	100	45
Dahlinger # 1	78	60
Erger # 1	76	50
Kallsen # 2	43	95
Reasoner # 1	61	79

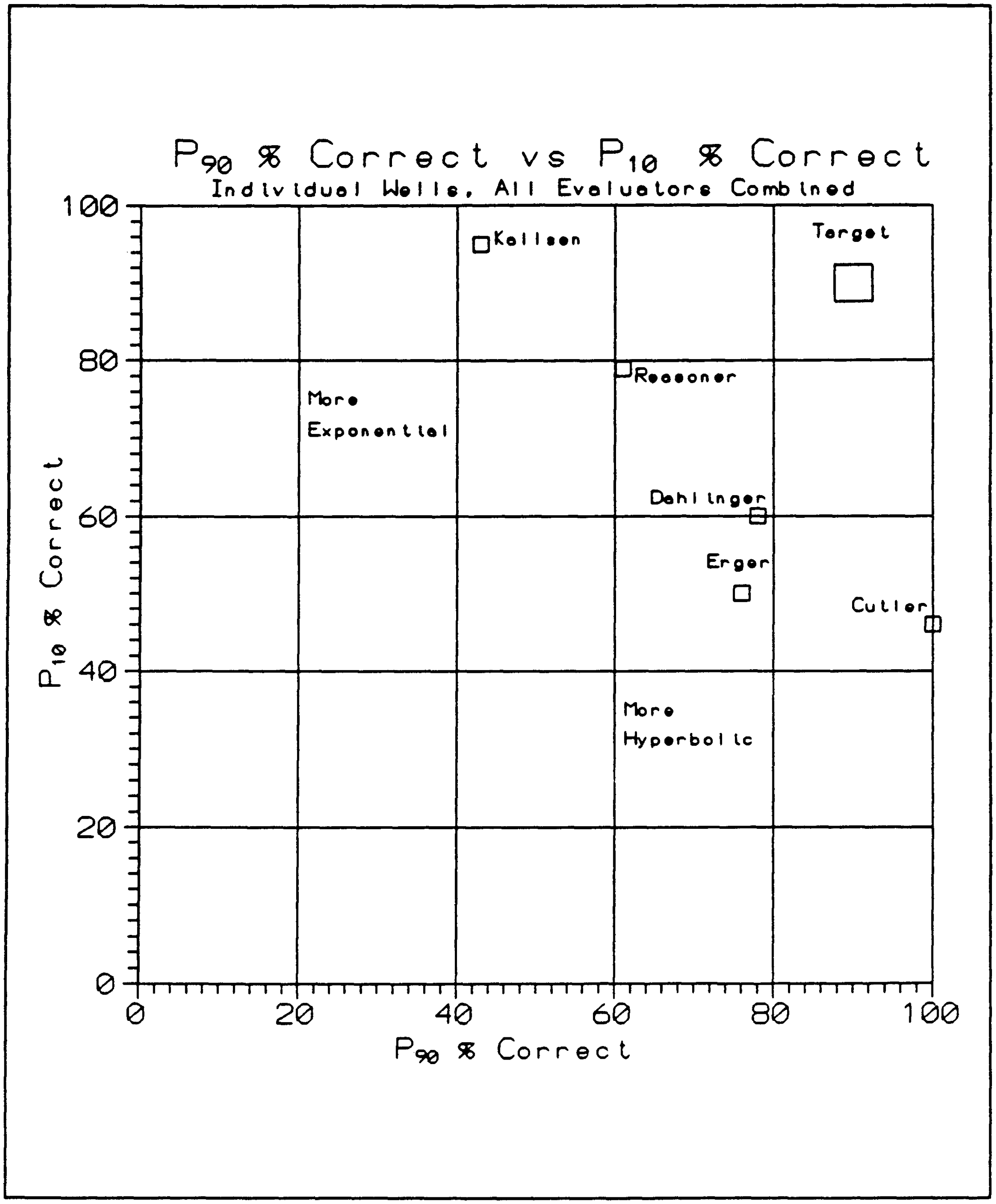


Figure 19 % P_{10} Correct versus % P_{90} Correct by Well

percent P_{90} correct. The wells that look "more" exponential score higher in percent P_{10} correct and lower in percent P_{90} correct. An explanation of this is presented in the following section.

5.5 Hyperbolic b value determination

In an effort to determine if an individual well's hyperbolic decline characteristics had an effect on an evaluators ability to accurately estimate P_{90} and P_{10}, a type curve computer program was used to determine the hyperbolic b value for each well. This computer program uses Fetkovich type curves to estimate b values.

In 1973, Fetkovich presented a type-curve for the hyperbolic family of decline curves. Using standard type-curve matching techniques, a data overlay may be used to determine the hyperbolic decline parameter b. Recently, with the advent of the personal computer, the use of the curves has increased. With the help of the computer, an engineer can quickly view the production data matched on several different b value curves.

The type curve program down-loads well production history and then allows the evaluator to match the data to a b value curve. These data can be "eye-balled" to determine the best match or the evaluator can match the data to several curves and the program will remember the best statistical fit and re-display that curve. For these wells, data was matched in several positions to each curve for values from 0 to 1 in increments of 0.1. Once this was done, the statistical best fit was used as the b value for that well. As is standard for Fetkovich type-curve matching, some data were deleted from the production history to get a better curve match. These data represented early time, transient data and obvious deviations from the established decline. An example of these obvious deviations would be data when the well was only partially produced for that month or the sudden increase in production immediately after a prior months low production.

All five wells were matched to the Fetkovich type-curve that gave the best statistical fit as computed by the computer program. Without exception, the curve representing the b value immediately above and below the "best fit" b also showed a good statistical fit. Therefore, the b value chosen is the best of 3 good fits. Also, in every case, the b value chosen gave one of the best "eye-balled" fits.

Table 24 shows the b values for each well.

Table 24: Computer Matched - Statistical Best Fit b Values for each Well

Fetkovich type-curve match	
Well Name	b value
Cutler # 1-A	0.8
Dahlinger# 1	0.6
Erger # 1	0.7
Kallsen # 1	0.2
Reasoner # 1	0.0

Figures 20 through 24 show the production data overlaid on the best fit b value.

This b value data was then plotted versus the P_{90} and P_{10} "score". Figure 25 shows b values versus percent P_{10} correct. There appears to be a definite trend. The percent P_{10} correct seems to be a function of the wells hyperbolic b value. As the b values increase, then the percent P_{10} correct decreases. Figure 26 shows b values versus percent P_{90} correct. Here again, a trend develops. As the b values increase, the percent P_{90} correct increases.

5.6 P90 and P10 Score versus Capen Quiz Results

In Figure 27, the evaluator's P_{90} "score" versus their Capen quiz results is shown. As you can see, there is no trend. This seems to state that regardless of an individual Capen score an individual has the potential to do fairly well in estimating P_{90} values. Figure 28 shows the evaluator's P_{10} "score" versus their Capen quiz results. This plot proves very interesting as a trend does develop. An evaluator's ability to estimate P_{10} seems to be a function of their ability to range answers for the Capen quiz. The "Best Fit" line is an eyeballed approximation.

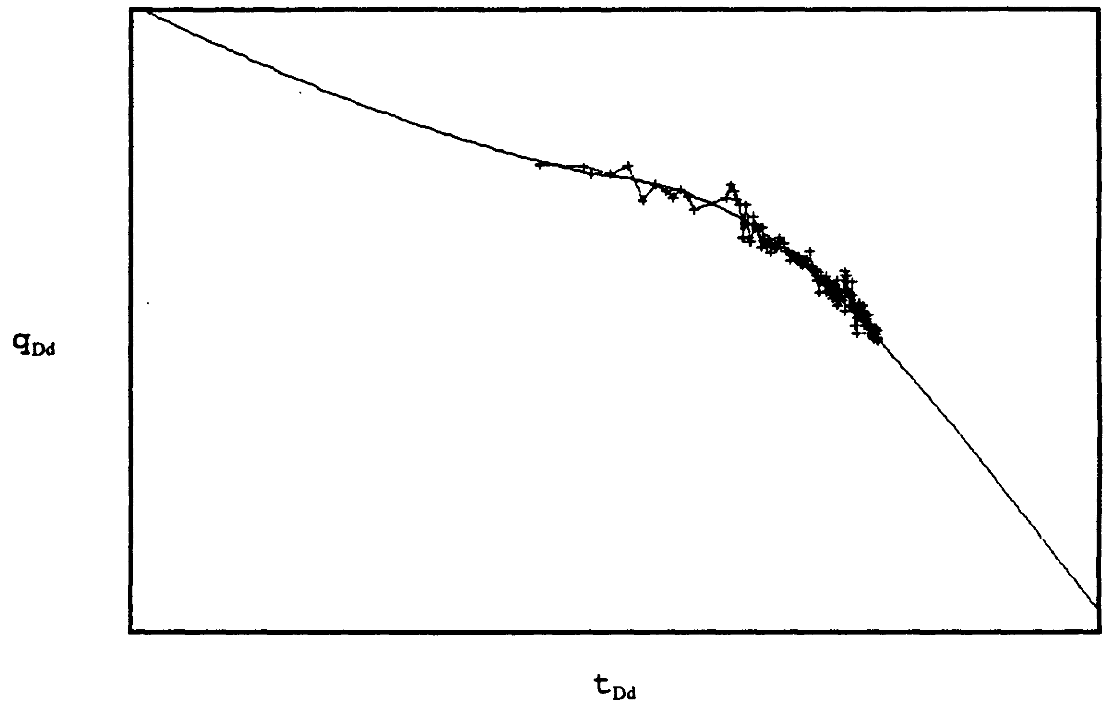


Figure 20 Cutler # 1-A Type-Curve Best Fit, b = 0.8

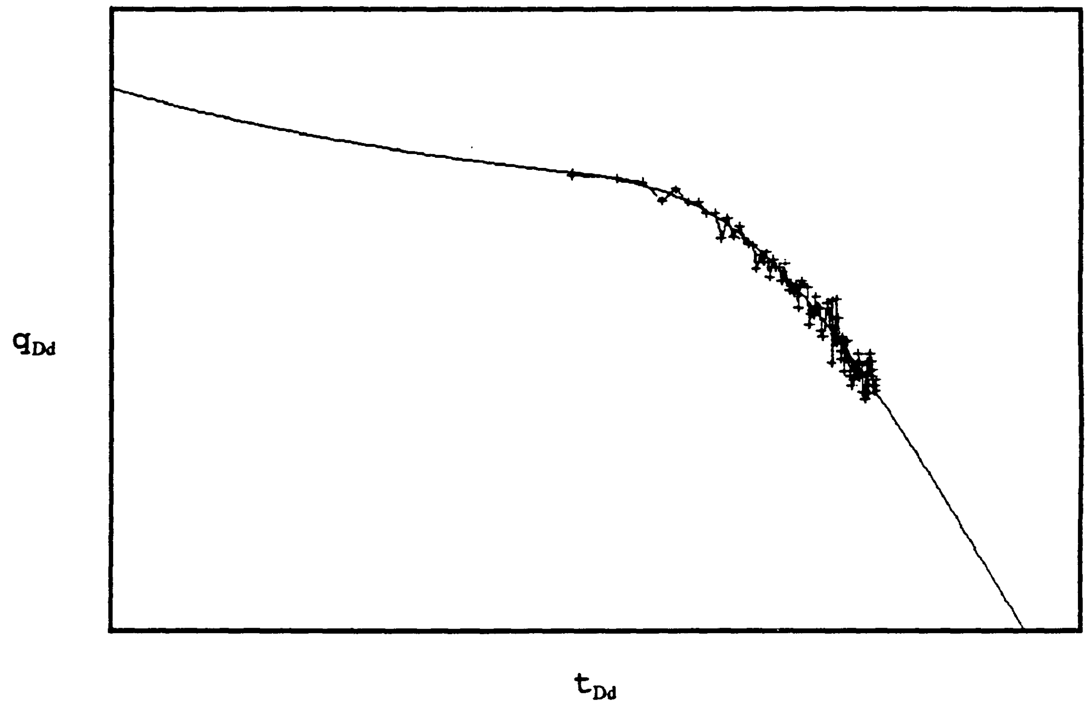


Figure 21 Dahlinger # 1 Type-Curve Best Fit, b = 0.6

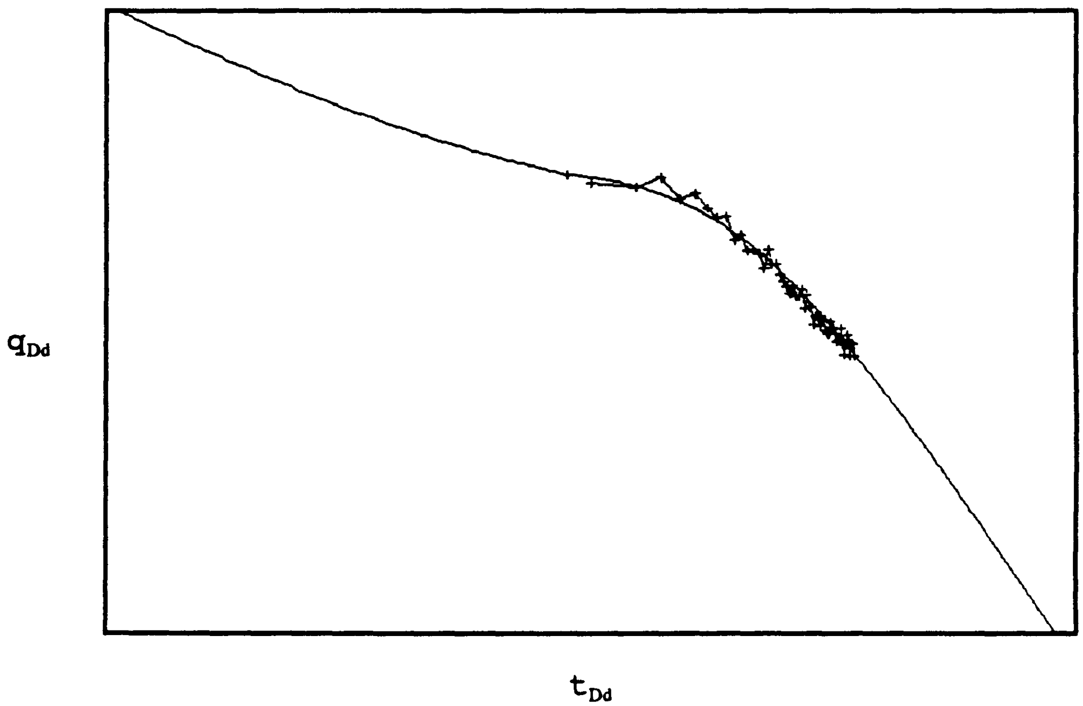


Figure 22 Erger # 1 Type-Curve Best Fit, b = 0.7

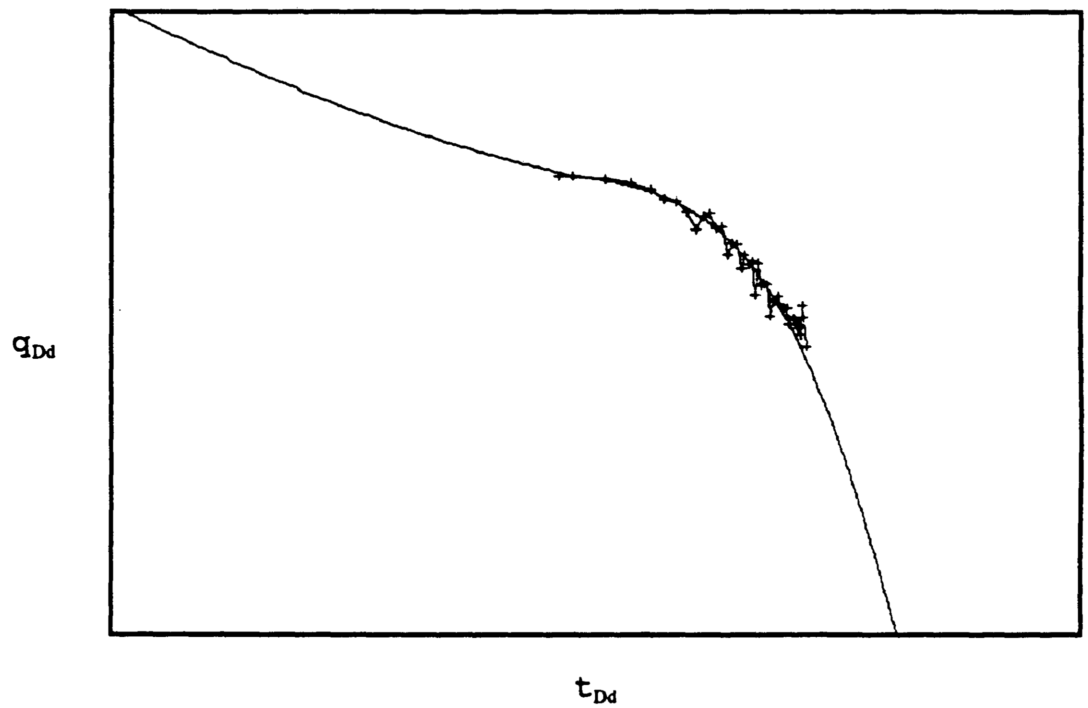


Figure 23 Kallsen # 2 Type-Curve Best Fit, b = 0.2

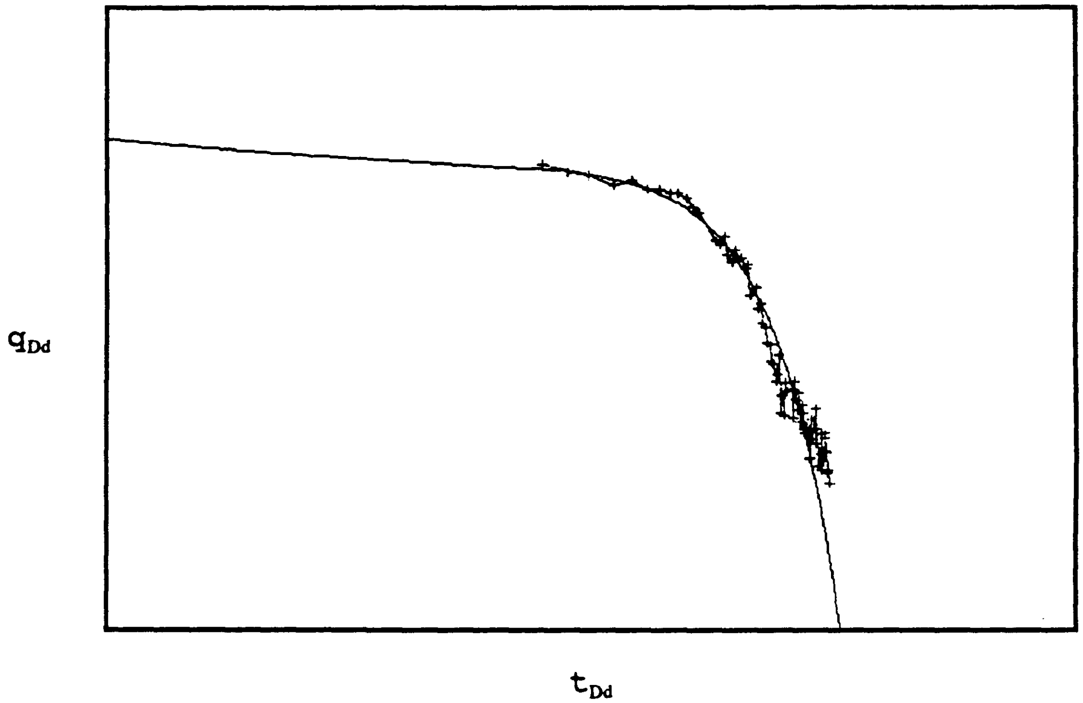


Figure 24 Reasoner # 1 Type-Curve Best Fit, b = 0.0

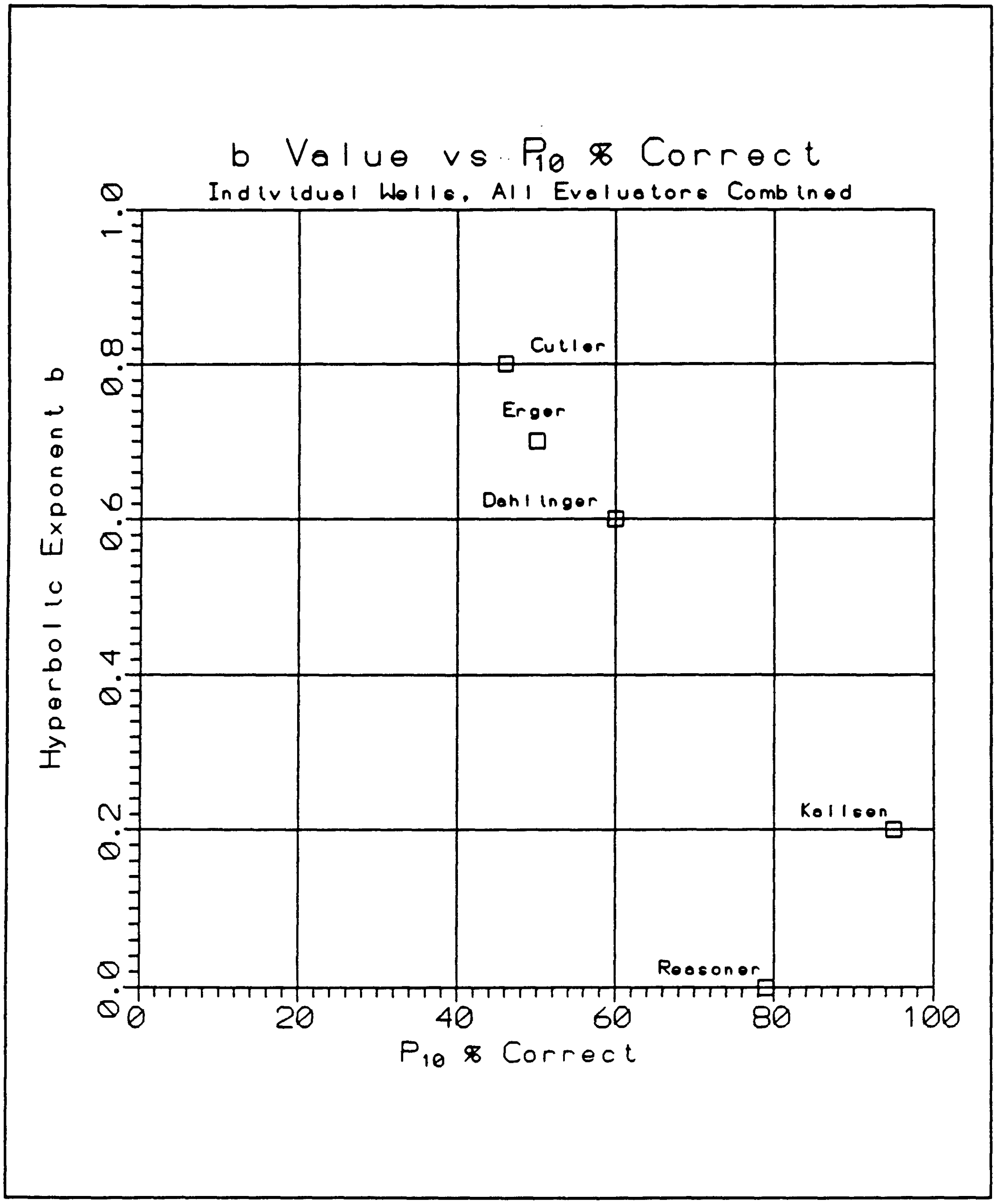


Figure 25 Best Fit b Value versus % P_{10} Correct for each Well

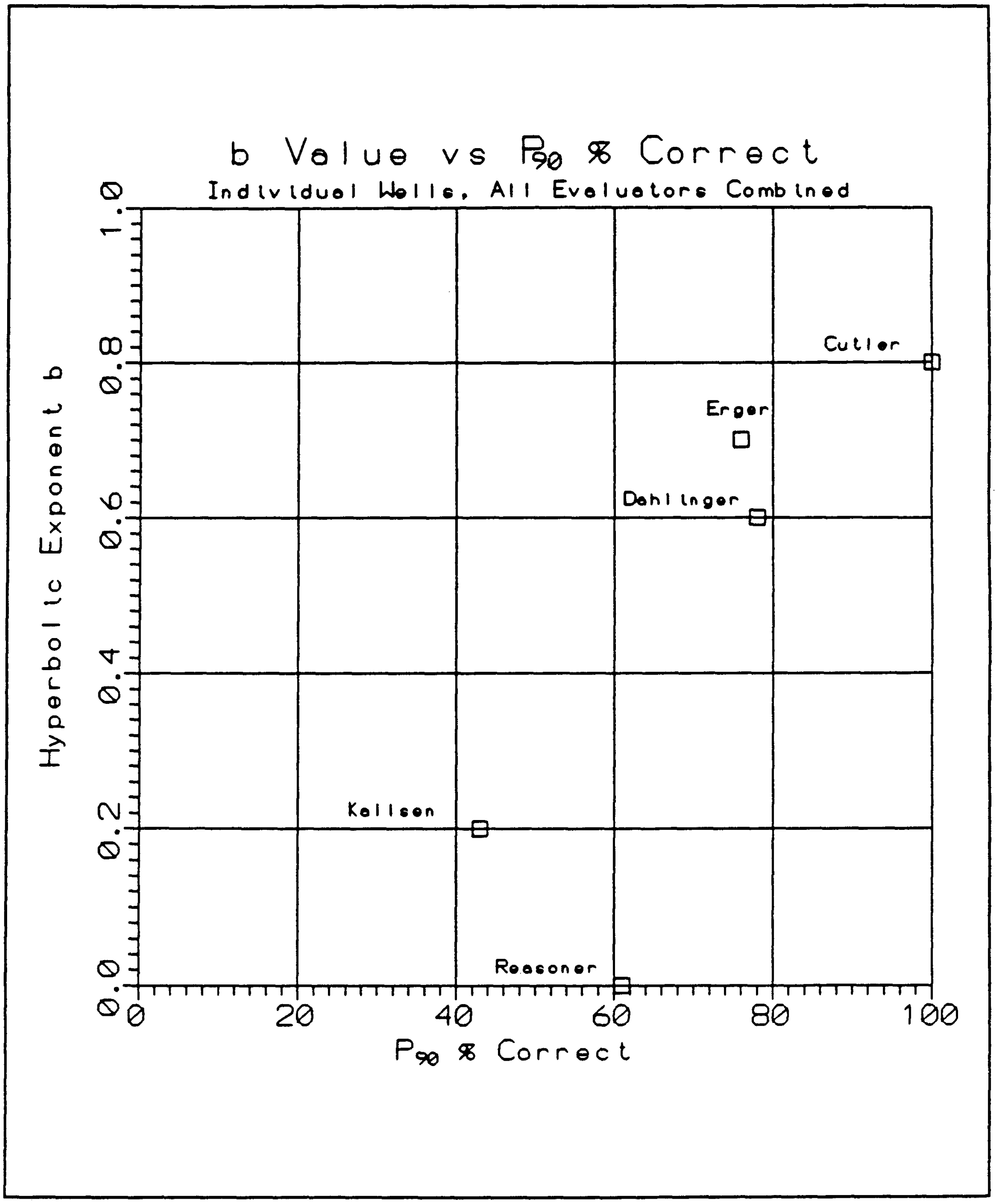


Figure 26 Best Fit b Value versus % P_{90} Correct for each Well

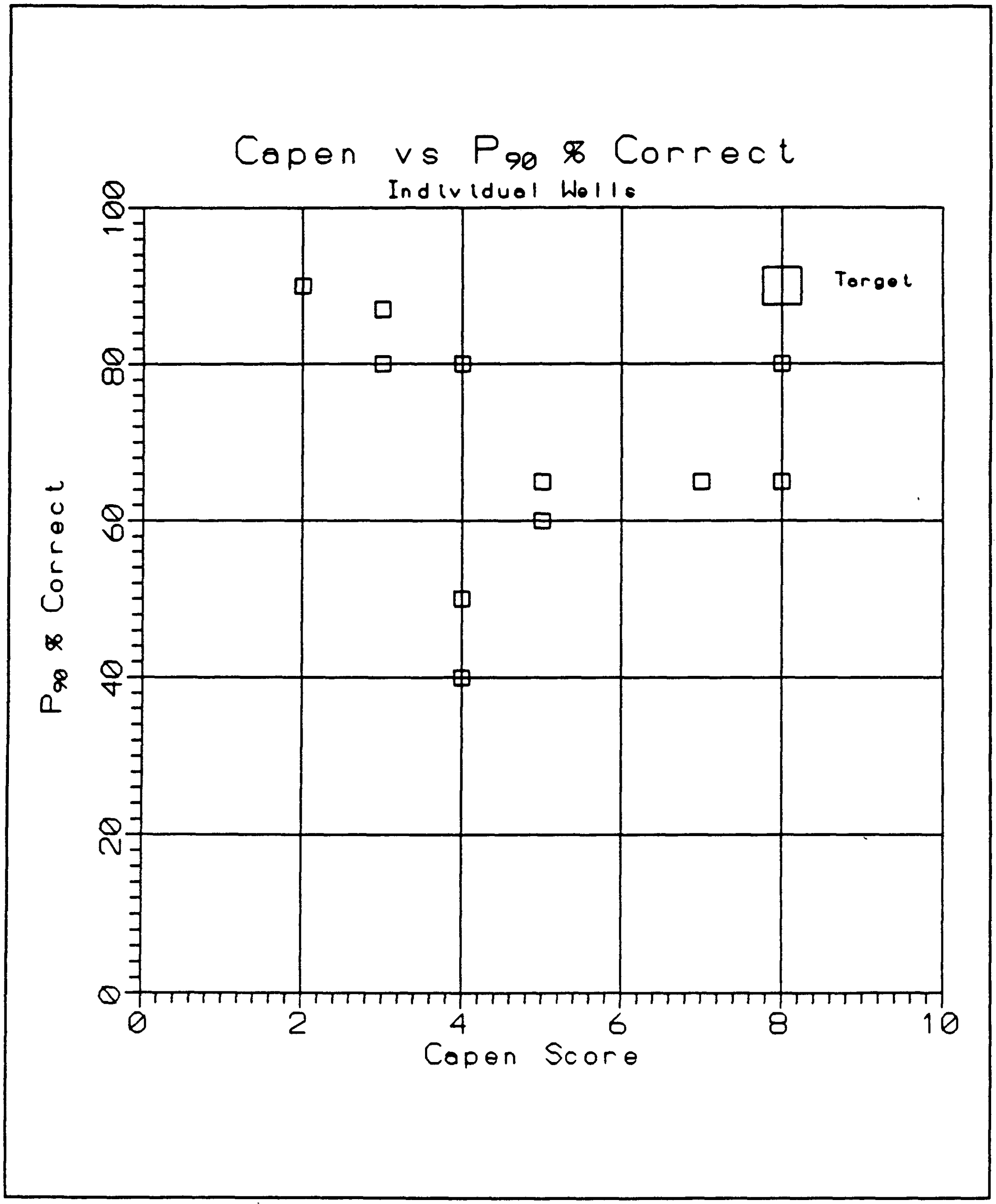


Figure 27 Individual Evaluators P_{90} % Correct versus Capen Quiz Score

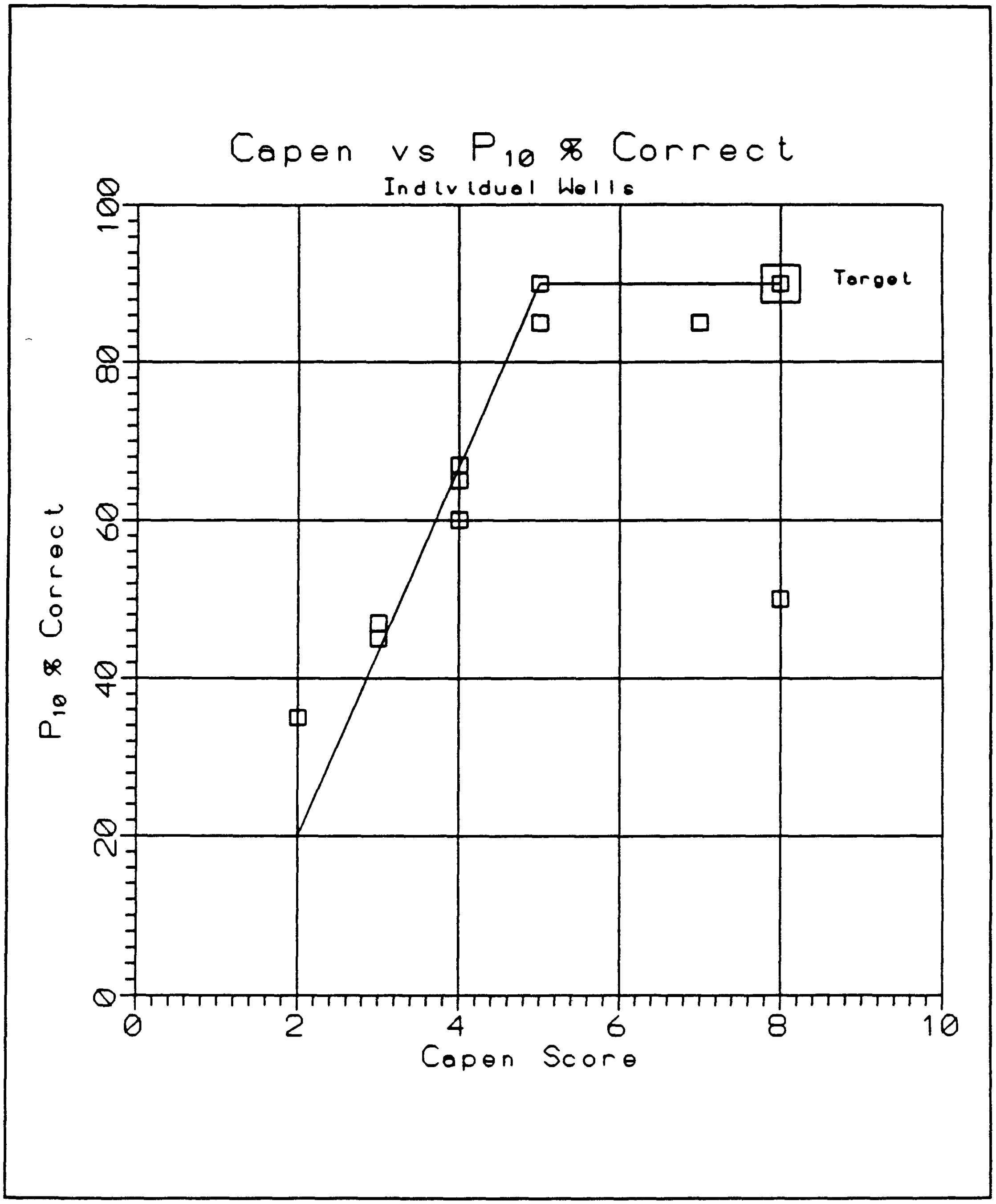


Figure 28 Individual Evaluators P_{10} % Correct versus Capen Quiz Score

The line is anchored at a Capen score of 5 because it appears, the evaluators who got 5 or more on the Capen quiz generally had the same P_{10} % correct score.

Since P_{10} % correct seems to be a function of the Capen score if that score is less than 5, an effort was made to determine if this information could be used to help an evaluator do better at estimating P_{10}. This was done by plotting, on log-normal probability paper, an evaluator's estimate for P_{10} not at P_{10} but at the P_x indicated by their Capen score. For instance, if an evaluator scored 3 on the Capen quiz, then they could expect to get about 45 % of the P_{10} estimates correct. Instead of plotting their estimates for P_{10} at P_{10}, the evaluator would plot P_{10} at 100 % - 45 % or P_{55}. Then, connecting their actual P_{90} with the replotted P_{10} (at P_{55}), the evaluator forms a new log-normal distribution. Then the revised P_{10} can be obtained from this new distribution. This example is shown in Figure 29. Following this same procedure for the 6 evaluators who scored less than 5, leads to a revised P_{10} versus Capen plot (Figure 30). Table 25 shows the before and after P_{10} scores. This revised plot shows that by following the above procedure, an evaluator can improve upon their individual P_{10} score. It should not be concluded that the results of a Capen quiz can be used to adjust the P_{10} estimates in all

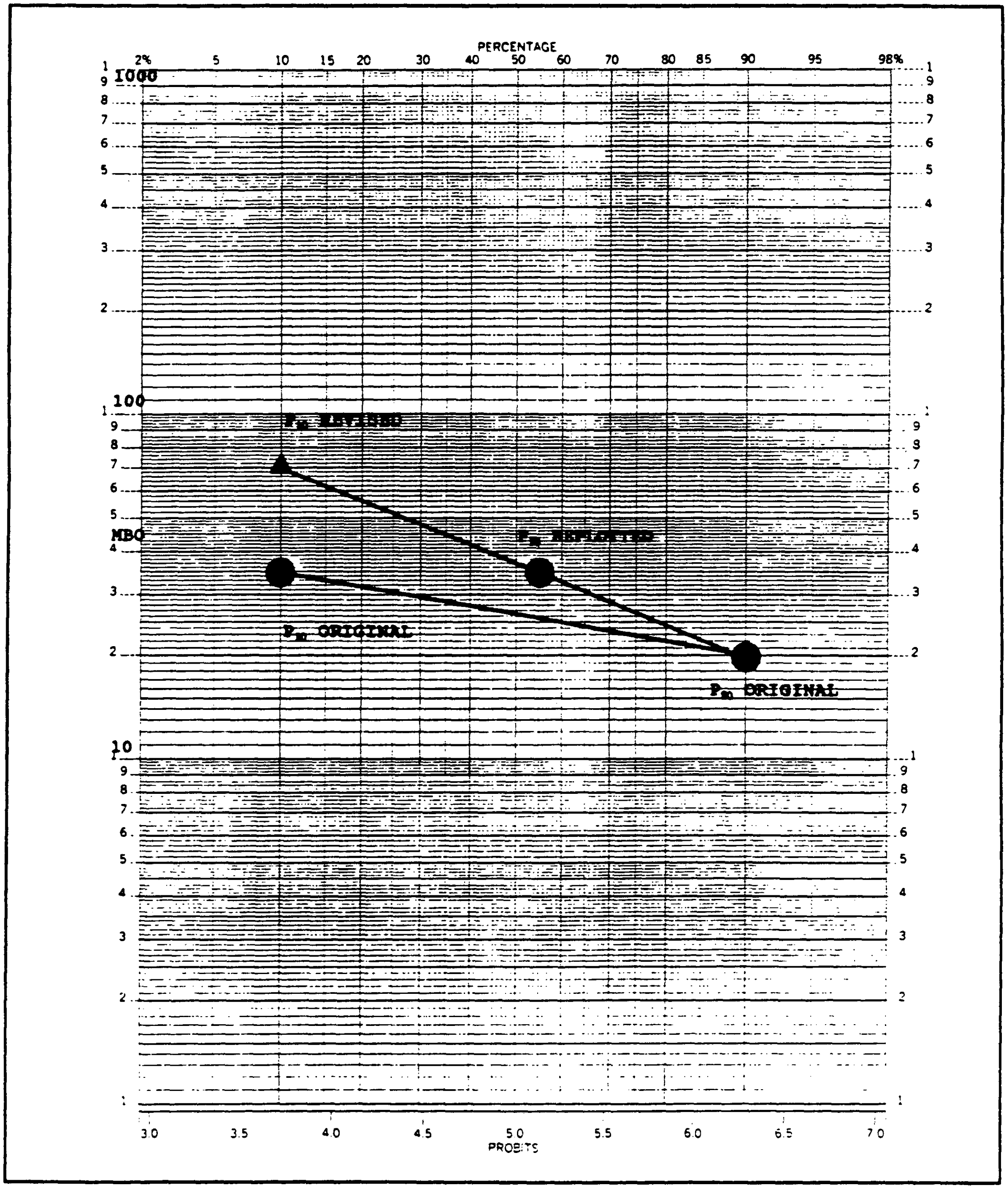


Figure 29 Probability paper showing the procedure for P_{10} revision based on Capen quiz score

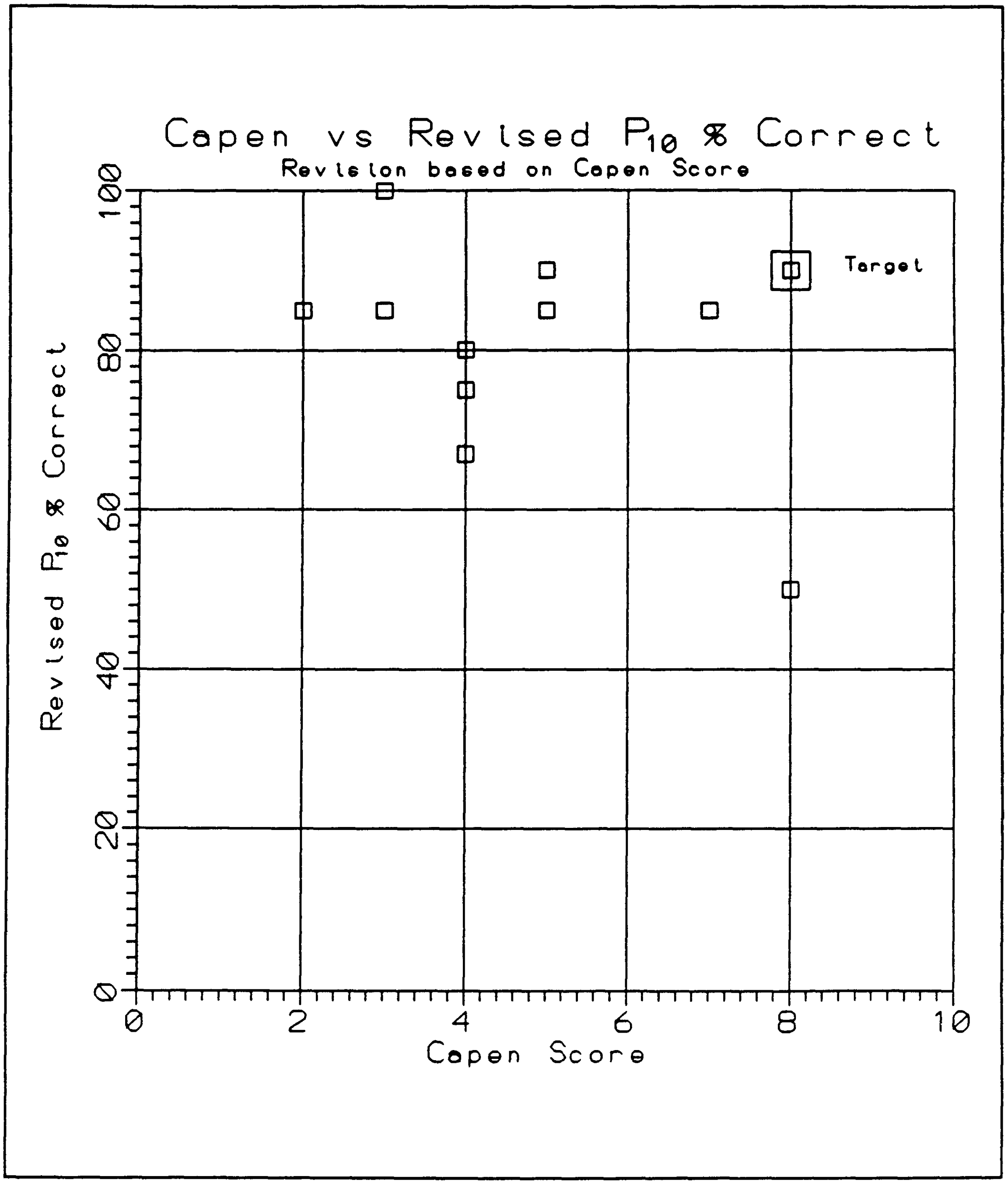


Figure 30 Revised P10 % Correct vs Capen

Table 25: P_{10} % correct before and after revision based on Capen score

Evaluator #	P10 Original	P10 Revised
4	67	67
9	60	80
18	45	85
20	35	85
21	47	100
31	65	75

cases. This method for revision may be a function of the five wells in this study. However, it is interesting to note that the "revised" P_{10} % correct exceeds 90 % in only one case. This may be true since the amount of revision for an individual is a function of the initial range between P_{90} and P_{10}. A small initial range would result in only a small revision in the P_{10} estimate. It may also be argued that the Capen quiz results may imply an ability to "deterministically" estimate P_{10}.

Keep in mind that all of these data come from evaluators who estimated probabilistic reserves based on a deterministic number. These trends do not represent data from statistically derived estimates. That is, no evaluator used a statistical approach to this study.

6.0 Validity of Study

All attempts were made to construct this study so that any conclusions that were drawn from the results would be considered valid. The wells and field chosen were actual real world examples and all pertinent information was made available to the evaluators. There were very few complaints about the information supplied. One evaluator did explain that he would have requested more information concerning the Reasoner #1 Phase II while another accused the author of making data up. The question was the cause of the decline in production late in that Phase.

As far as the representativeness of the evaluators, it is felt that they represent a disproportionately high amount of experience and qualifications. The average years of experience is 18 with 6 evaluators members of the Society of Evaluation Engineers and 9 registered professional engineers. Therefore, their results may be considered to be better than the average industry petroleum engineer. It is unfortunate that more of the evaluators were not able to finish the study. Twelve of twenty-nine represents a 41 % completion rate.

A question exists as to whether these evaluators put effort into this project. Each evaluator was asked to estimate the time it took to complete each Phase of the study. The results show that most evaluators put considerable time and effort into the early Phases of the study then decreased as they became familiar with the procedure and the wells. This was expected. The time and effort reflect the everyday work load of an engineer. It is felt that the evaluators put the necessary effort into this project. Their professionalism and desire to get the correct answers assured this.

The b values obtained were taken as the statistical best fit from a Fetkovich type-curve program and are believed to be reasonable. As stated before, the curve immediately above and below the best fit also proved to be good fits but with slightly more statistical error. It was decided to allow the computer to fit the curve rather than "eyeballing" the best fit to eliminate any personal influence. The values for the hyperbolic exponent b are felt to be reliable.

7.0 Conclusions

1. Evaluator's tend to use the easiest method of estimation at their disposal. For this study no one used a statistical approach for the probabilistic values. The majority used the results of the decline curve analysis as the basis for the probabilistic estimates.

2. The ability to consistently range a wells P_{90} and P_{10} values is related to that wells hyperbolic b value. Accurate P_{90} values are easier when b values are high. Accurate P_{10} values are easier when b values are low. The opposite is also true. It is difficult to estimate the P_{90} value when the b value is low and it is difficult to estimate the P_{10} value when the b value is high. This conclusion is based on the methodology used by the study evaluators.

3. When comparing evaluator's estimates for Deterministic, P_{90}, P_{50}, P_{10} values, the variability in the estimates is large especially P_{10}.

4. An evaluator's ability to determine P_{10} is a function of their ability to accurately range answers for a Capen type quiz. A high score on the Capen quiz generally means a better estimate for P_{10}. This is a function of the wells in the study.

5. Evaluators added individual well P_{90}, P_{50}, P_{10} values to calculate a combined distribution for the five wells. If the reserve distribution is log-normal, only the mean values are additive. Adding individual P_{90} reserves results in a combined confidence of P_{90+}. Likewise, adding individual P_{10} values results in a combined confidence of P_{10-}.

RECOMMENDATIONS

1. The proposed probabilistic reserve definitions is a significant change from current U.S. definitions. In many cases the evaluators interpreted the proposed definitions very differently from one another. Also, the evaluators added individual well P_{10} and P_{90} to get a company P_{10} and P_{90}. This is not a correct procedure. If the SPE adopts the proposed definitions, these are two areas that need to be clarified.

2. Additional research and study is needed to develop a method to help evaluators better estimate P_{90}, P_{50}, P_{10} from both a deterministic and probabilistic approach.

NOMENCLATURE

Notation	Description	Units
ARR	Actual Remaining Reserves	vol
AUR	Actual Ultimate Reserves	vol
b	Hyperbolic decline exponent	-
Bbl	Barrel	vol
BOPD	Barrel of Oil per Day	vol
BOPM	Barrel of Oil per Month	vol
ERR	Estimated Remaining Reserves	vol
EUR	Estimated Ultimate Reserves	vol
MBO	Thousand Barrels of Oil	vol
Mcfg	Thousand cubic feet of Gas	vol
P_{10}	"Proved + Probable + Possible" reserves under proposed definitions	vol
P_{50}	"Proved + Probable" reserves under proposed definitions	vol
P_{90}	"Proved" reserves under proposed definitions	vol
Rw	Formation Water Resistivity	ohm m

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APPENDIX A

ERR and Standard Deviation plots for all study wells and the Company Total.

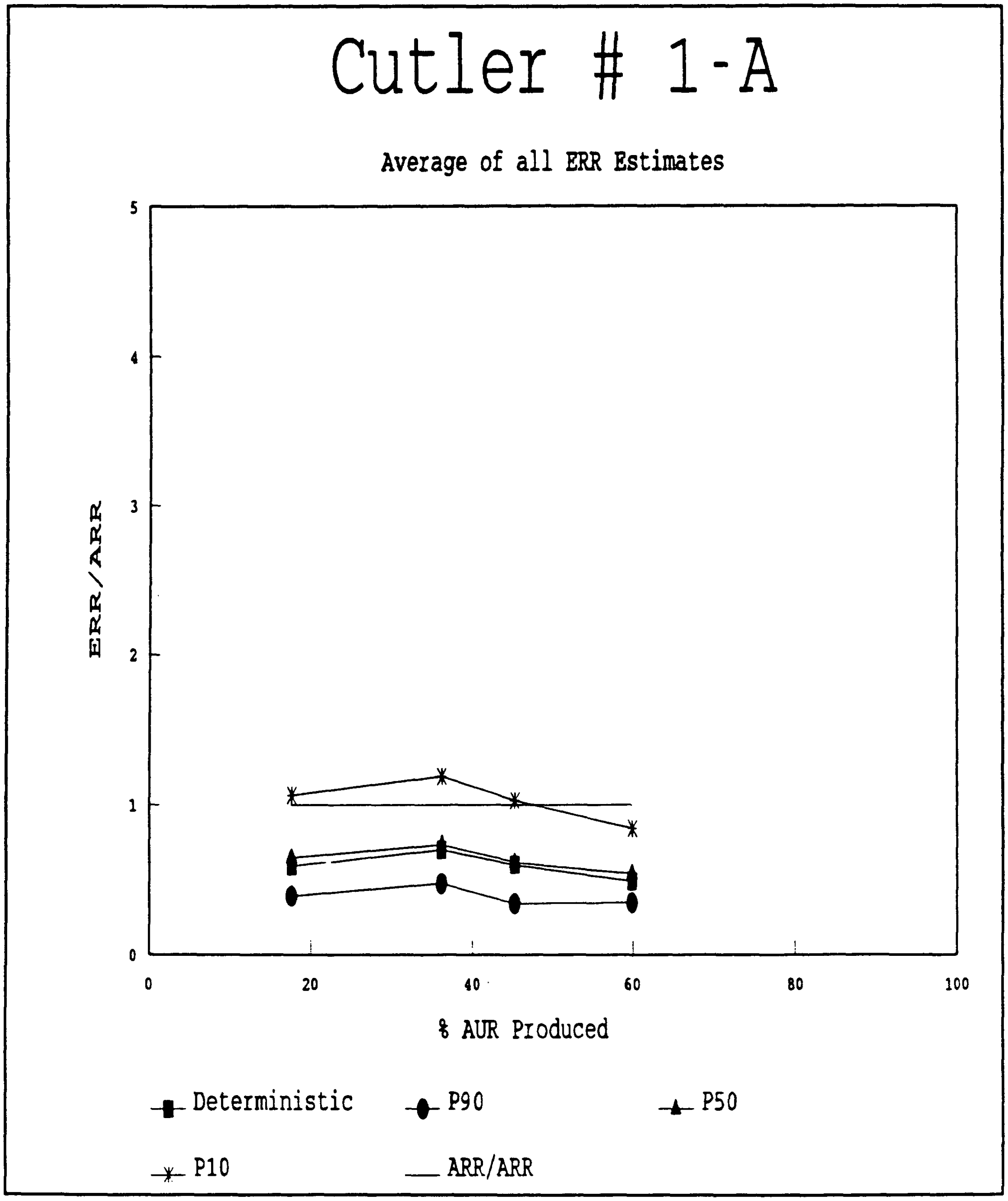

Figure A-1 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Cutler # 1-A

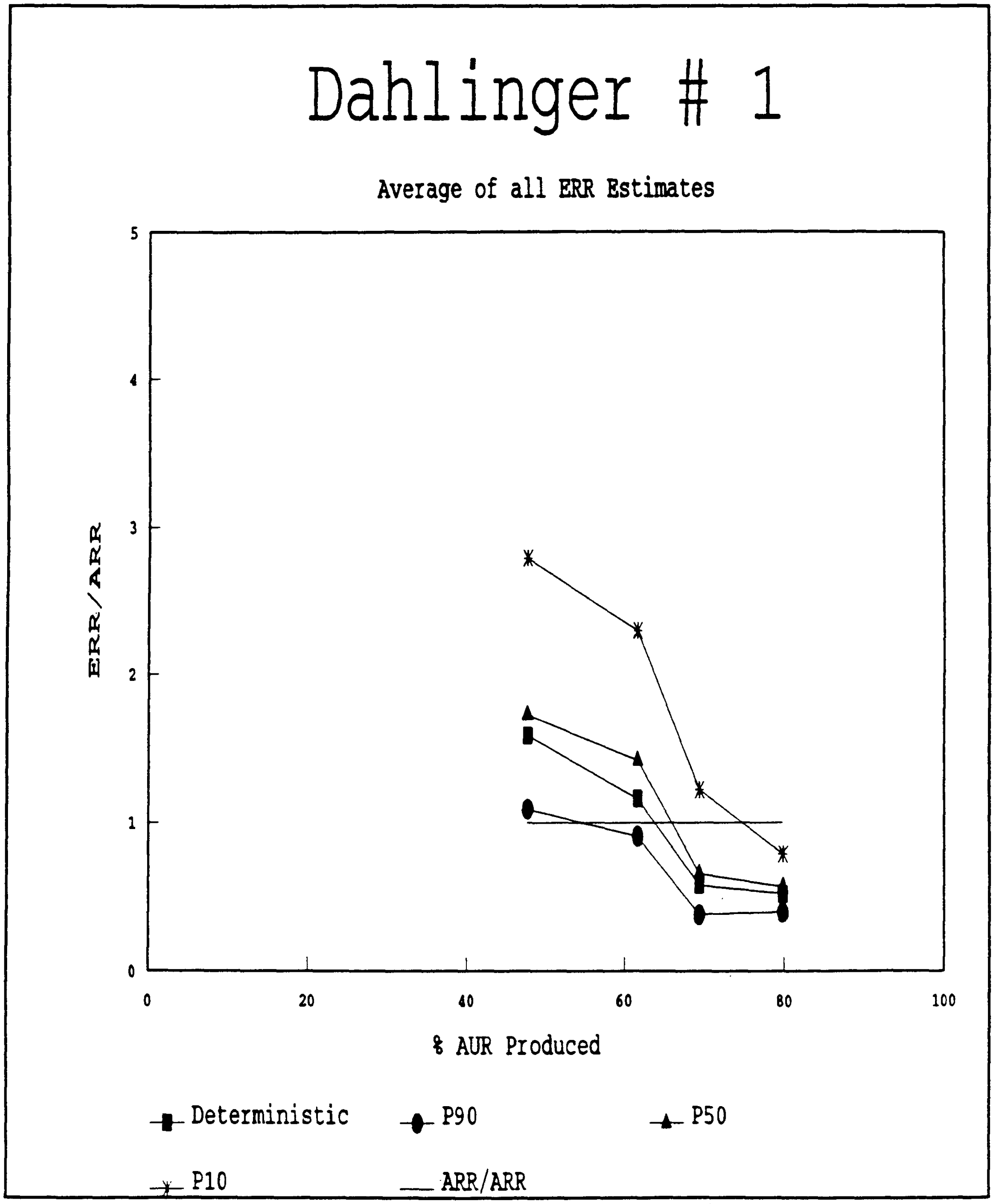

Figure A-2 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Dahlinger # 1

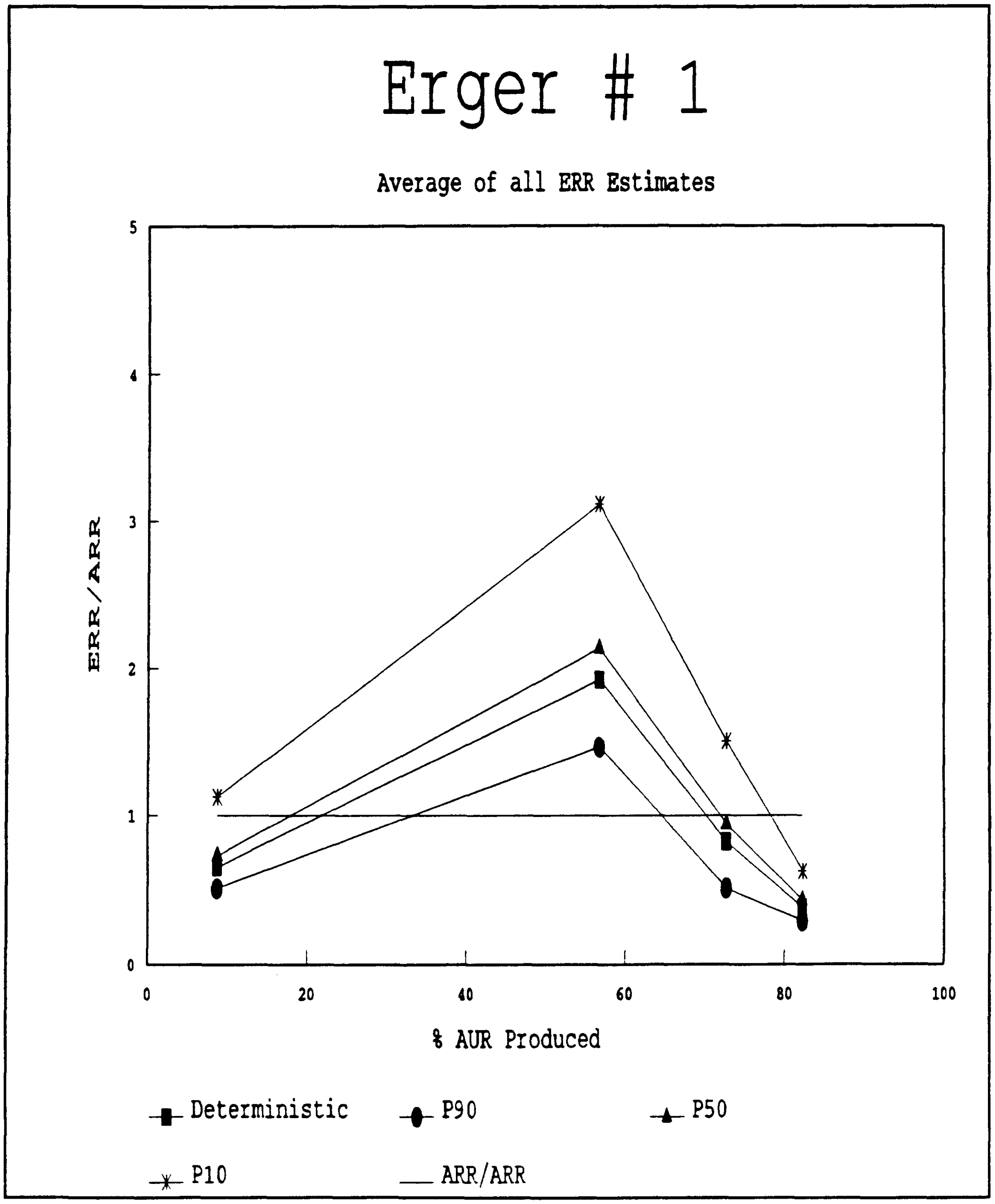

Figure A-3 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Erger # 1

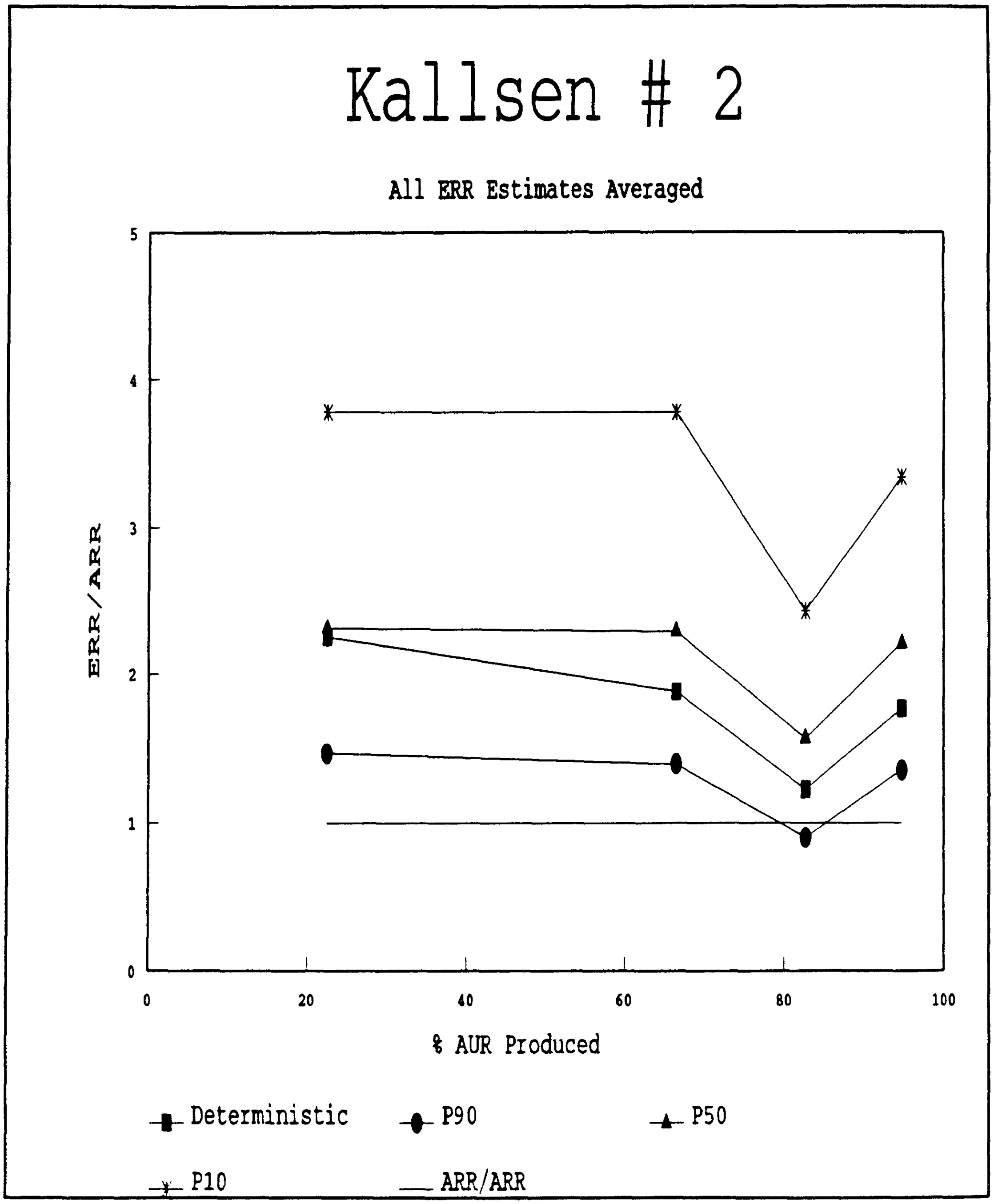

Figure A-4 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Kallsen # 2

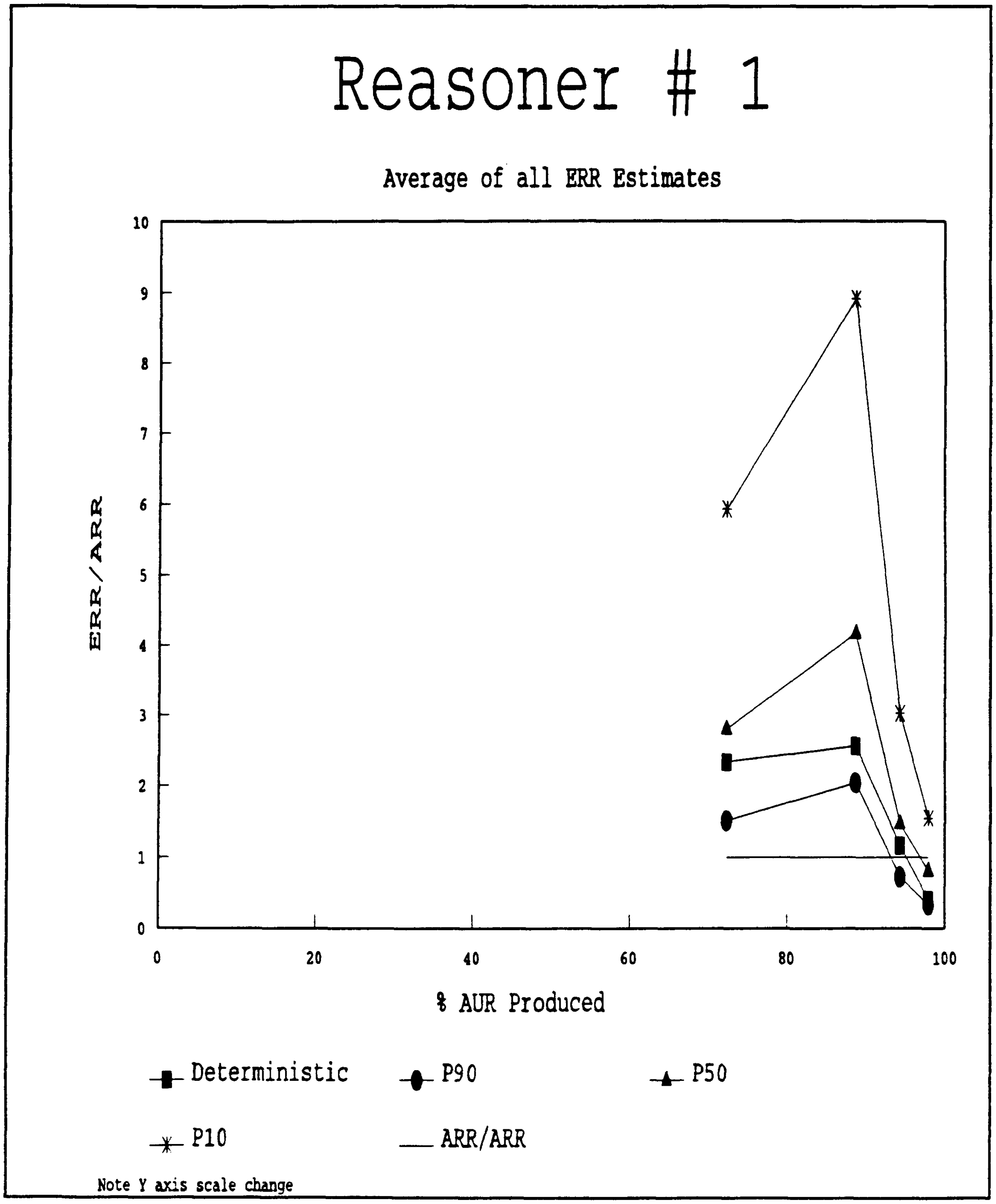

Figure A-5 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Reasoner # 1

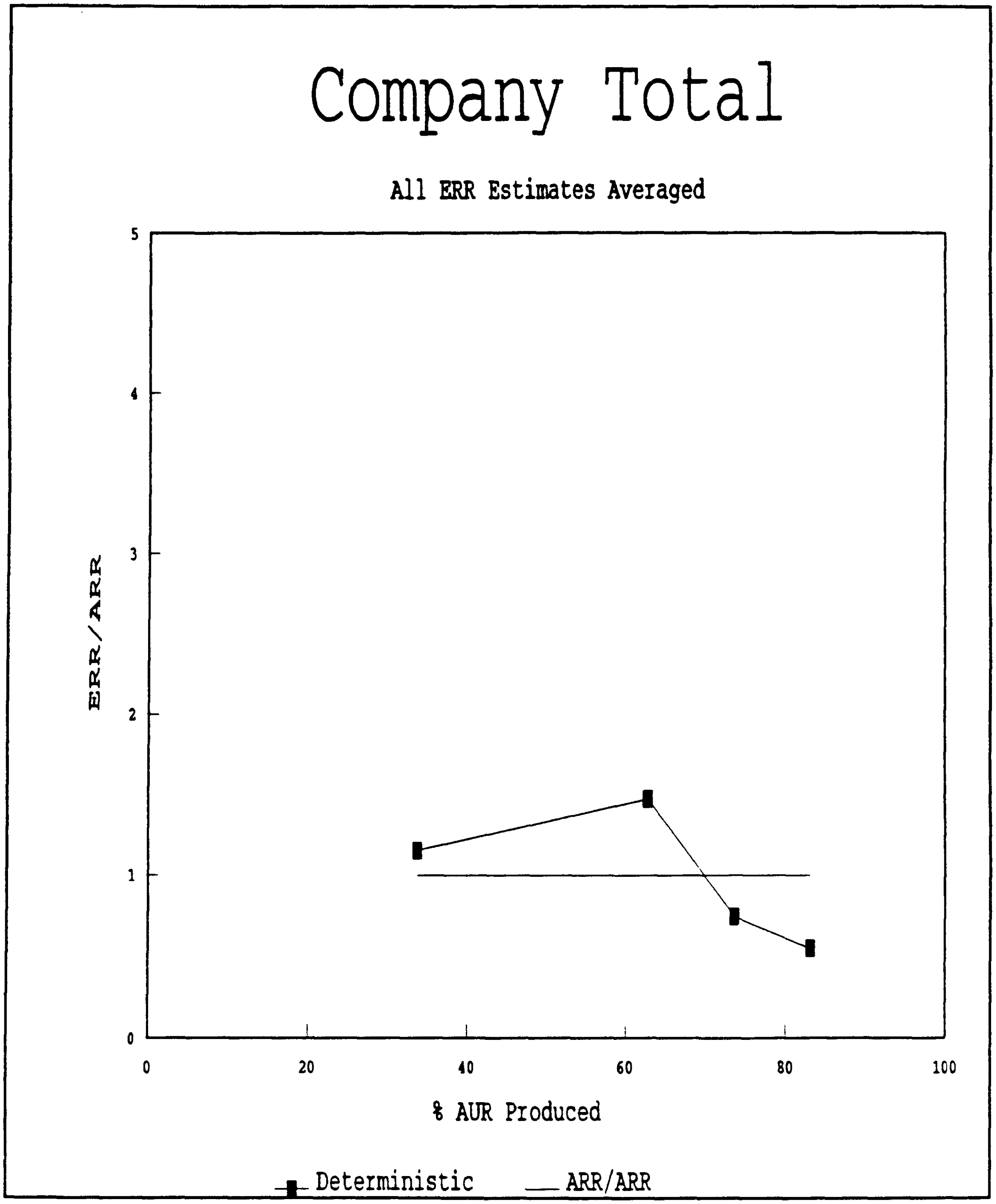

Figure A-6 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Company Total

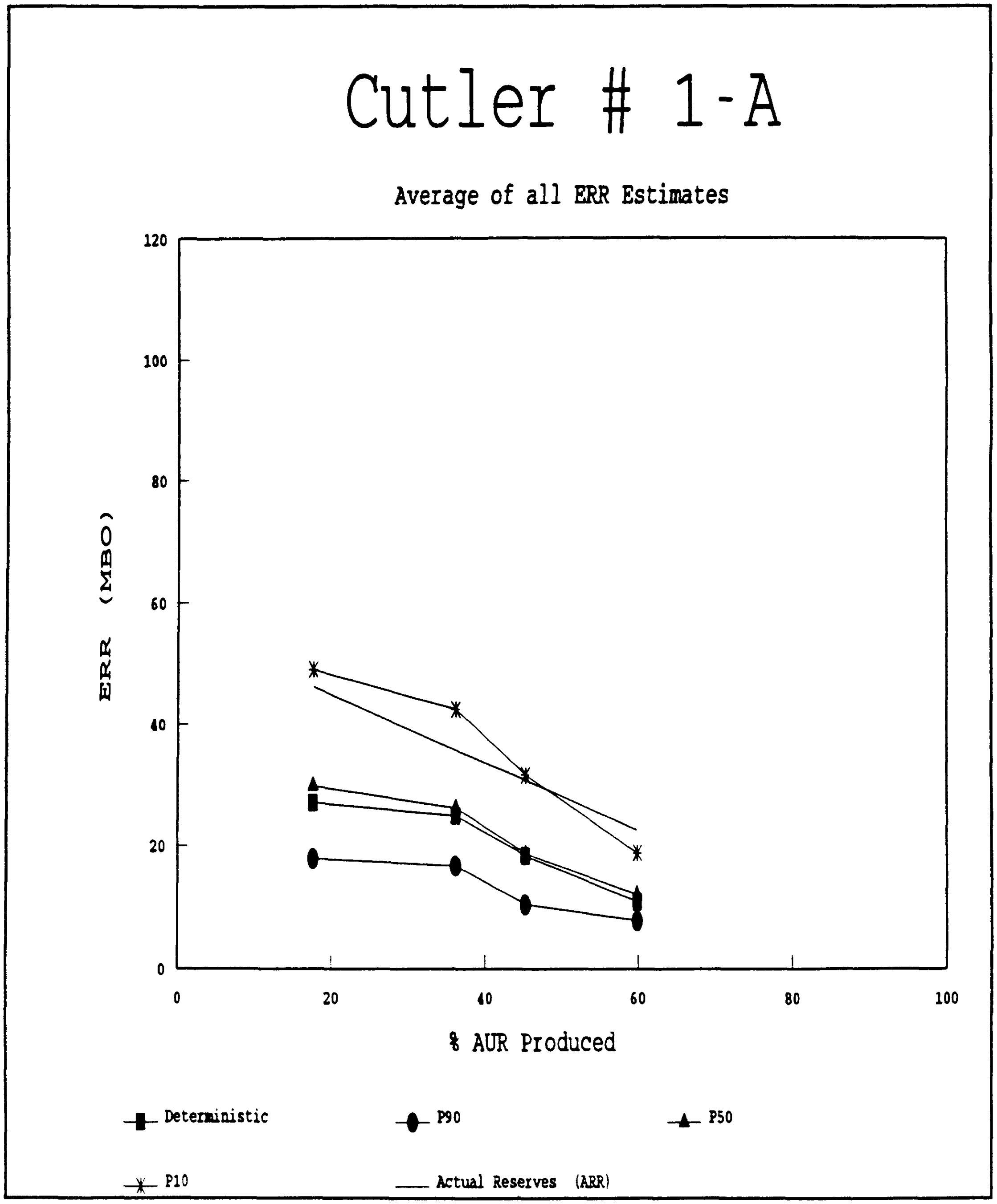

Figure A-7 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Cutler # 1-A. Y axis in MBO

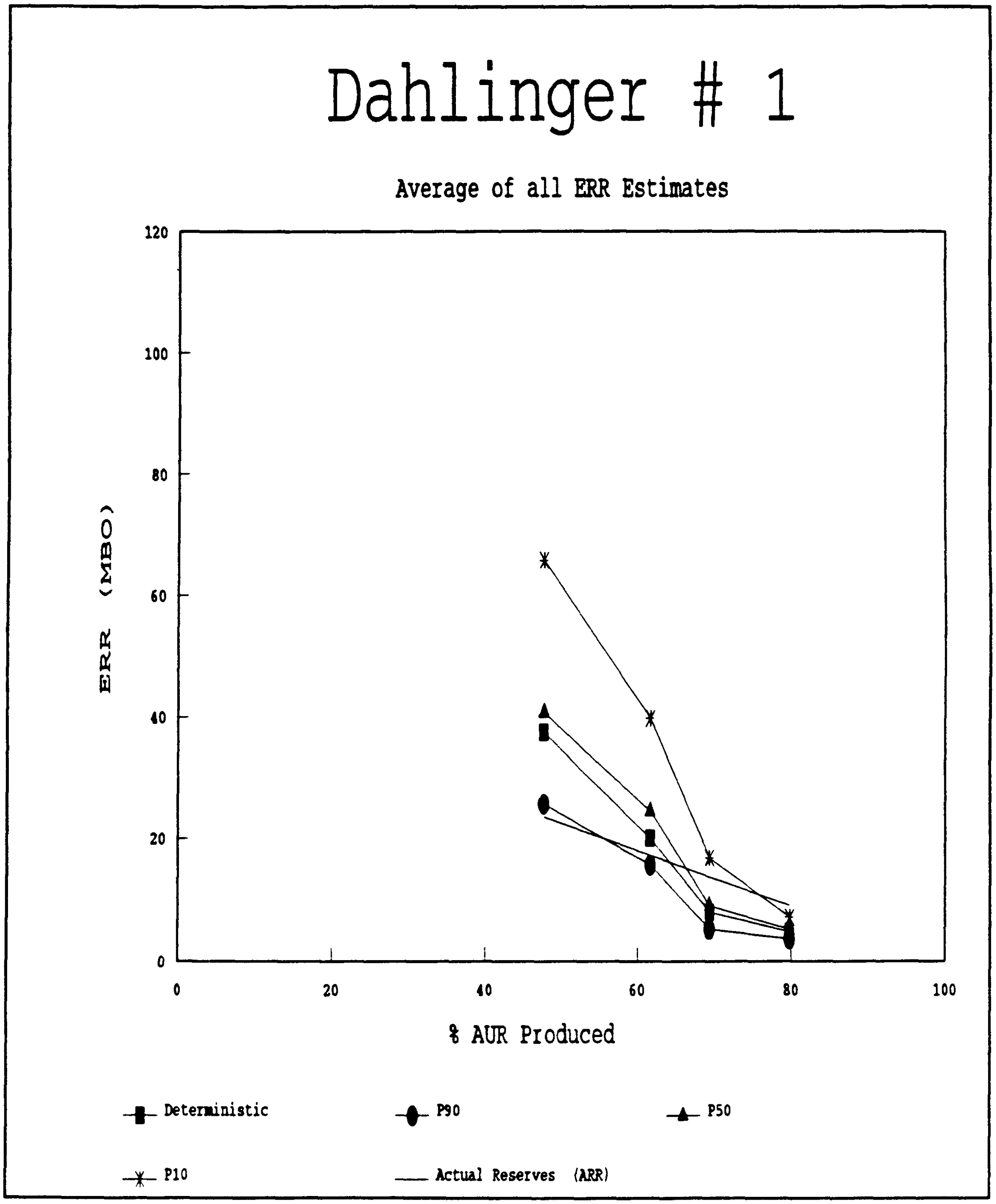

Figure A-8 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Dahlinger # 1. Y axis in MBO

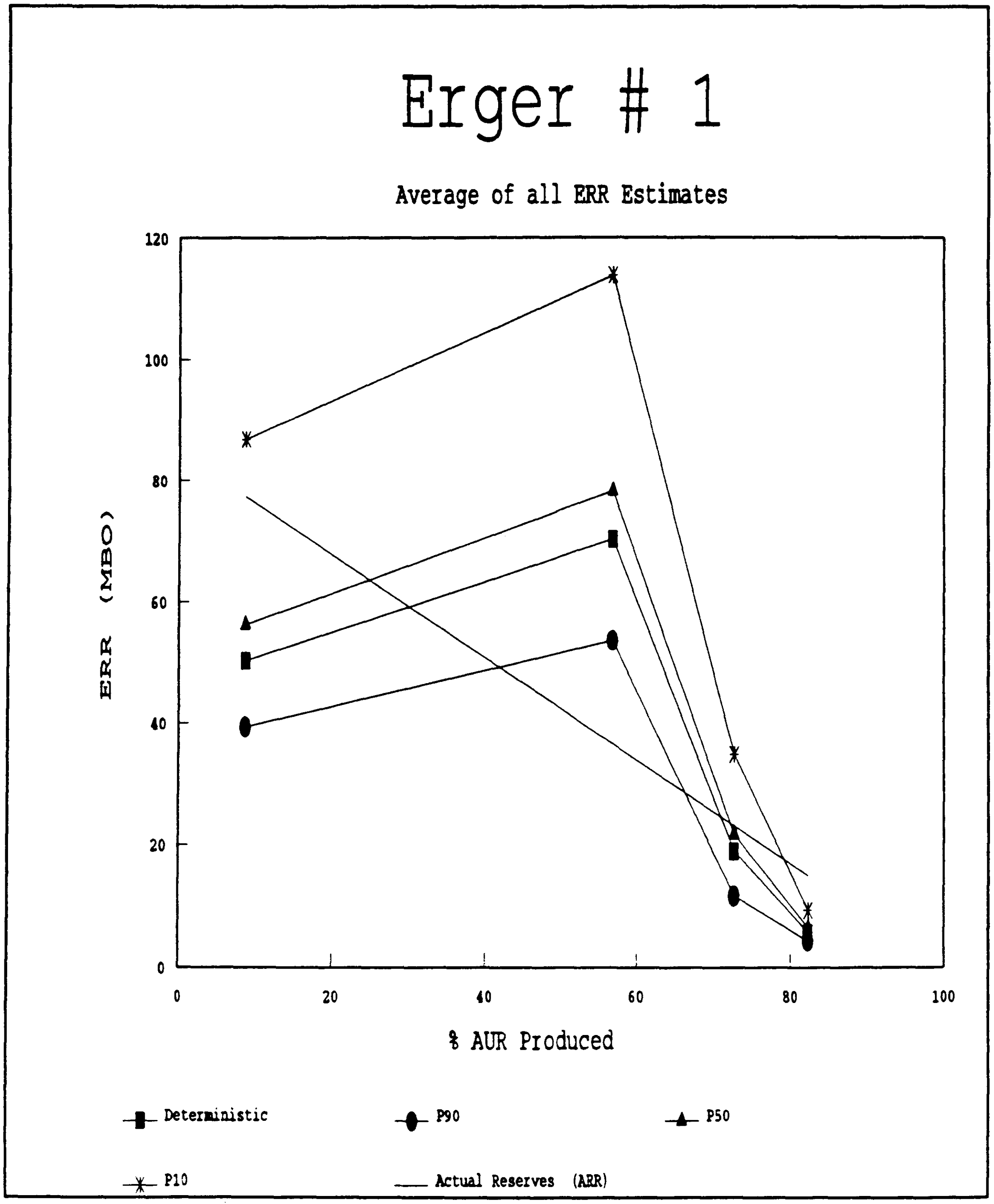

Figure A-9 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Erger # 1. Y axis in MBO

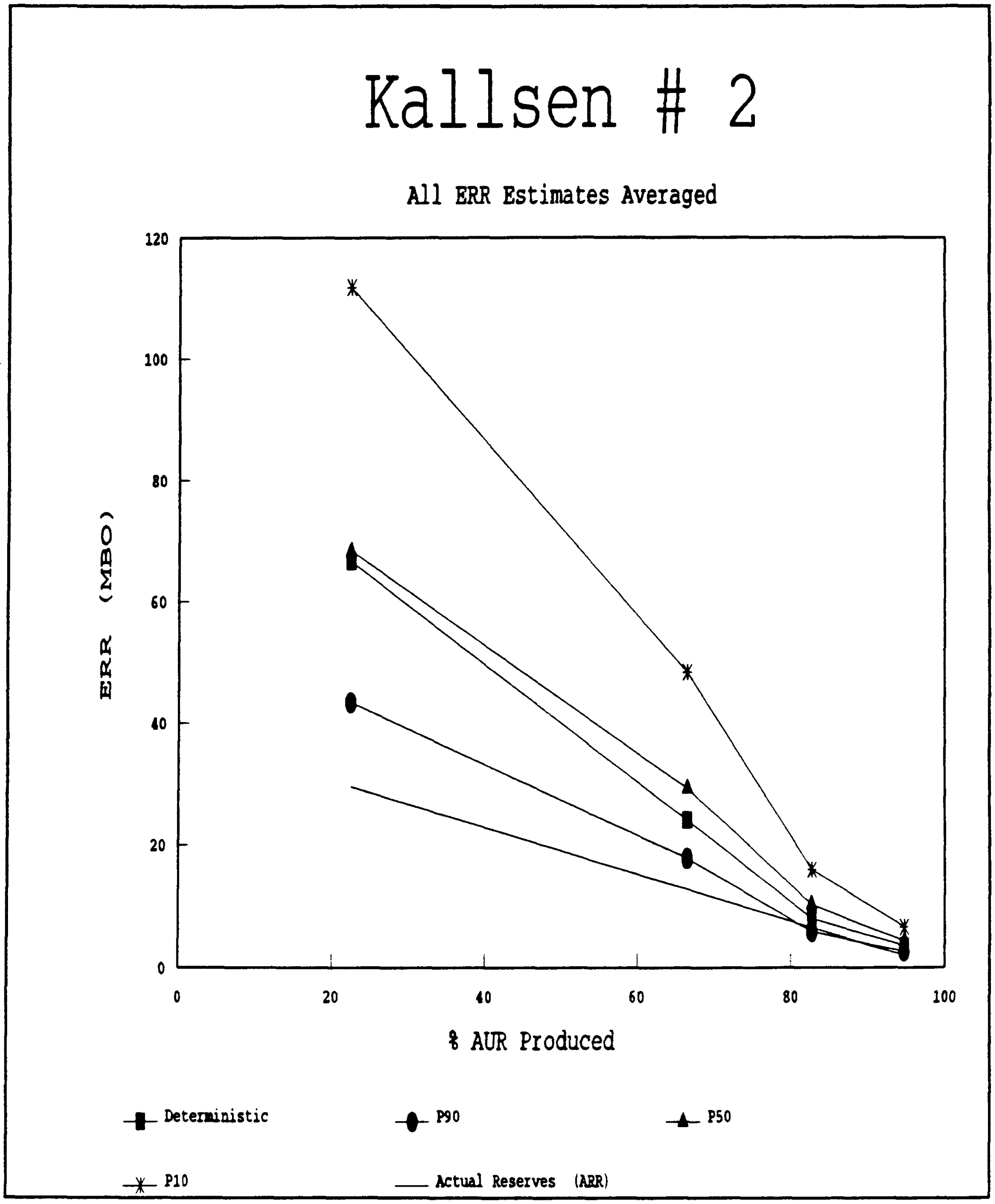

Figure A-10 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Kallsen # 2. Y axis in MBO

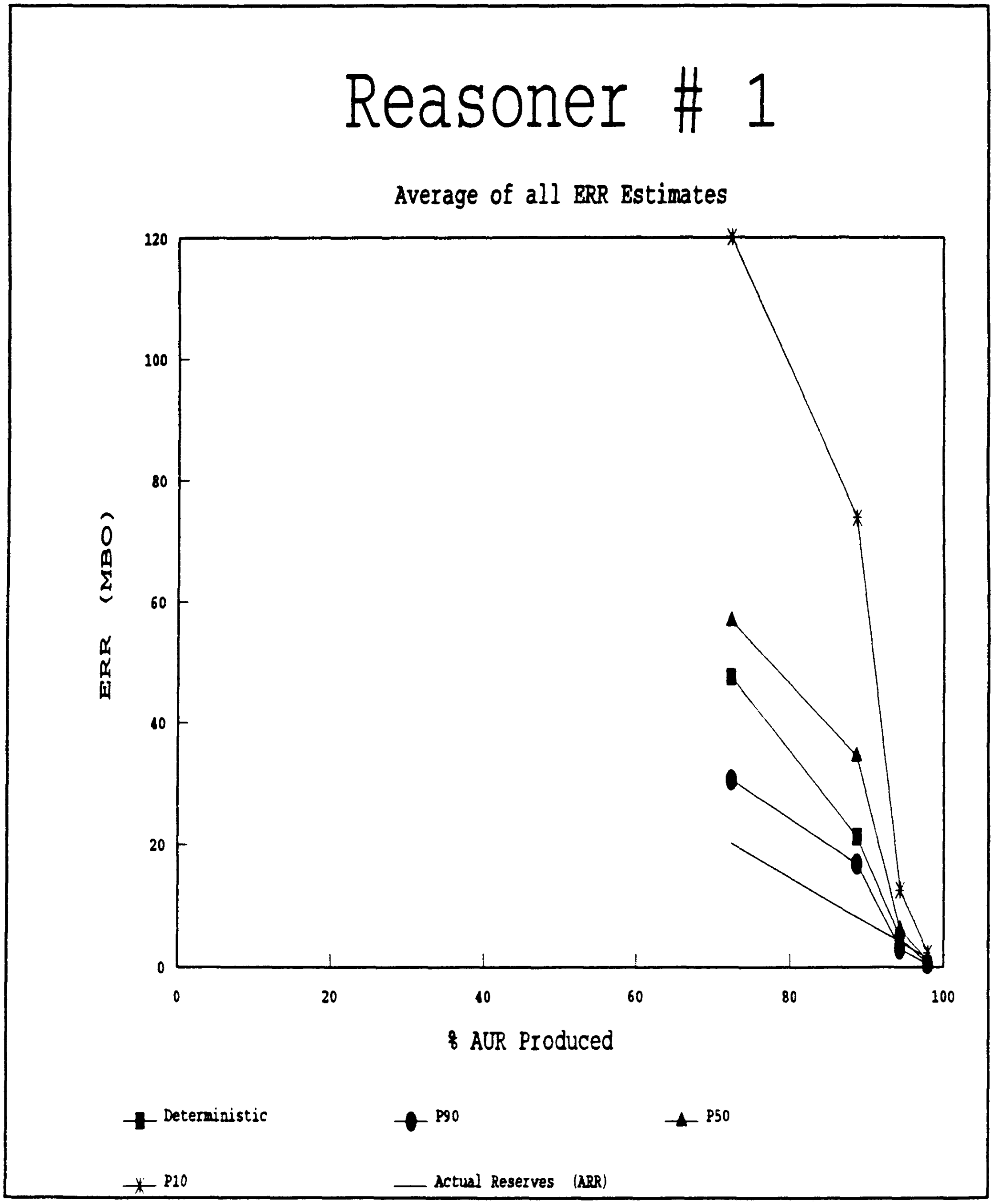

Figure A-11 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Reasoner # 1. Y axis in MBO

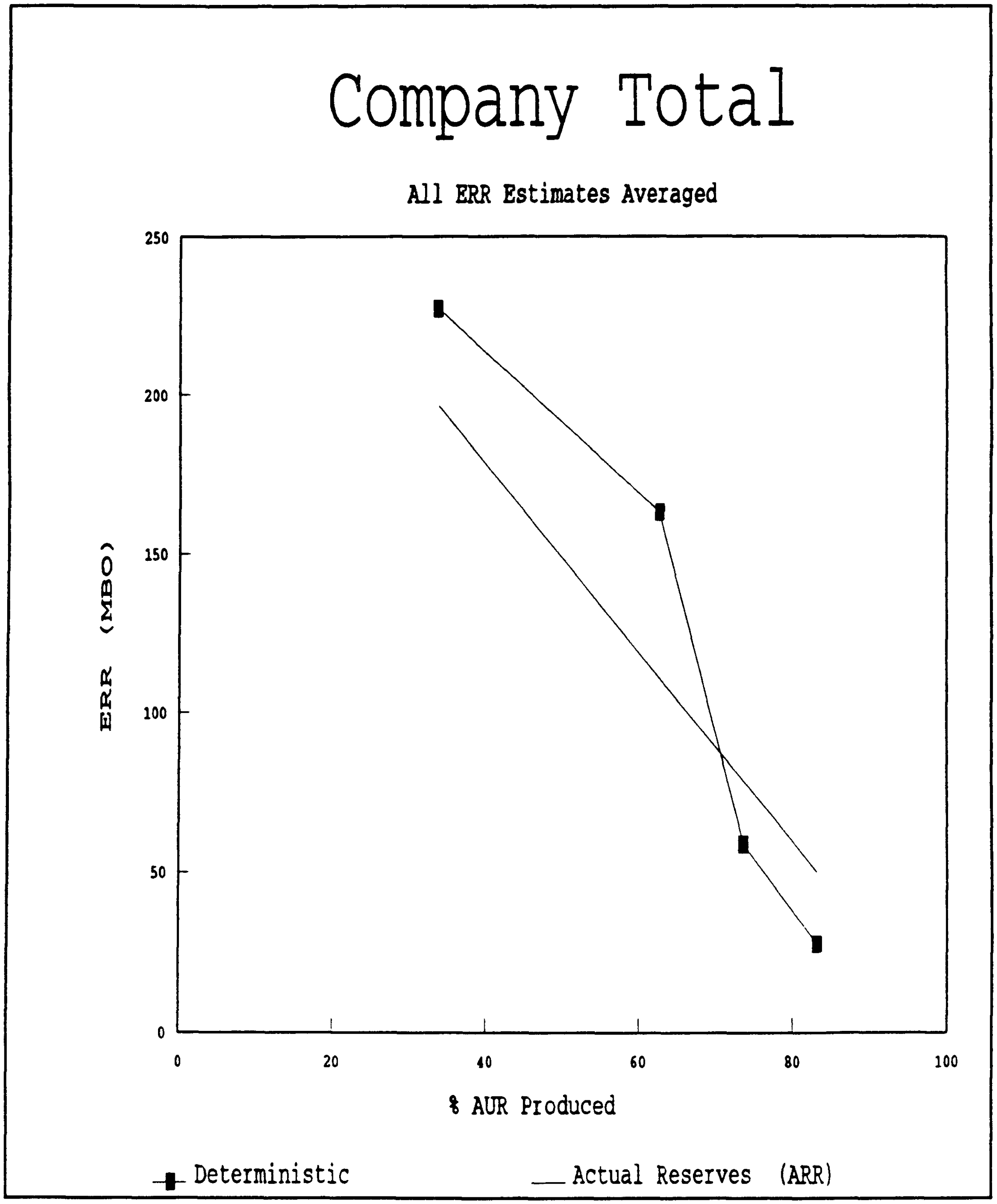

Figure A-12 Average P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Company Total. Y axis in MBO

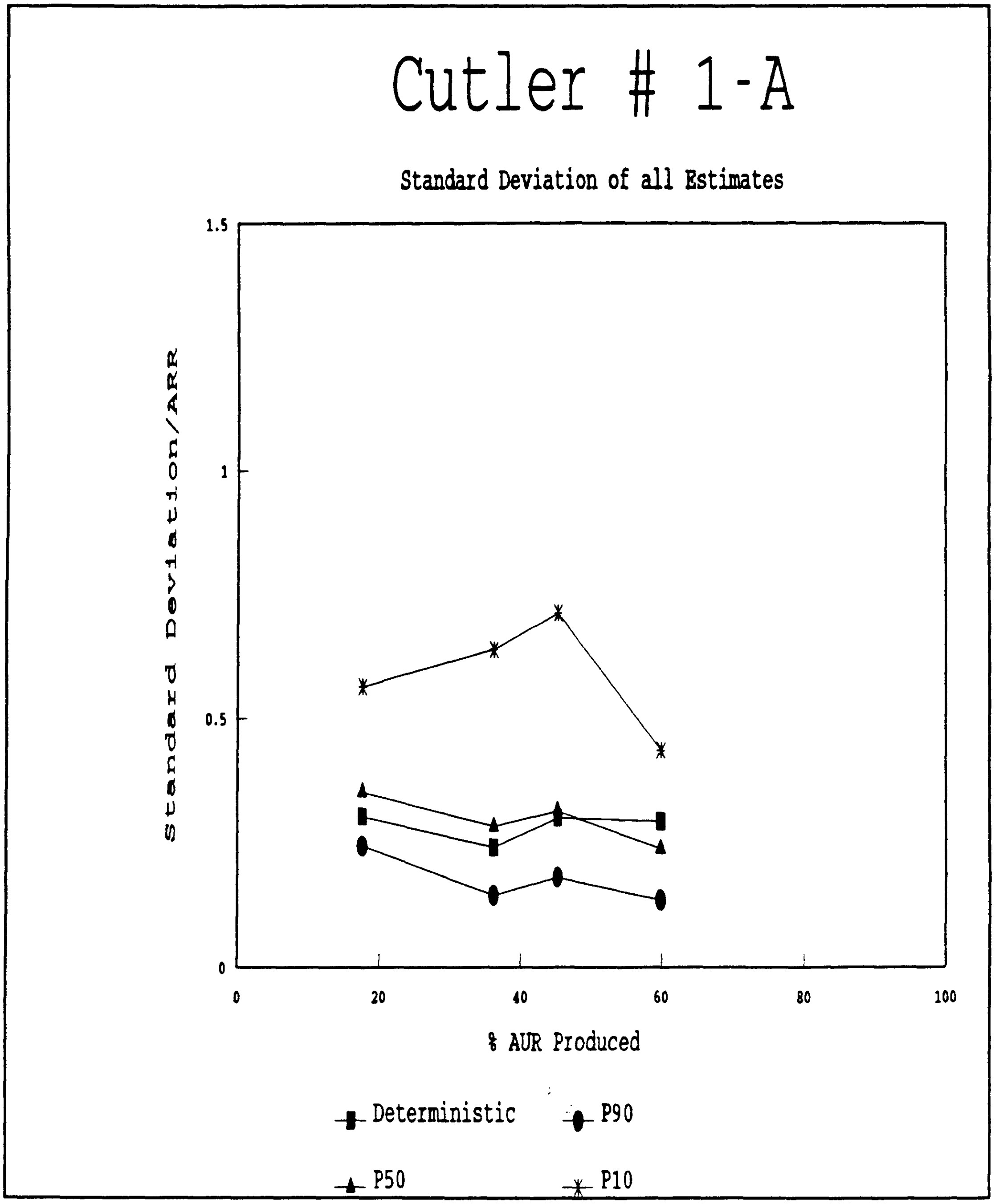

Figure A-13 Standard Deviations/ARR of P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Cutler # 1-A

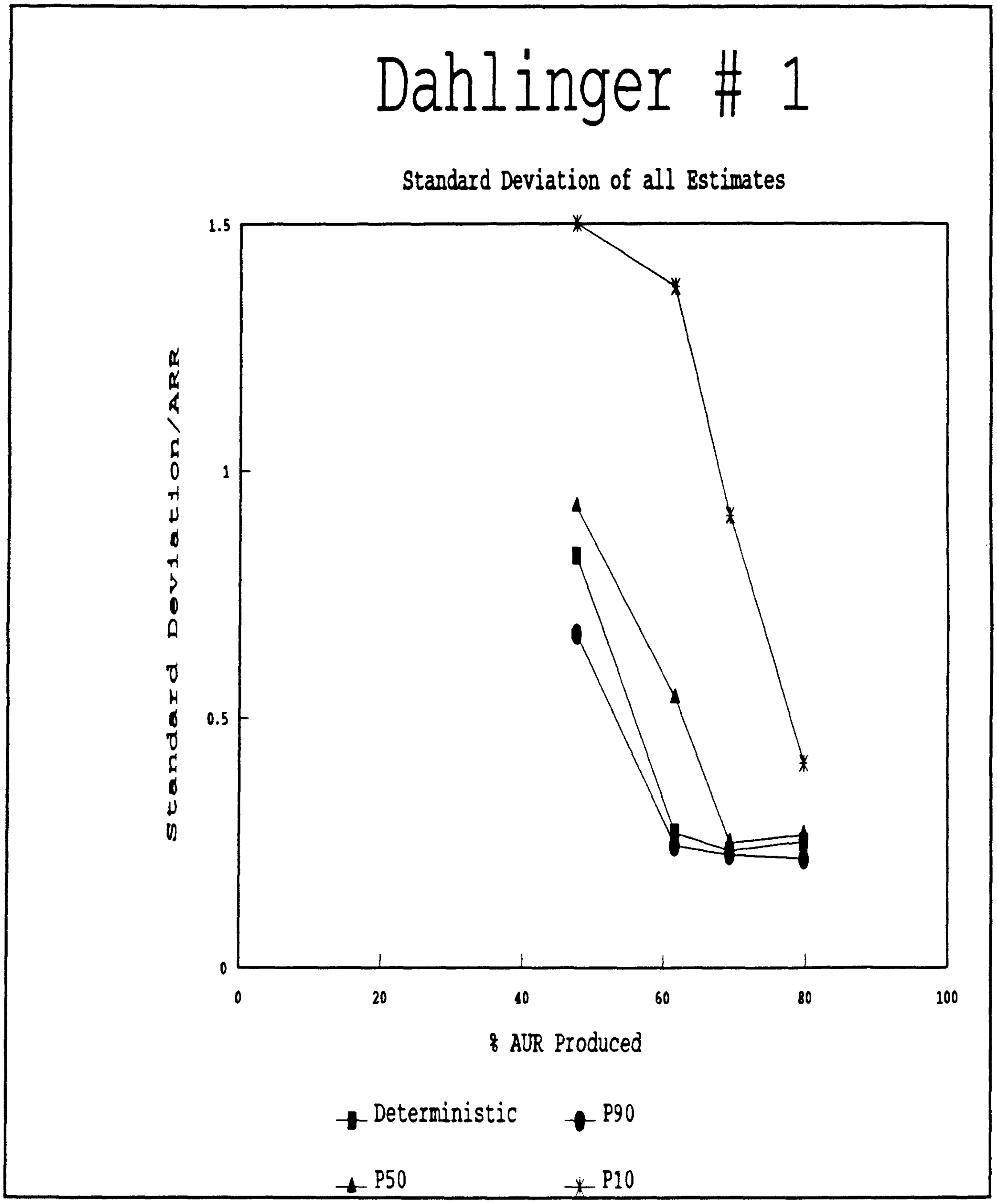

Figure A-14 Standard Deviations/ARR for P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Dahlinger # 1

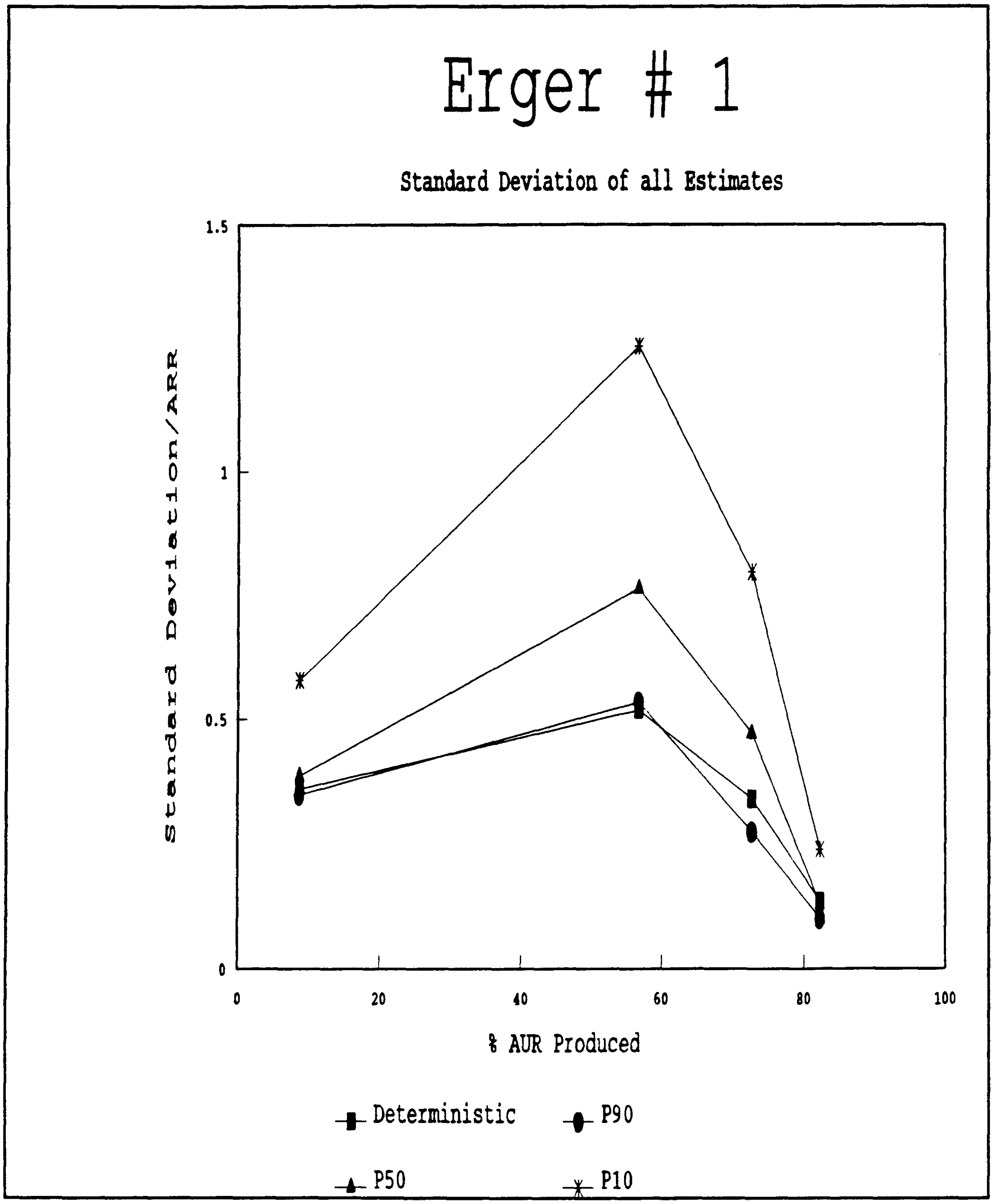

Figure A-15 Standard Deviations/ARR for P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Erger # 1

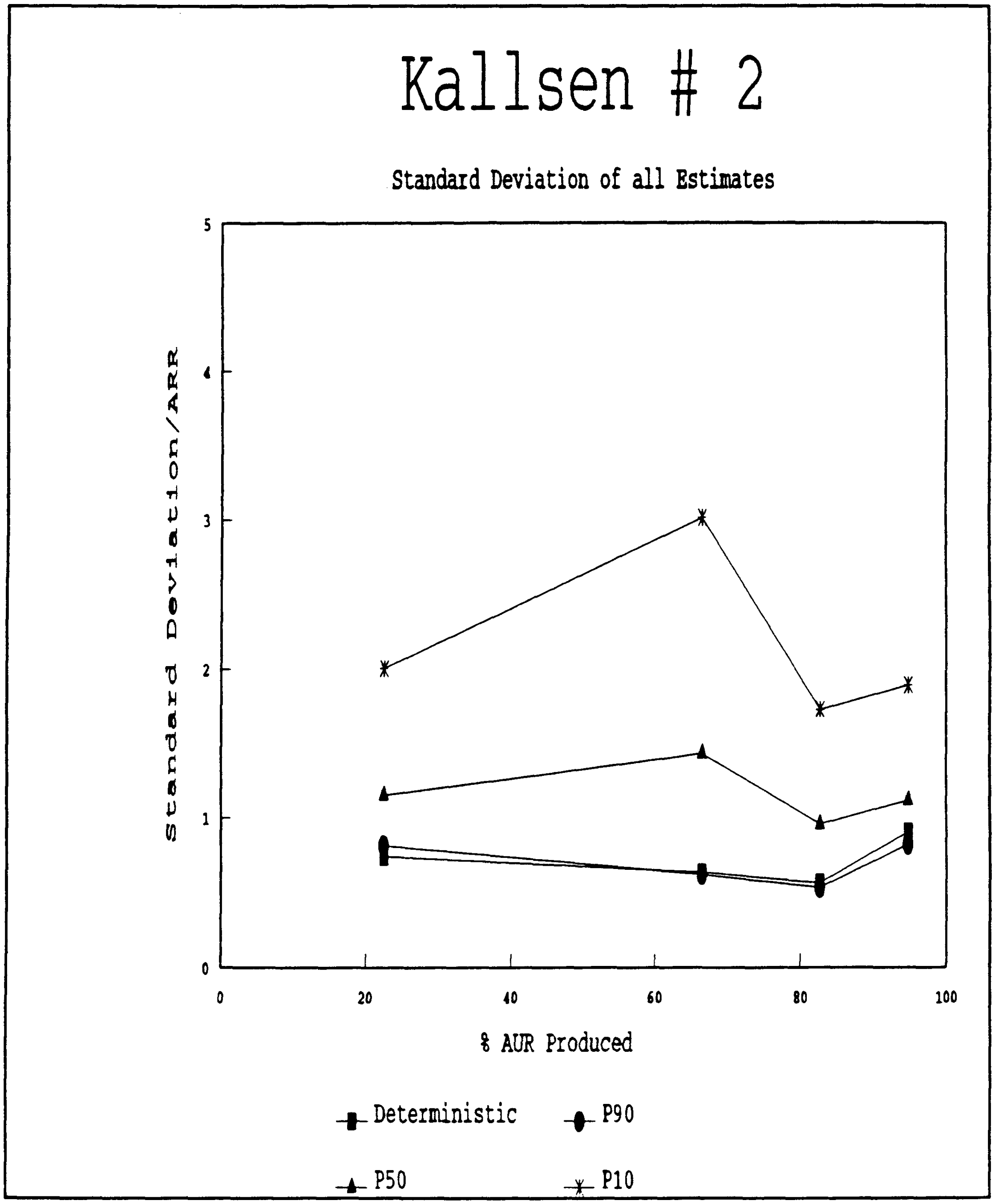

Figure A-16 Standard Deviations/ARR of P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Kallsen # 2

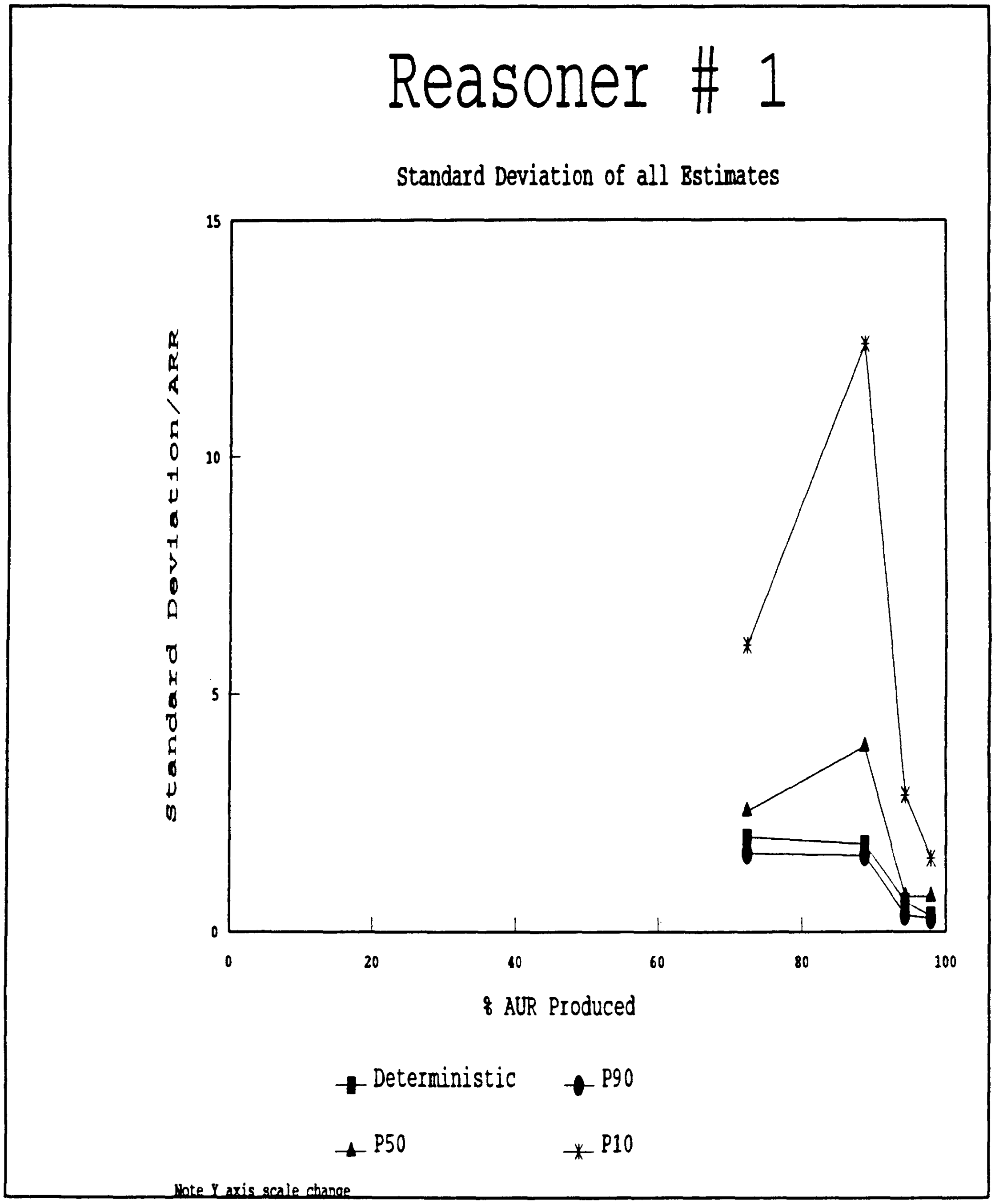

Figure A-17 Standard Deviations/ARR of P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Reasoner # 1

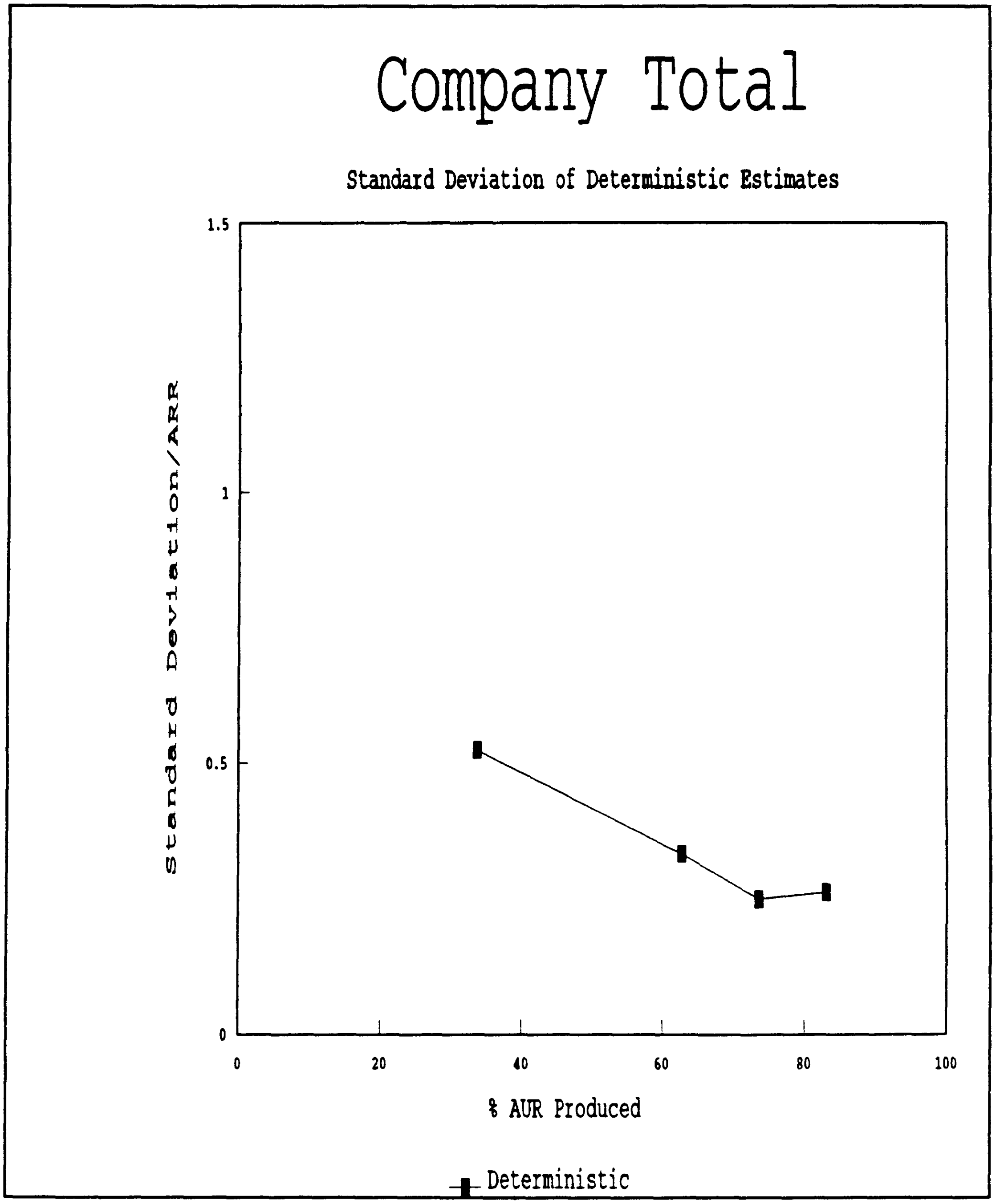

Figure A-18 Standard Deviations/ARR for P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Company Total

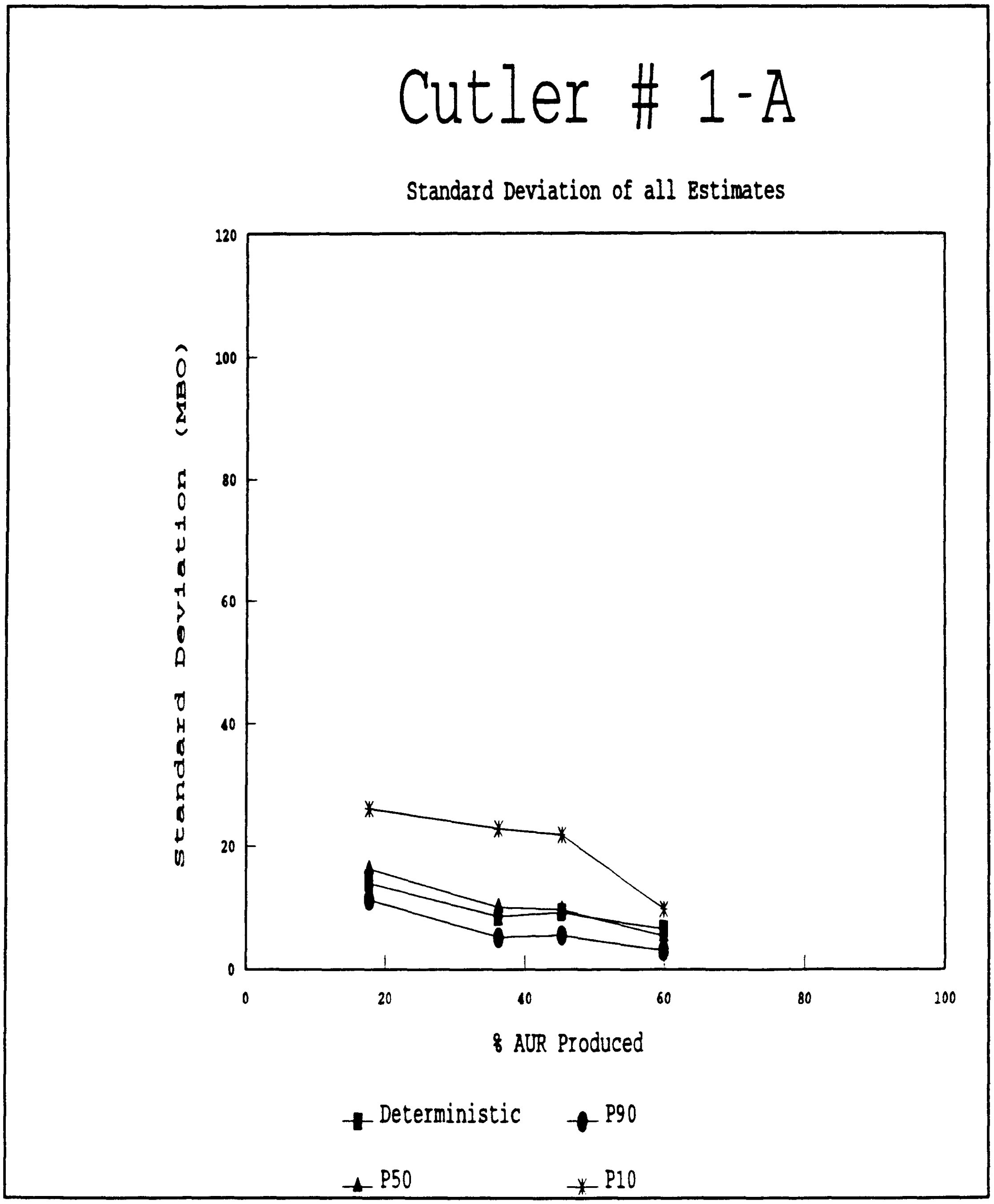

Figure A-19 Standard Deviation for P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Dahlinger # 1. Y axis in MBO

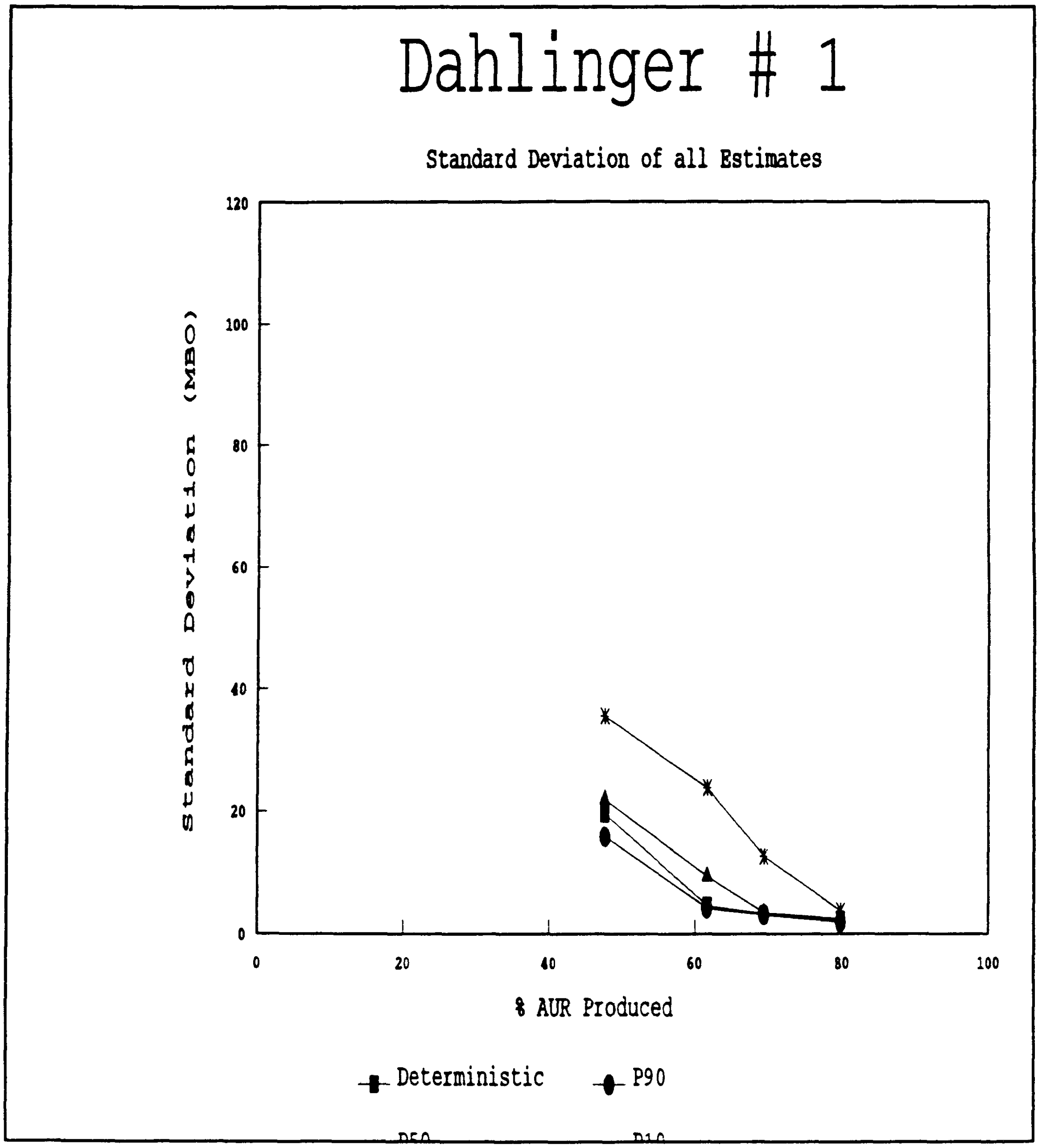

Figure A-20 Standard Deviation for P_{90}, P_{50}, P_{10} and Deterministic estimate by phase for the Cutler # 1-A. Y axis in MBO.

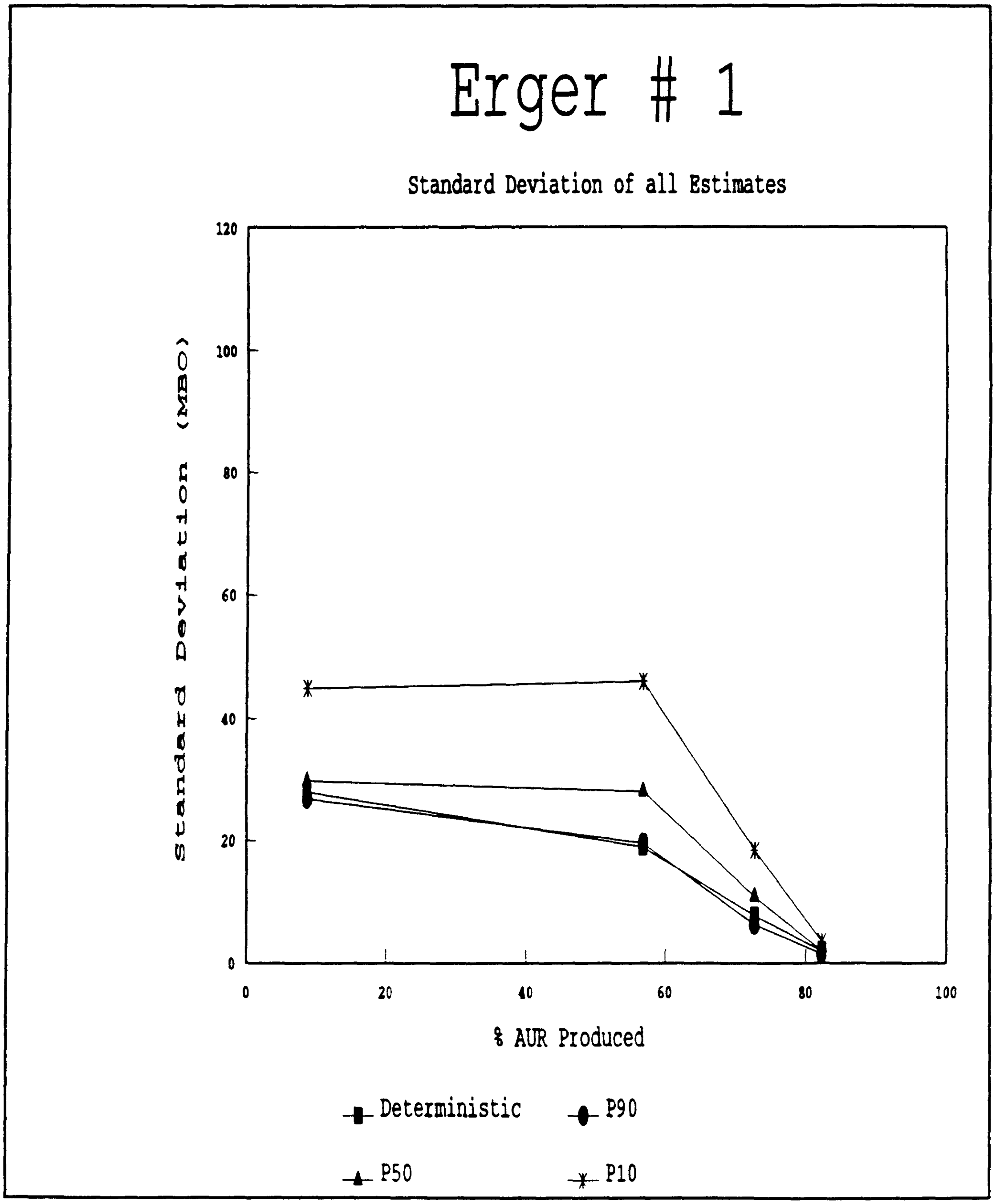

Figure A-21 Standard Deviation for P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Erger # 1. Y axis in MBO.

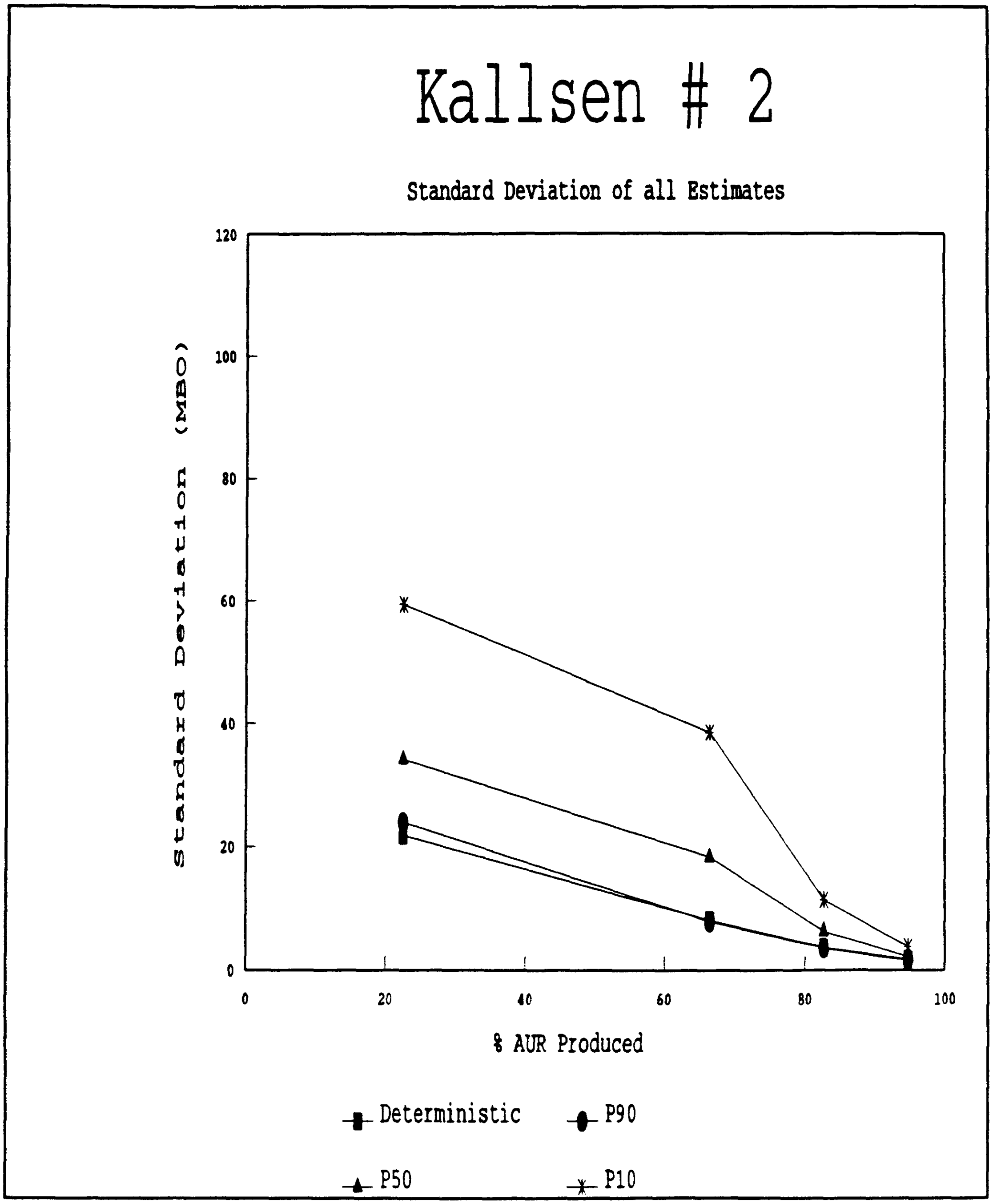

Figure A-22 Standard Deviation for P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Kallsen # 2. Y axis in MBO.

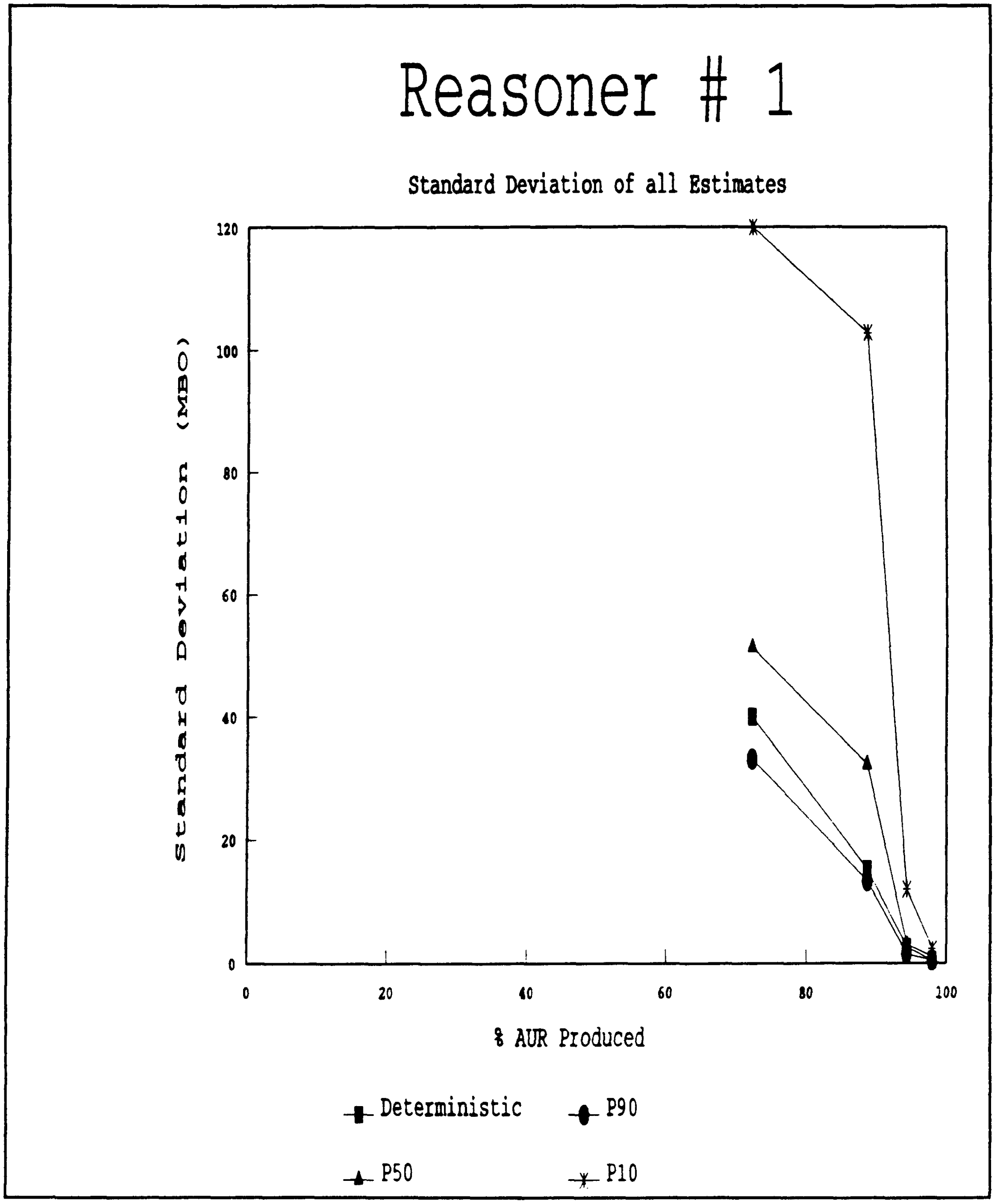

Figure A-23 Standard Deviation for P_{90}, P_{50}, P_{10} and Deterministic estimates by phase for the Reasoner # 1. Y axis in MBO

APPENDIX B

Quartile plots for all wells and the Company Total.

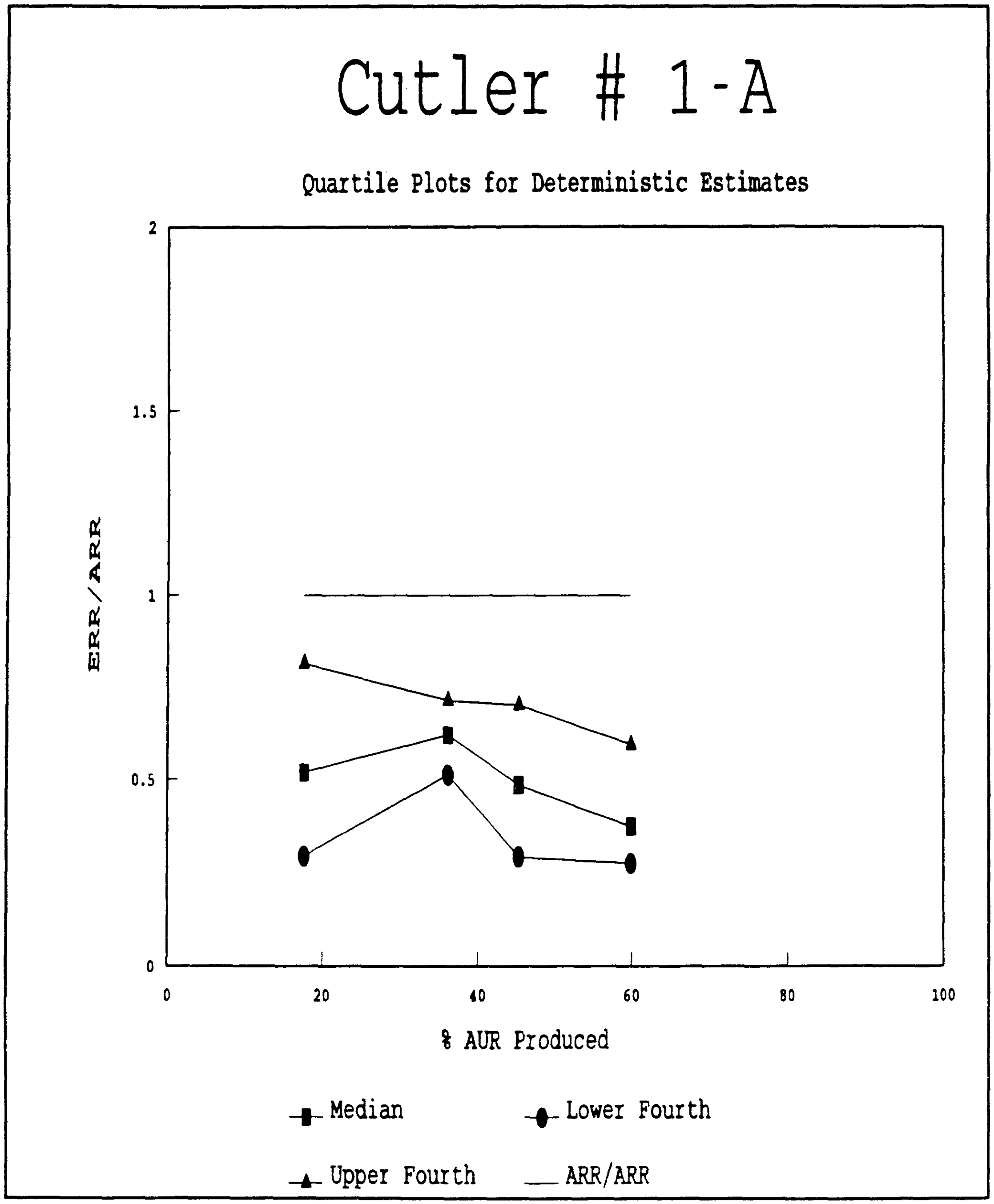

Figure B-1 Quartile plot of Deterministic Estimates for the Cutler # 1-A

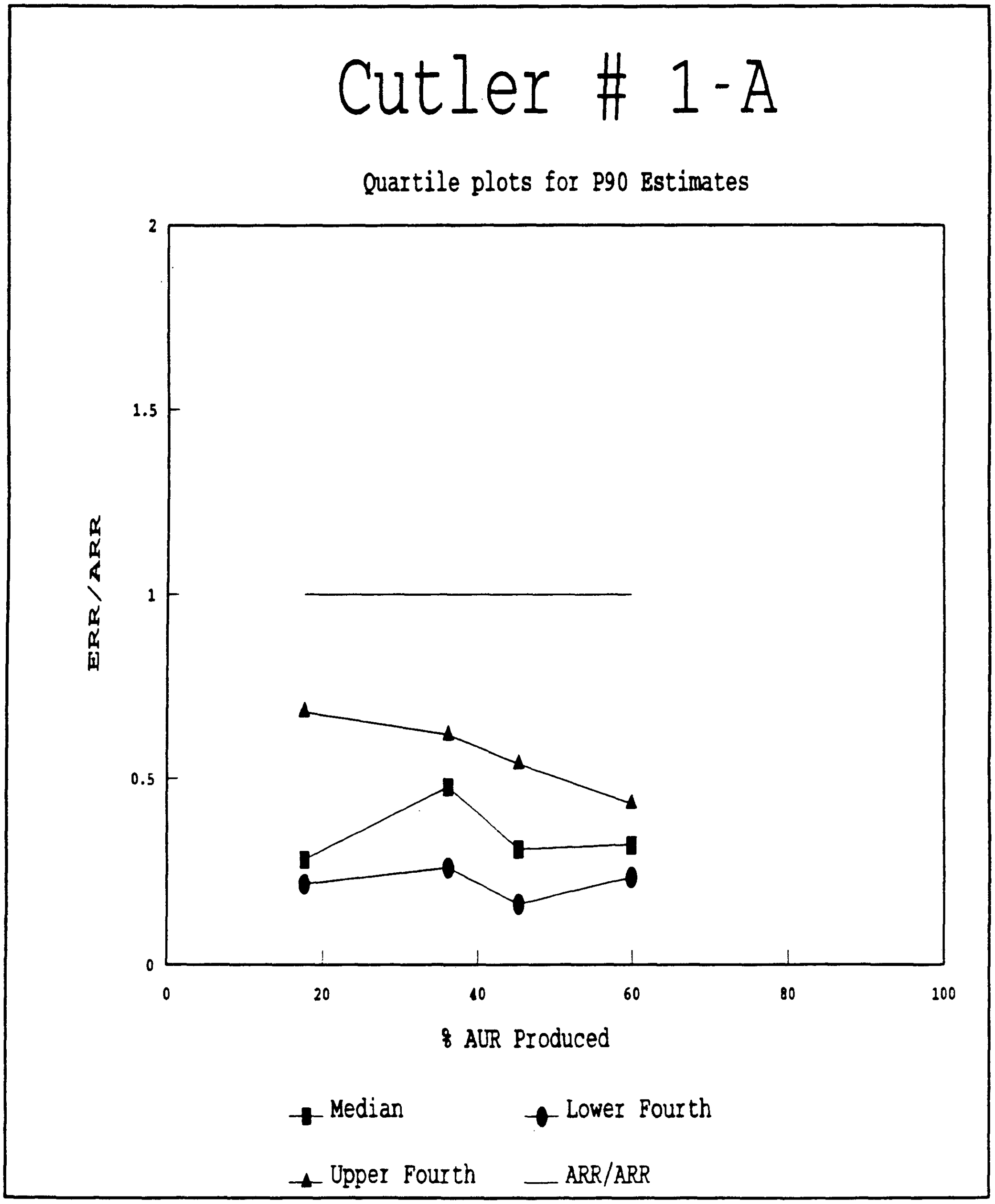

Figure B-2 Quartile Plot of P_{90} Estimates for the Cutler # 1-A

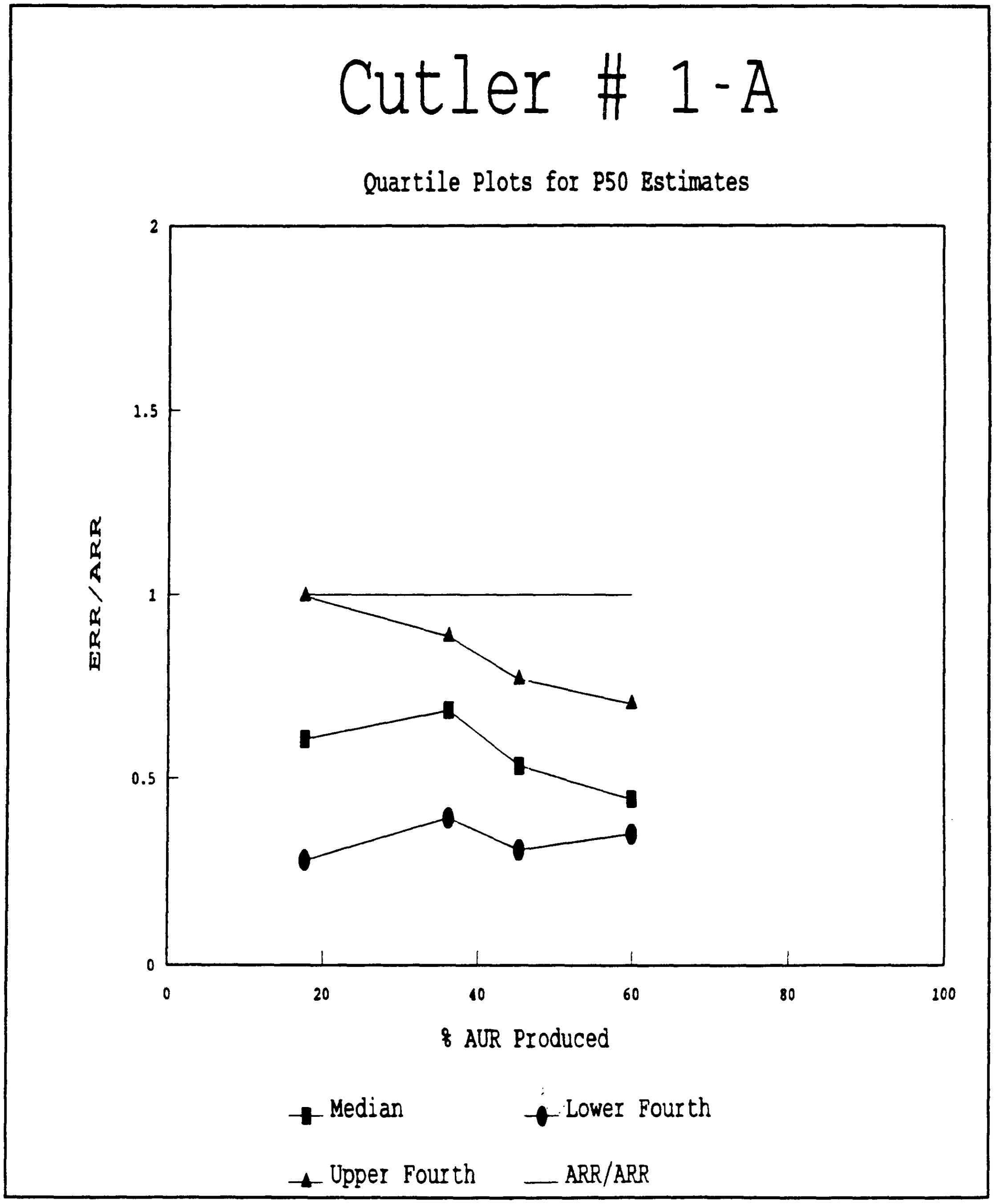

Figure B-3 Quartile Plot of P_{50} Estimates for the Cutler # 1-A

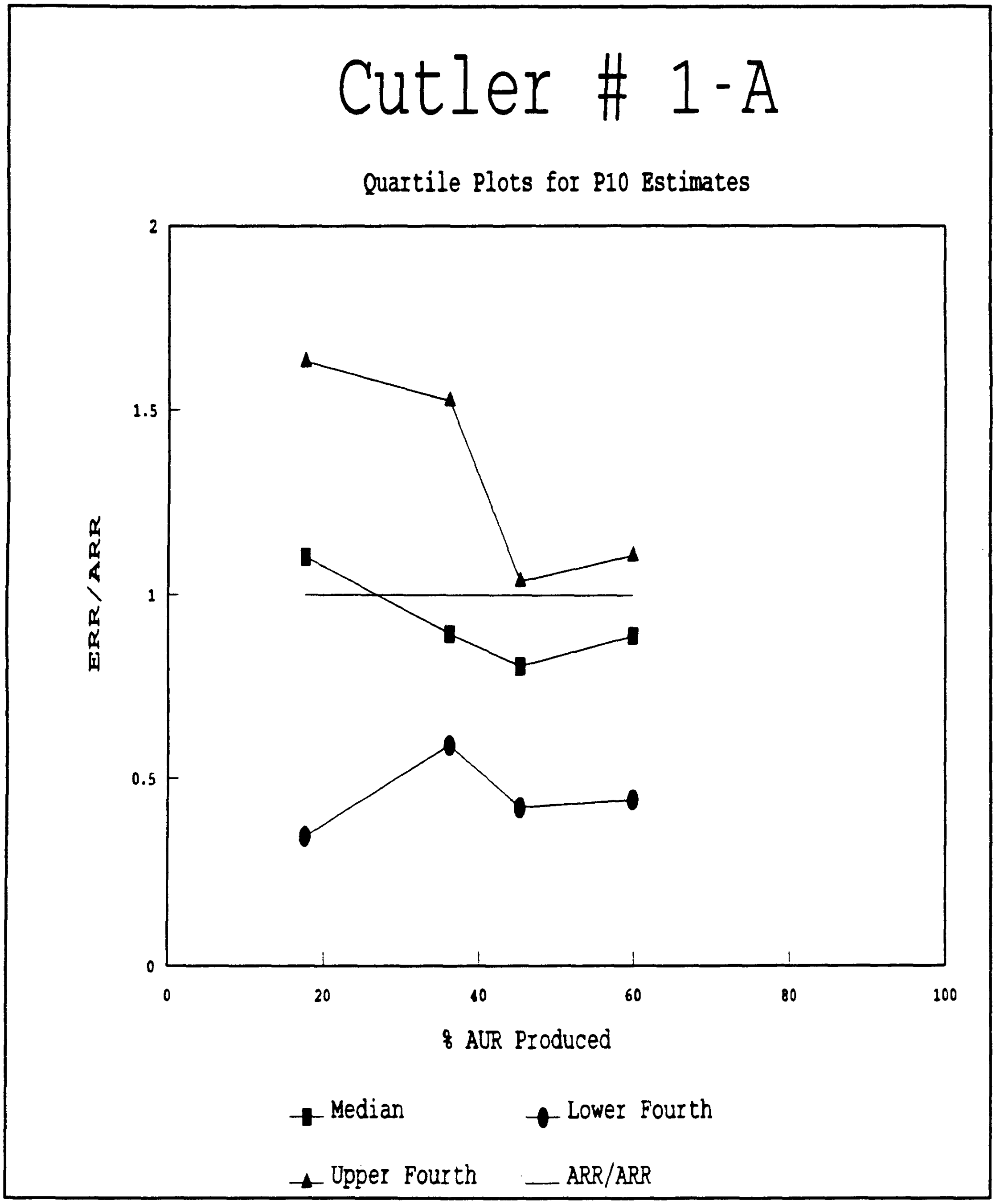

Figure B-4 Quartile Plot of P_{10} Estimates for the Cutler # 1-A

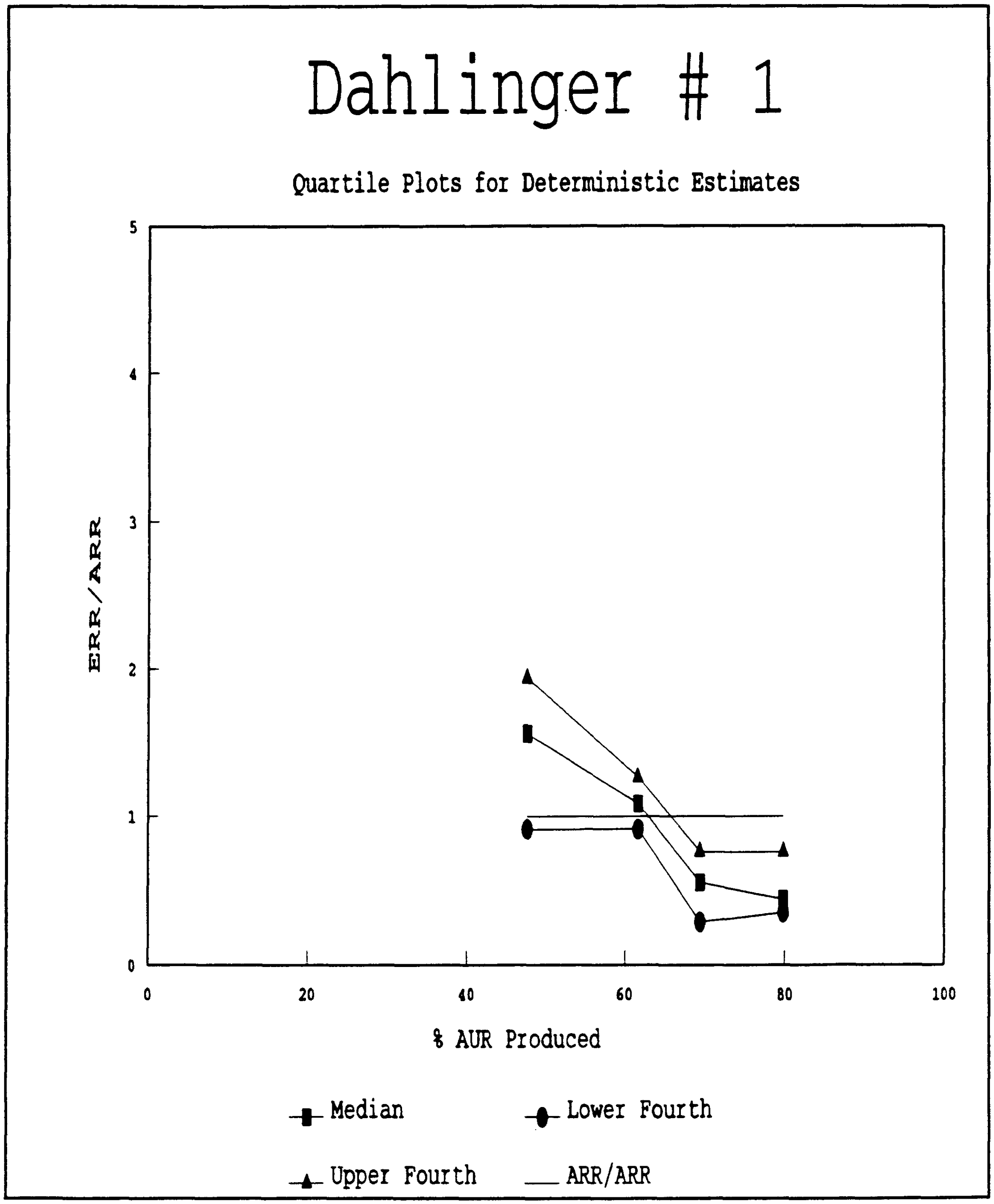

Figure B-5 Quartile Plots of Deterministic Estimates for the Dahlinger # 1

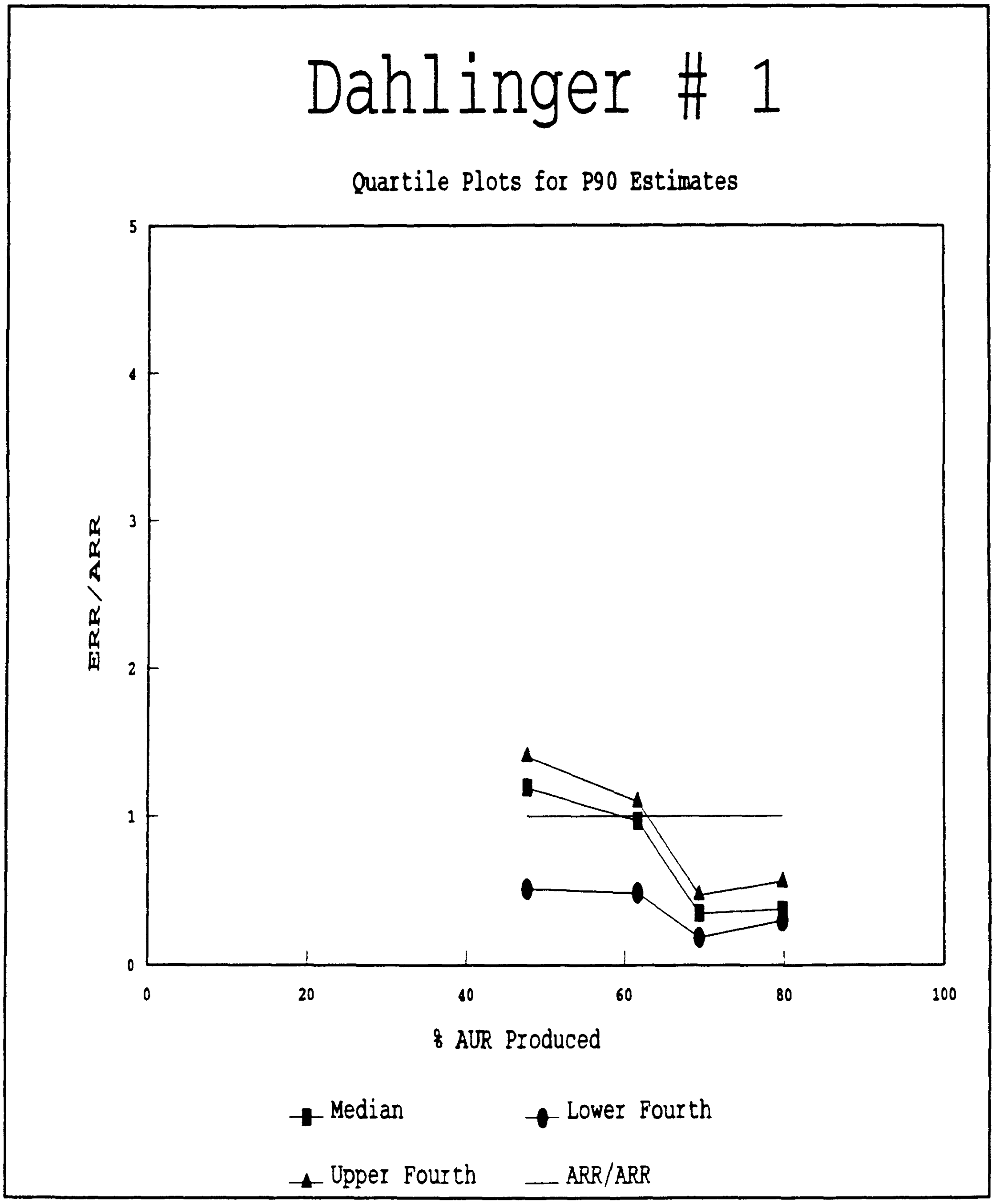

Figure B-6 Quartile Plots of P_{90} Estimates for the Dahlinger #1

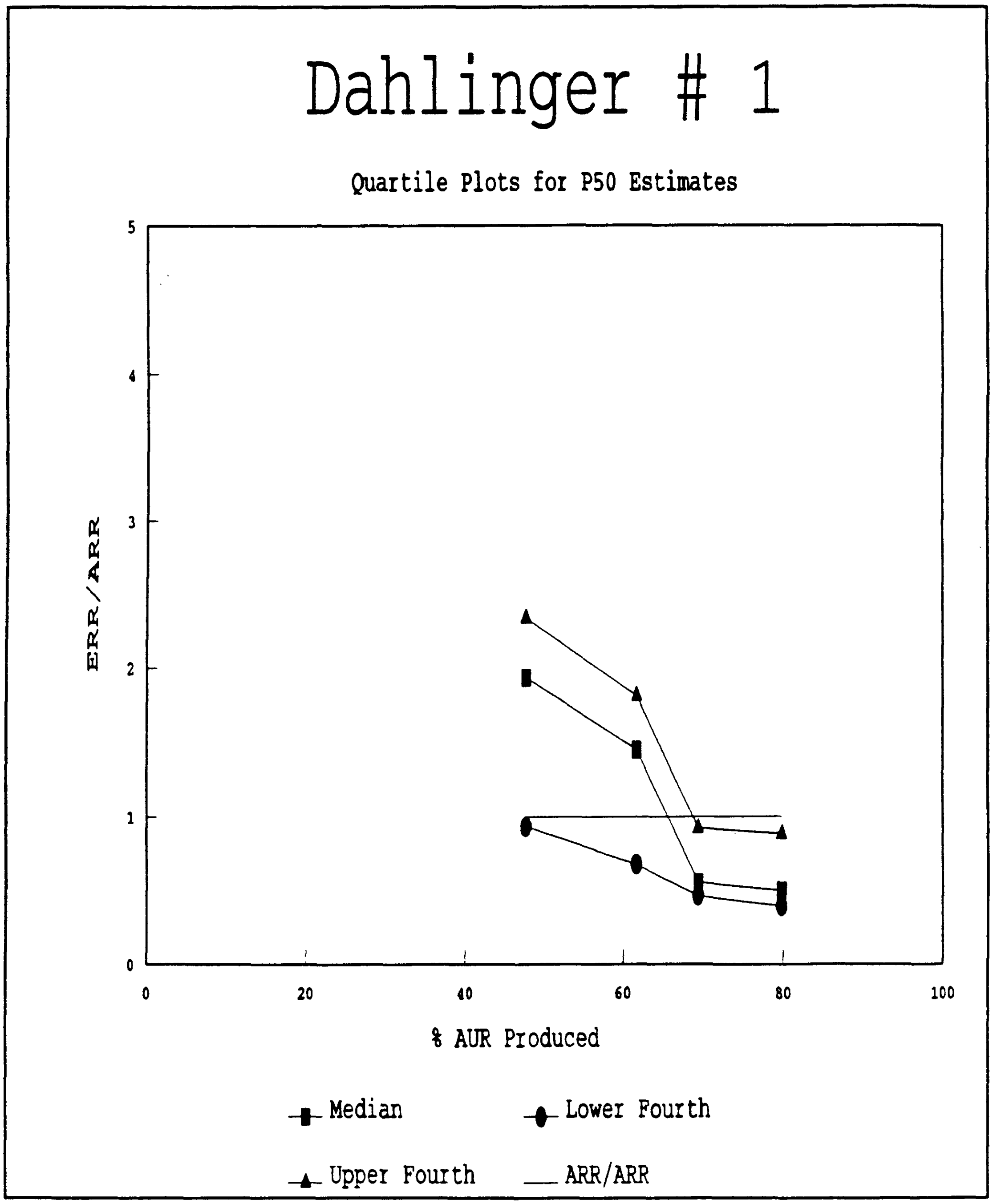

Figure B-7 Quartile Plots of P_{50} Estimates for the Dahlinger # 1

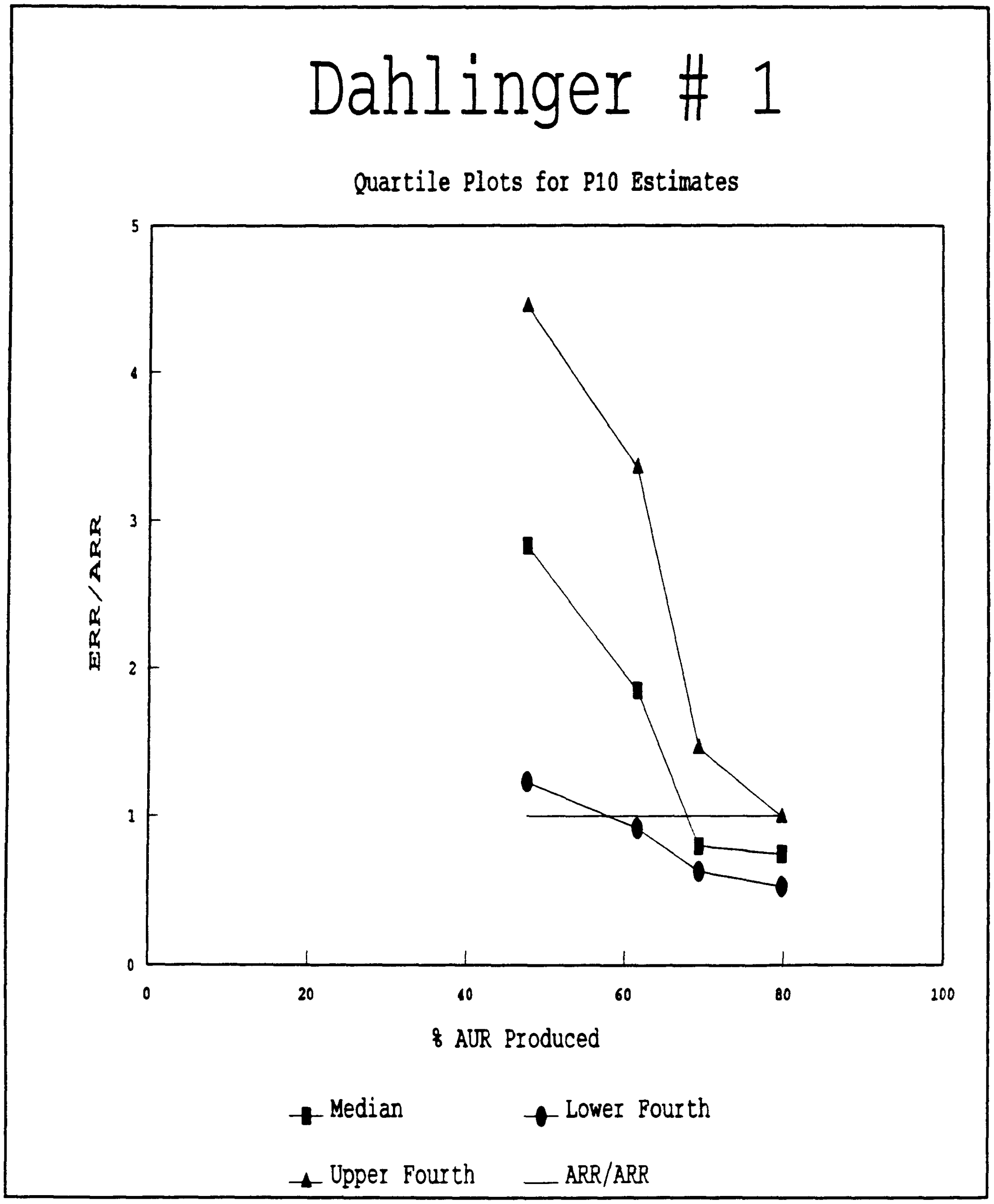

Figure B-8 Quartile Plots of P_{10} Estimates for the Dahlinger # 1

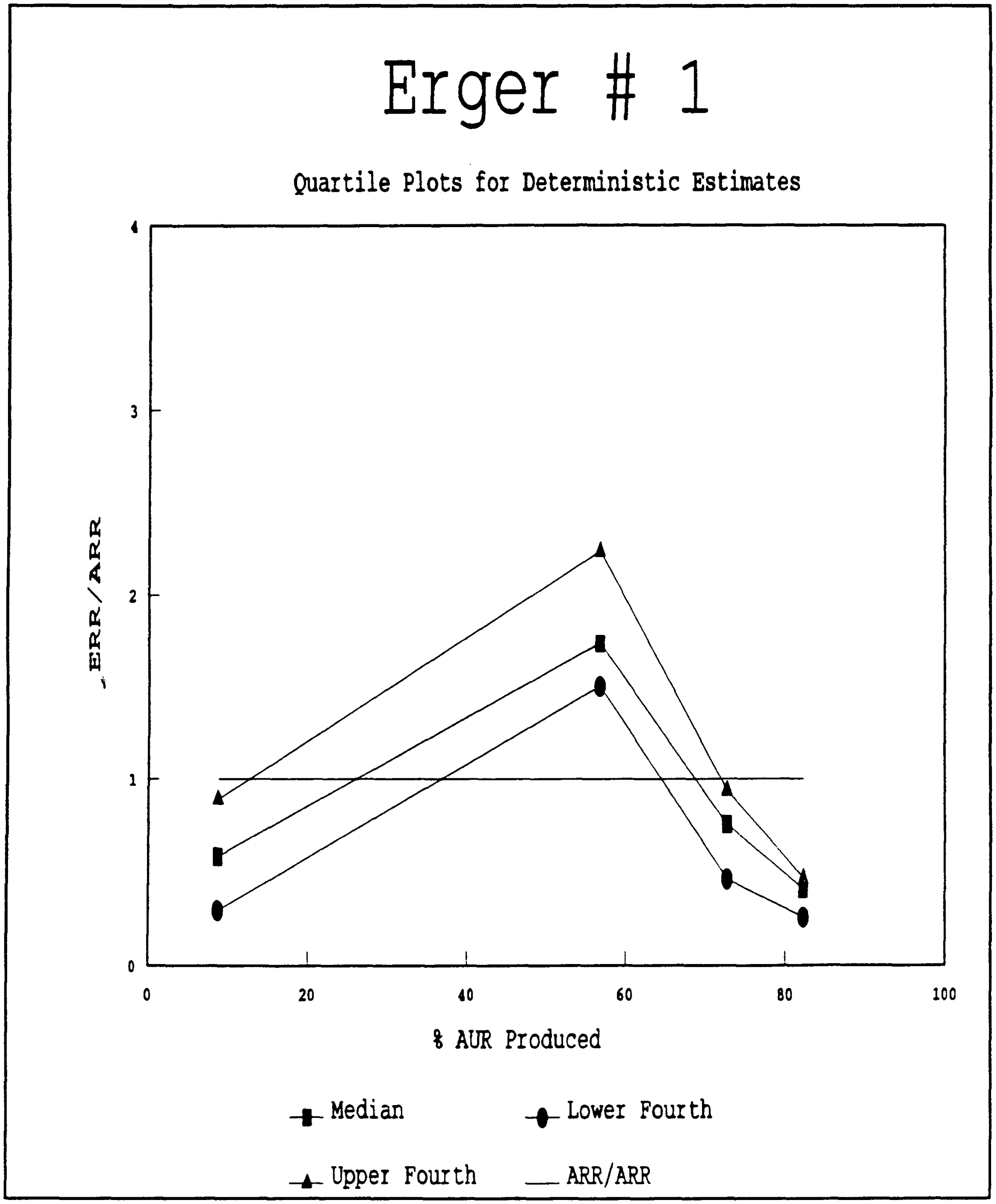

Figure B-9 Quartile Plots of Deterministic Estimates for the Erger # 1

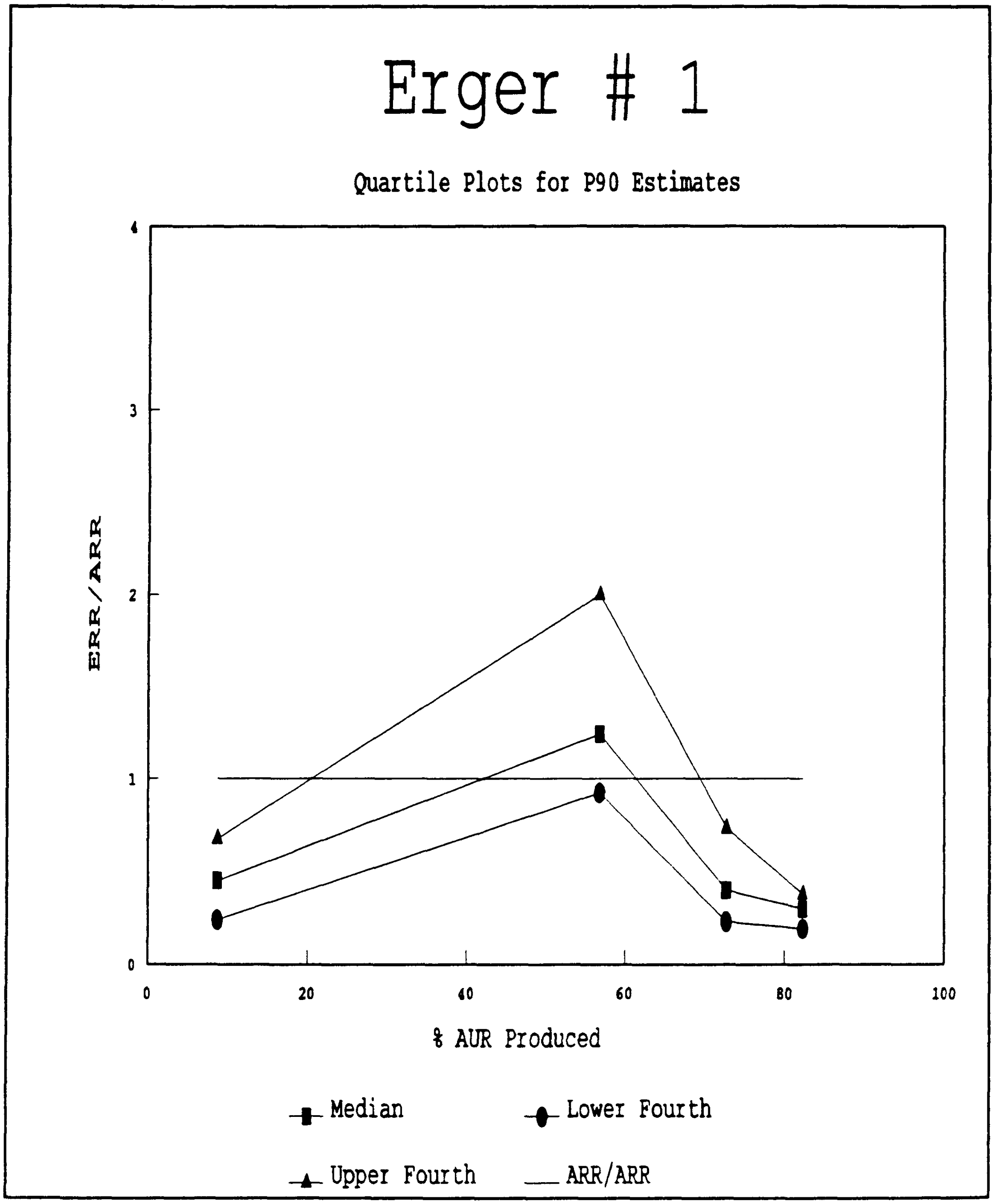

Figure B-10 Quartile Plot of P_{90} Estimates for the Erger # 1

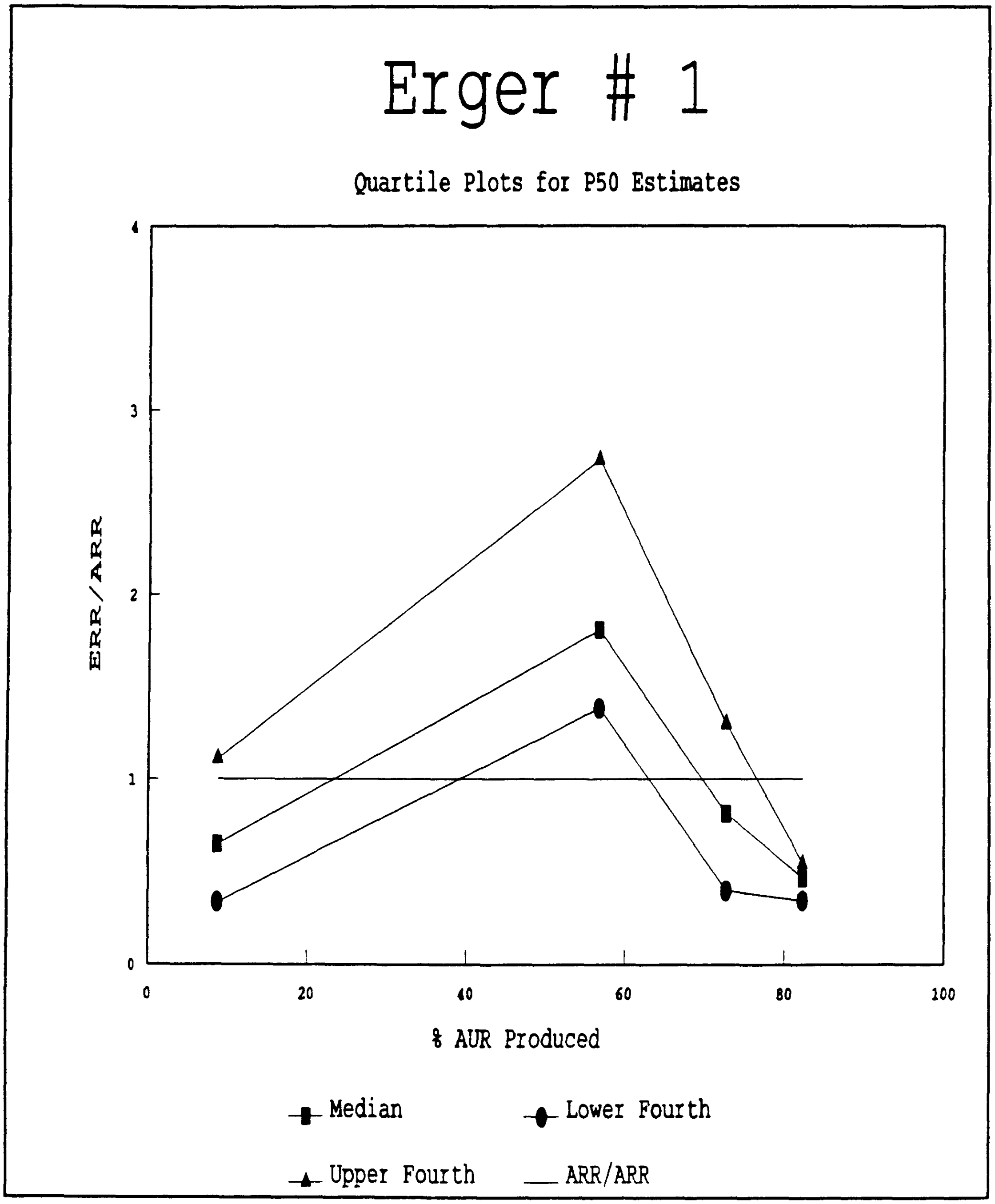

Figure B-11 Quartile Plot of P_{50} Estimates for the Erger #1

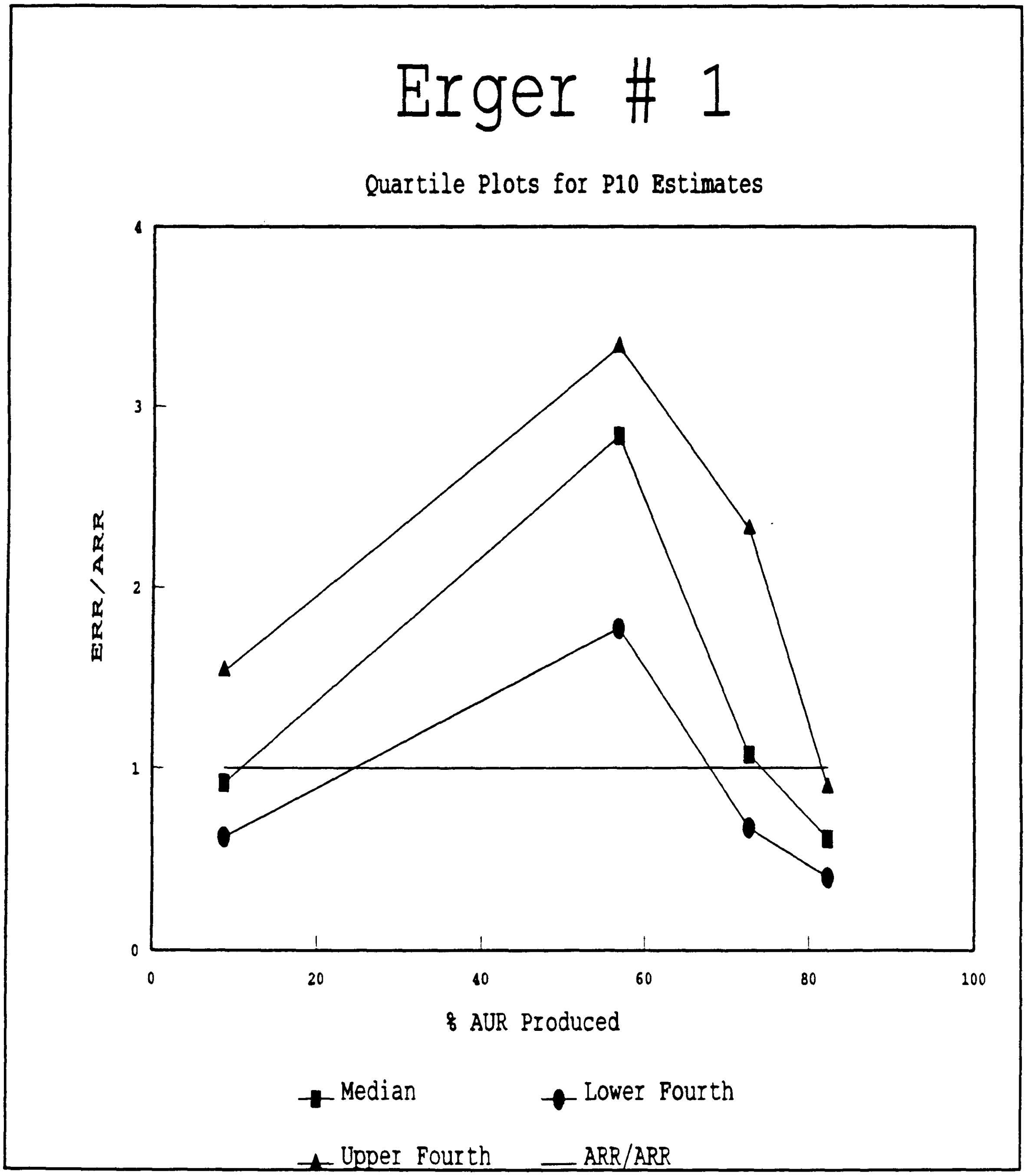

Figure B-12 Quartile Plots of P_{10} Estimates for the Erger # 1

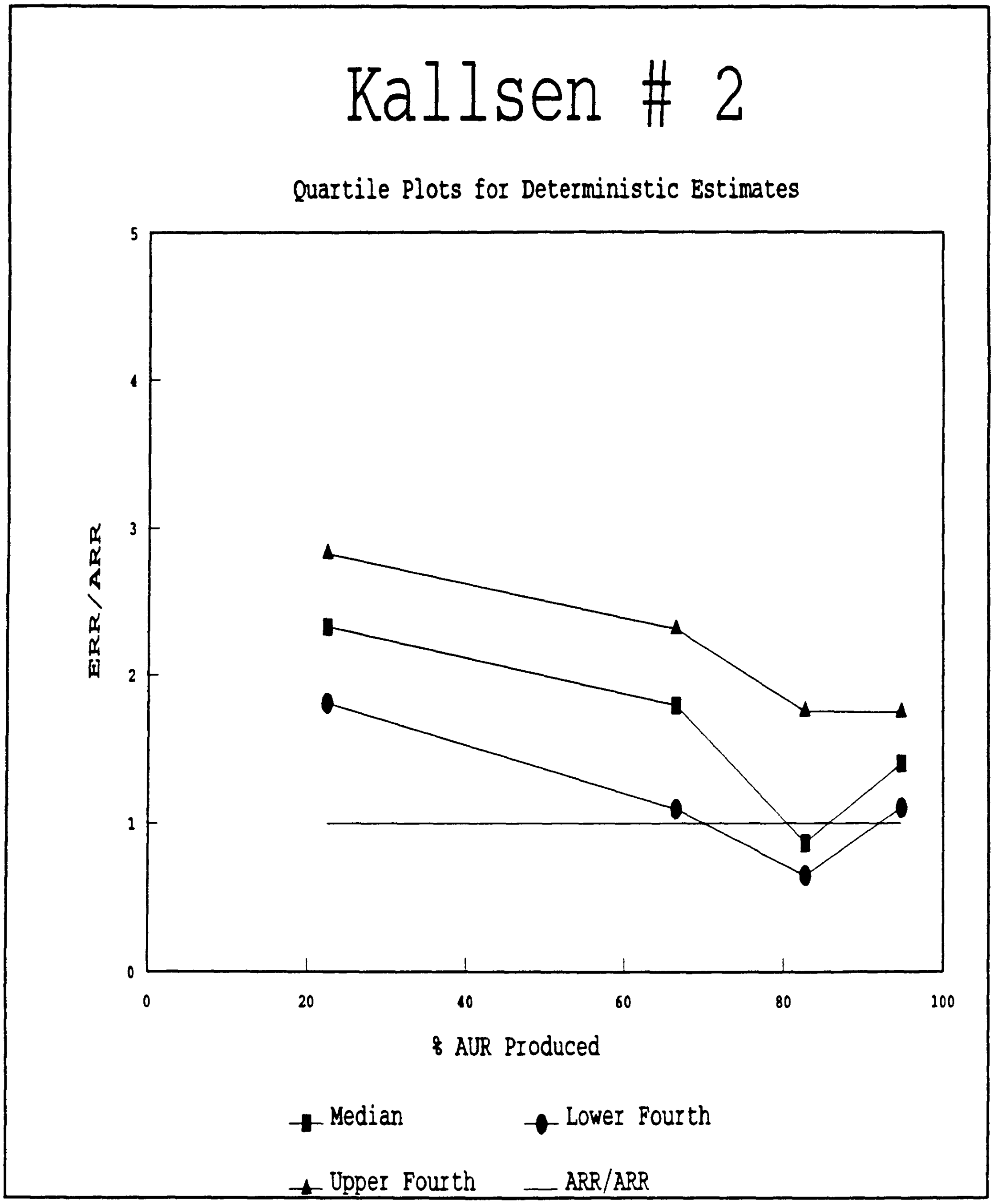

Figure B-13 Quartile Plots of Deterministic Estimates for the Kallsen # 2

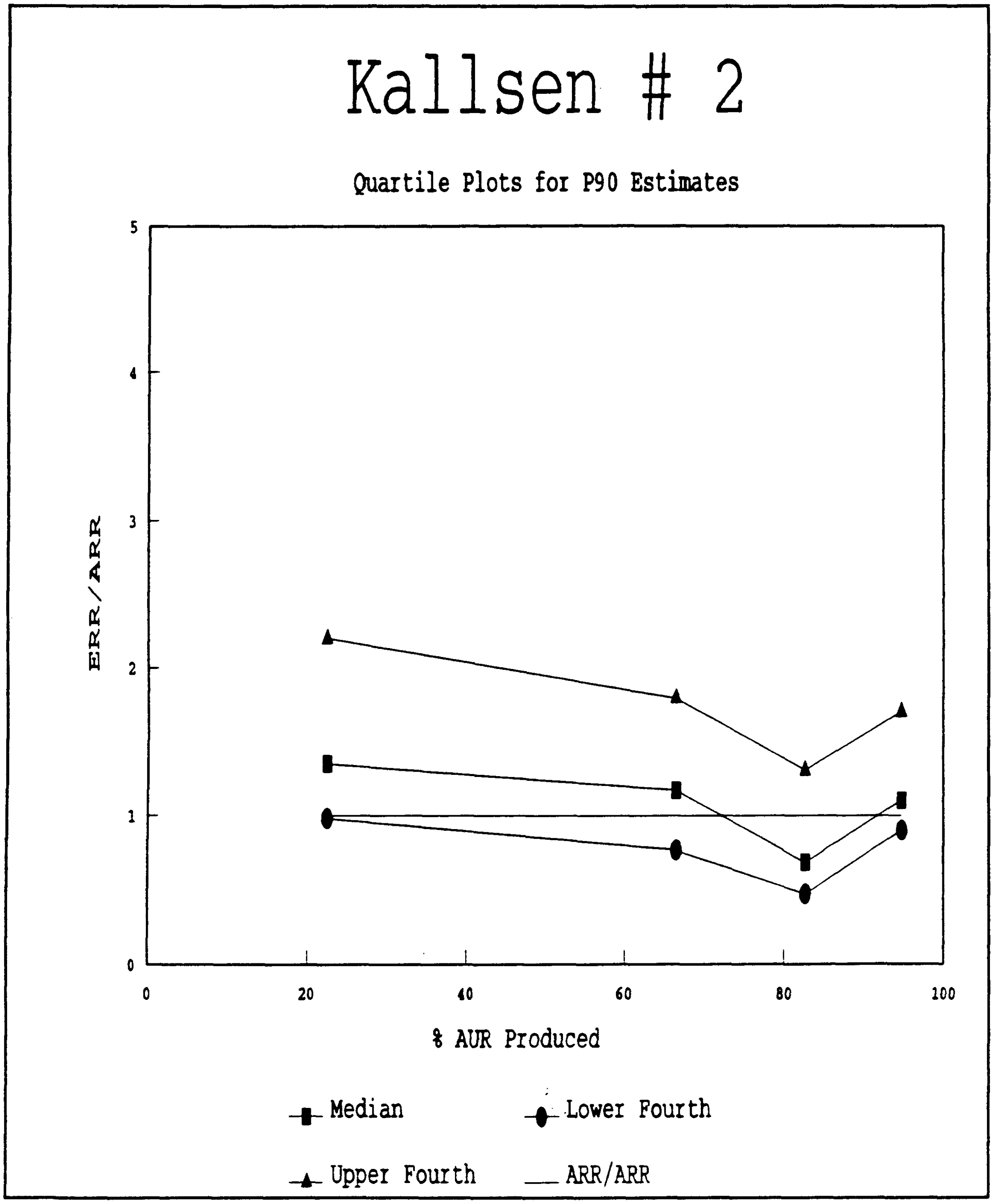

Figure B-14 Quartile Plots of P_{90} Estimates for the Kallsen # 2

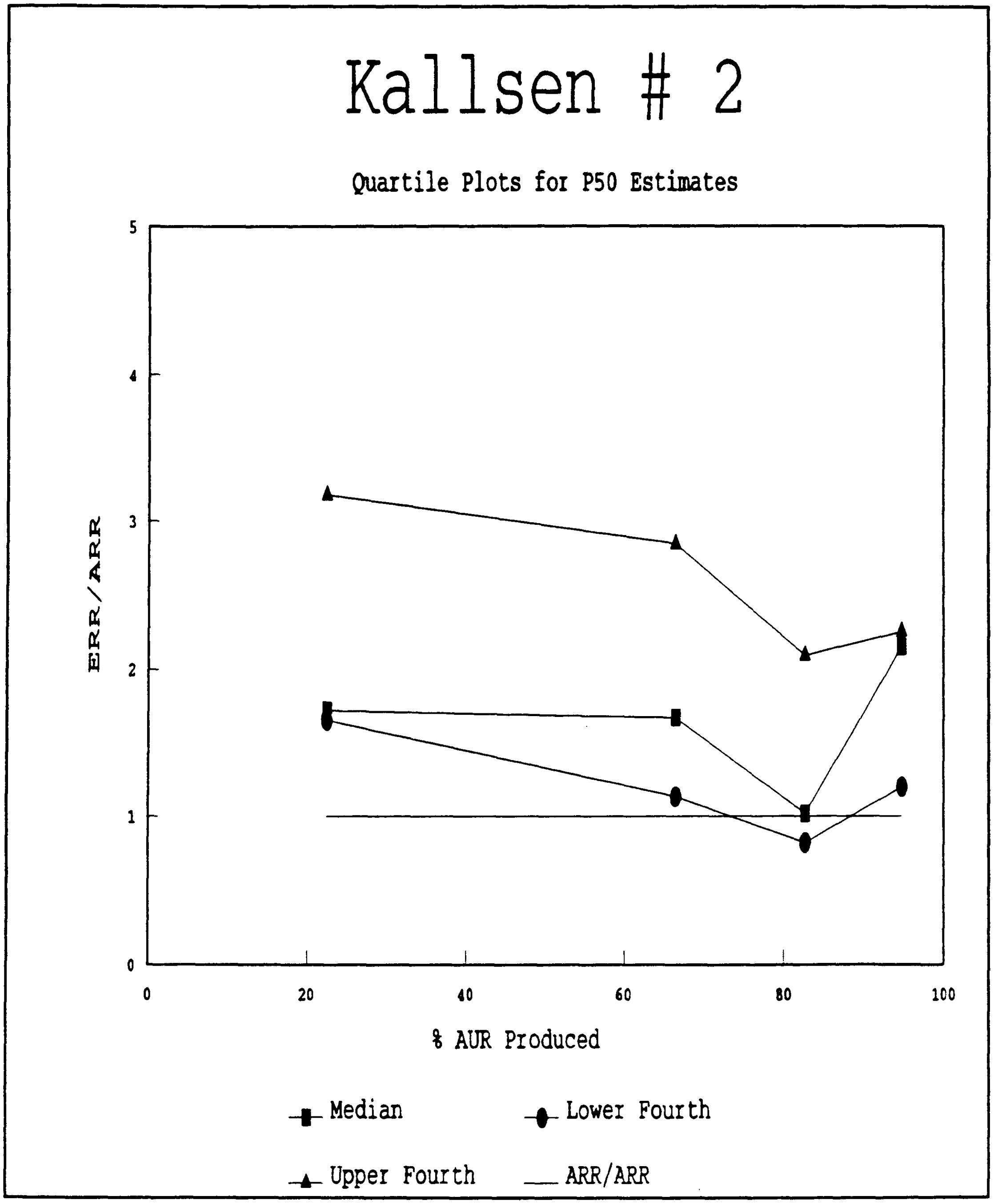

Figure B-15 Quartile Plot for P_{50} Estimates for the Kallsen # 2

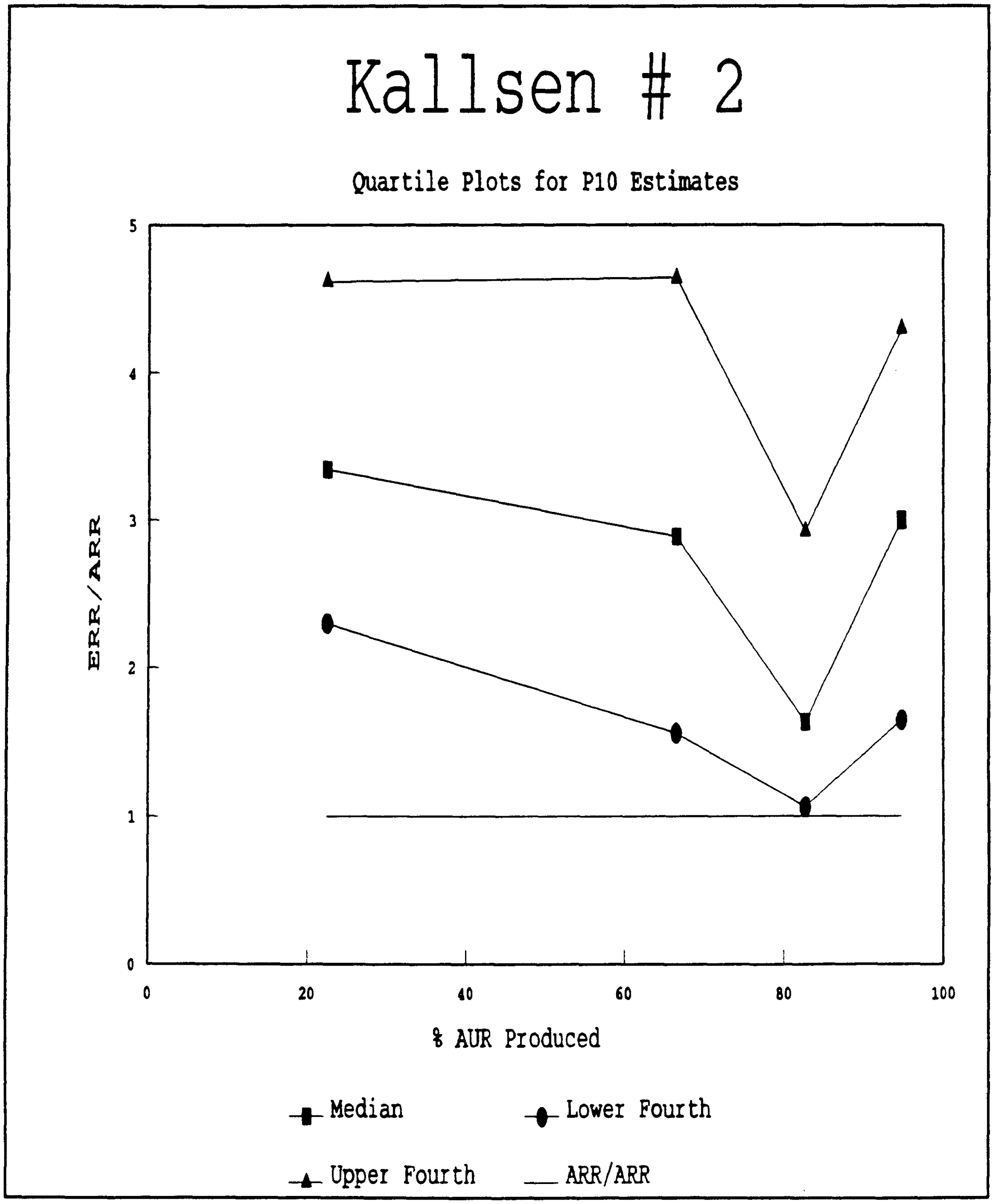

Figure B-16 Quartile Plot of P_{10} Estimates for the Kallsen # 2

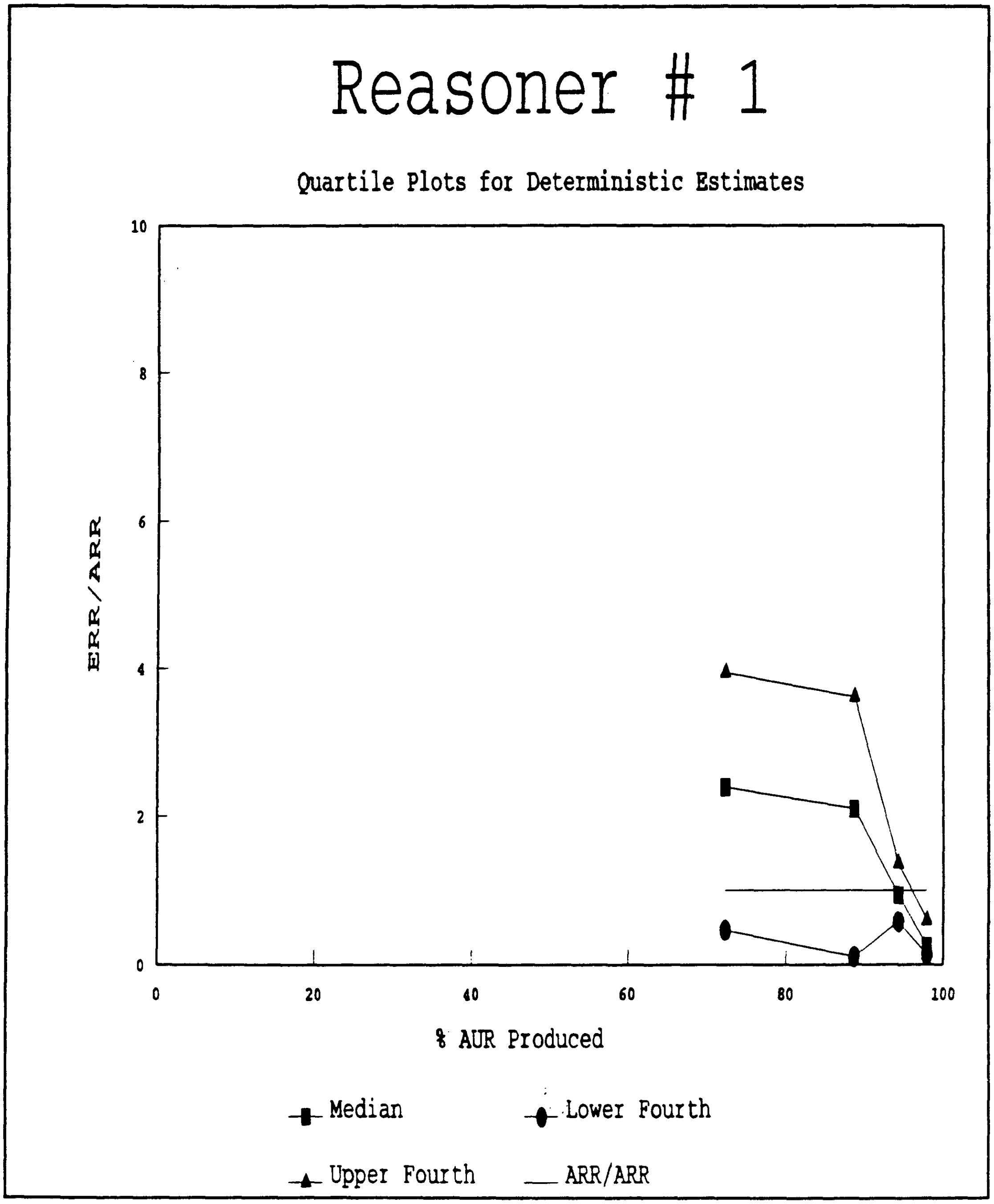

Figure B-17 Quartile Plot of Deterministic Estimates for the Reasoner # 1

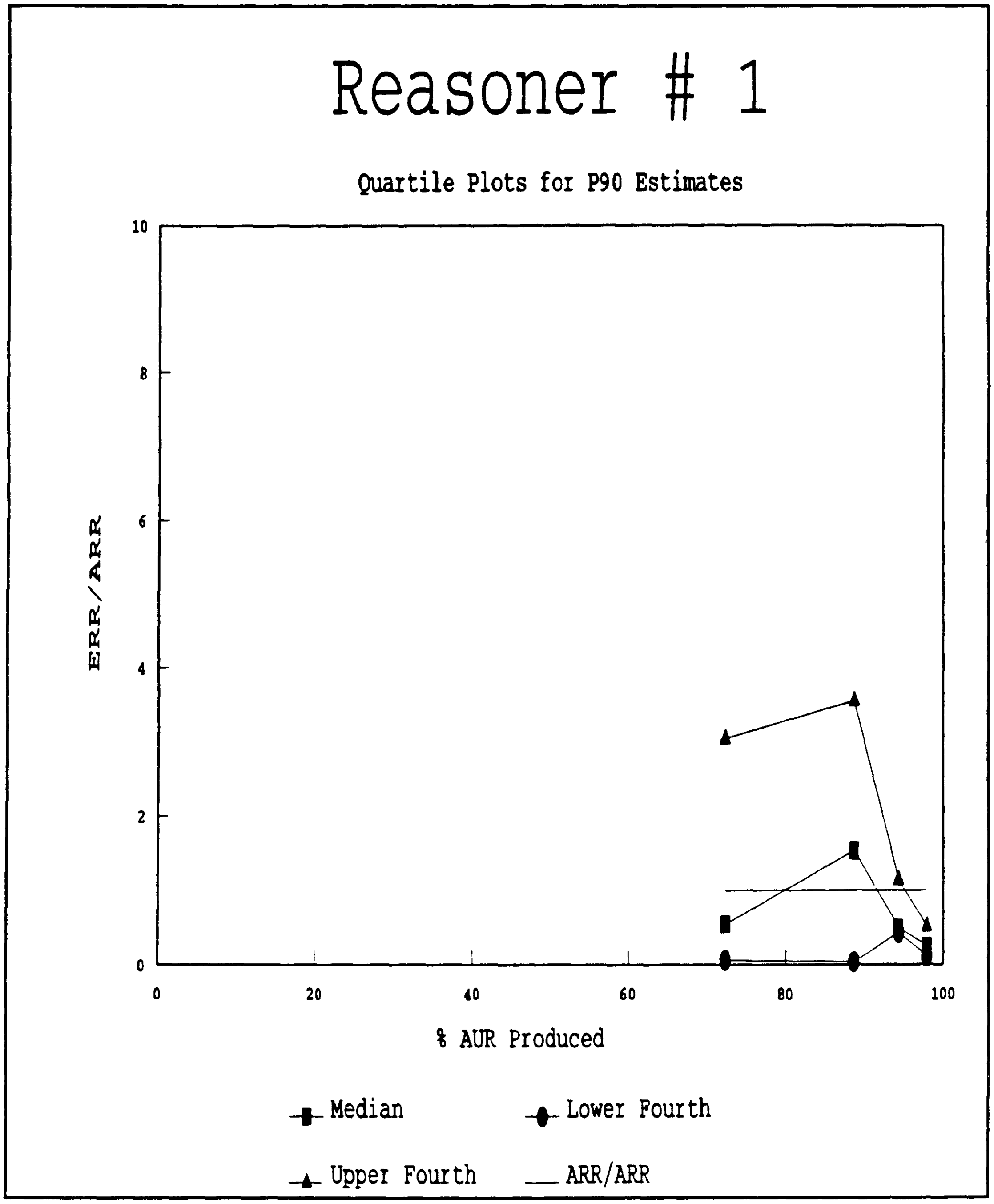

Figure B-18 Quartile Plot of P_{90} Estimates for the Reasoner # 1

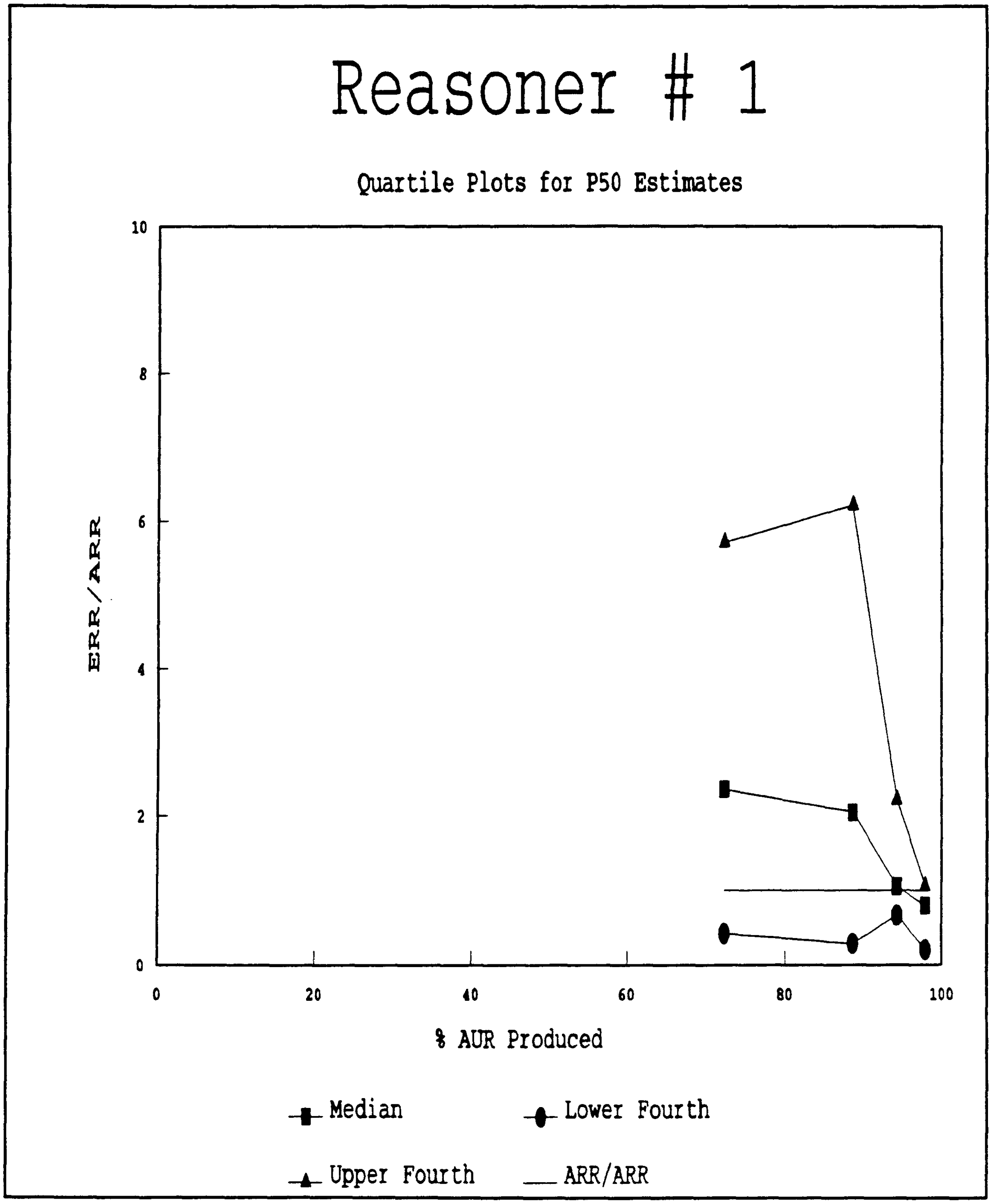

Figure B-19 Quartile Plot of P_{50} Estimates for the Reasoner # 1

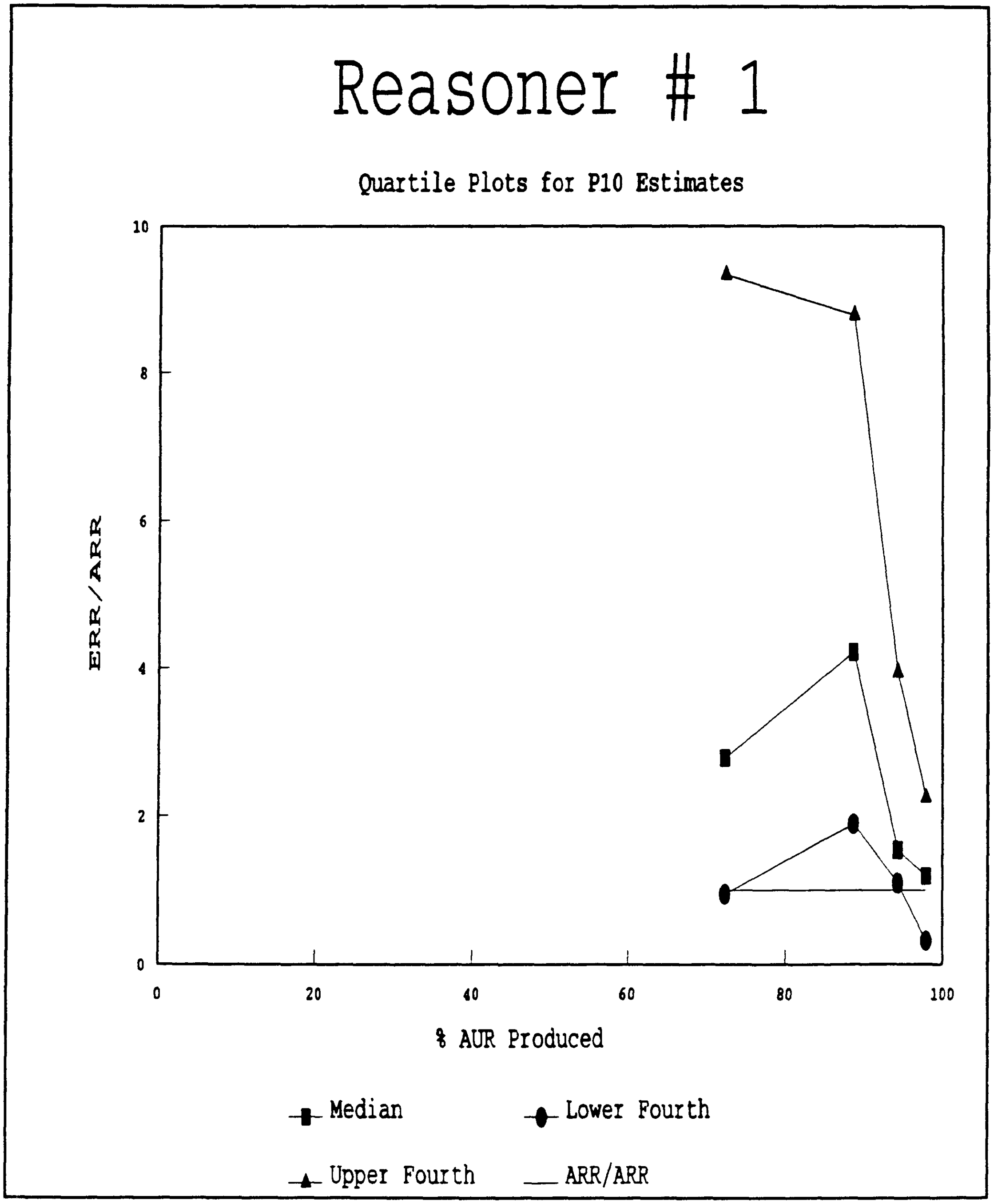

Figure B-20 Quartile Plot of P_{10} Estimates for the Reasoner # 1

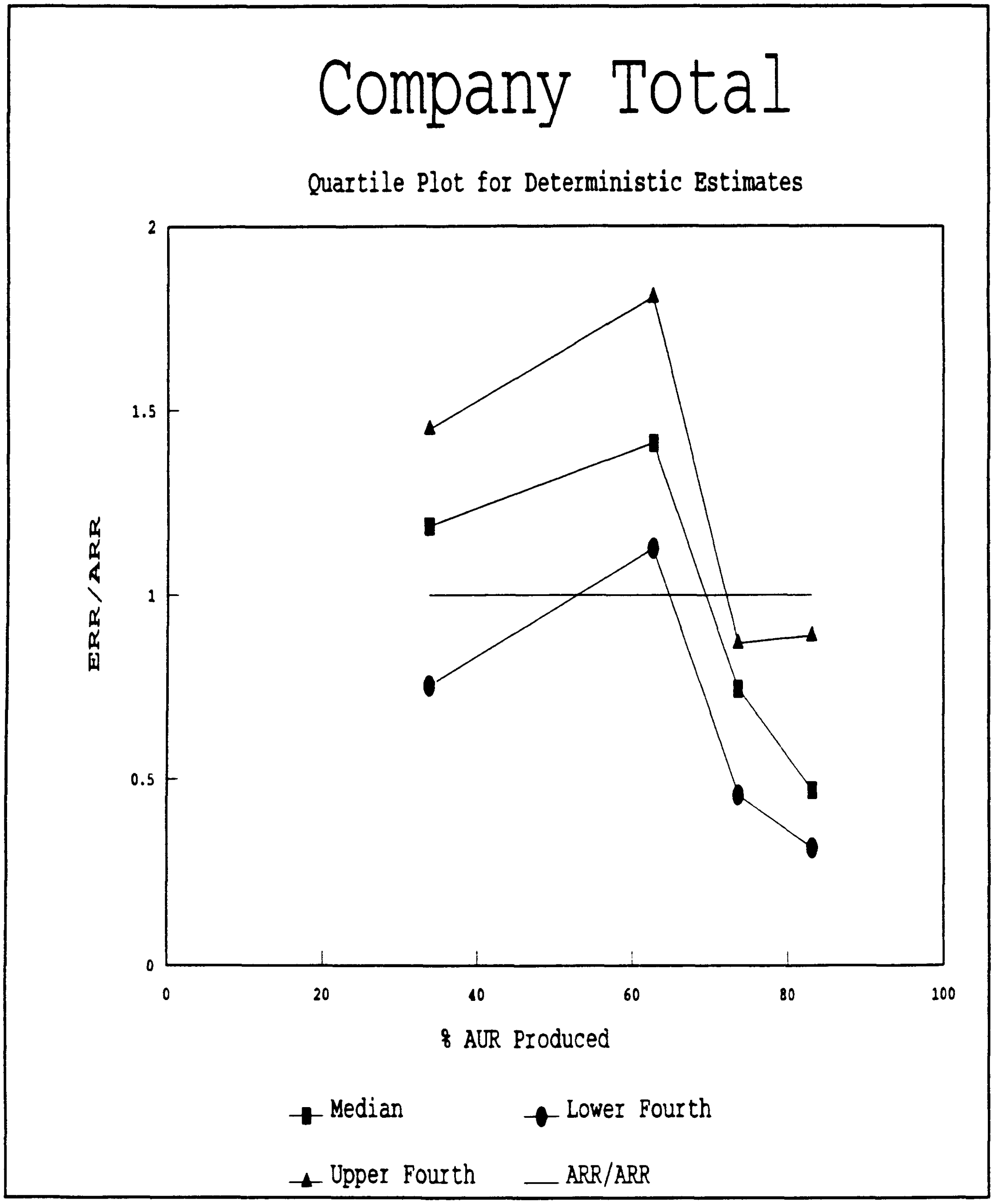

Figure B-21 Quartile Plot of Deterministic Estimates for the Company Total

APPENDIX C

Graphs of individual evaluator estimates for Deterministic, P_{90}, P_{50}, and P_{10} values for the Cutler # 1-A.

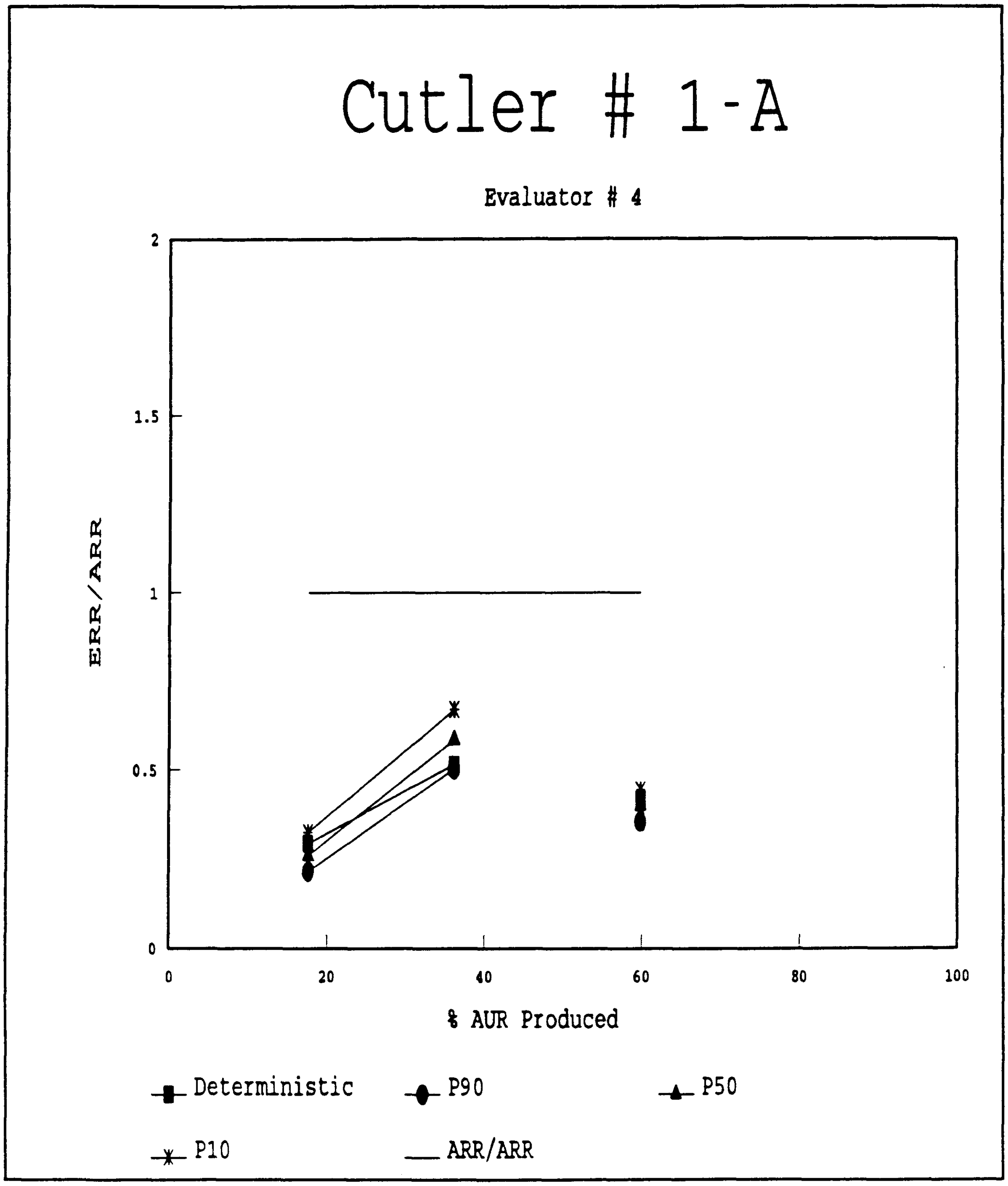

Figure C-1 Evaluator # 4, Estimates of Deterministic P_{90}, P_{50}, P_{10} values for the Cutler # 1-A

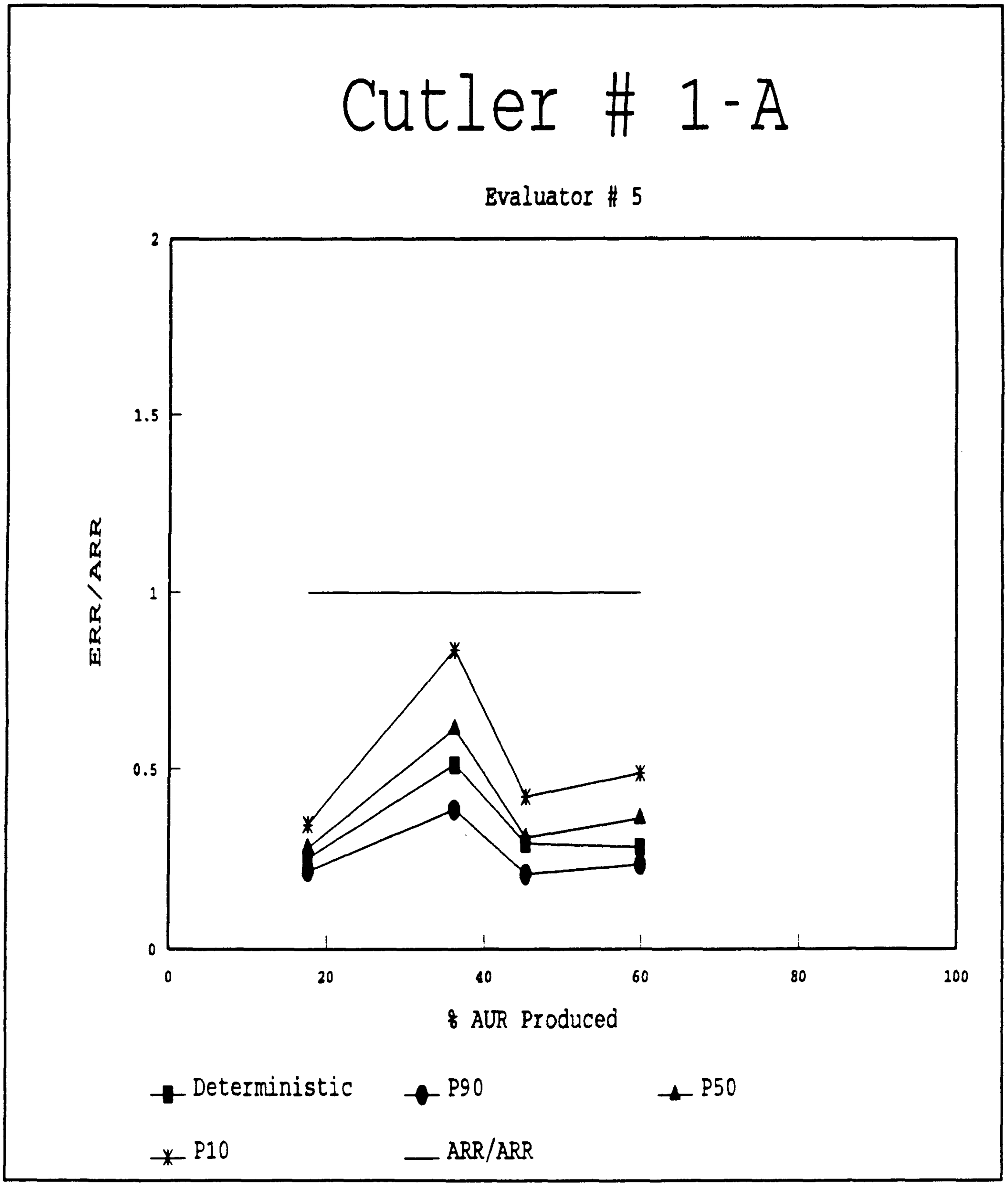

Figure C-2 Evaluator # 5, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A

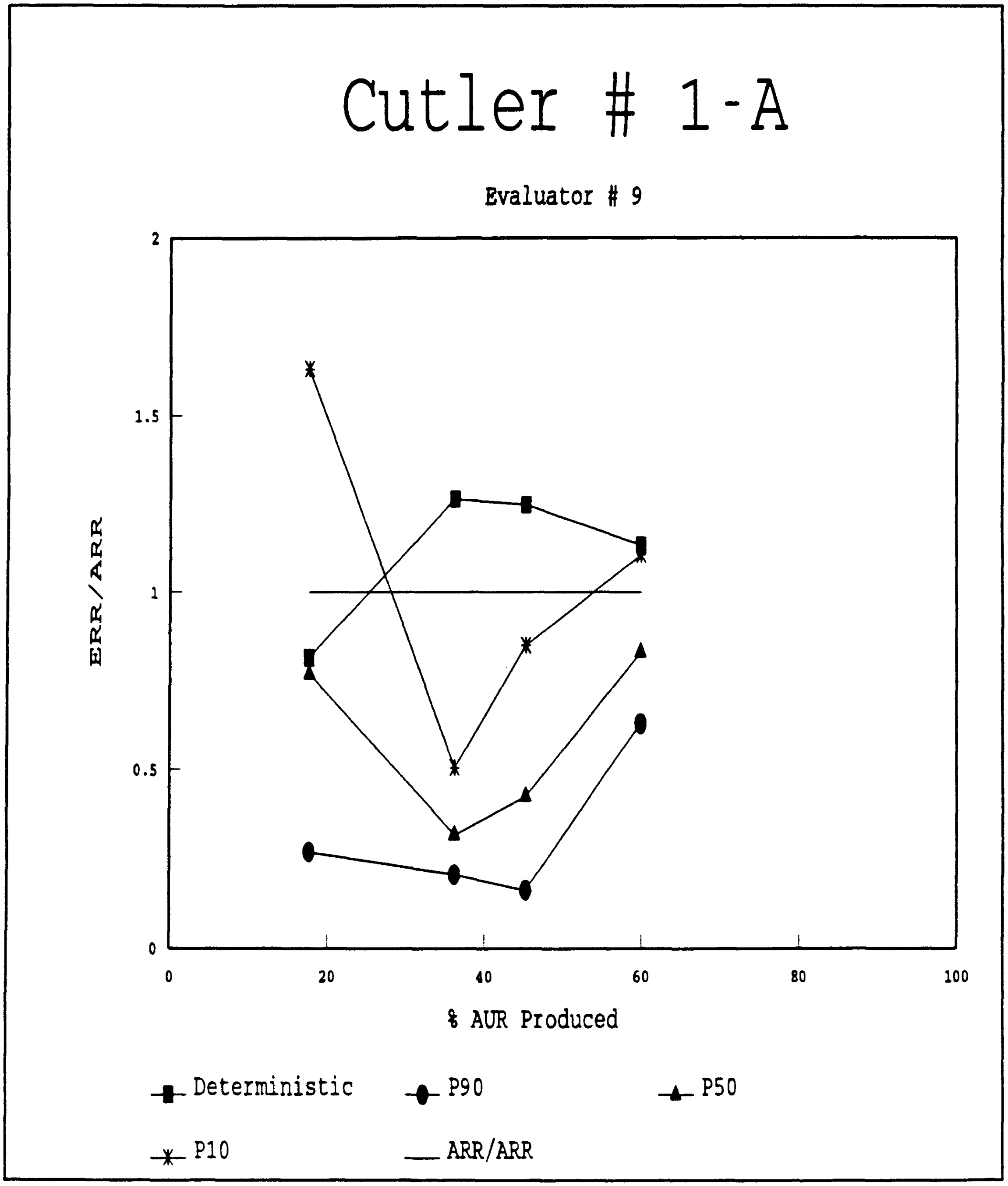

Figure C-3 Evaluator # 9, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A

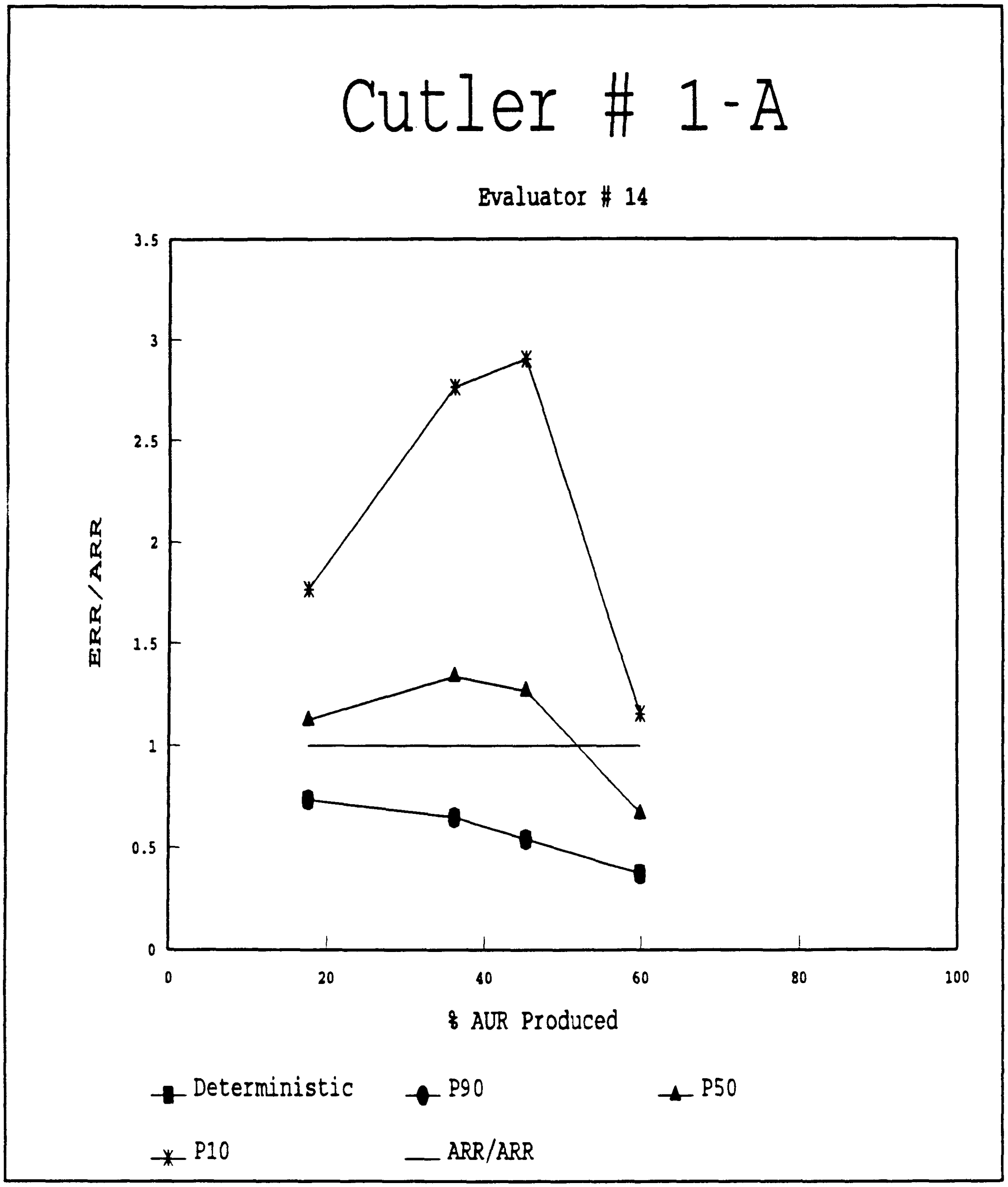

Figure C-4 Evaluator # 14, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A

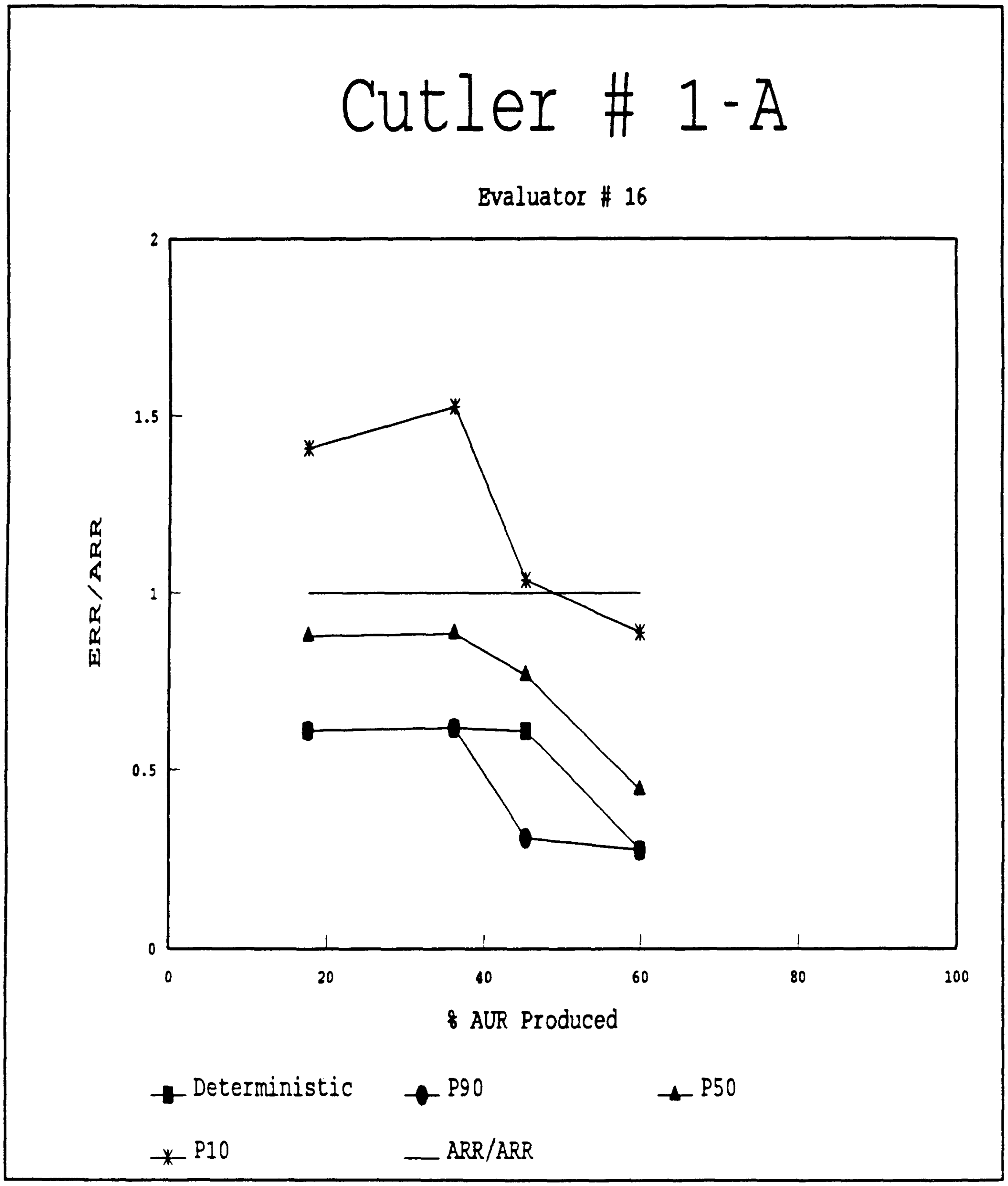

Figure C-5 Evaluator # 16, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A

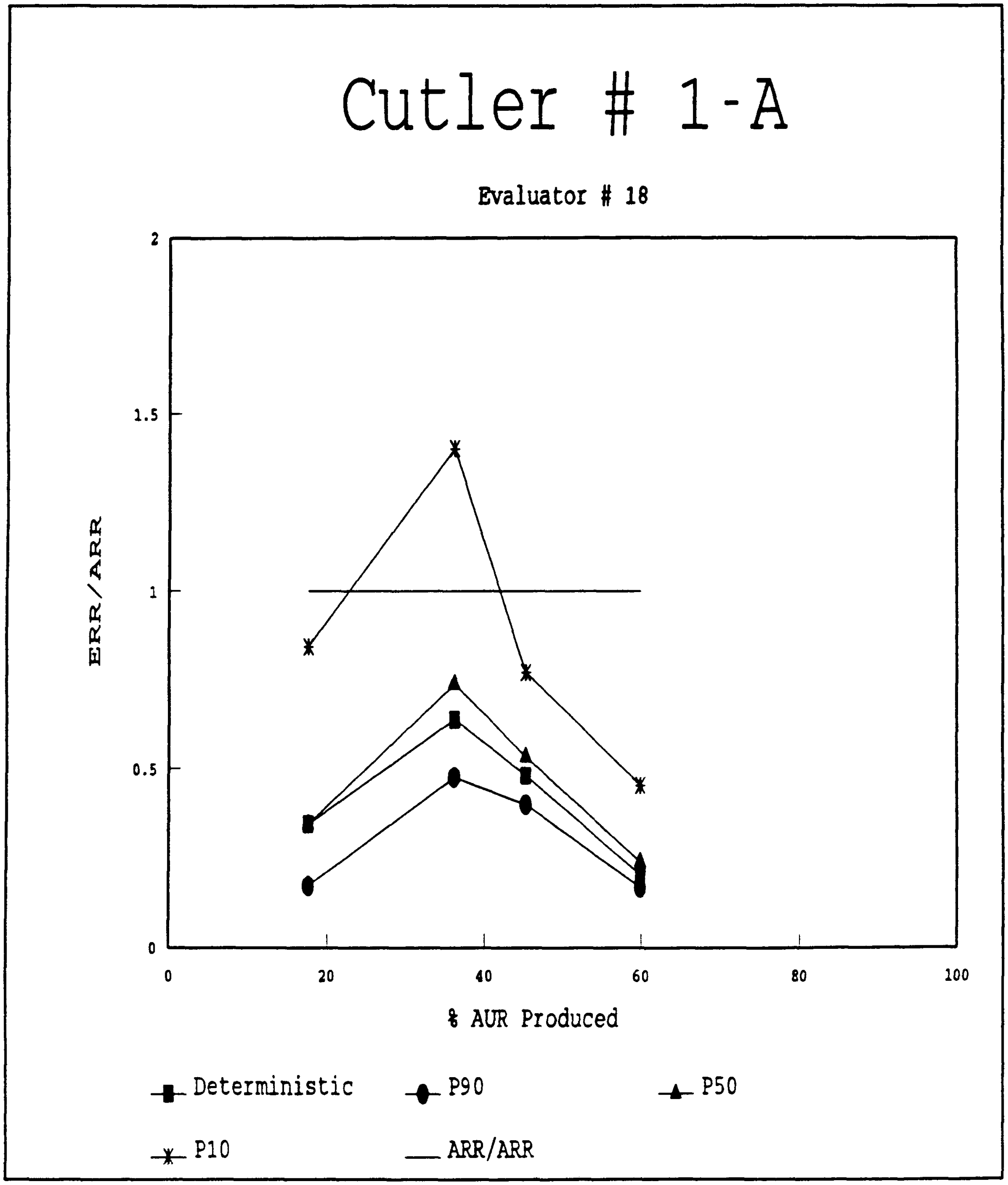

Figure C-6 Evaluator # 18, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A

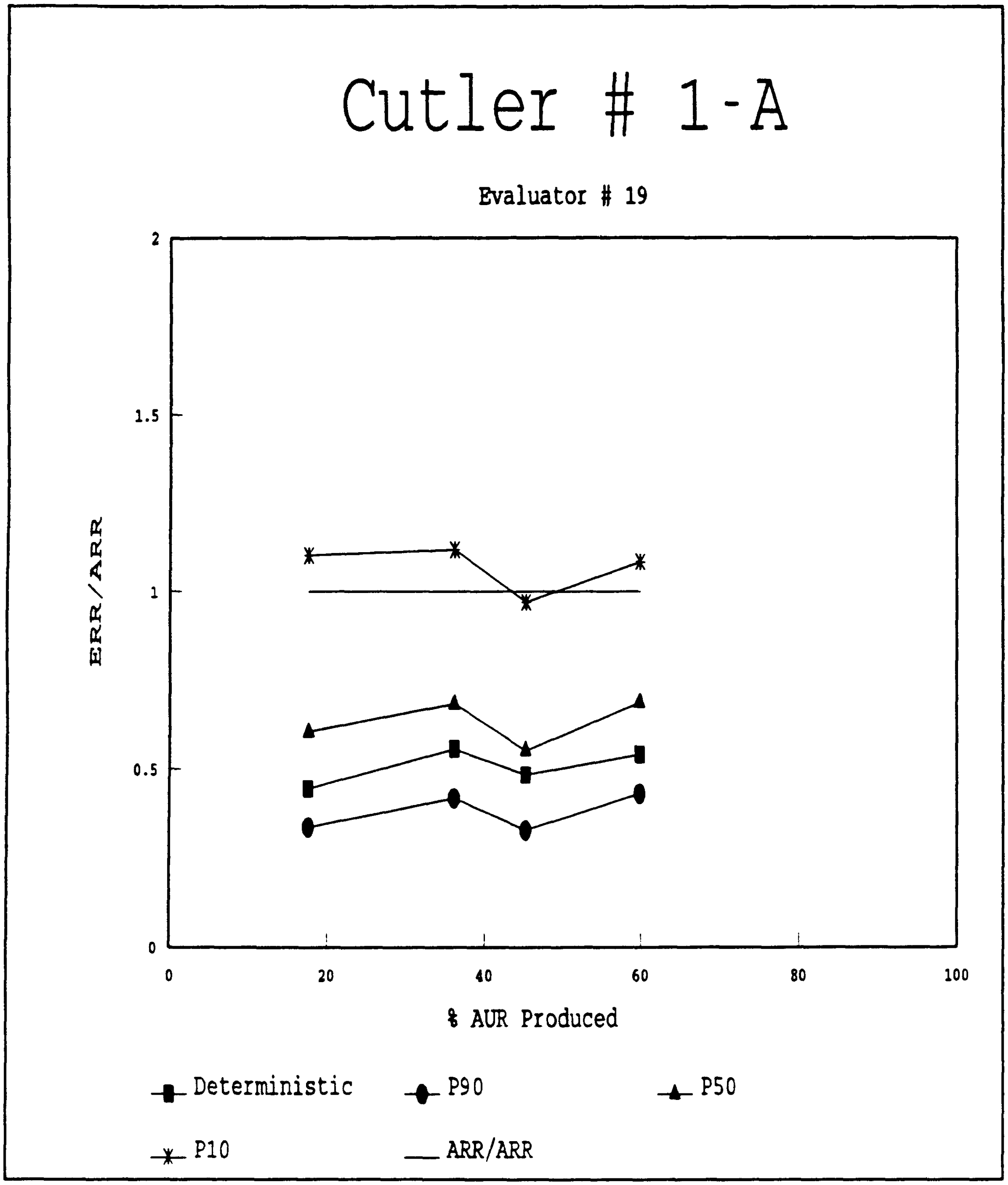

Figure C-7 Evaluator # 19, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A

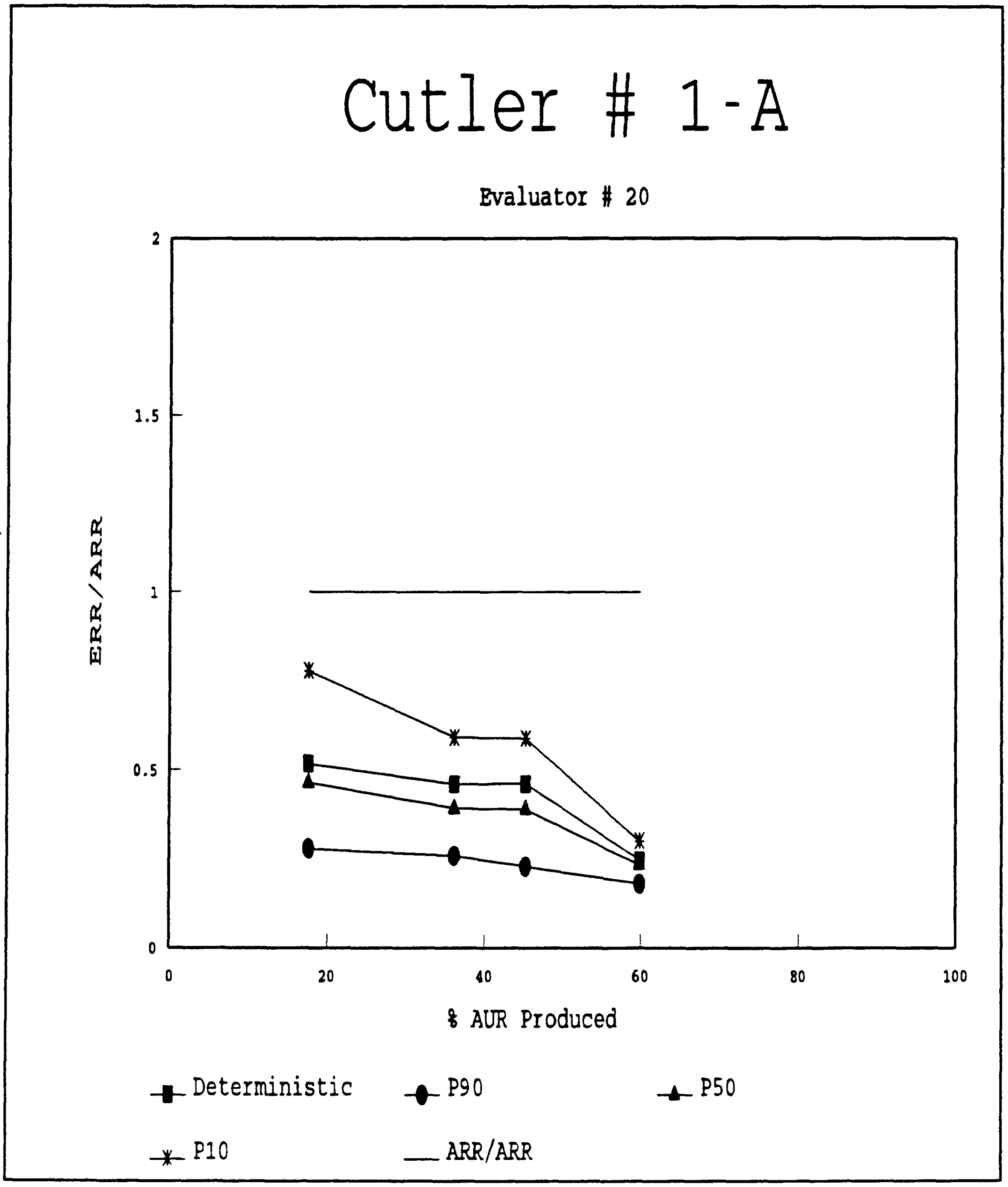

Figure C-8 Evaluator # 20, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A

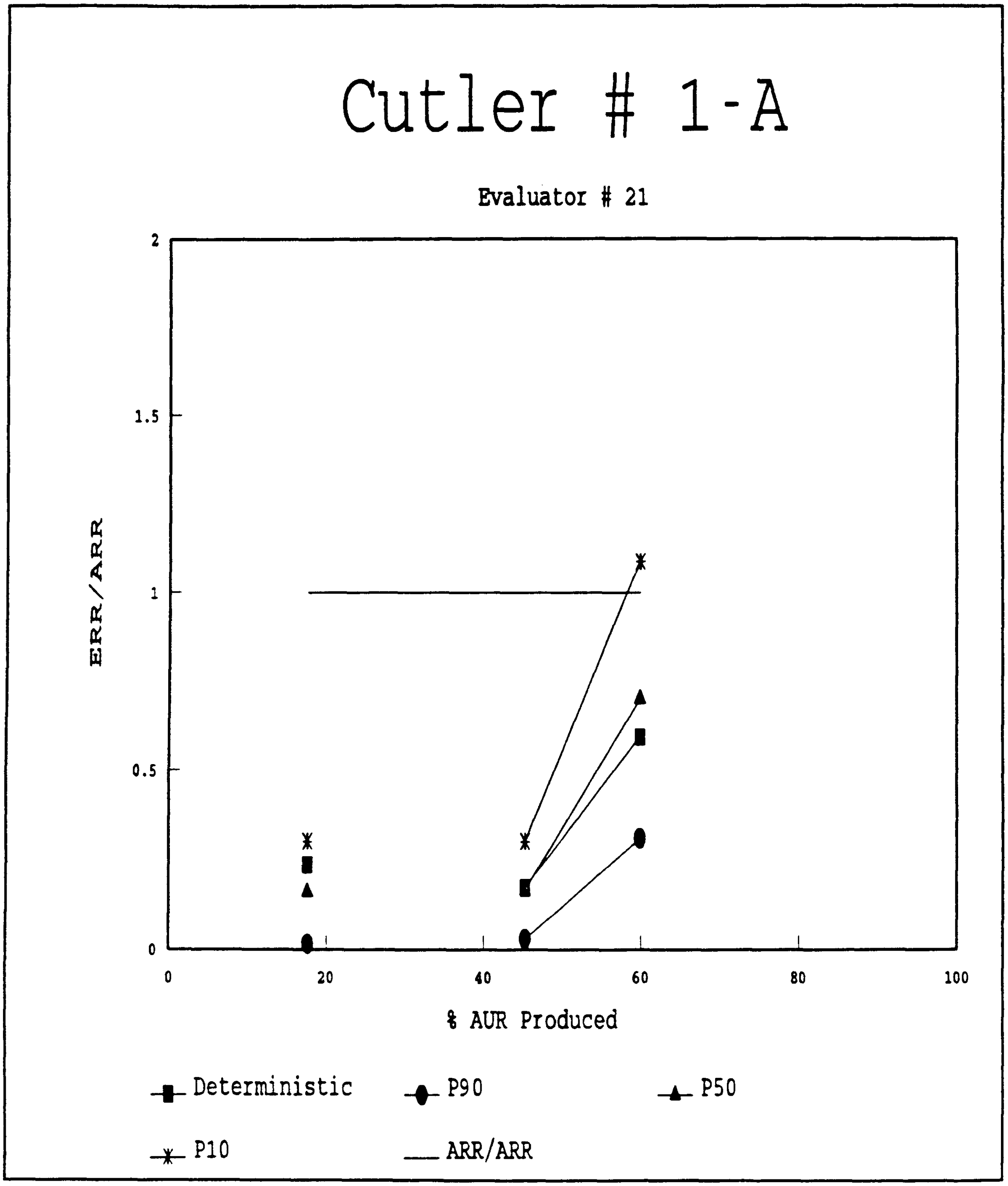

Figure C-9 Evaluator # 21, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A

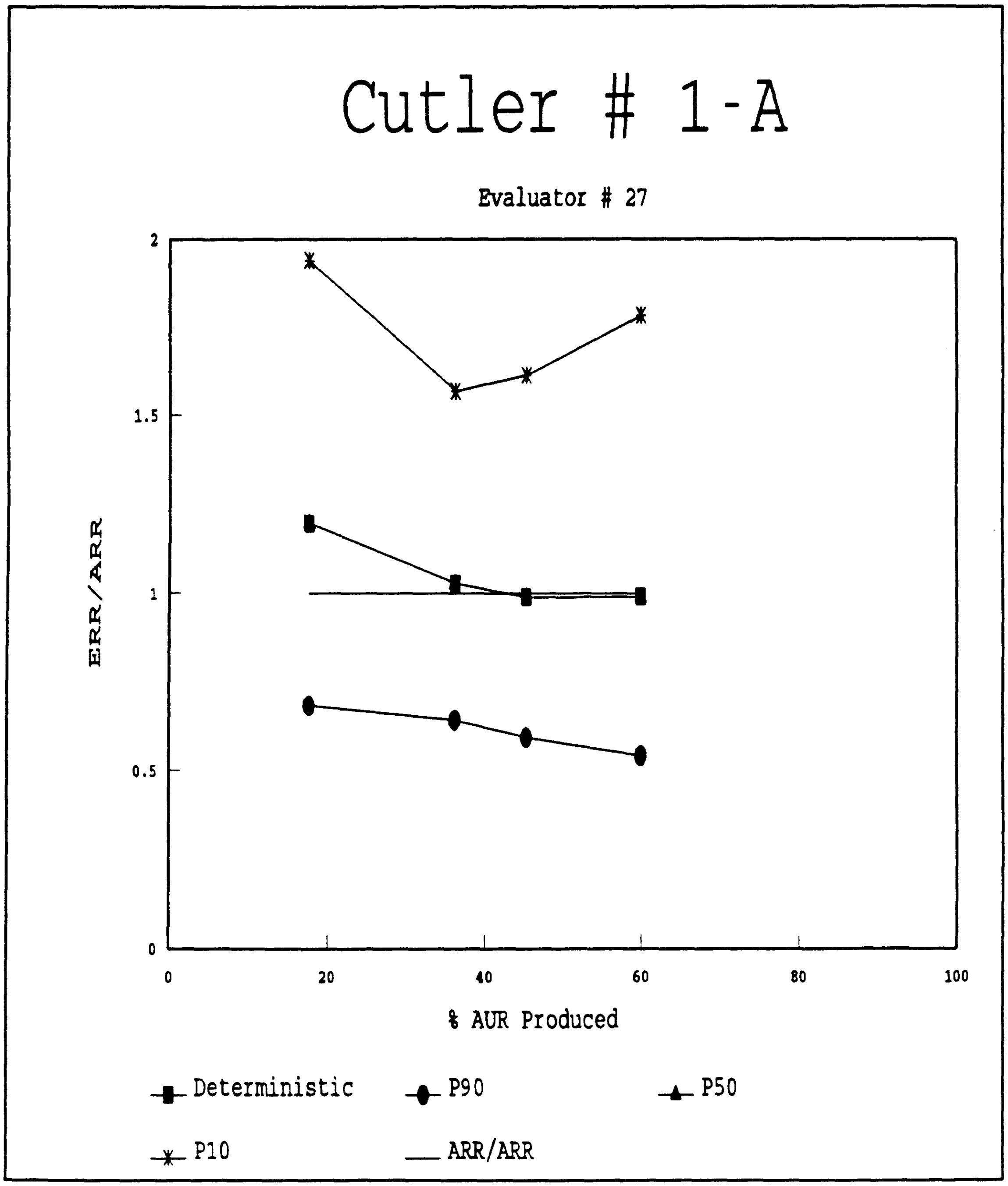

Figure C-10 Evaluator # 27, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A

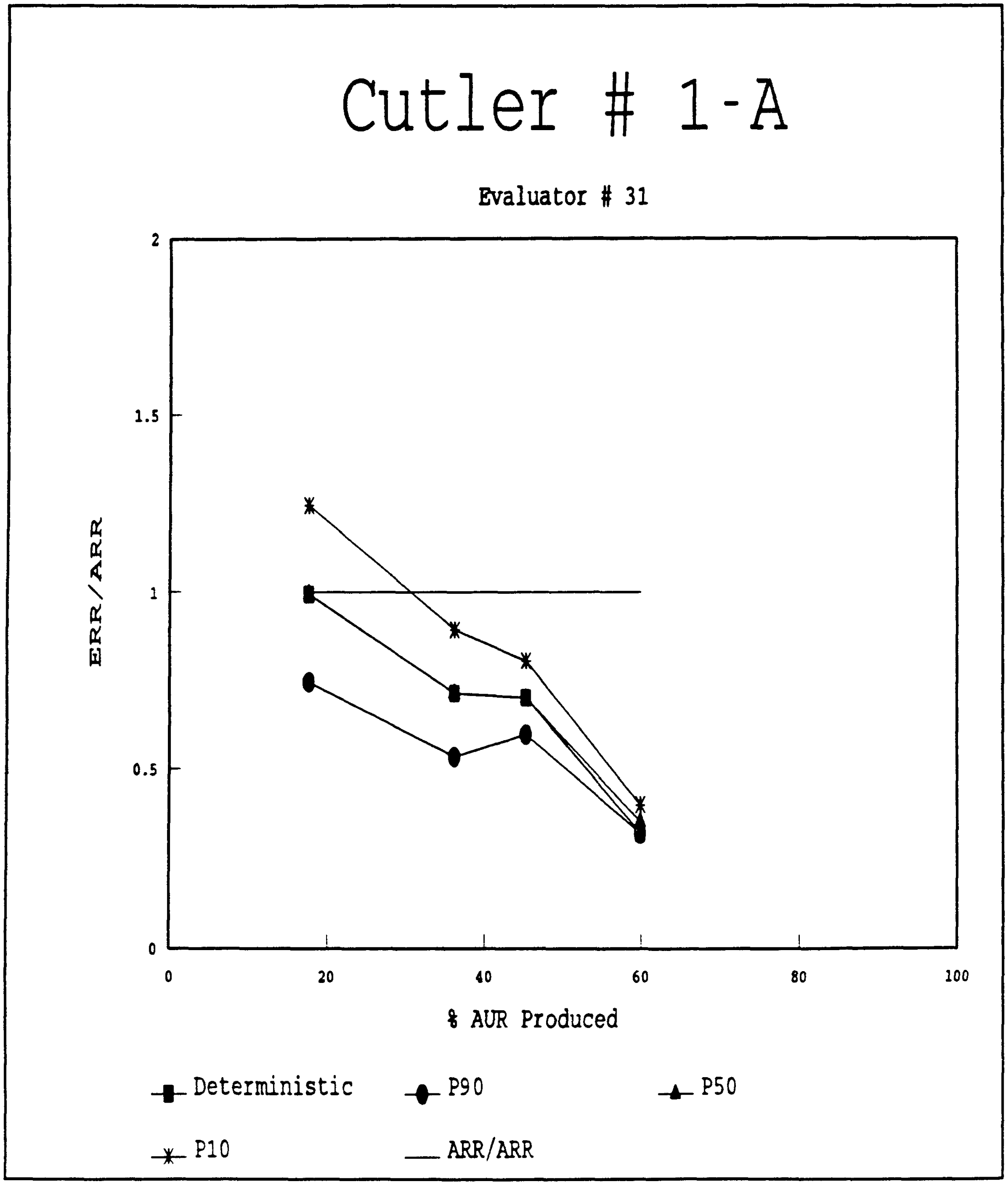

Figure C-11 Evaluator # 31, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Cutler # 1-A

APPENDIX D

Graphs of individual evaluator estimates for Deterministic, P_{90}, P_{50}, and P_{10} values for the Dahlinger # 1.

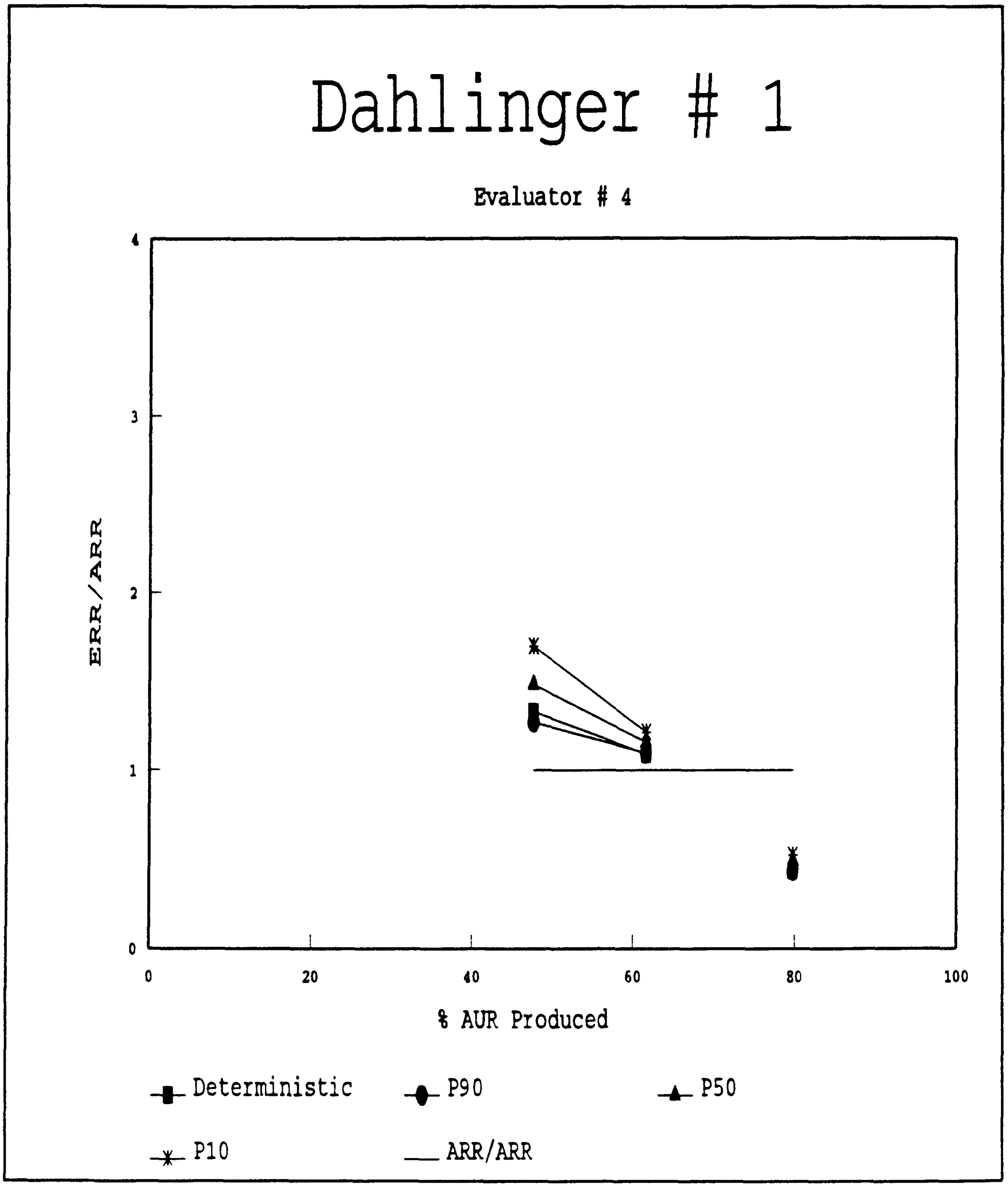

Figure D-1 Evaluator # 4, Estimates of Deterministic P_{90}, P_{50}, P_{10} values for the Dahlinger # 1

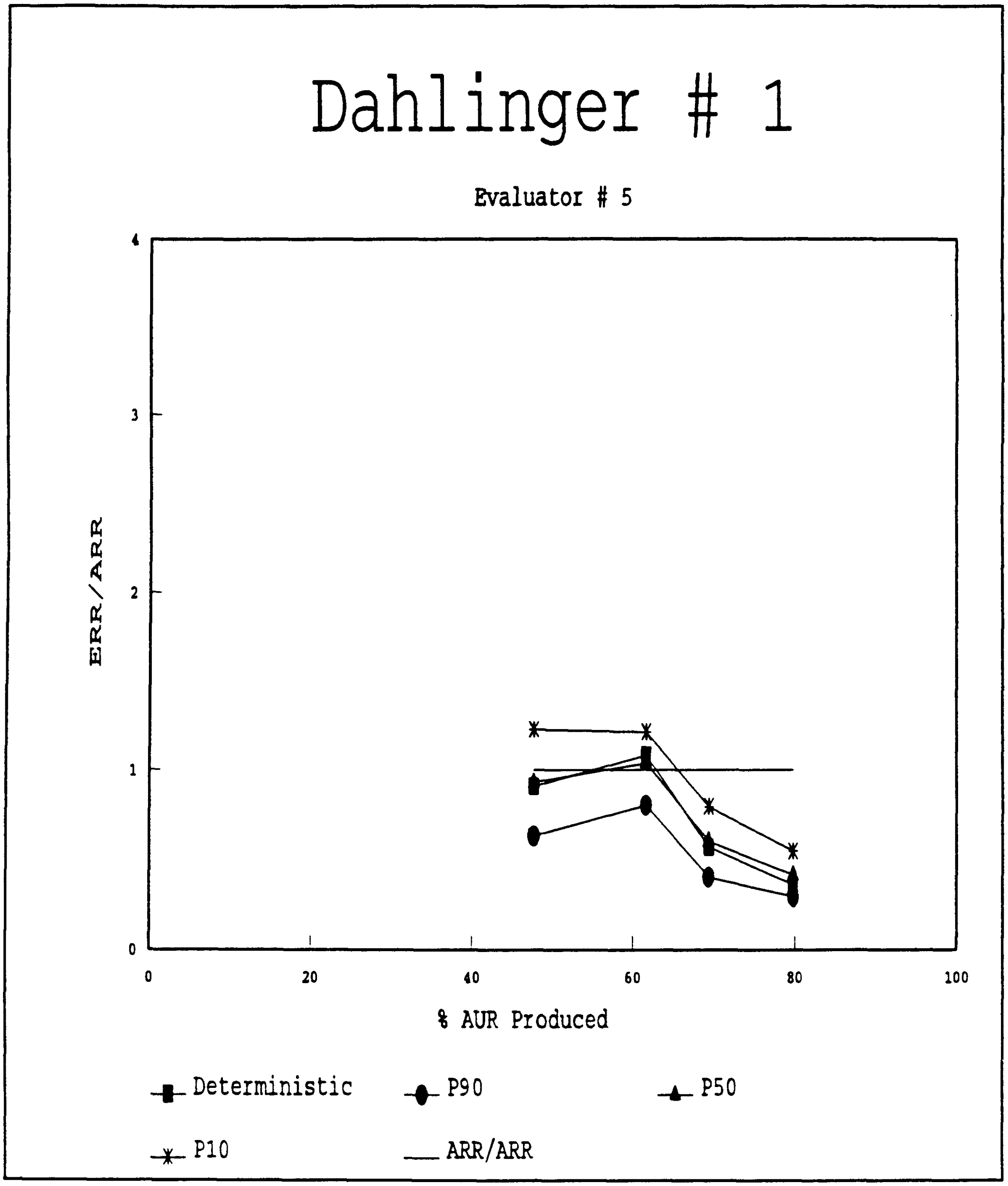

Figure D-2 Evaluator # 5, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1

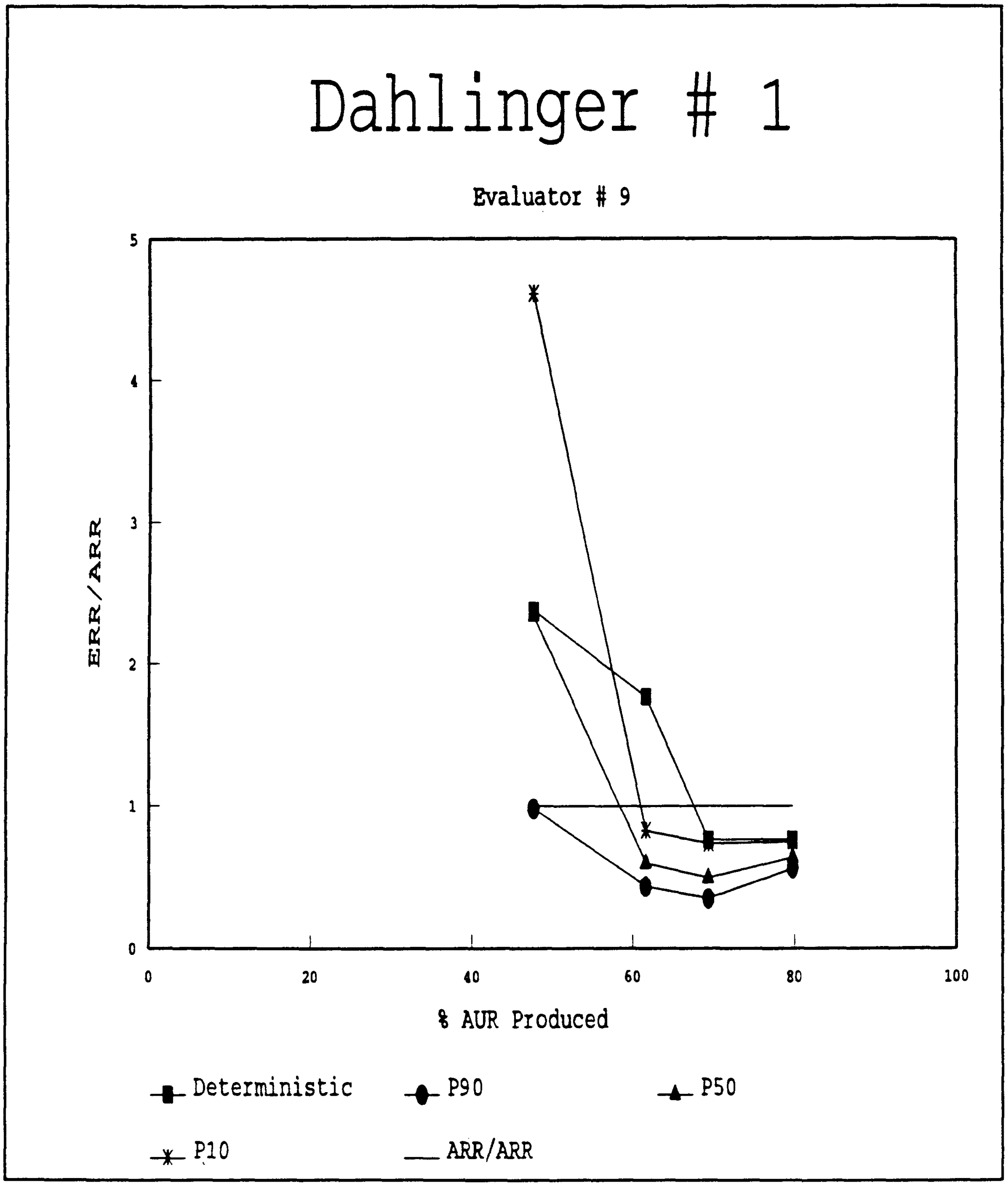

Figure D-3 Evaluator # 9, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1

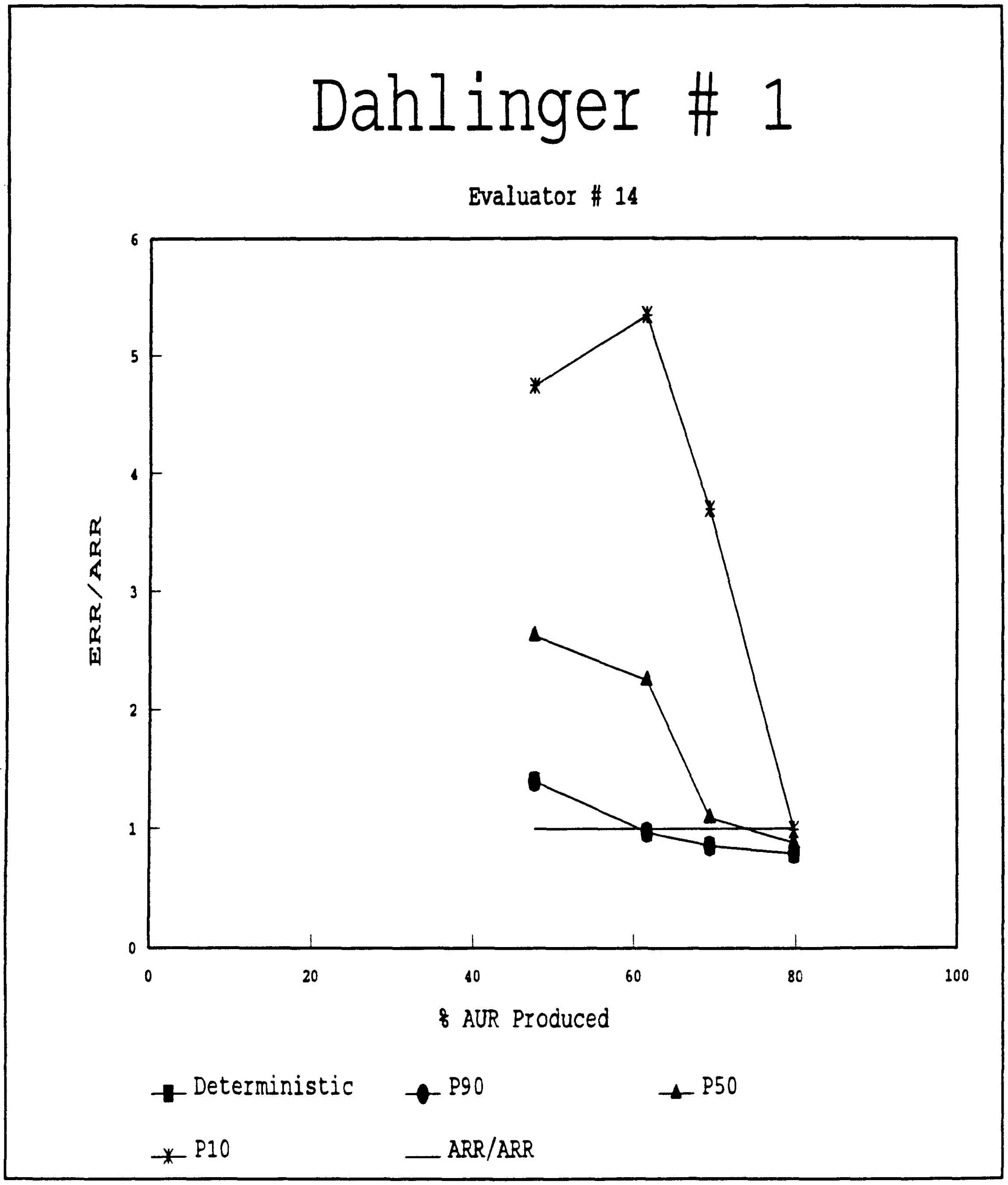

Figure D-4 Evaluator # 14, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1

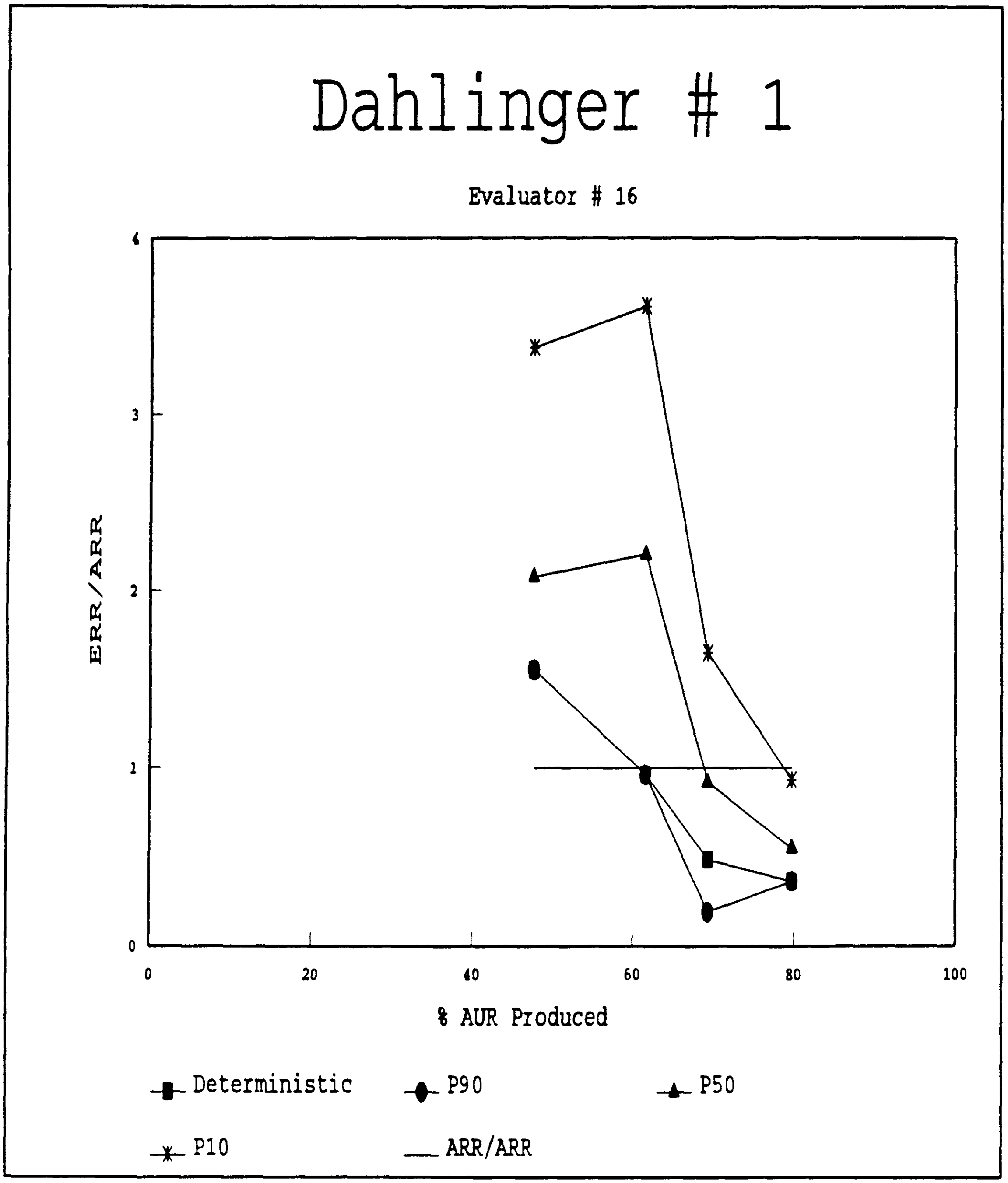

Figure D-5 Evaluator # 16, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1

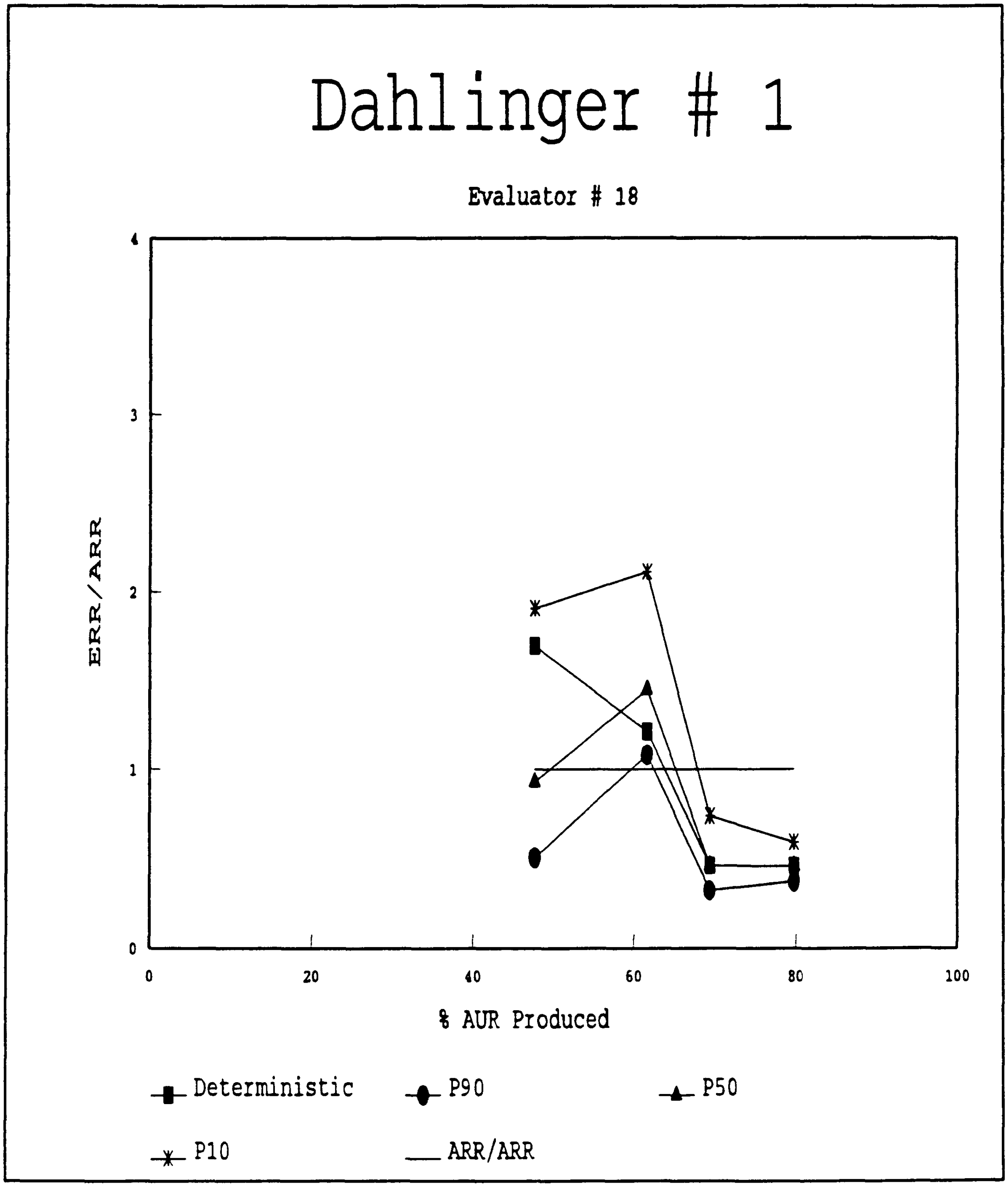

Figure D-6 Evaluator # 18, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1

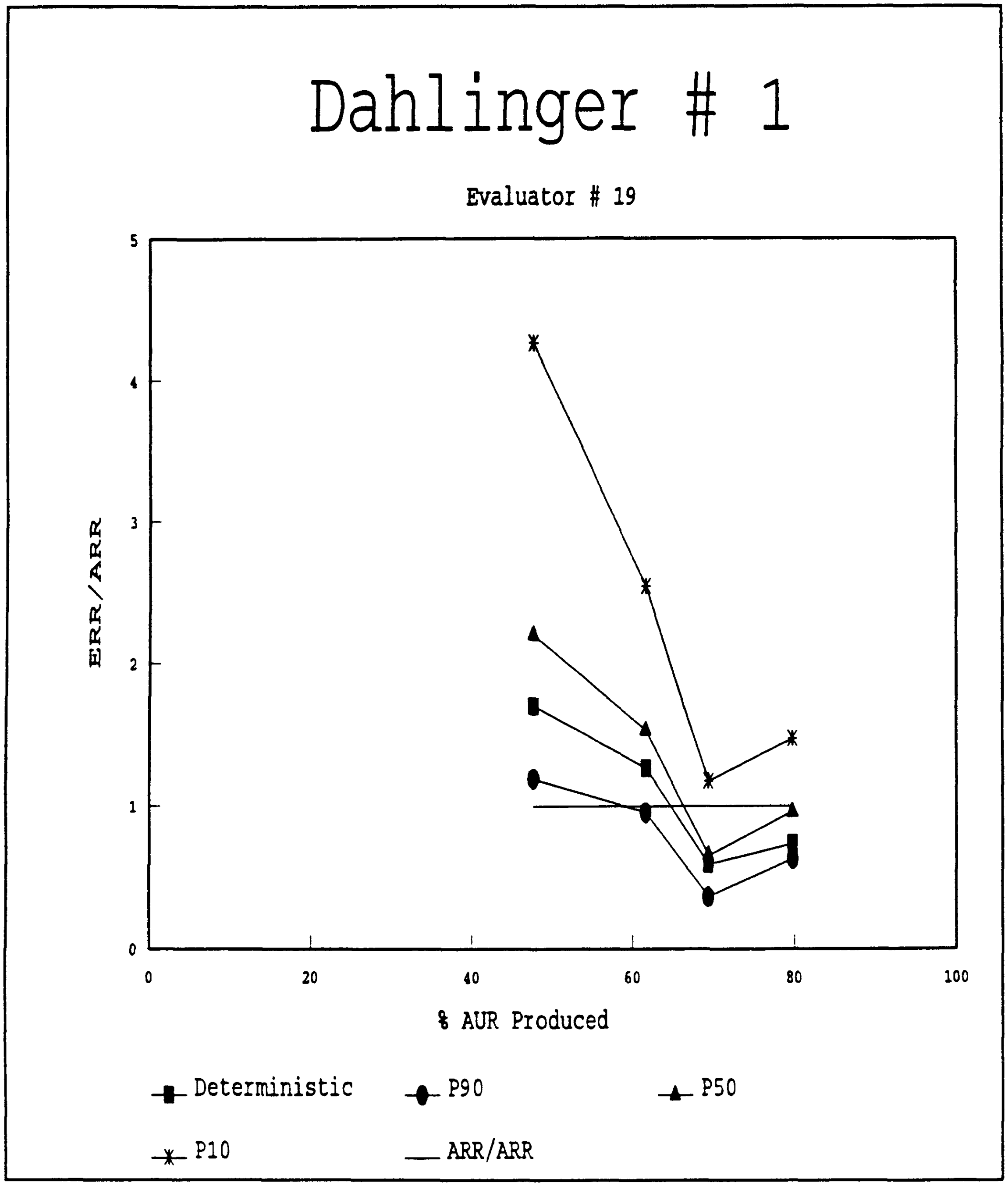

Figure D-7 Evaluator # 19, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1

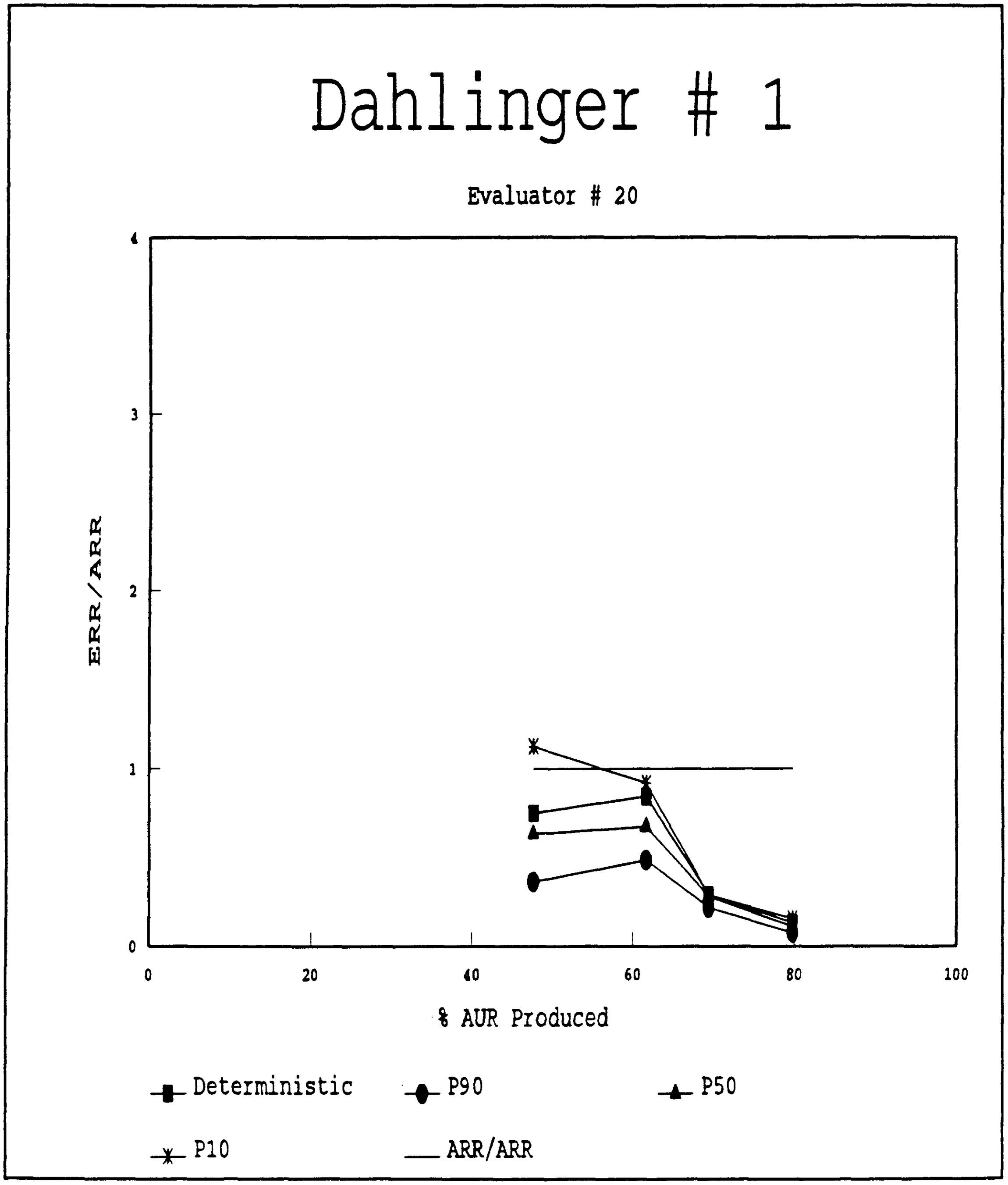

Figure D-8 Evaluator # 20, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1

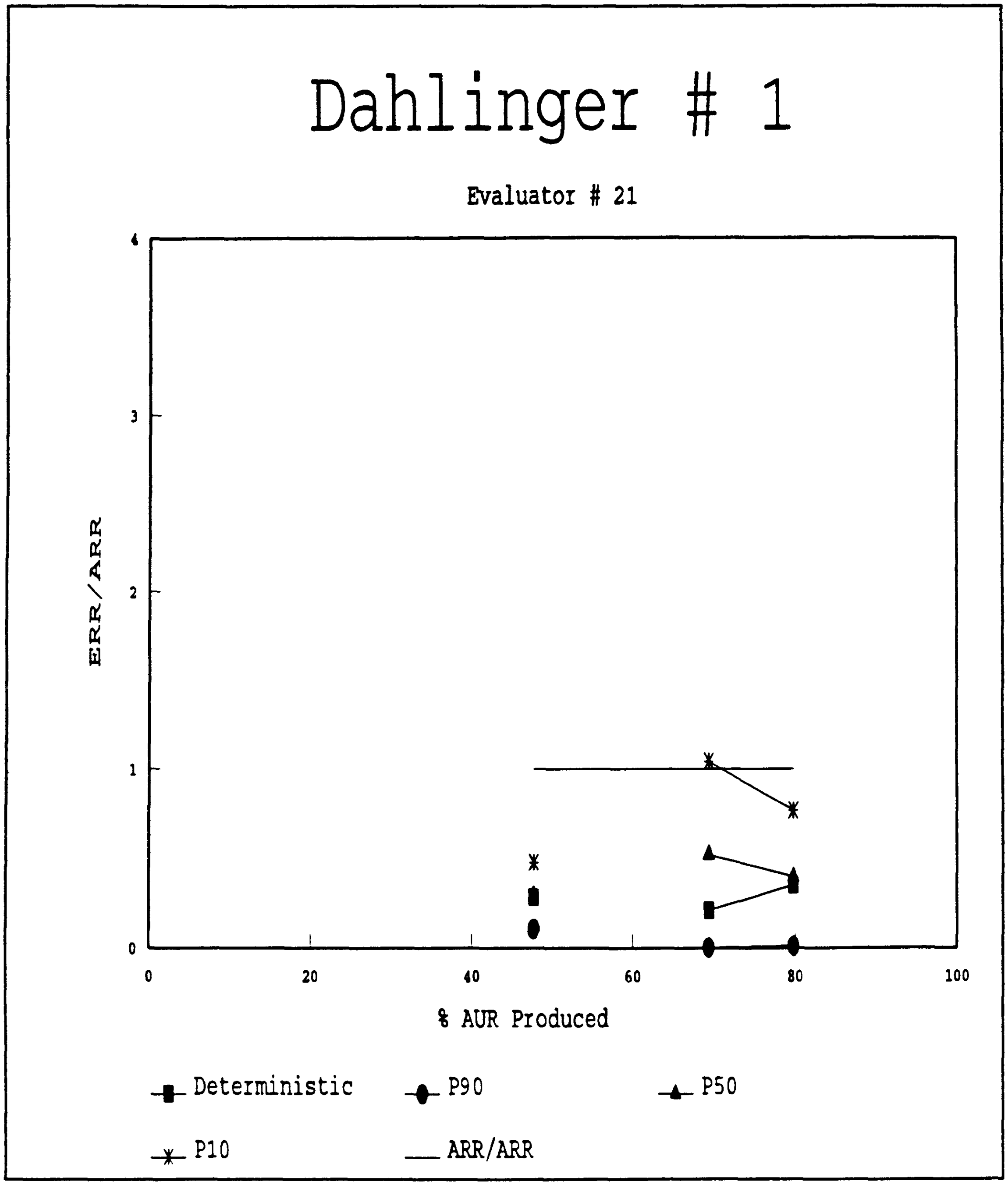

Figure D-9 Evaluator # 21, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1

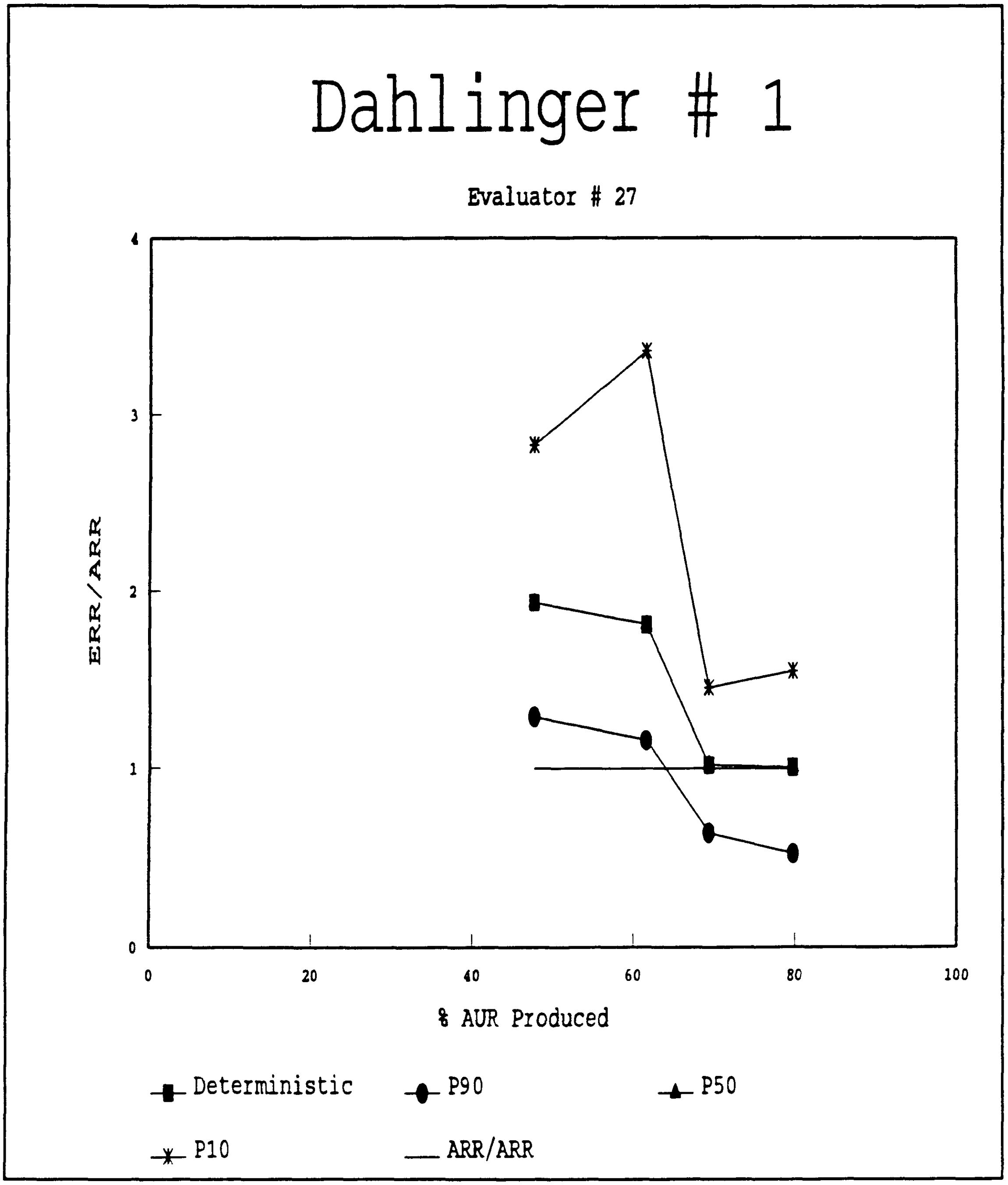

Figure D-10 Evaluator # 27, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1

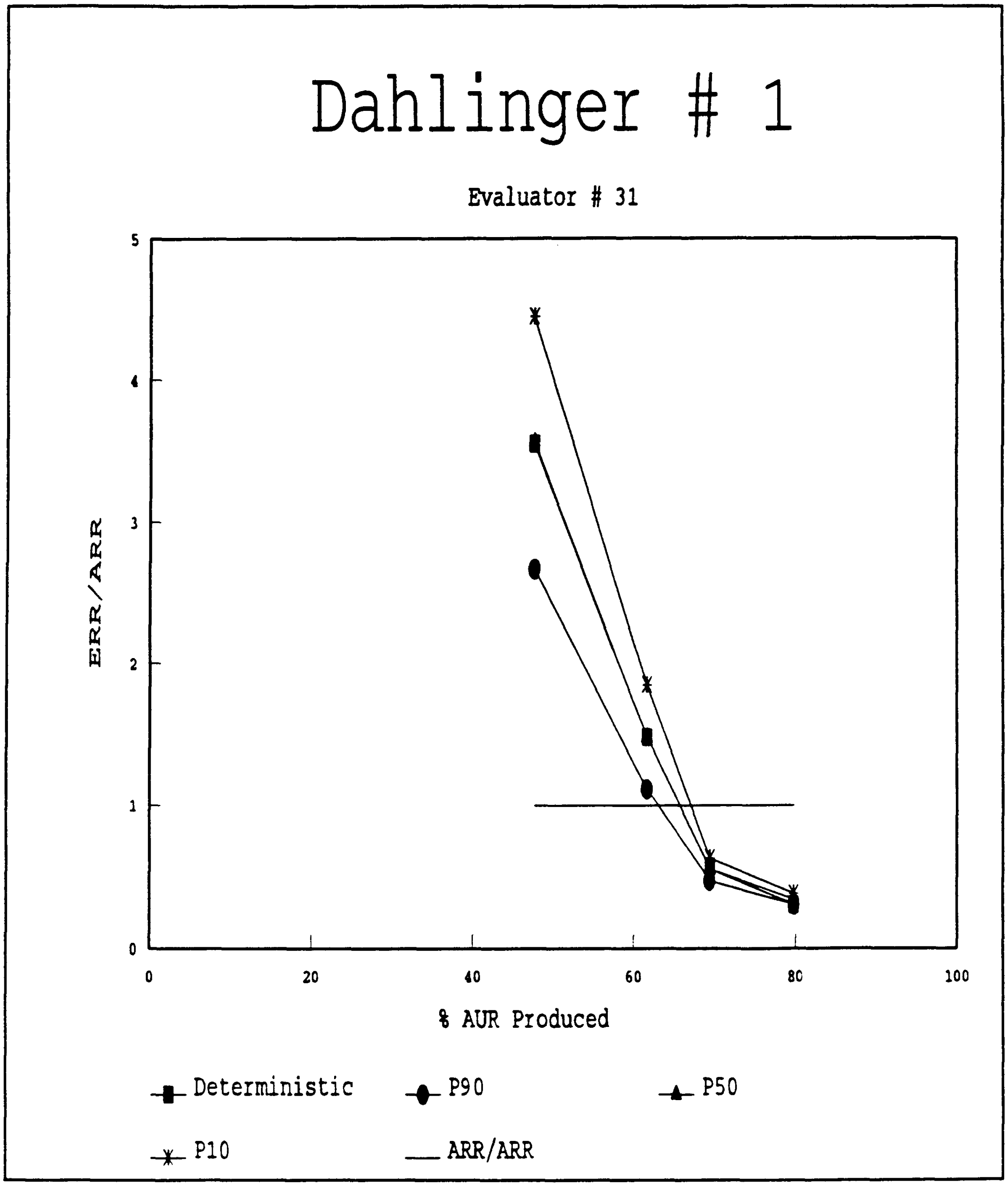

Figure D-11 Evaluator # 31, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Dahlinger # 1

APPENDIX E

Graphs of individual evaluator estimates for Deterministic, P_{90}, P_{50}, and P_{10} values for the Erger # 1.

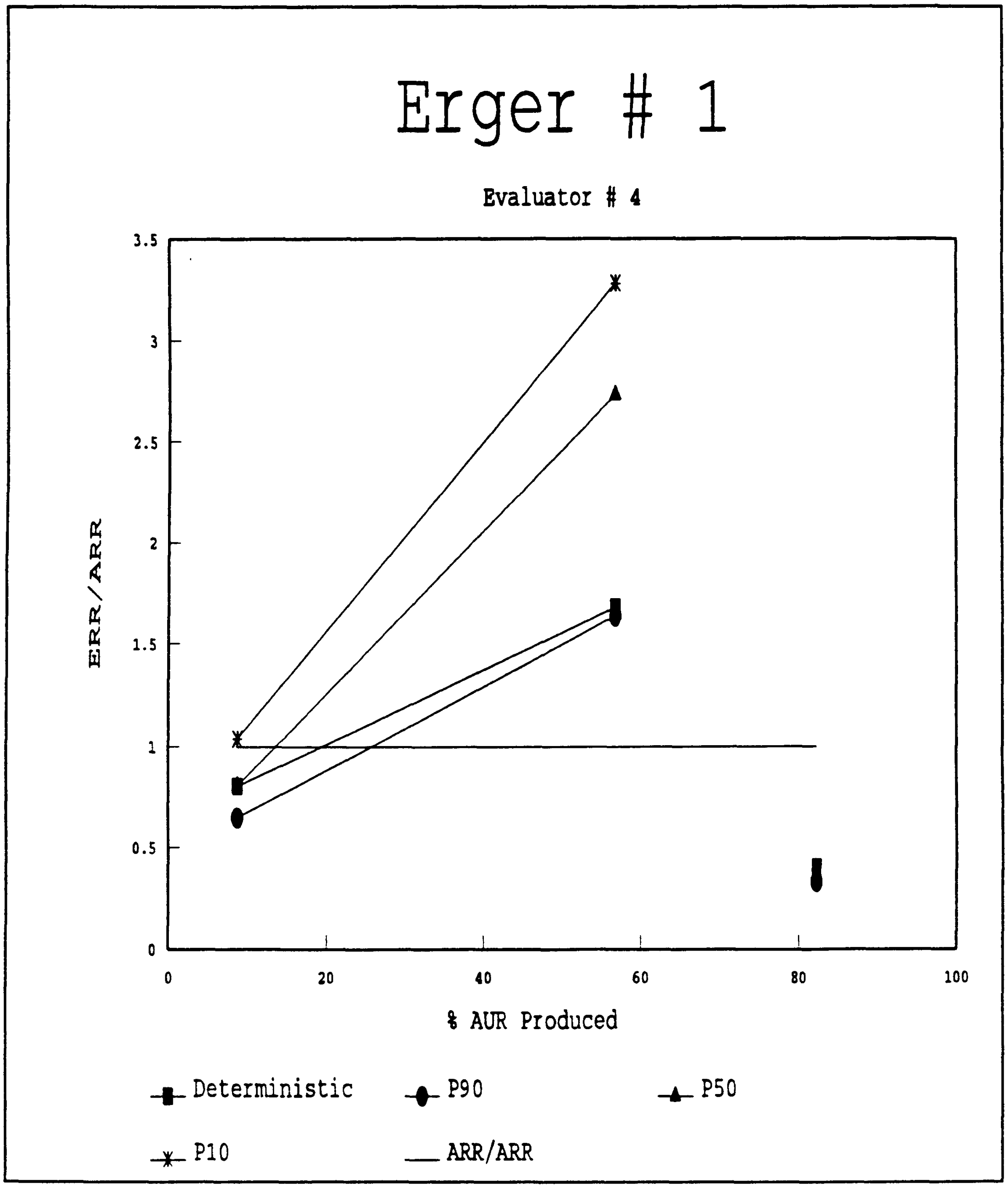

Figure E-1 Evaluator # 4, Estimates of Deterministic P_{90}, P_{50}, P_{10} values for the Erger # 1

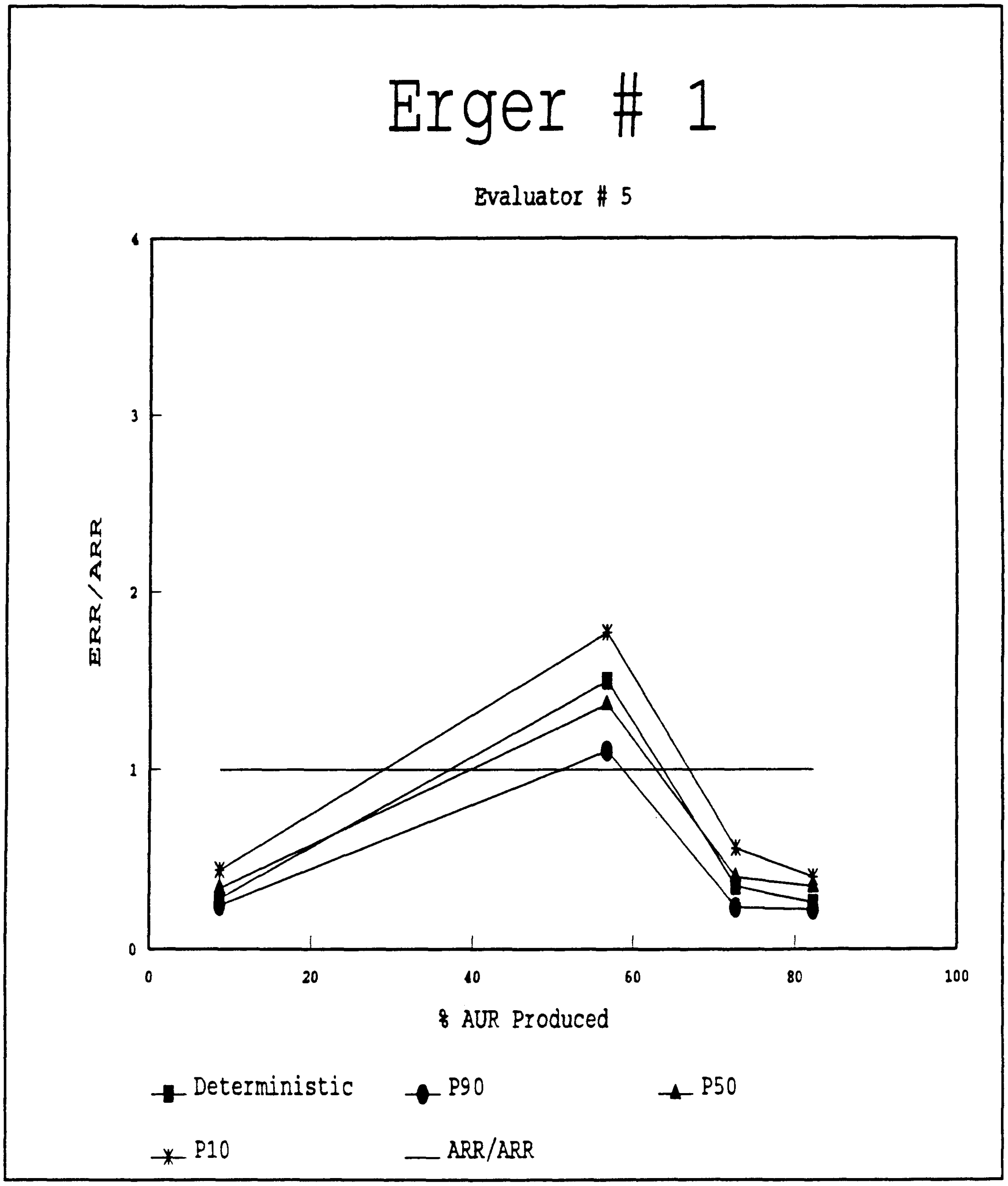

Figure E-2 Evaluator # 5, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1

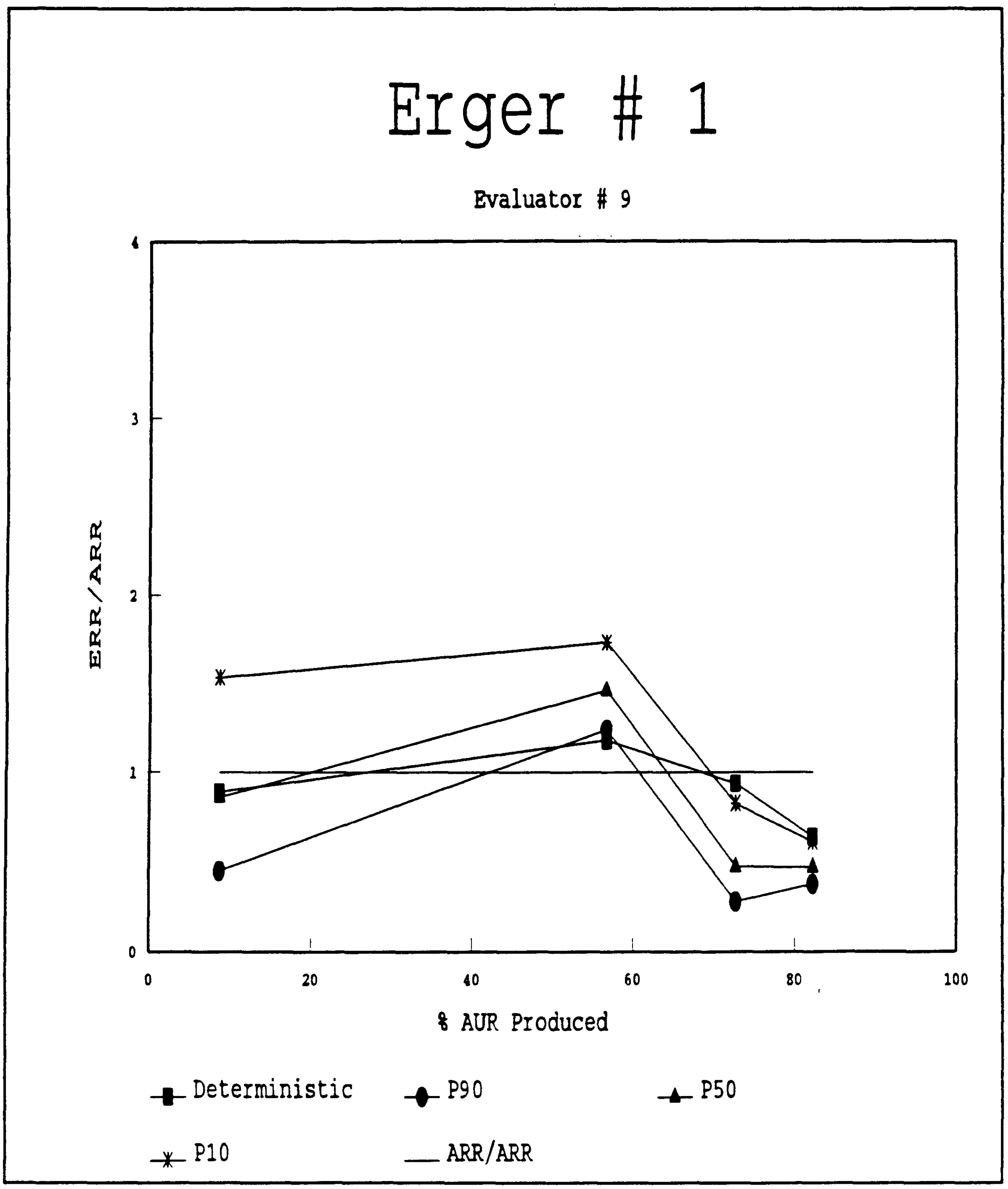

Figure E-3 Evaluator # 9, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1

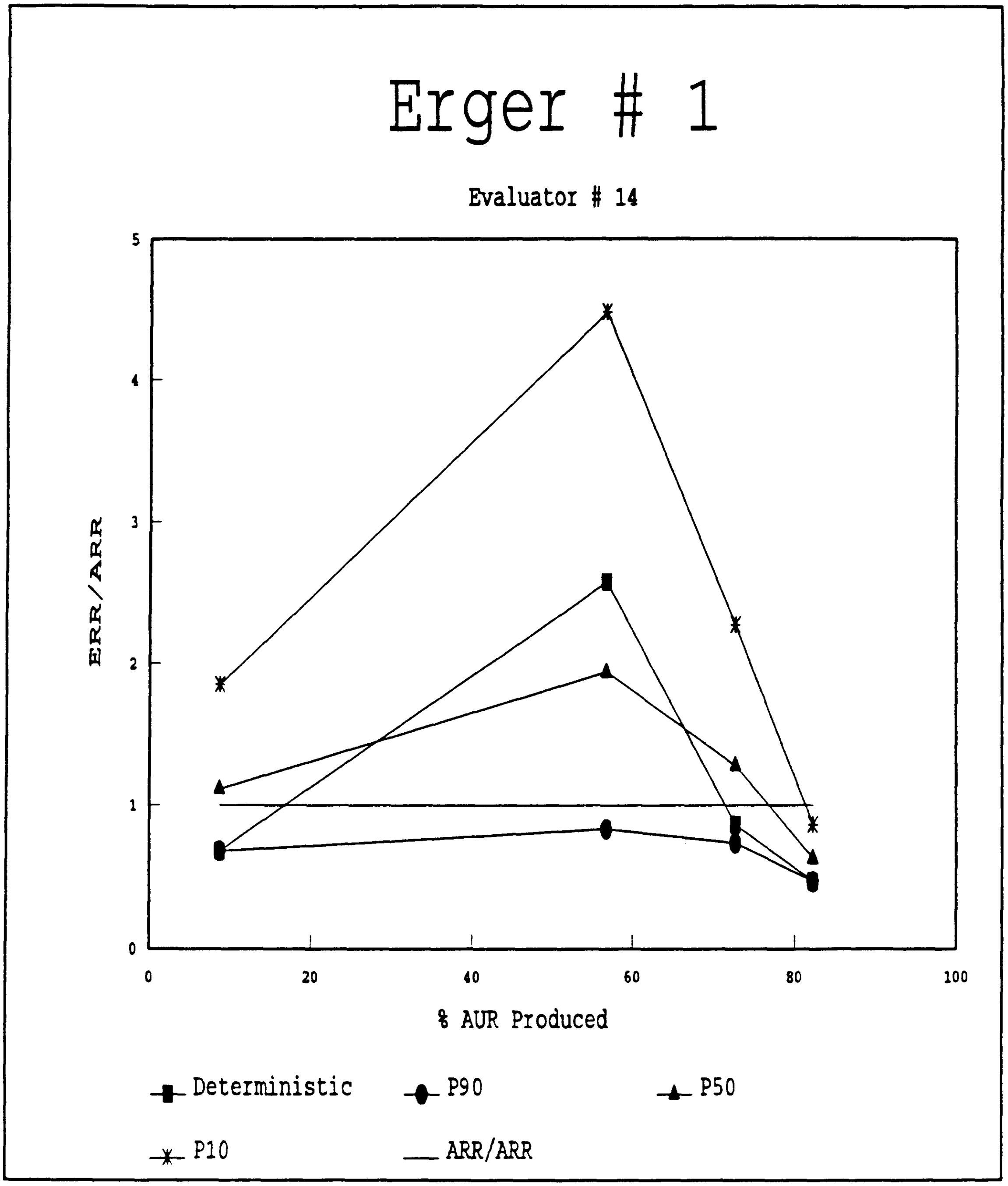

Figure E-4 Evaluator # 14, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1

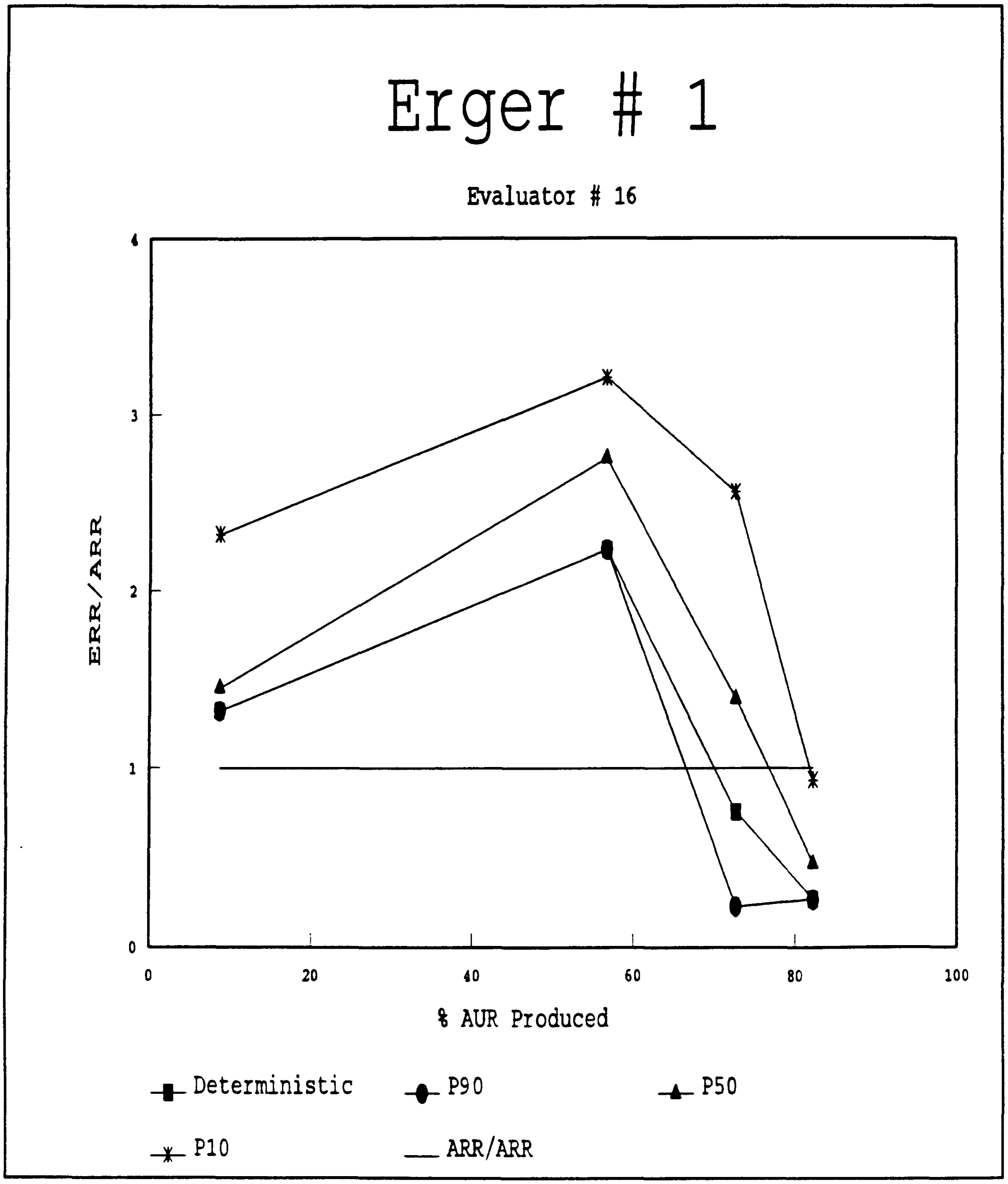

Figure E-5 Evaluator # 16, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1

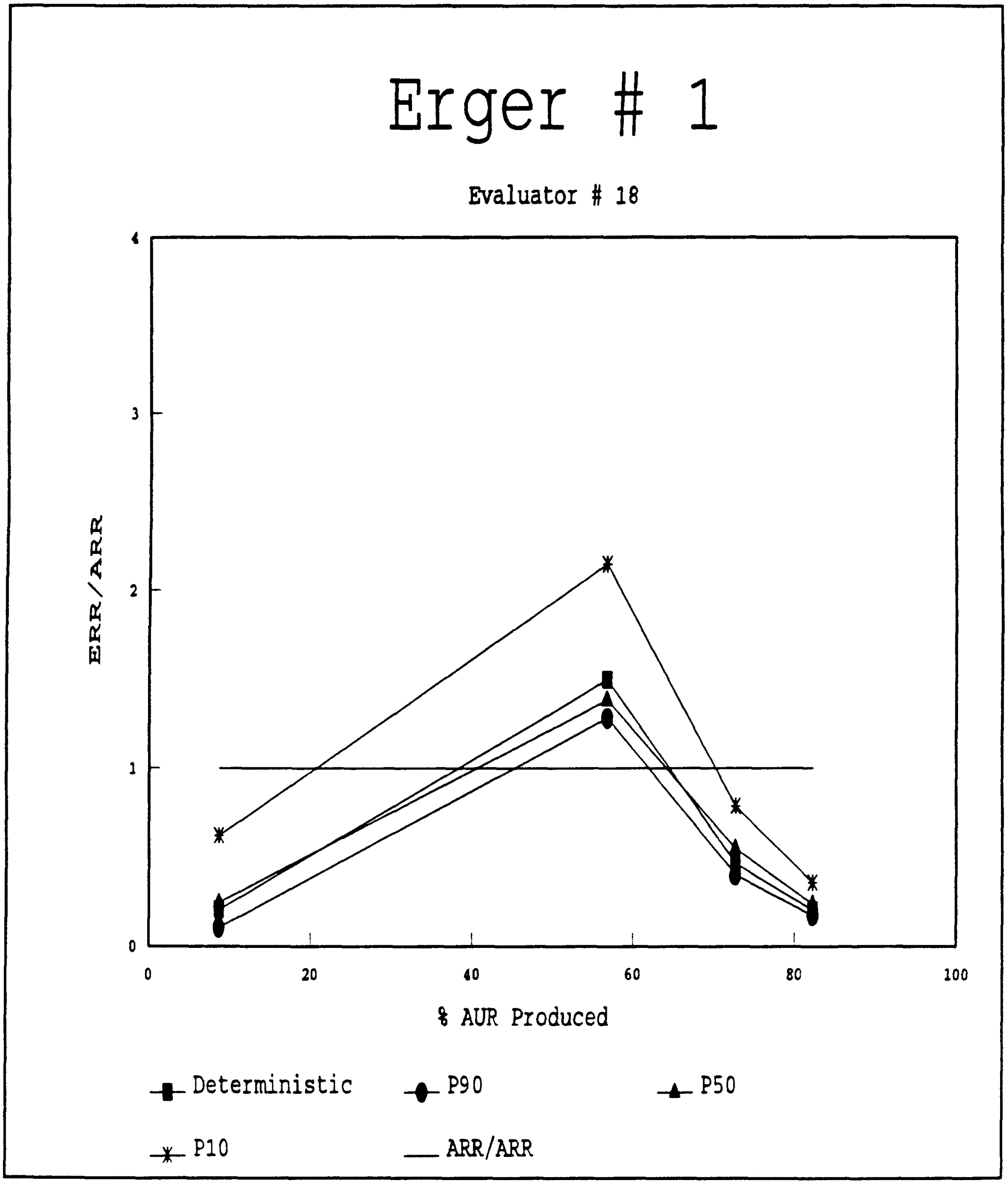

Figure E-6 Evaluator # 18, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1

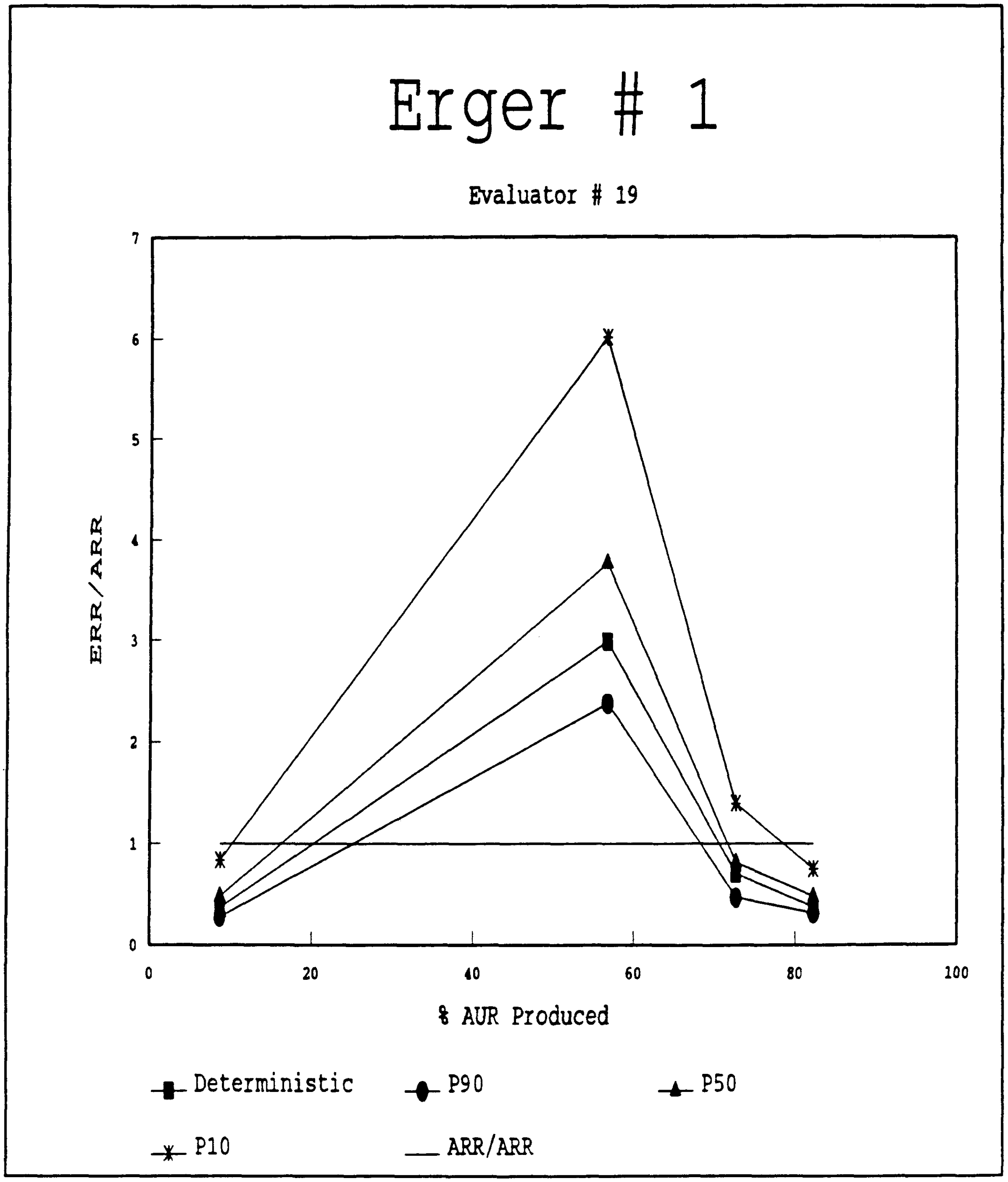

Figure E-7 Evaluator # 19, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1

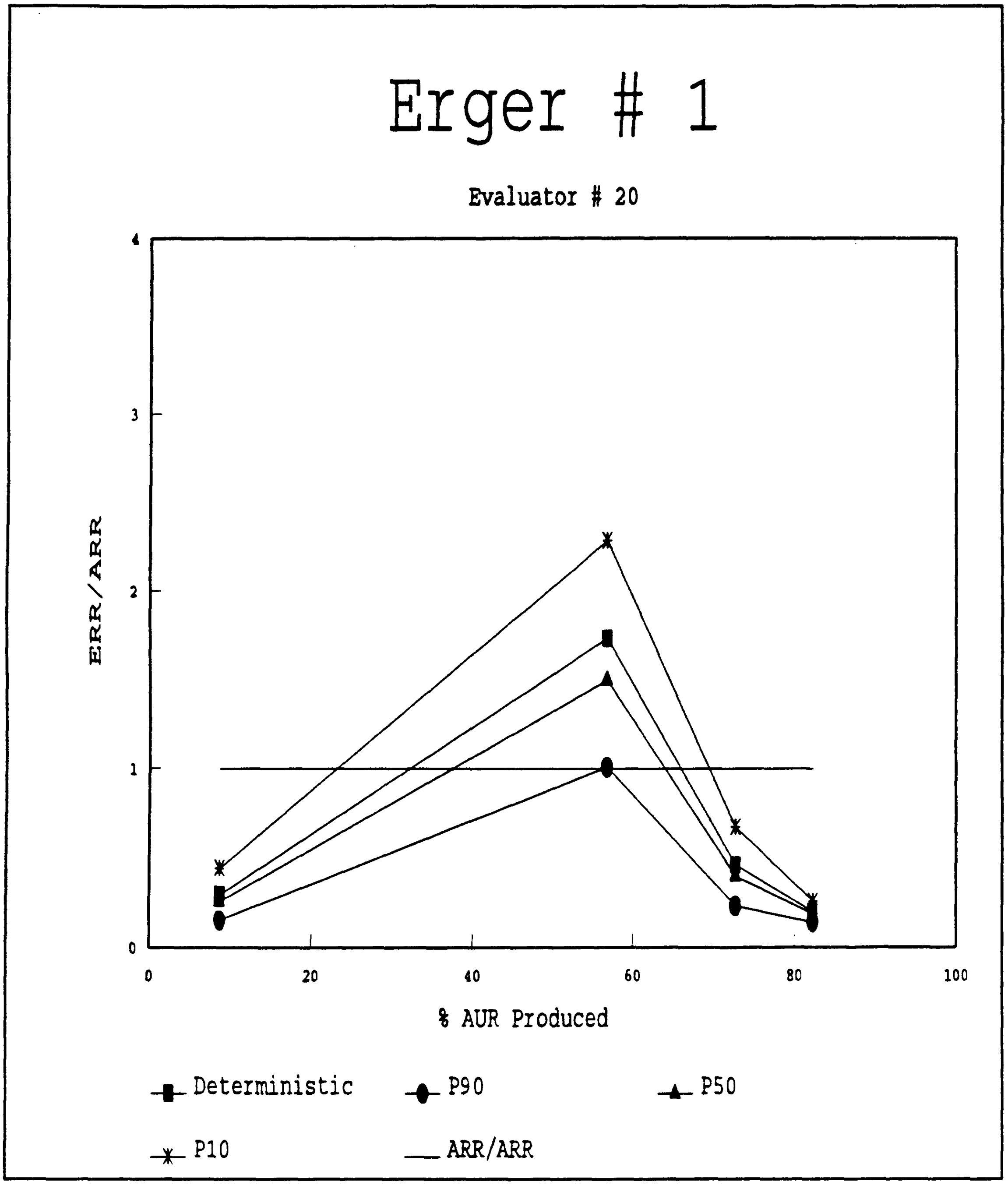

Figure E-8 Evaluator # 20, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1

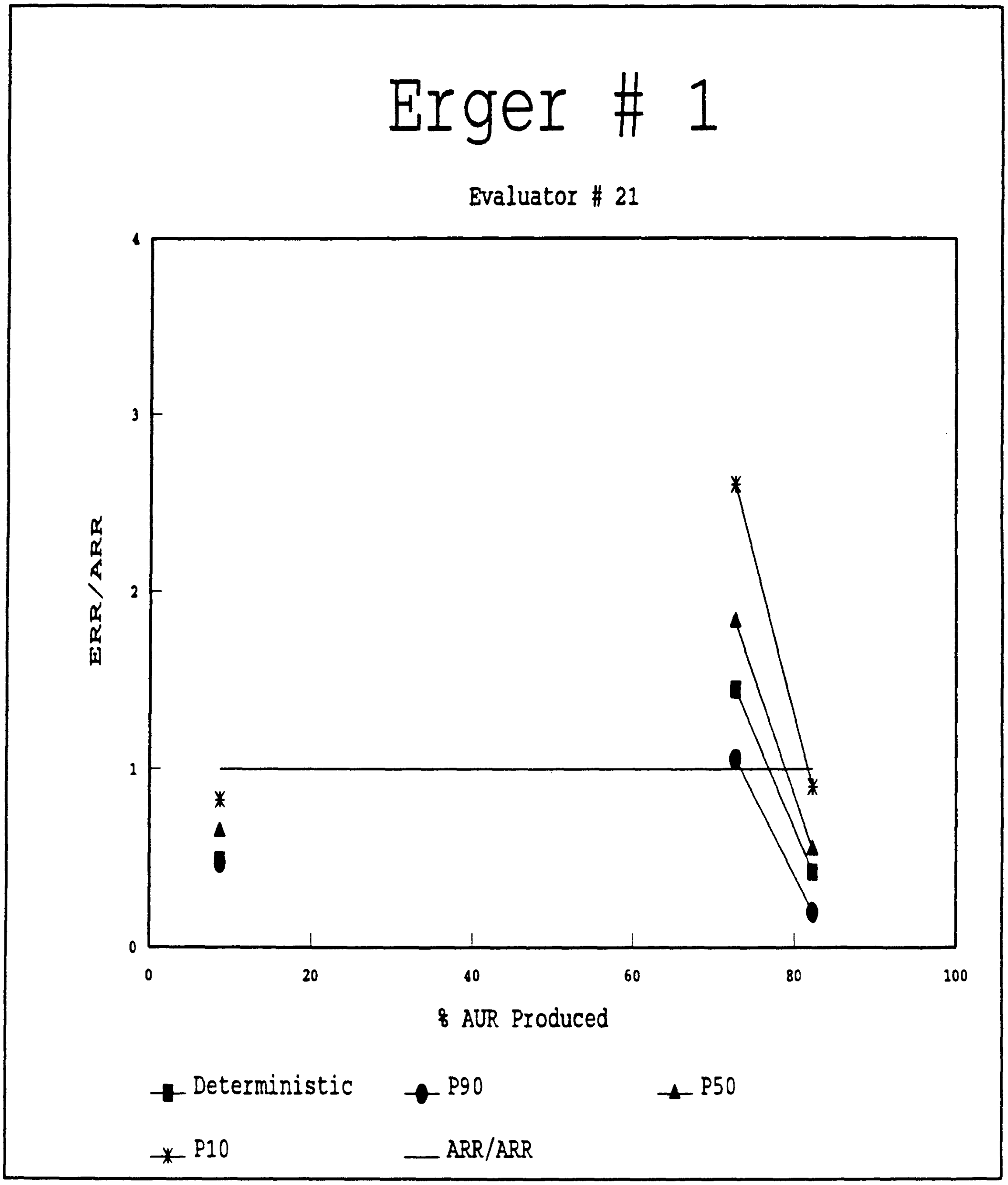

Figure E-9 Evaluator # 21, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1

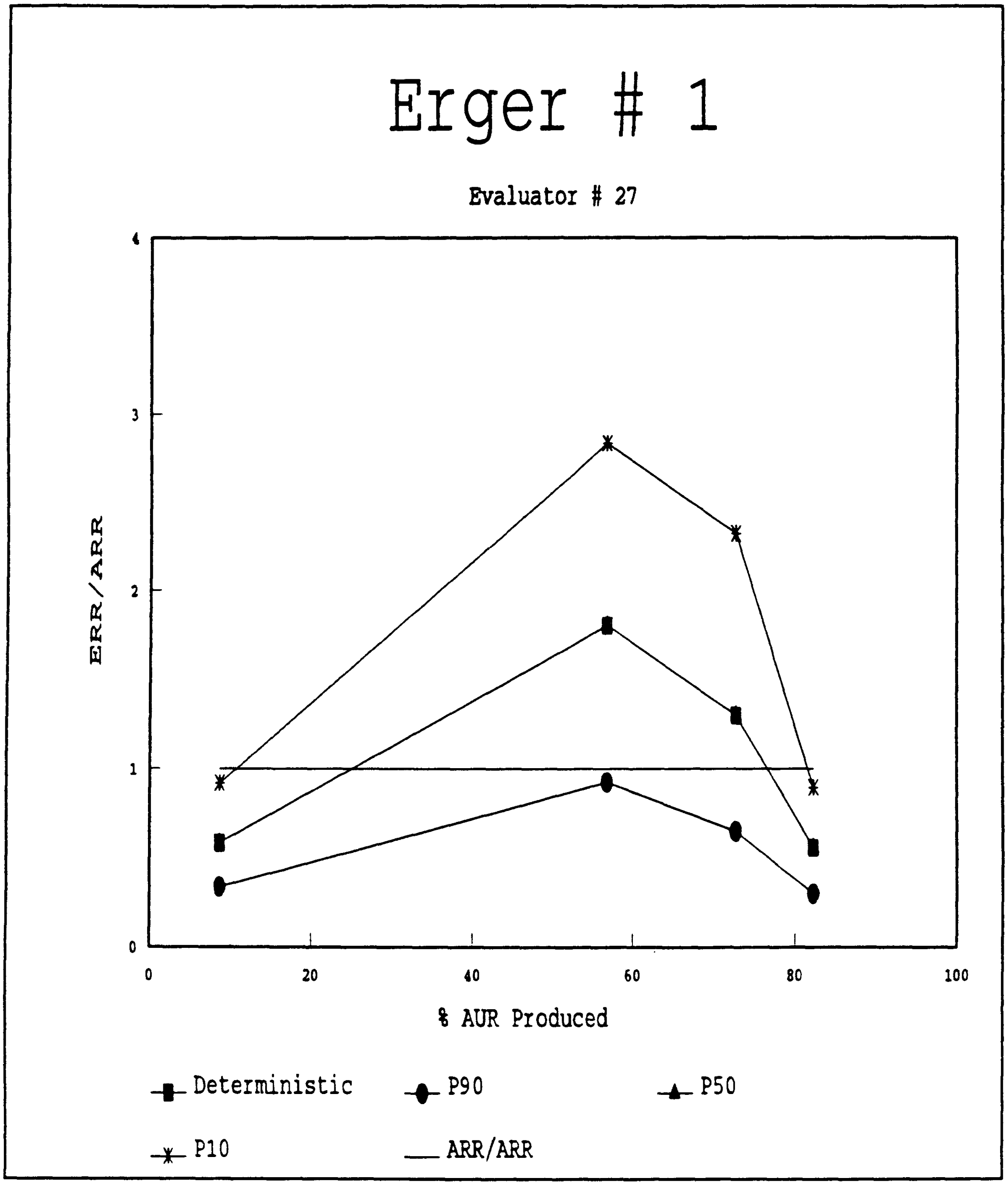

Figure E-10 Evaluator # 27, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1

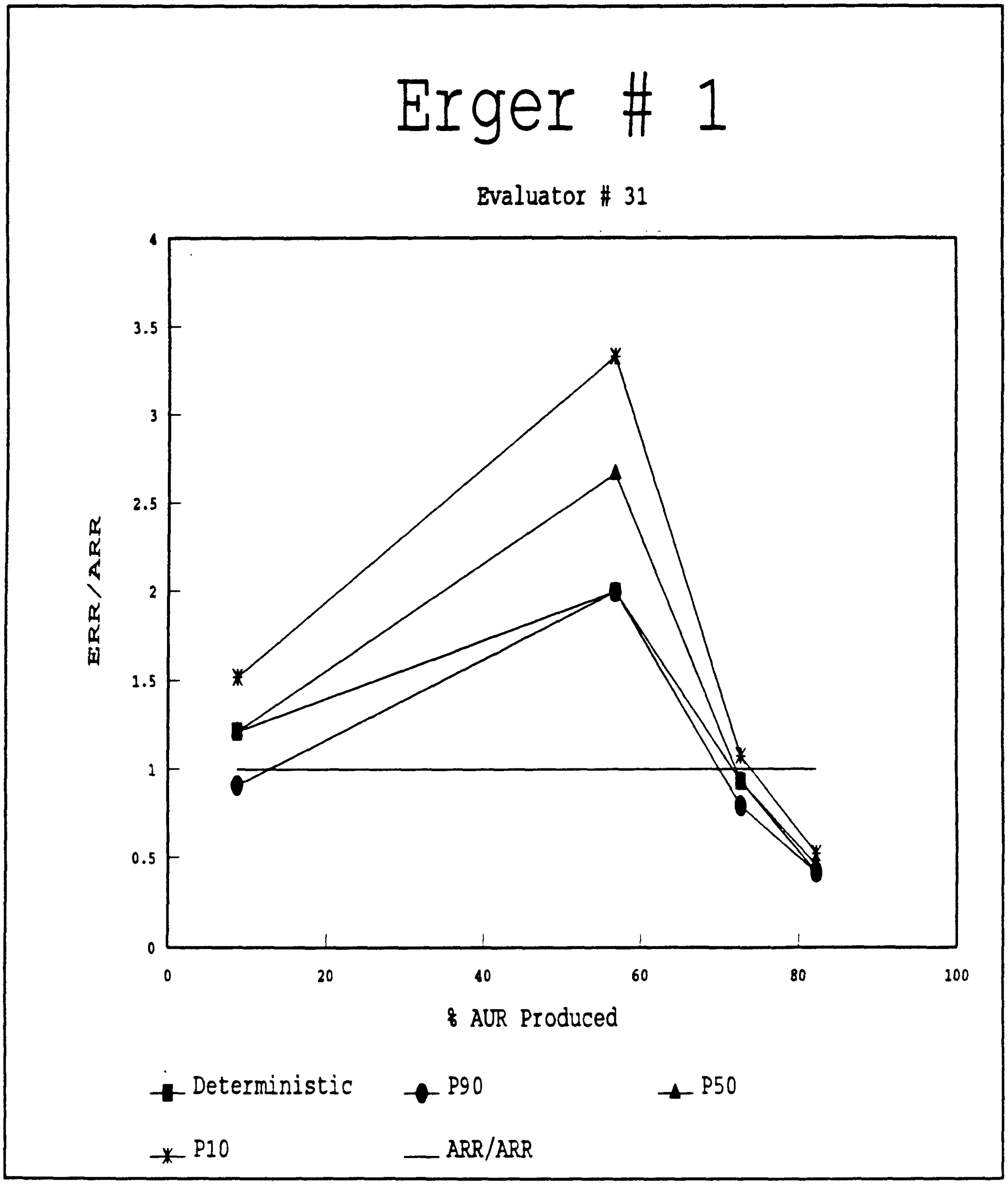

Figure E-11 Evaluator # 31, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Erger # 1

APPENDIX F

Graphs of individual evaluator estimates for Deterministic, P_{90}, P_{50}, and P_{10} values for the Kallsen # 2.

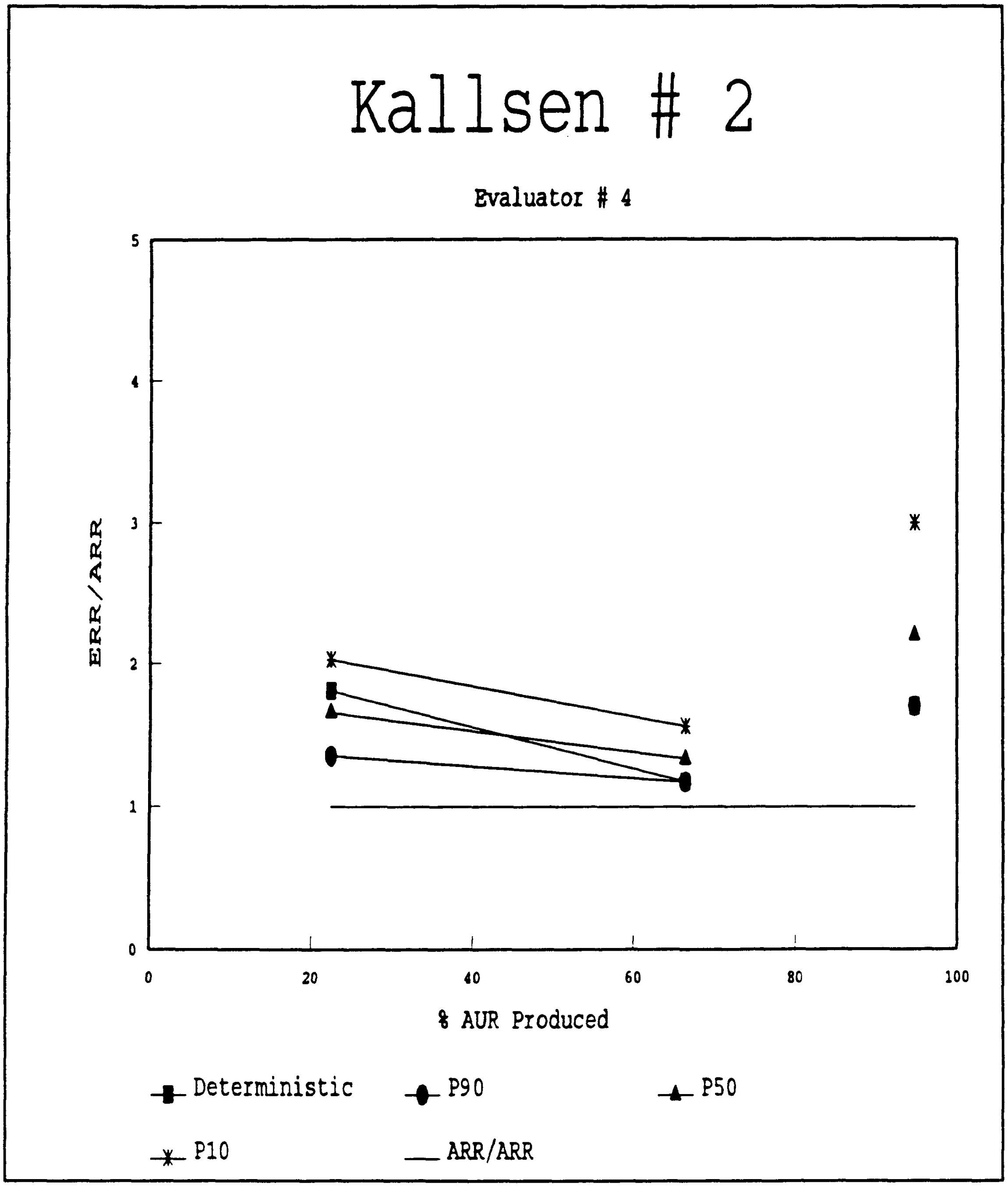

Figure F-1 Evaluator # 4, Estimates of Deterministic P_{90}, P_{50}, P_{10} values for the Kallsen # 2

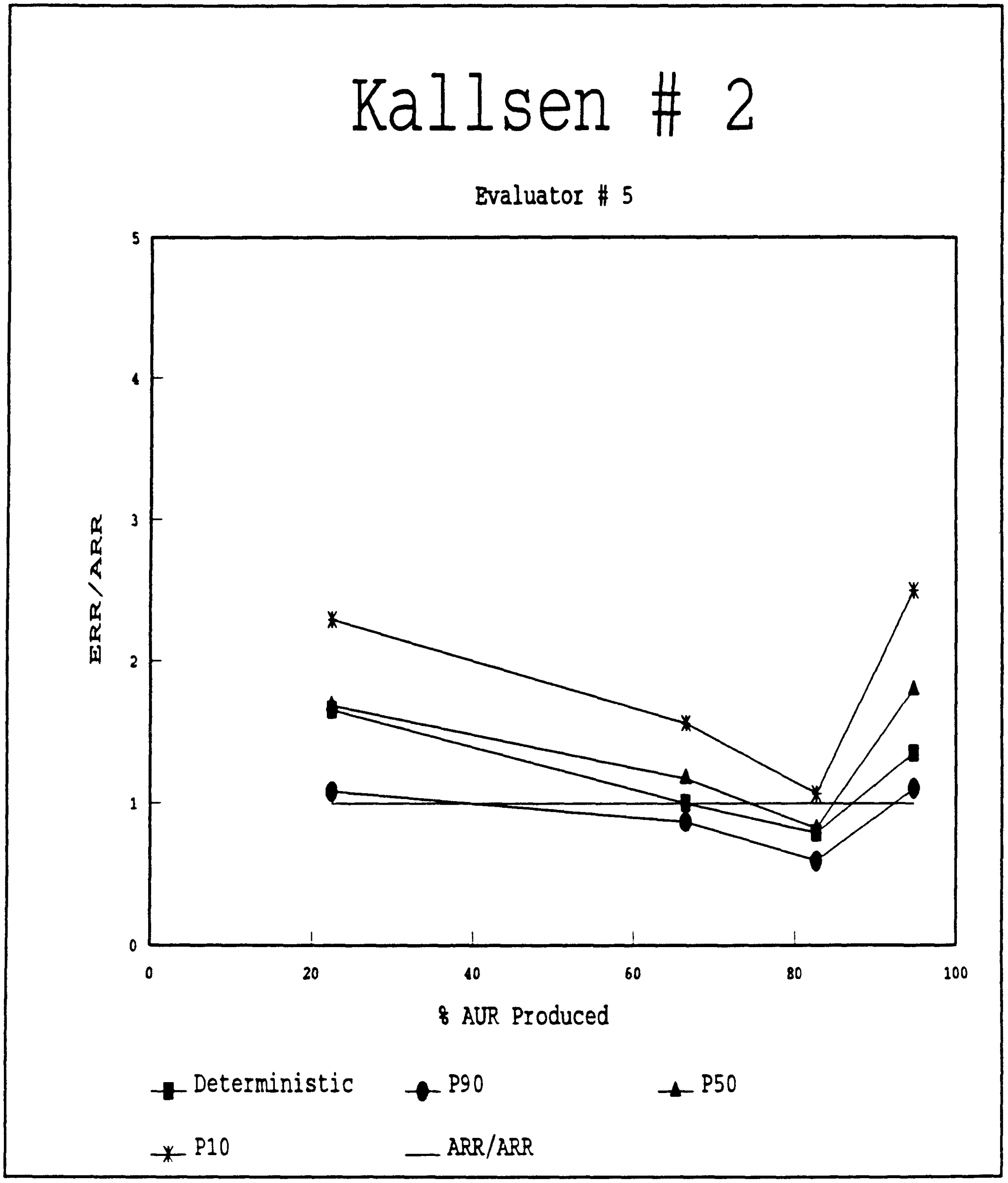

Figure F-2 Evaluator # 5, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2

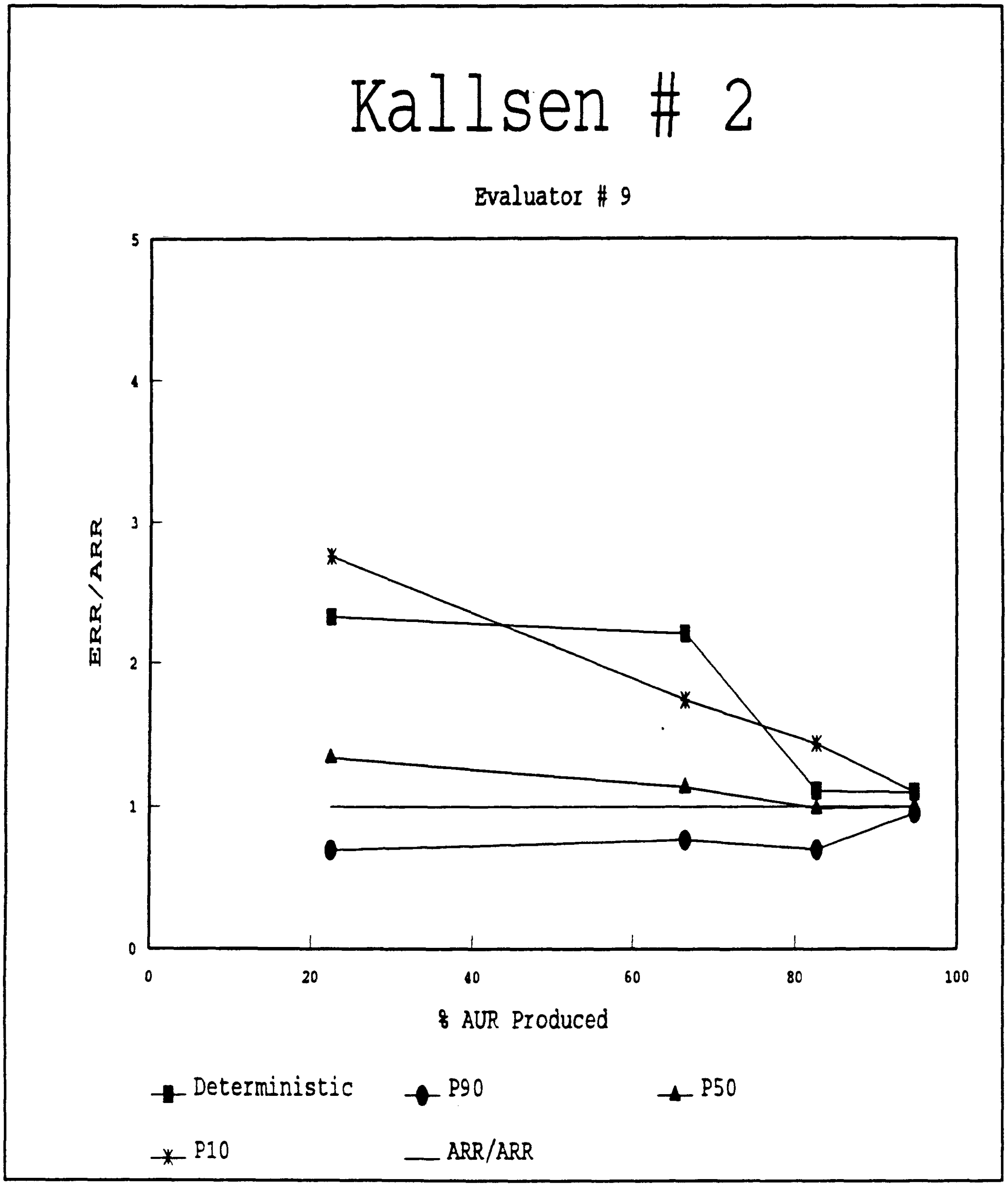

Figure F-3 Evaluator # 9, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2

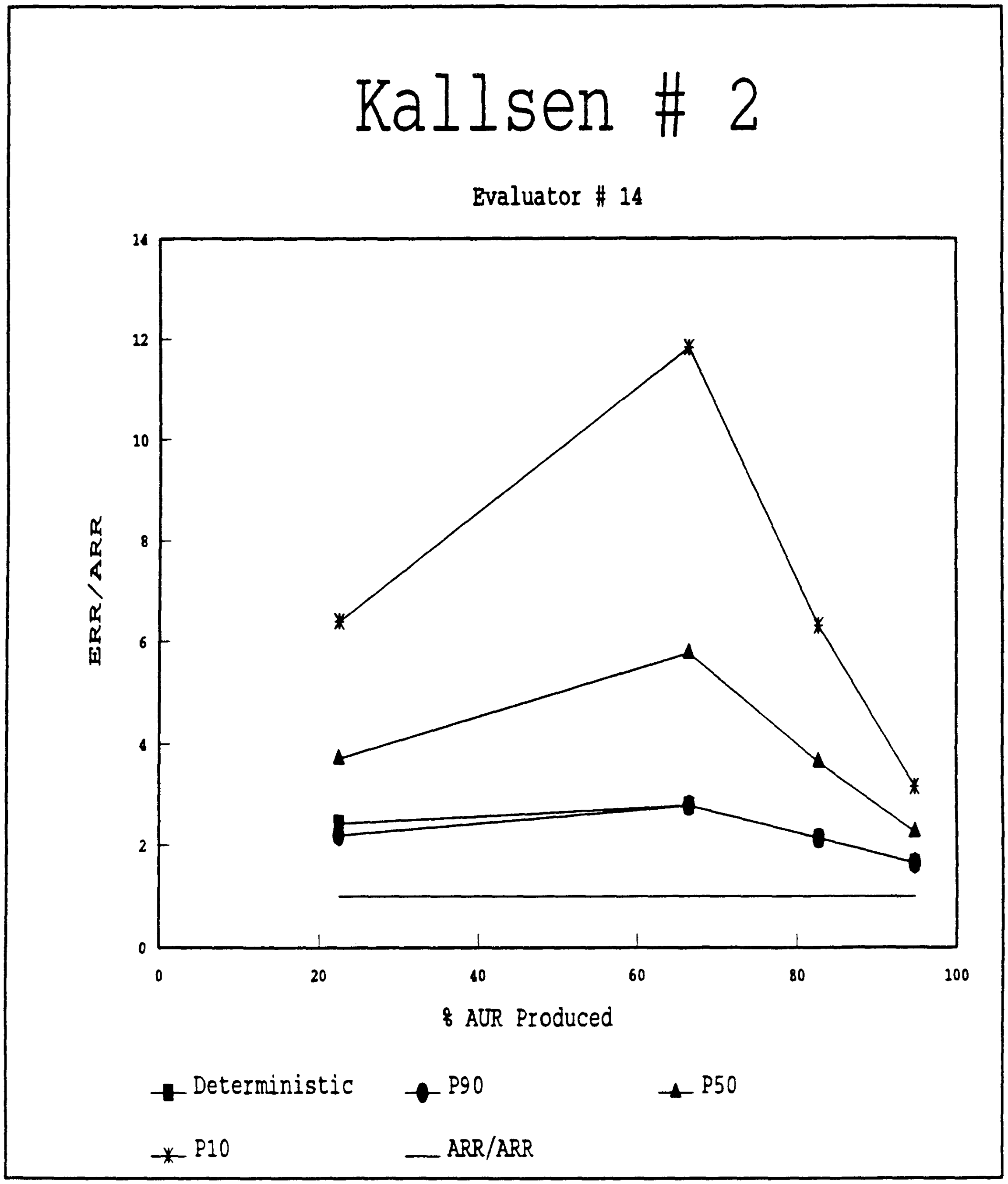

Figure F-4 Evaluator # 14, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2

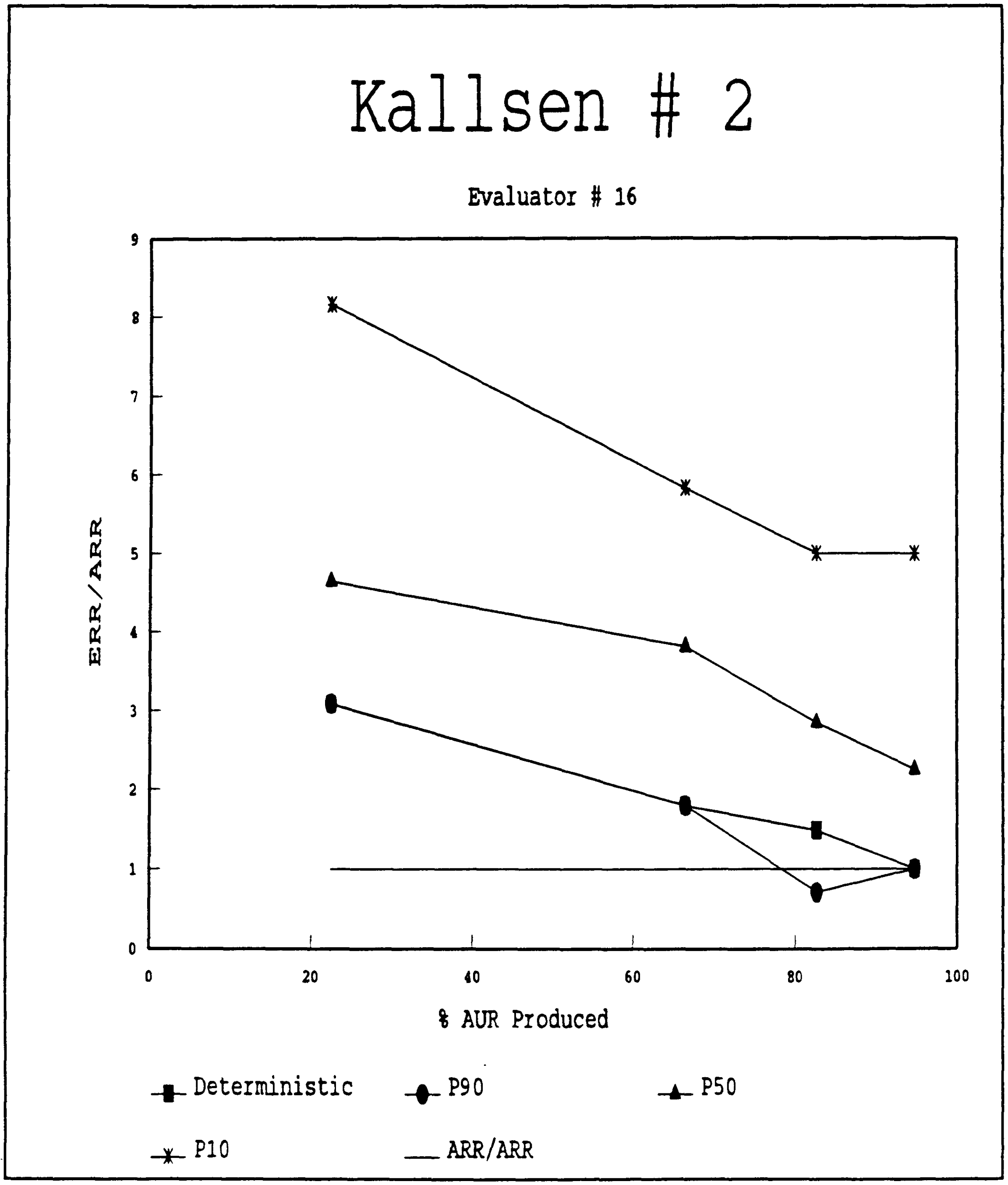

Figure F-5 Evaluator # 16, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2

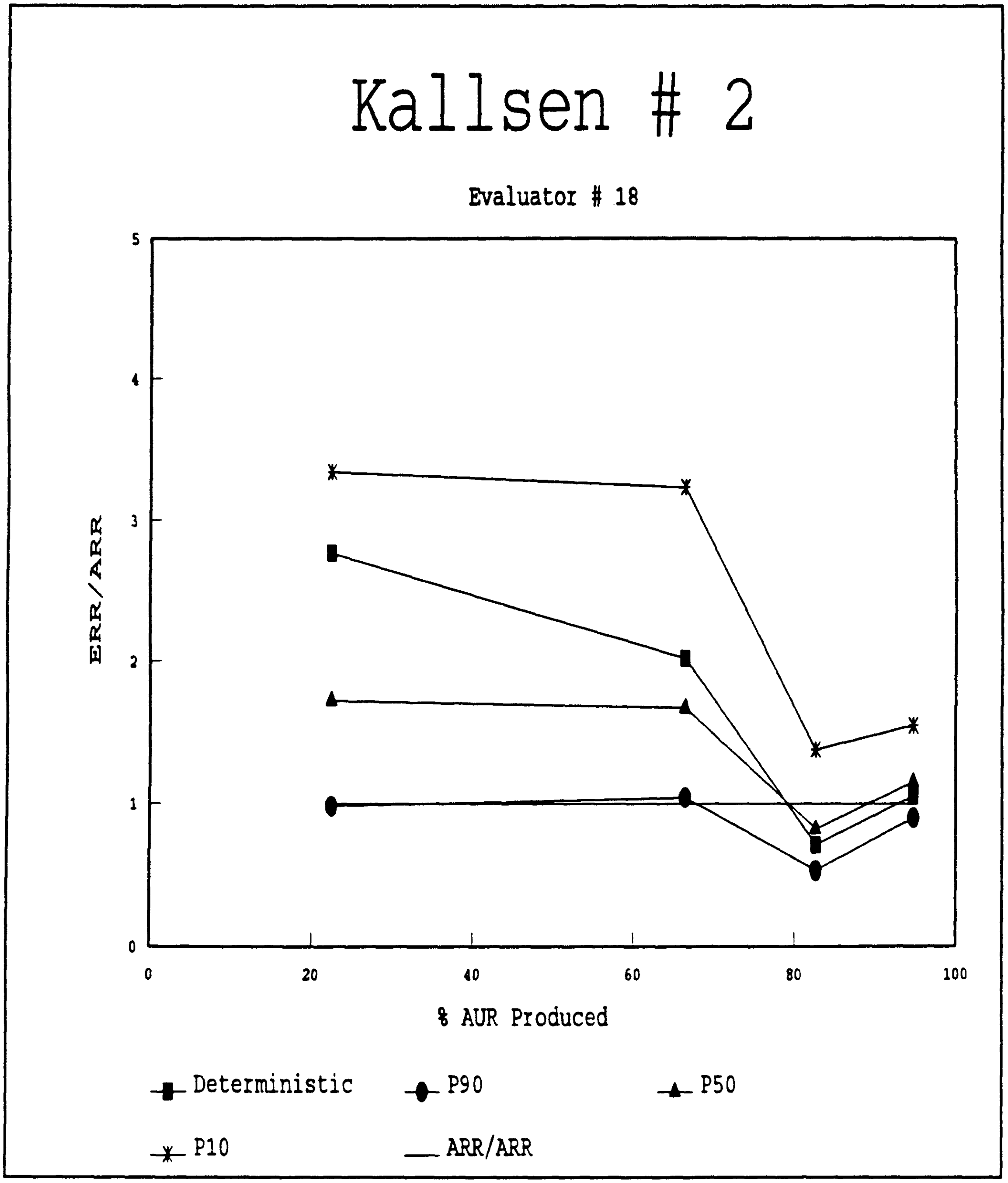

Figure F-6 Evaluator # 18, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2

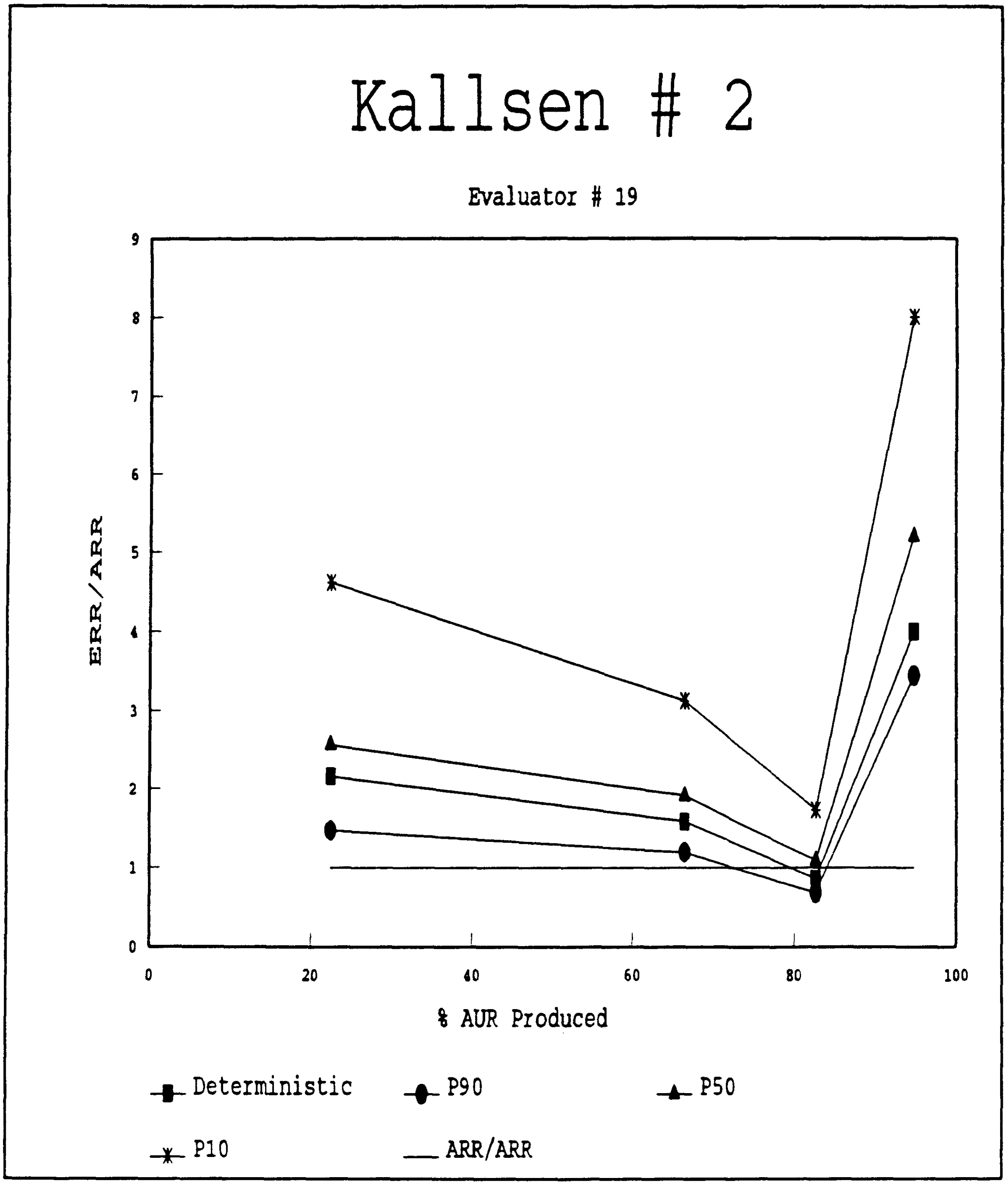

Figure F-7 Evaluator # 19, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2

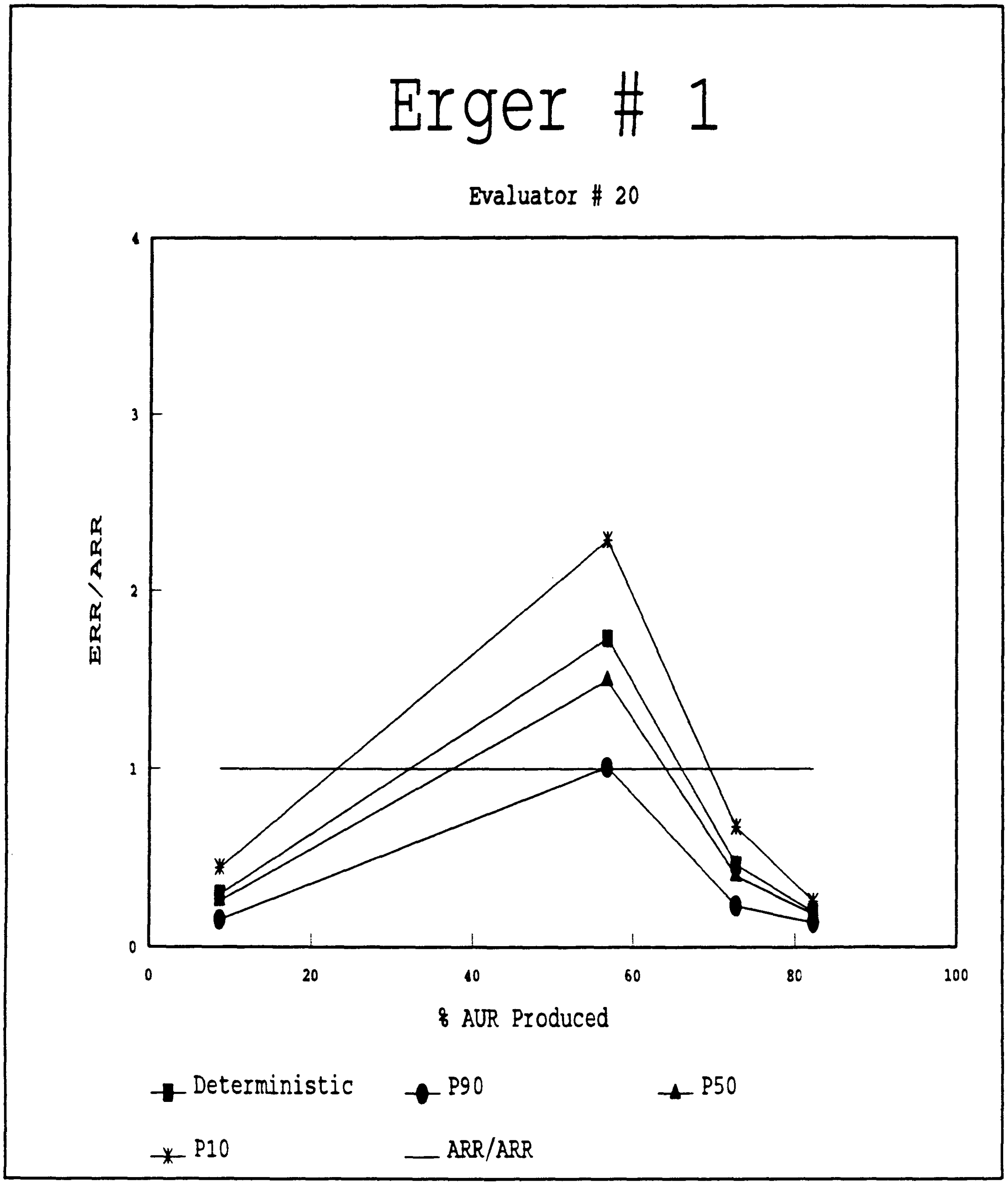

Figure F-8 Evaluator # 20, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2

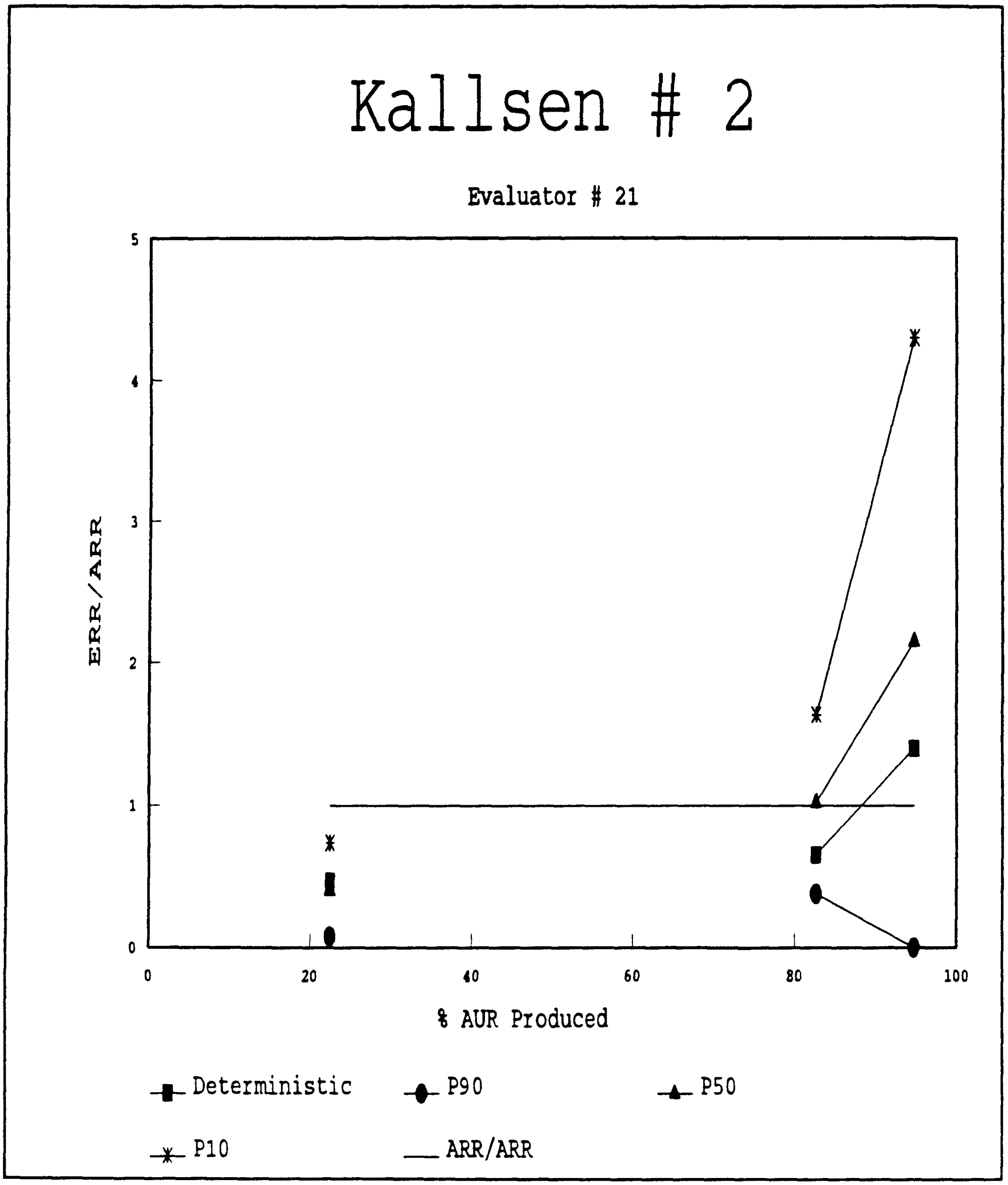

Figure F-9 Evaluator # 21, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2

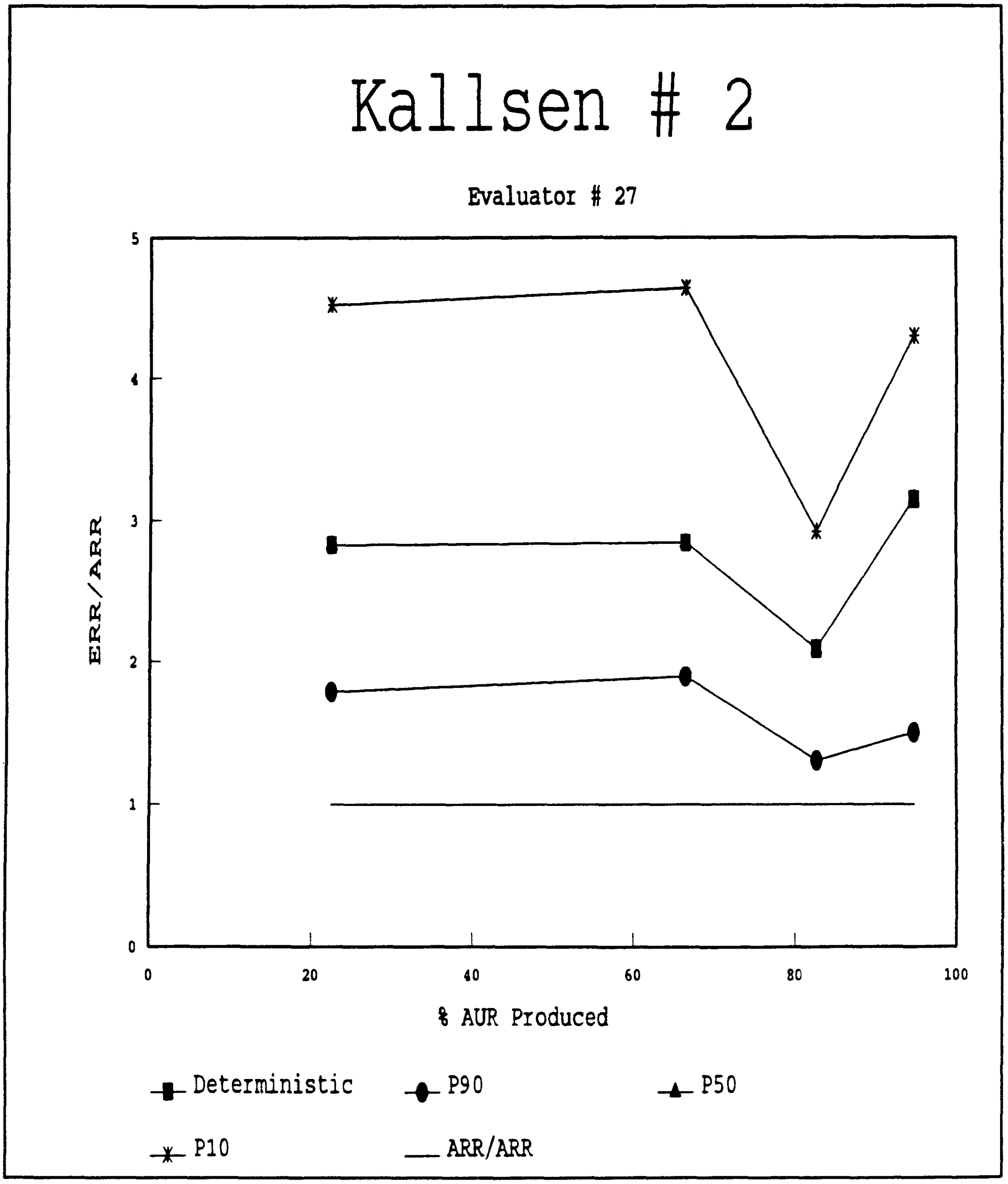

Figure F-10 Evaluator # 27, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2

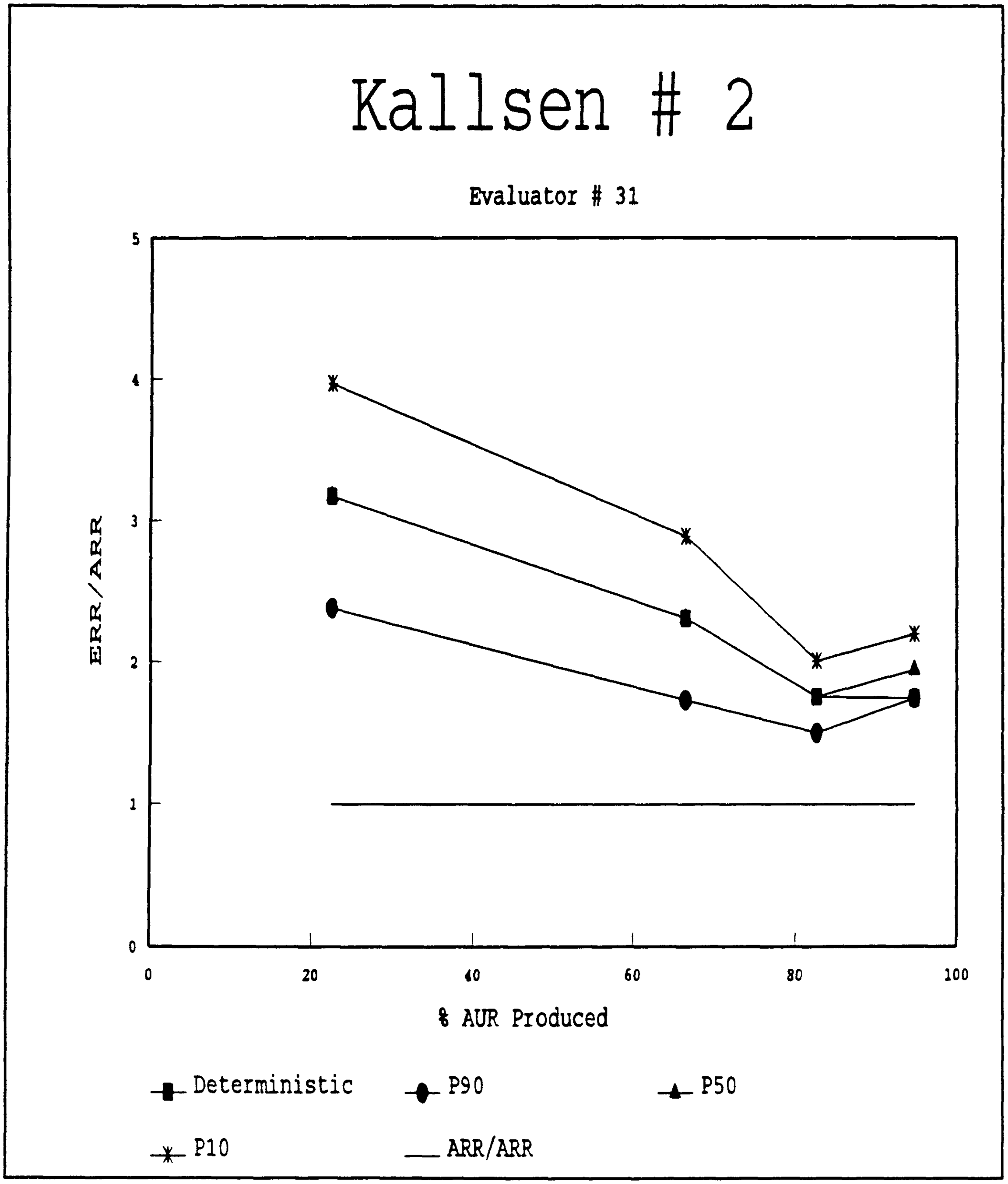

Figure F-11 Evaluator # 31, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Kallsen # 2

APPENDIX G

Graphs of individual evaluator estimates for Deterministic, P_{90}, P_{50}, and P_{10} values for the Reasoner # 1.

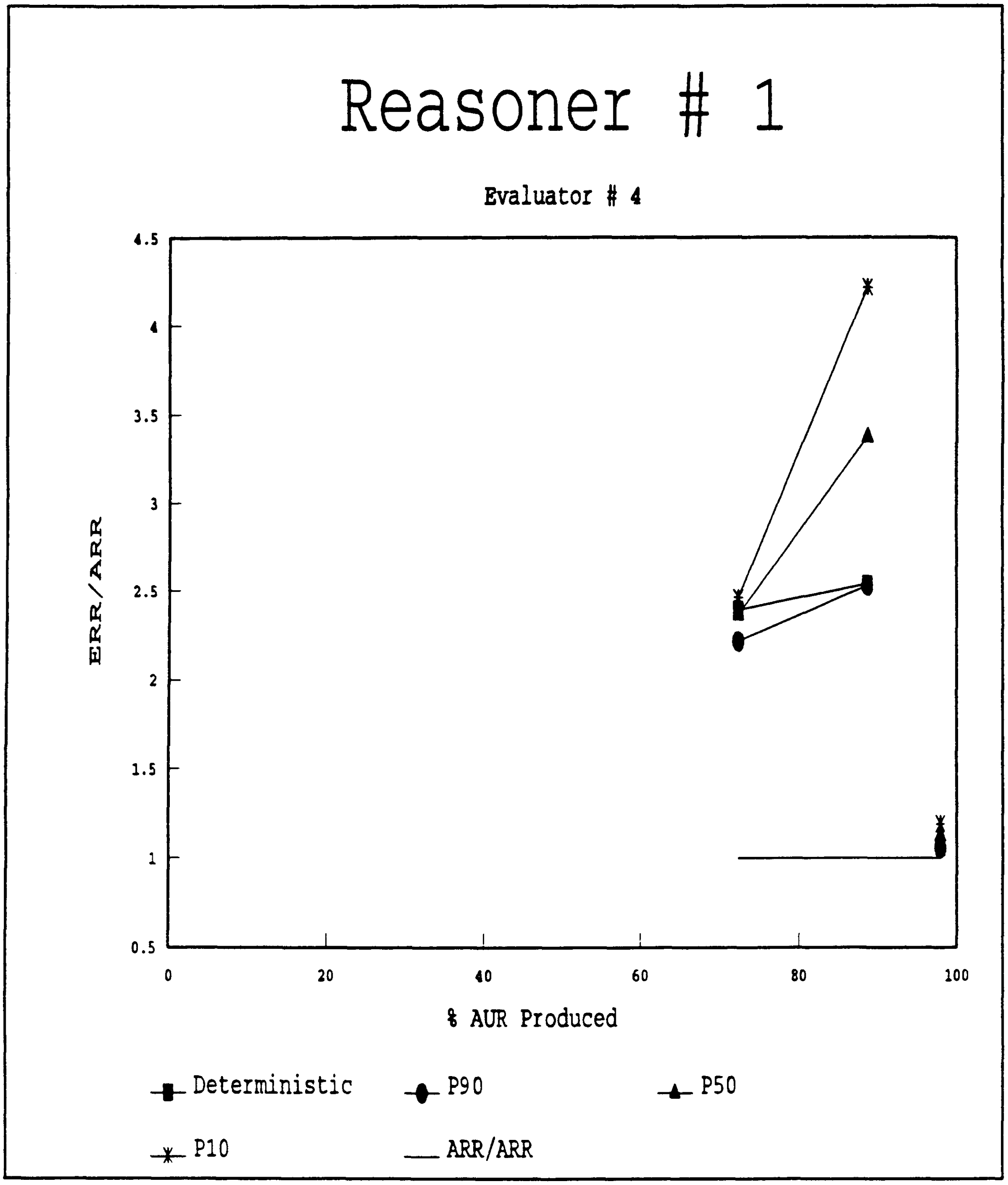

Figure G-1 Evaluator # 4, Estimates of Deterministic P_{90}, P_{50}, P_{10} values for the Reasoner # 1

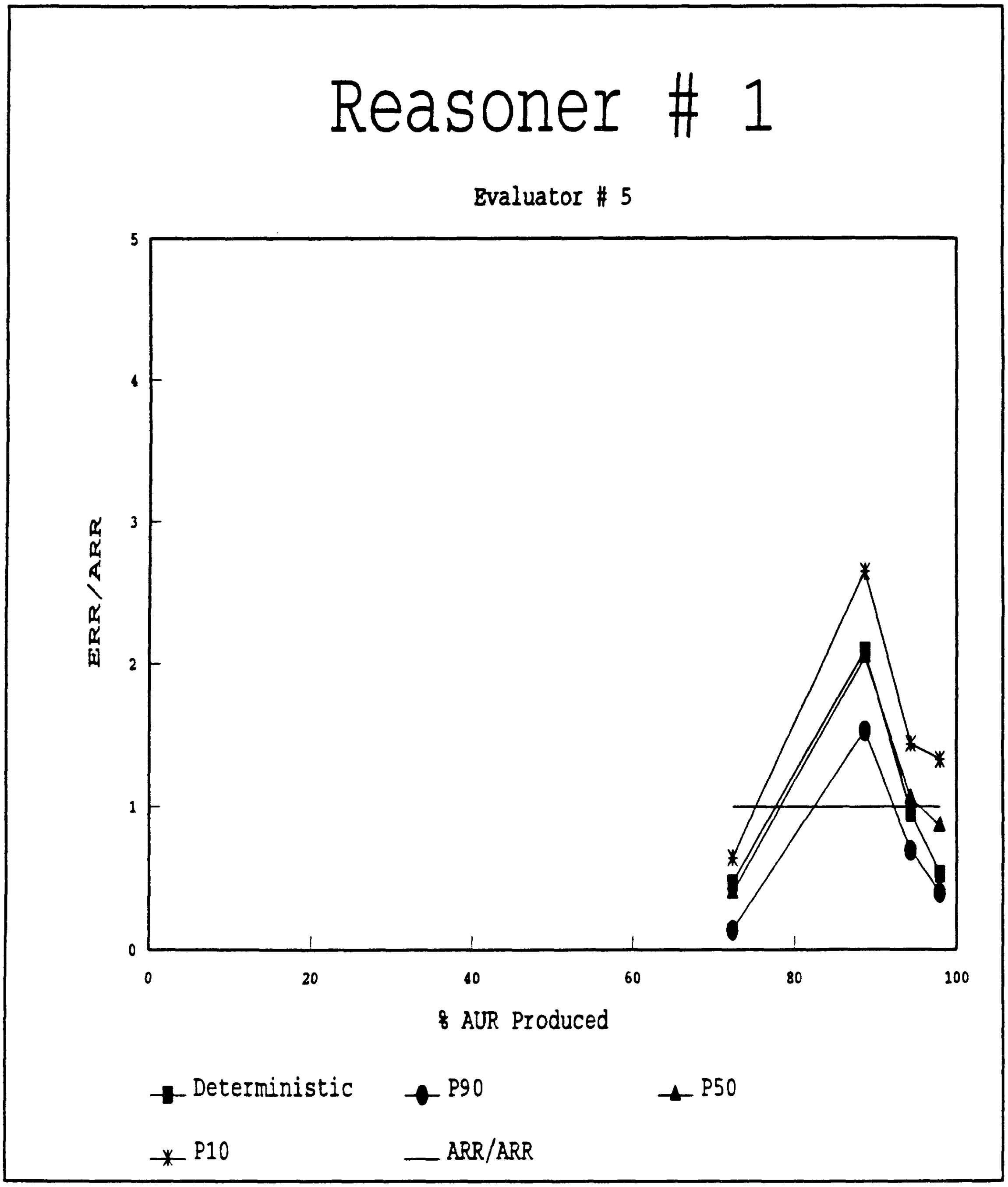

Figure G-2 Evaluator # 5, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1

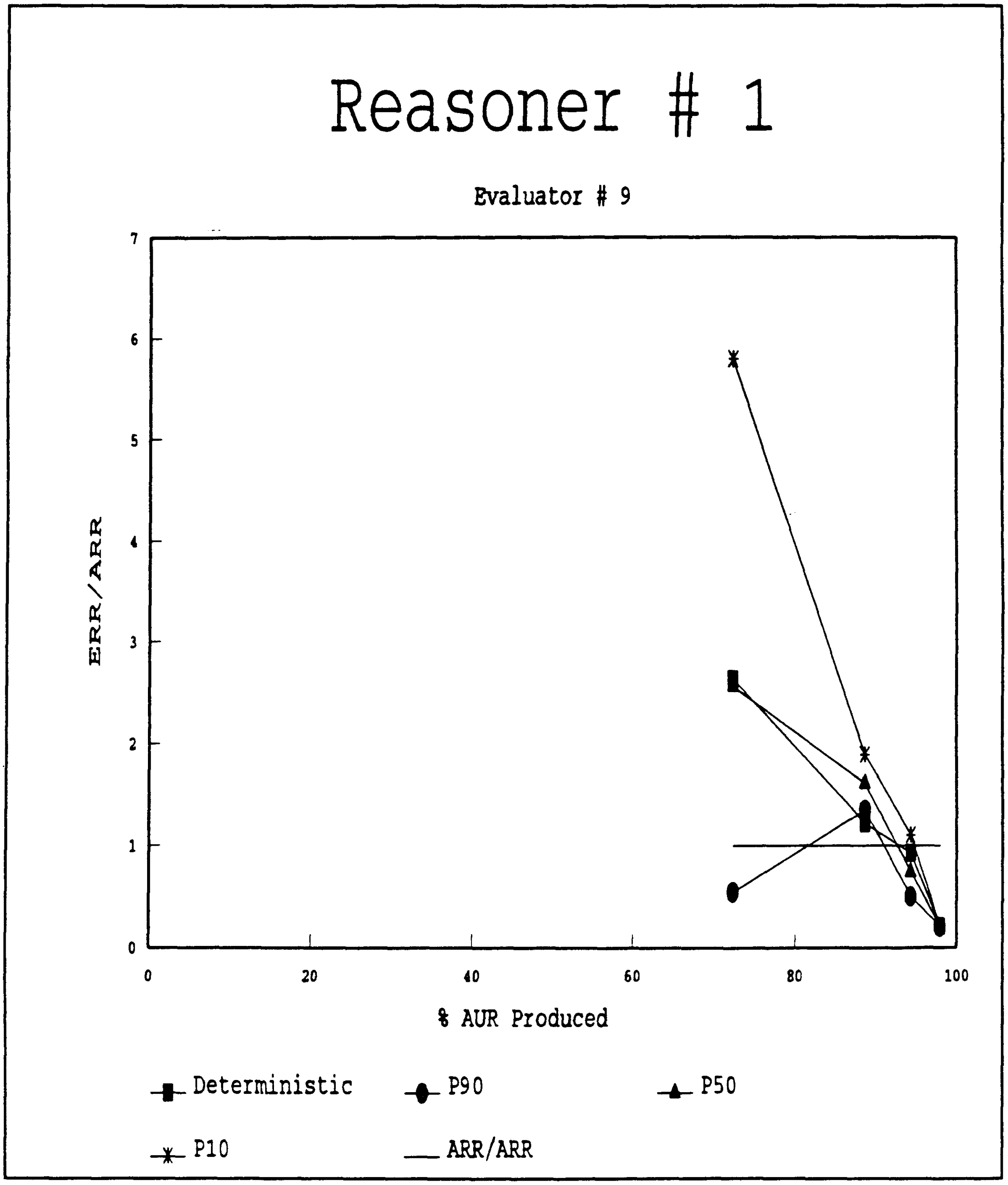

Figure G-3 Evaluator # 9, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1

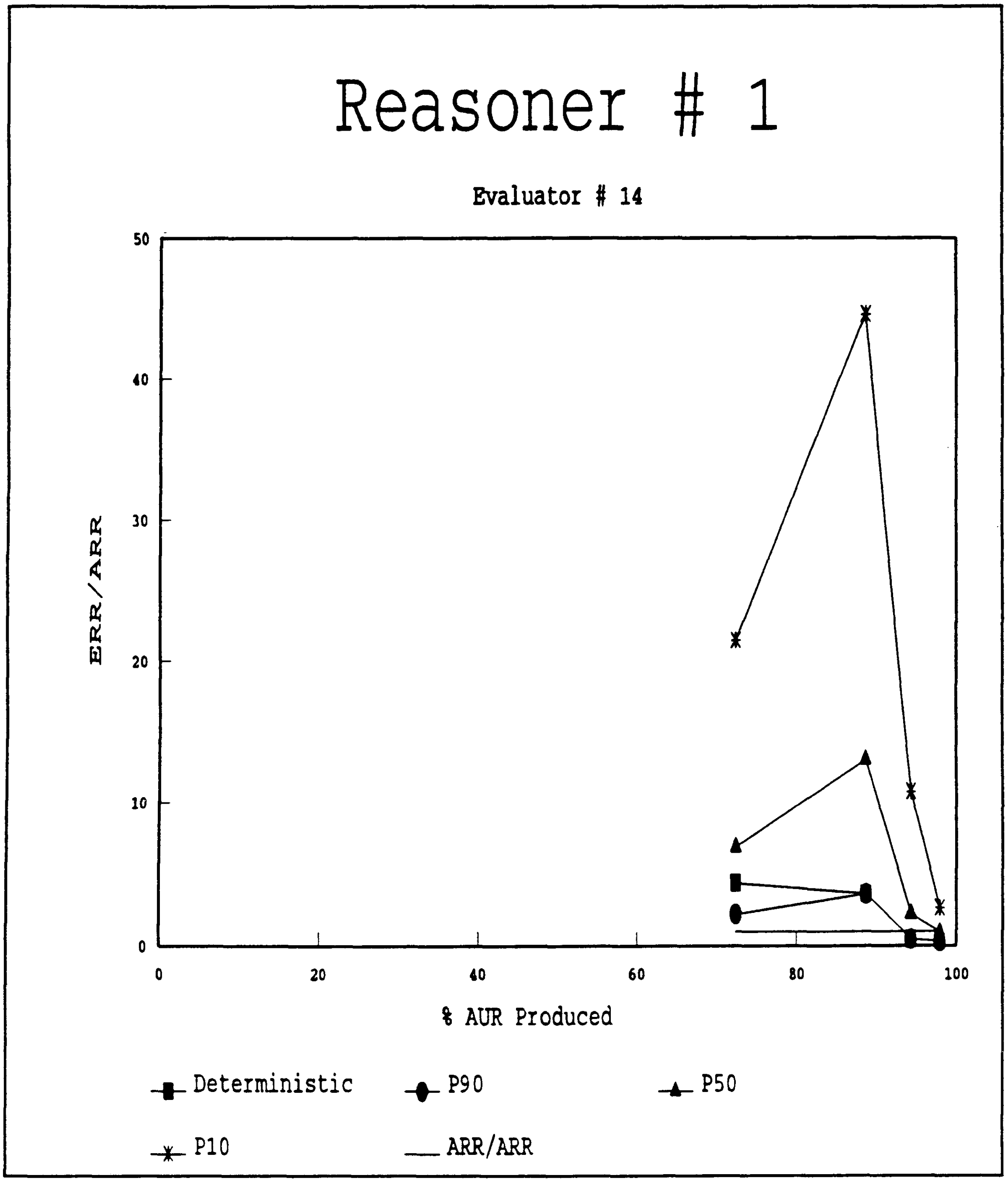

Figure G-4 Evaluator # 14, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1

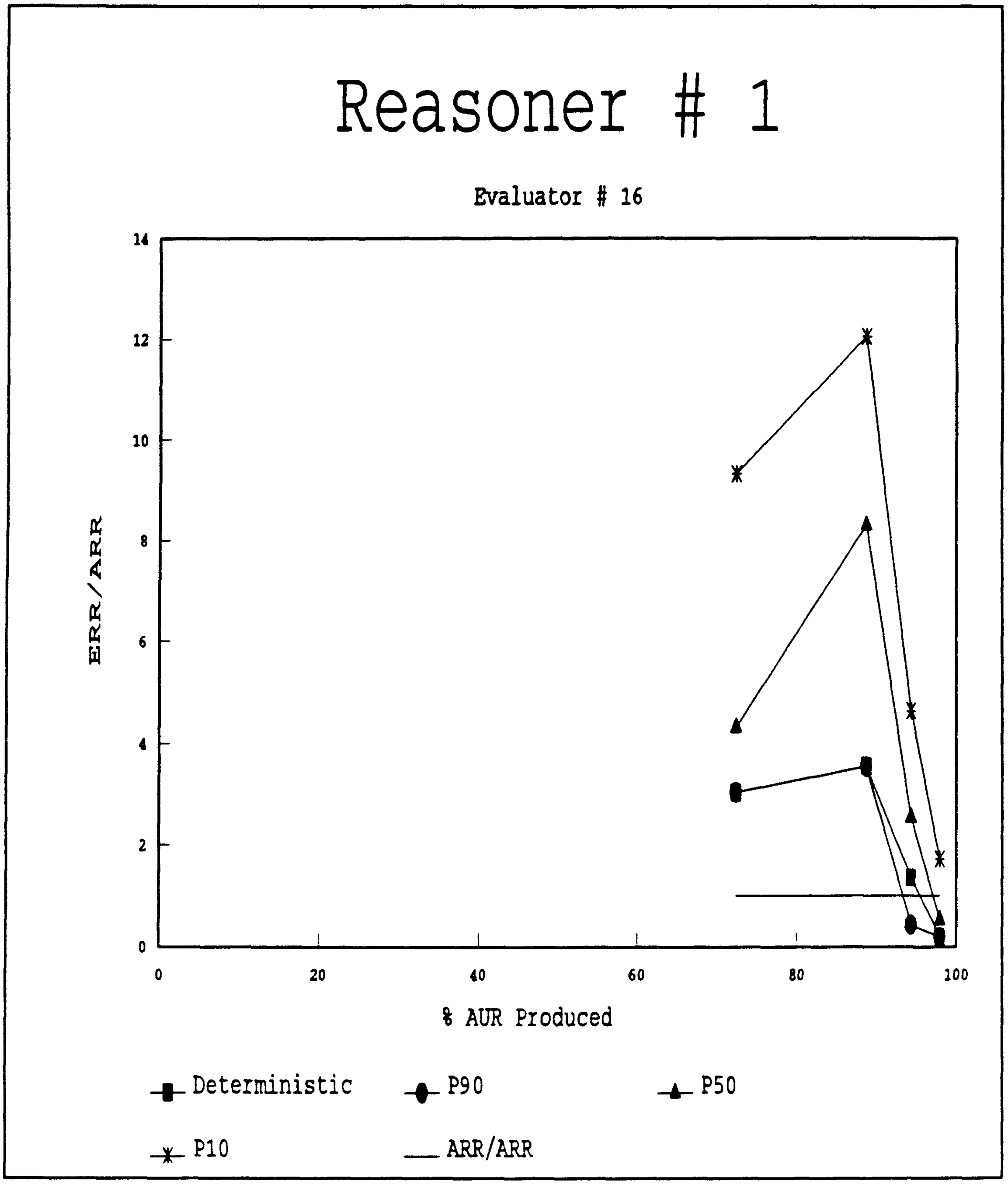

Figure G-5 Evaluator # 16, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1

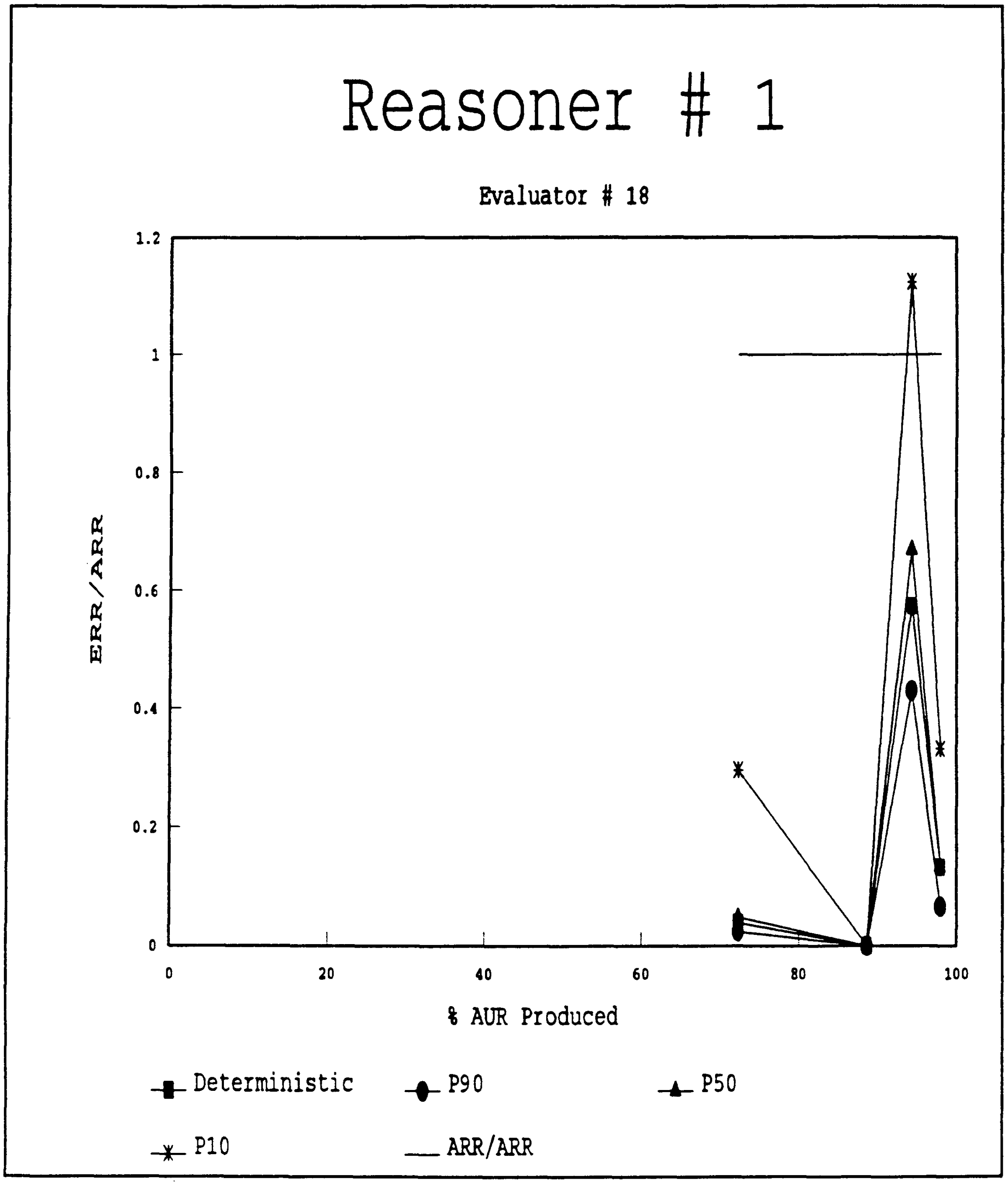

Figure G-6 Evaluator # 18, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1

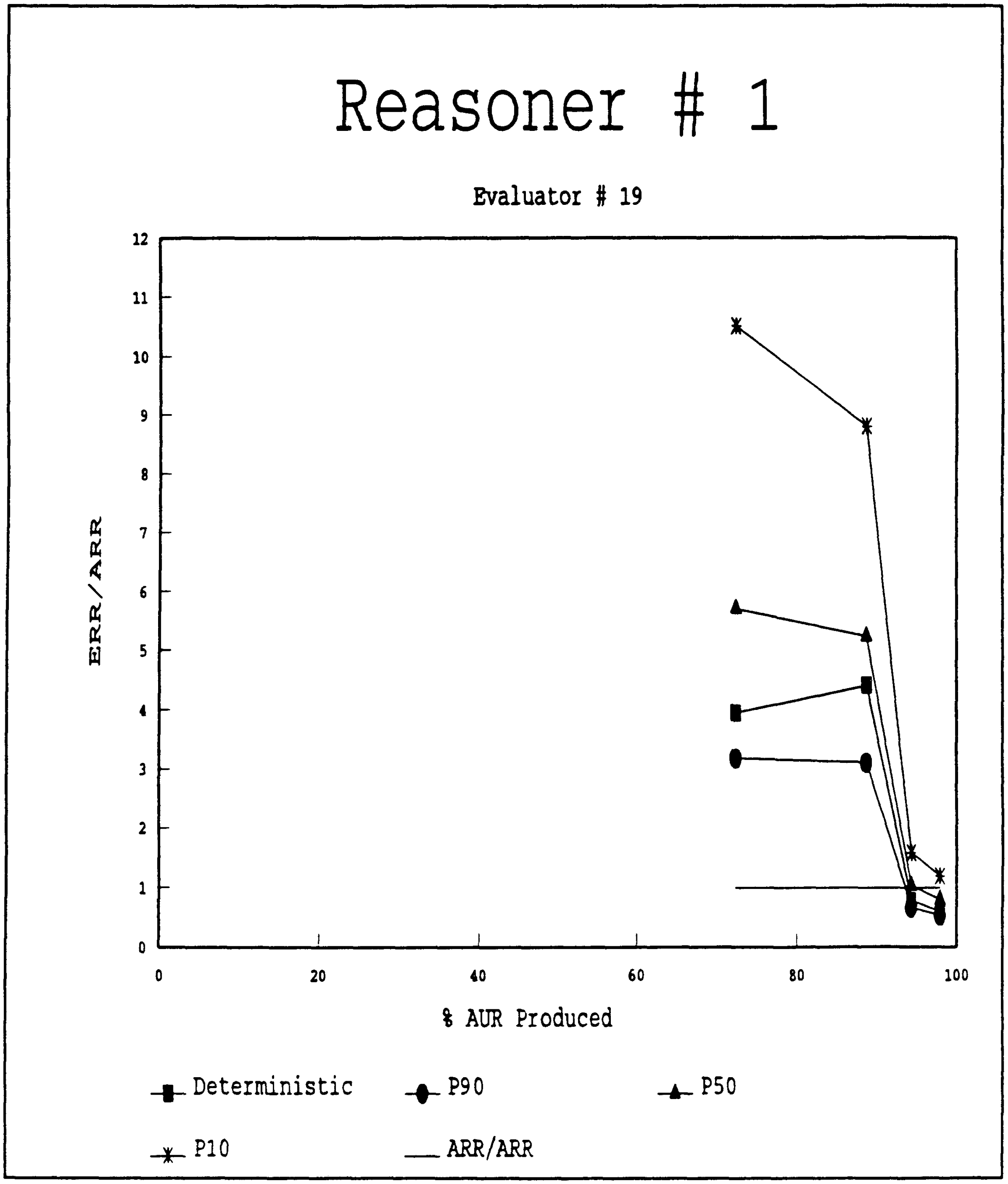

Figure G-7 Evaluator # 19, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1

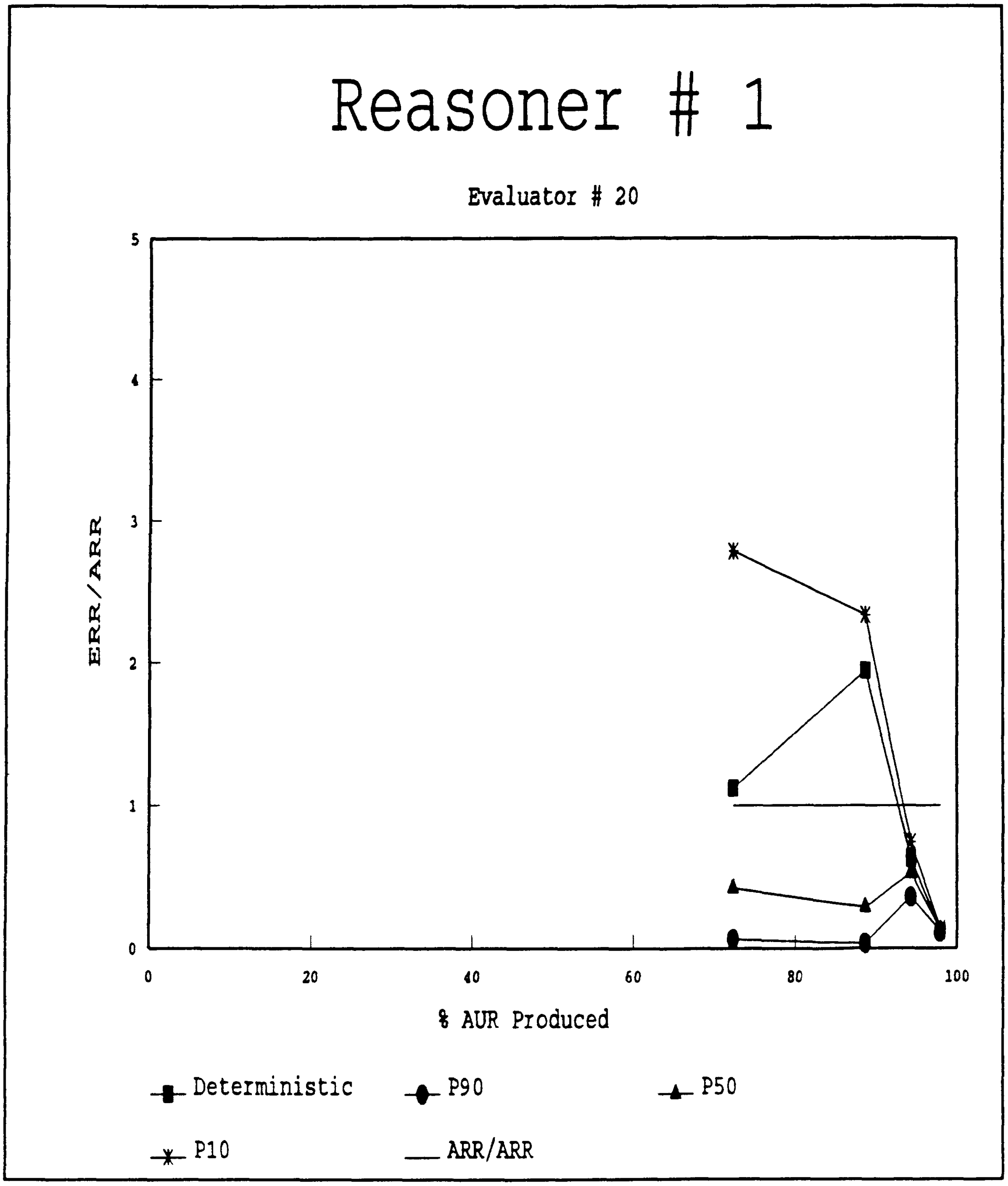

Figure G-8 Evaluator # 20, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1

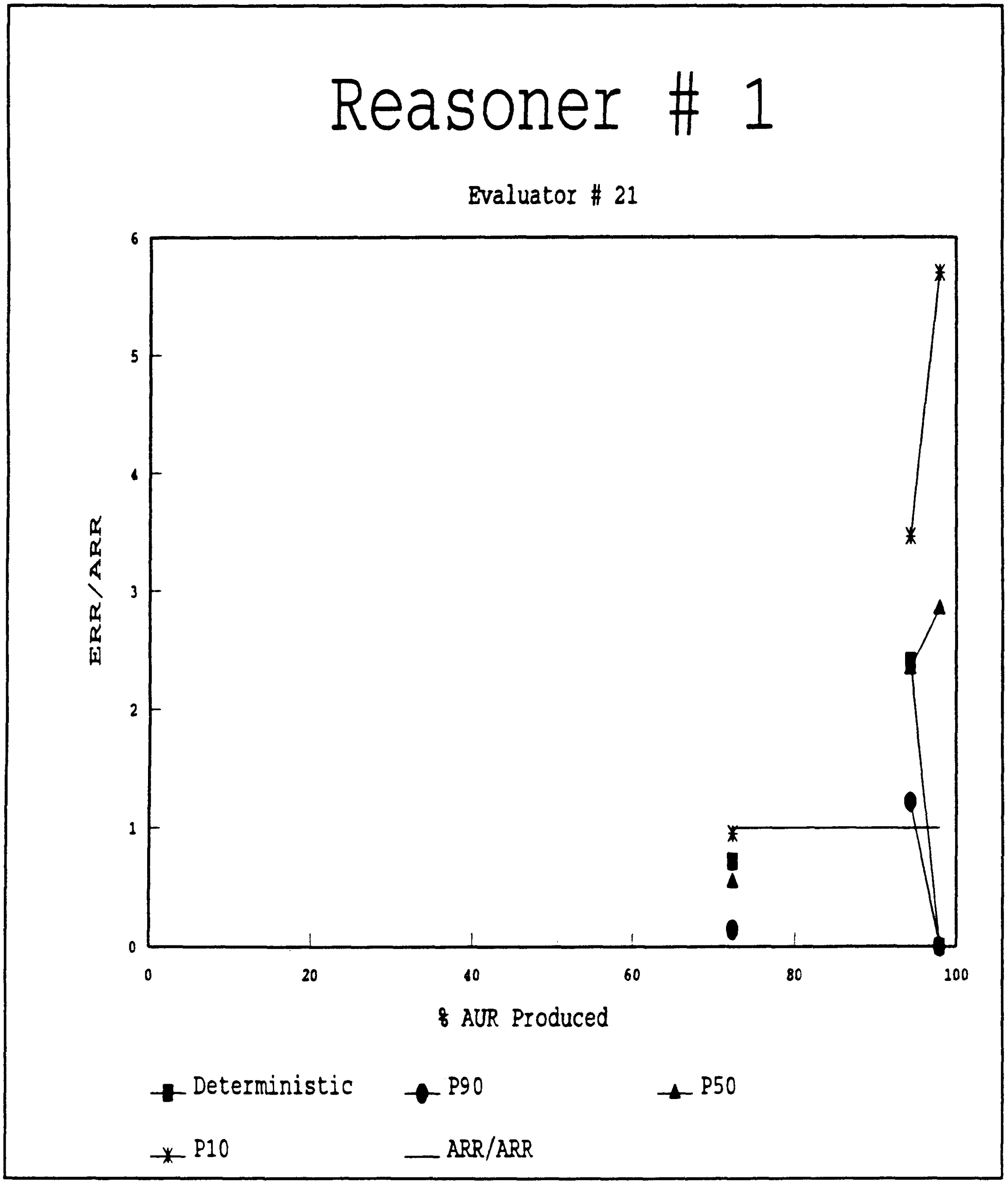

Figure G-9 Evaluator # 21, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1

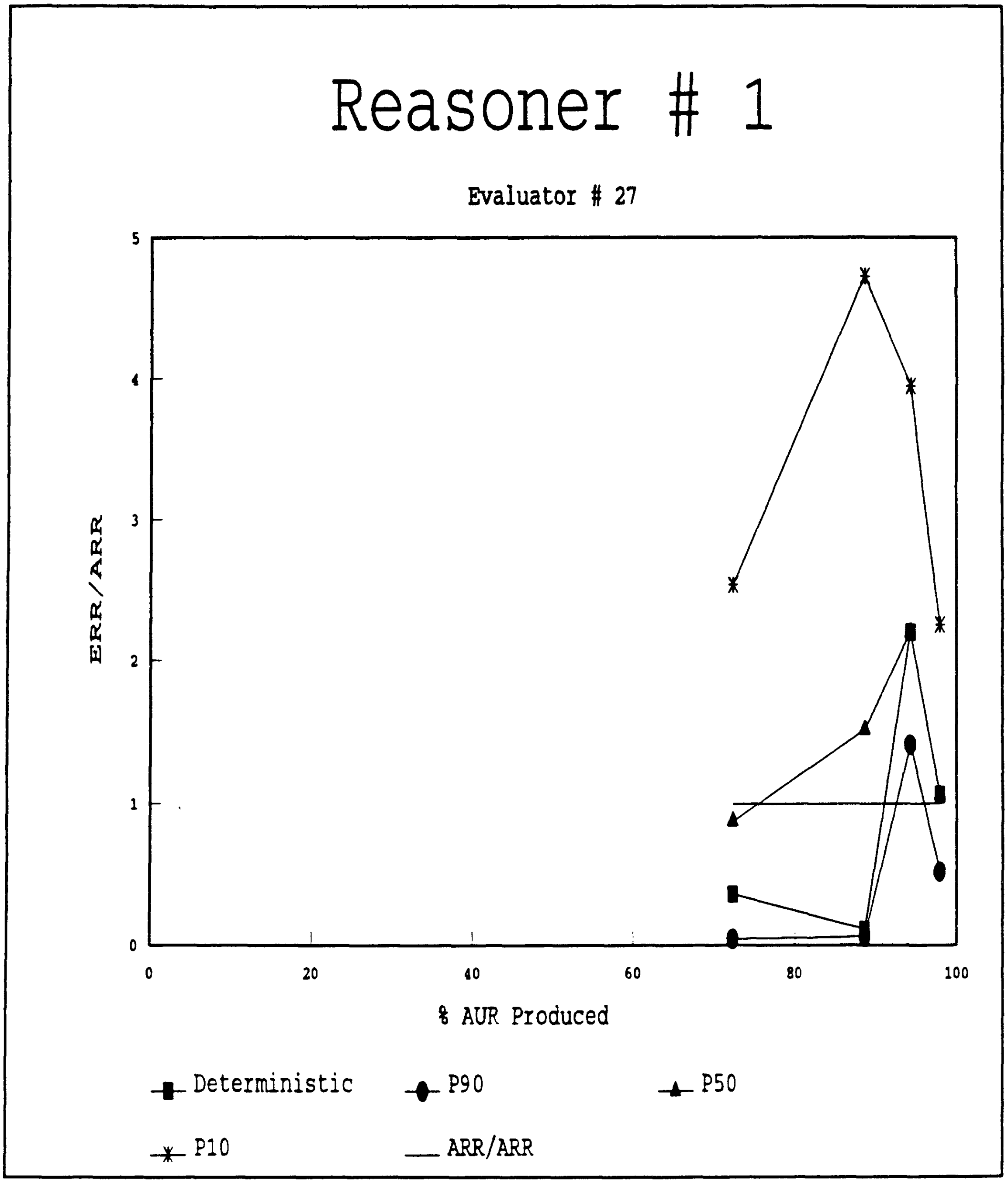

Figure G-10 Evaluator # 27, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1

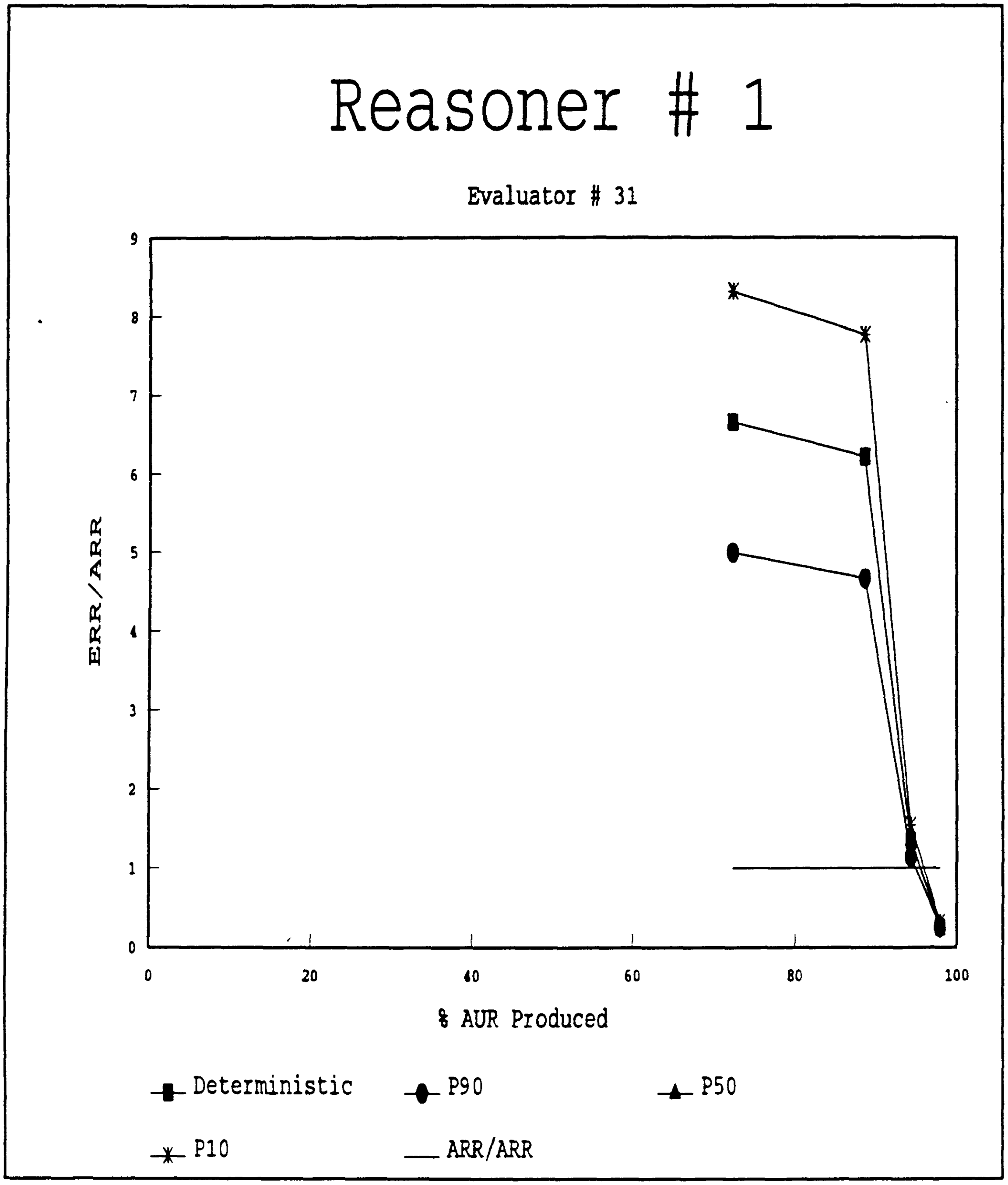

Figure G-11 Evaluator # 31, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Reasoner # 1

APPENDIX H

Graphs of individual evaluator estimates for Deterministic, P_{90}, P_{50}, and P_{10} values for the Company Total.

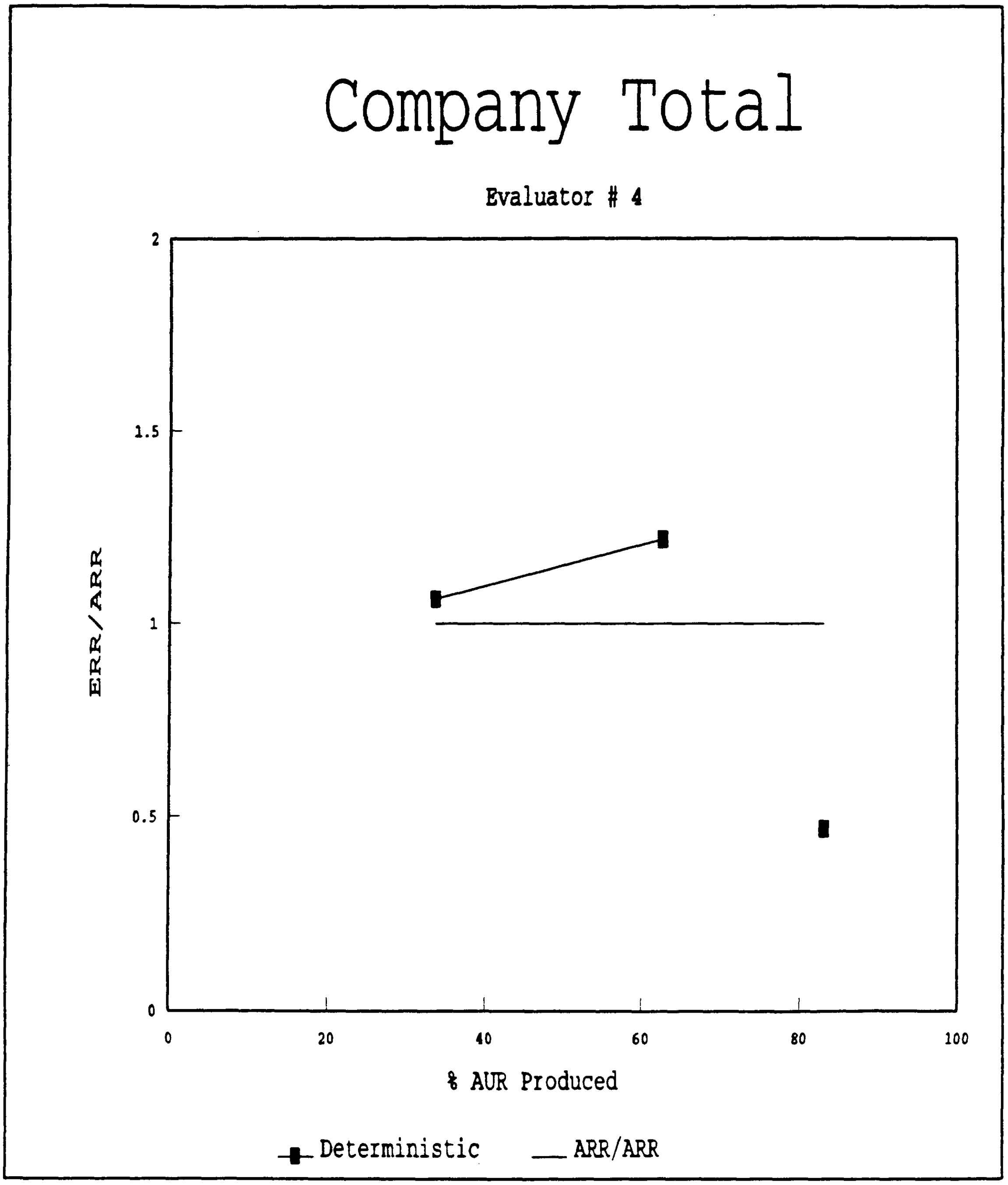

Figure H-1 Evaluator # 4, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total

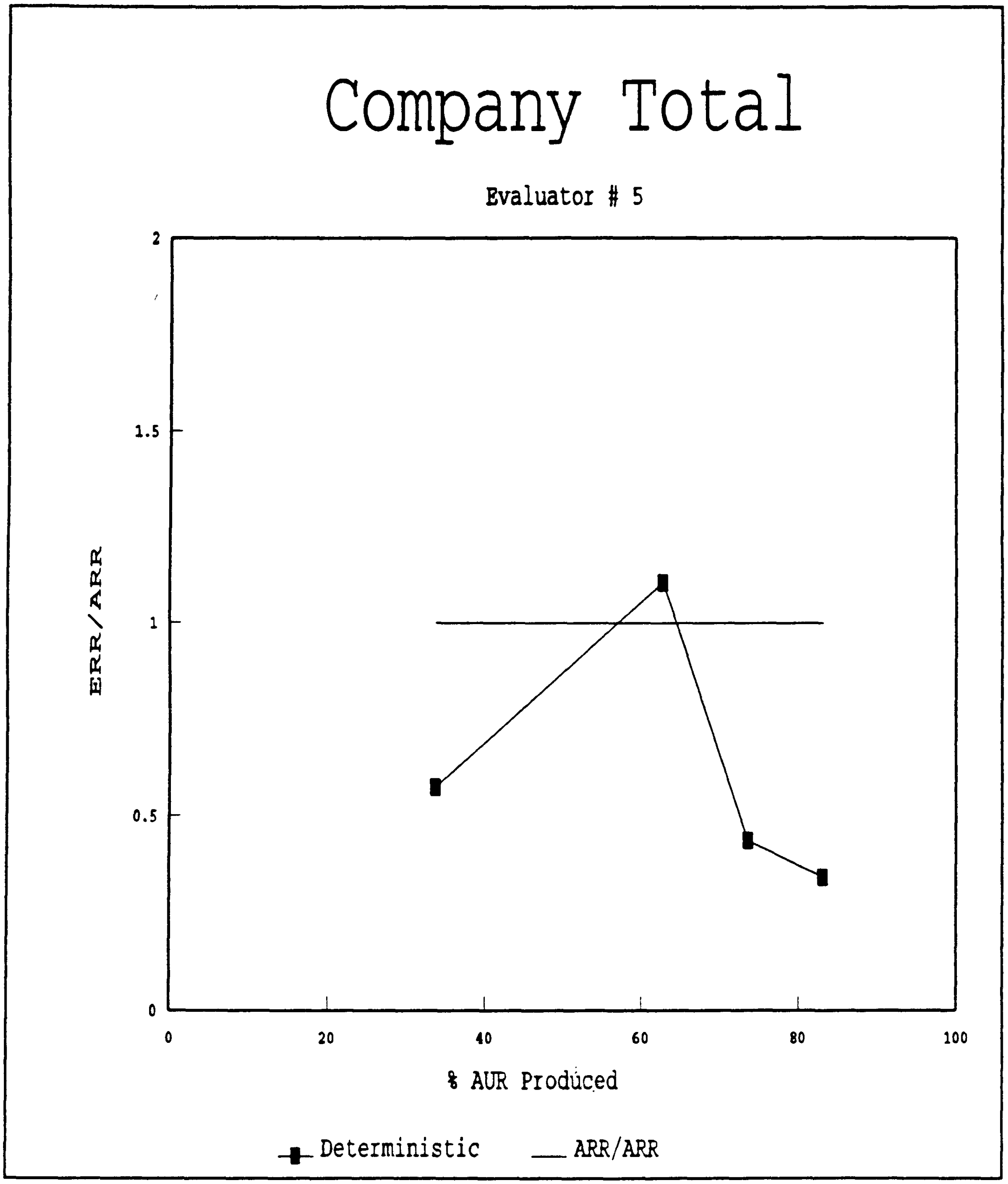

Figure H-2 Evaluator # 5, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total

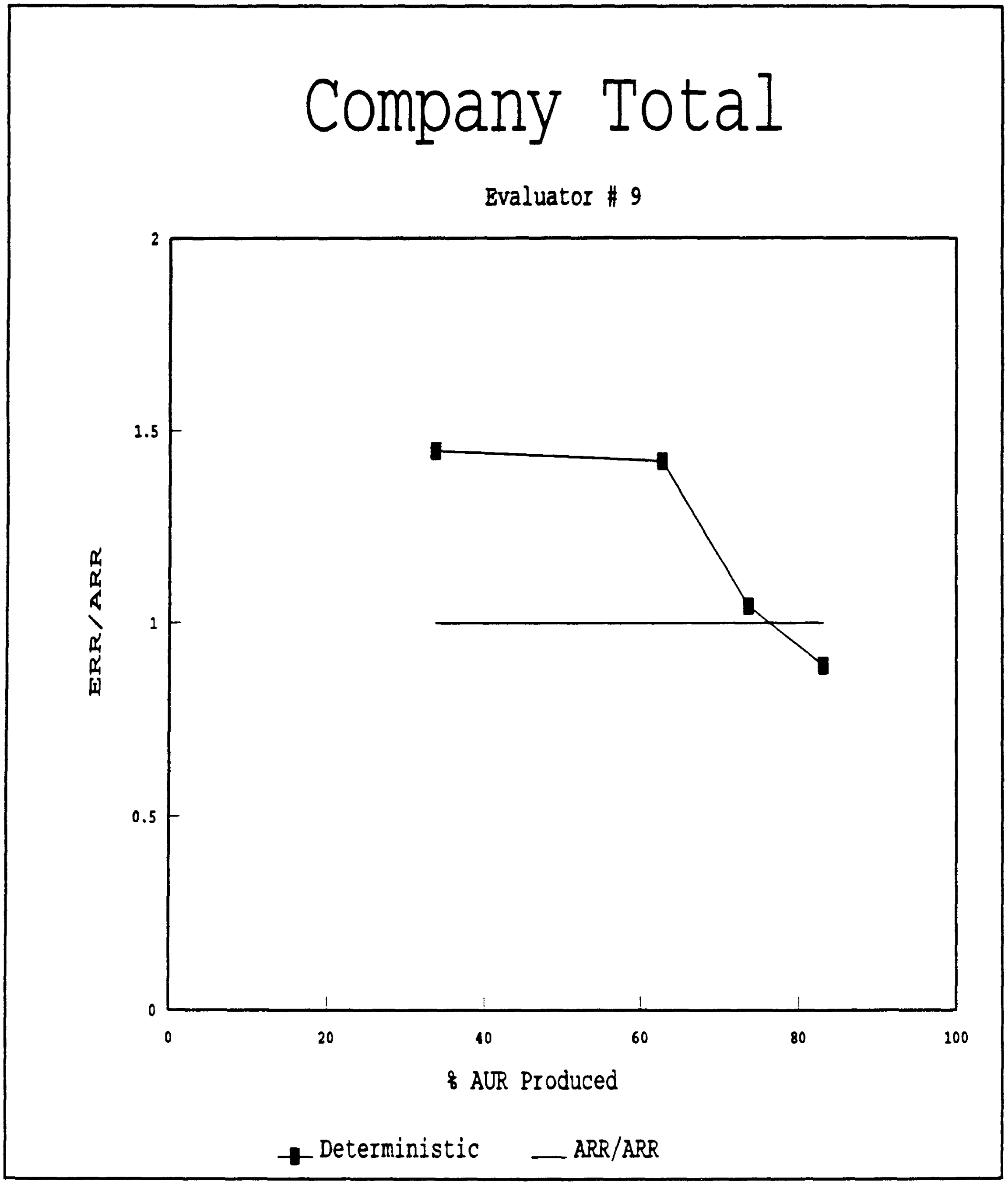

Figure H-3 Evaluator # 9, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total

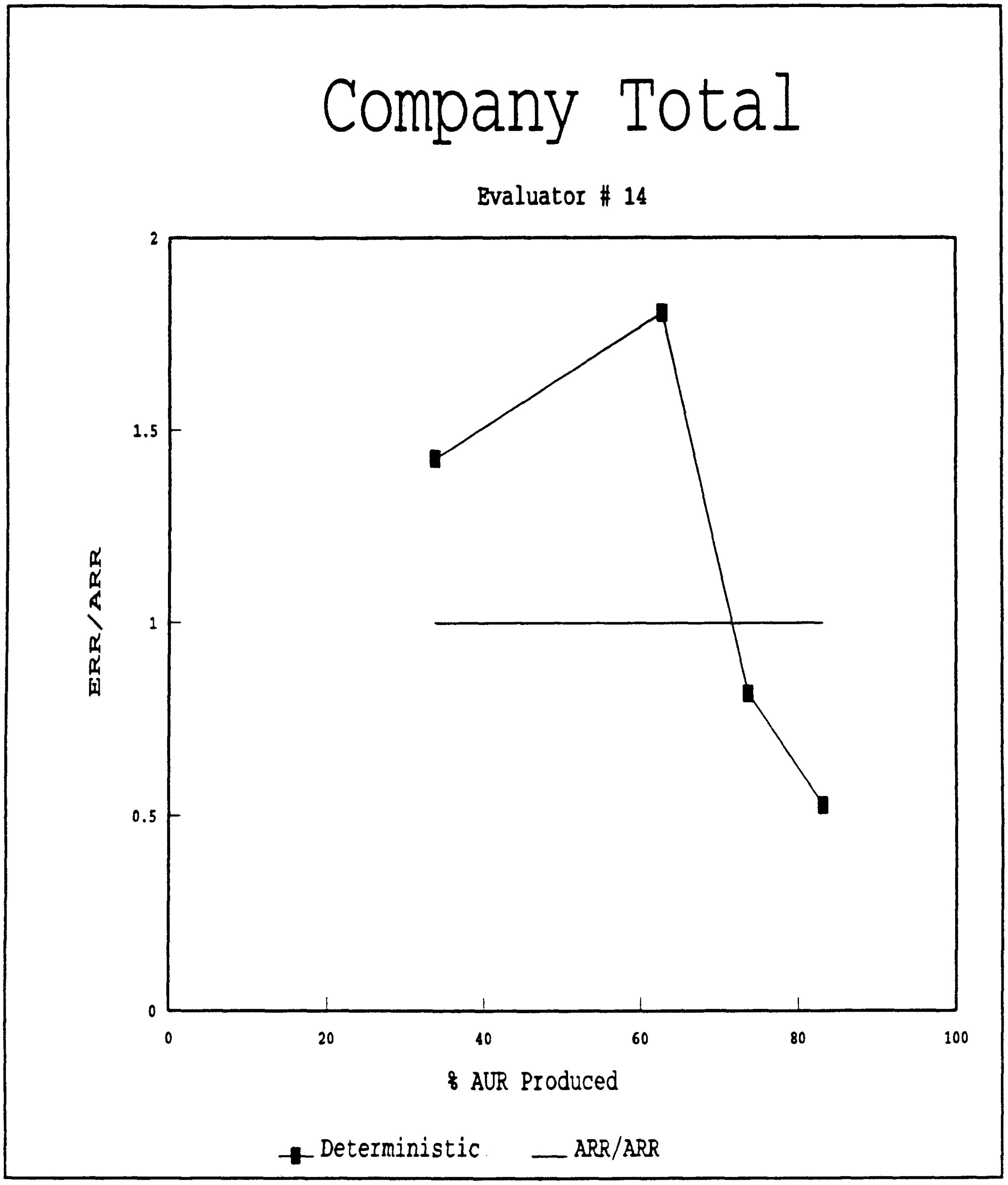

Figure H-4 Evaluator # 14, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total

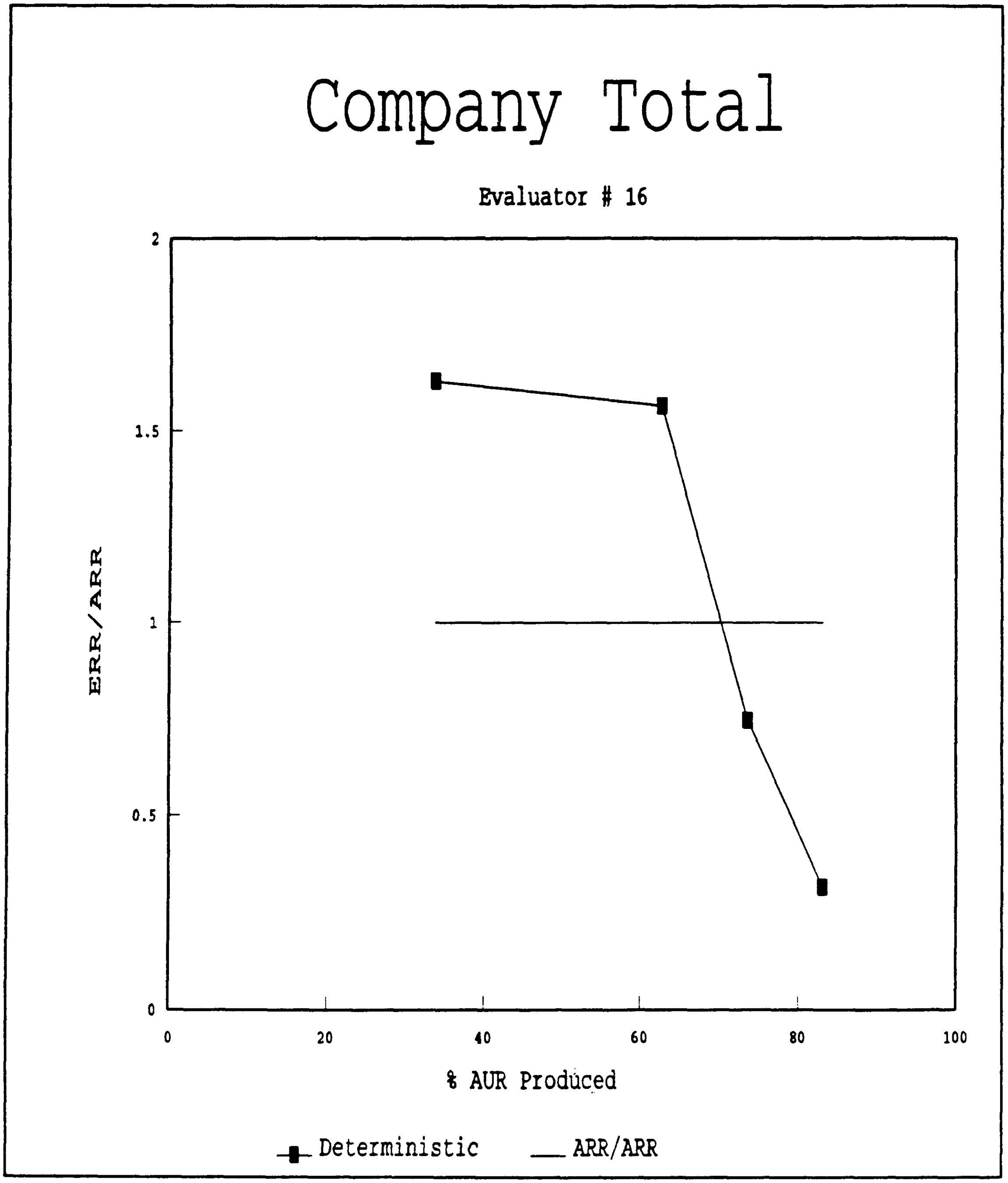

Figure H-5 Evaluator # 16, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total

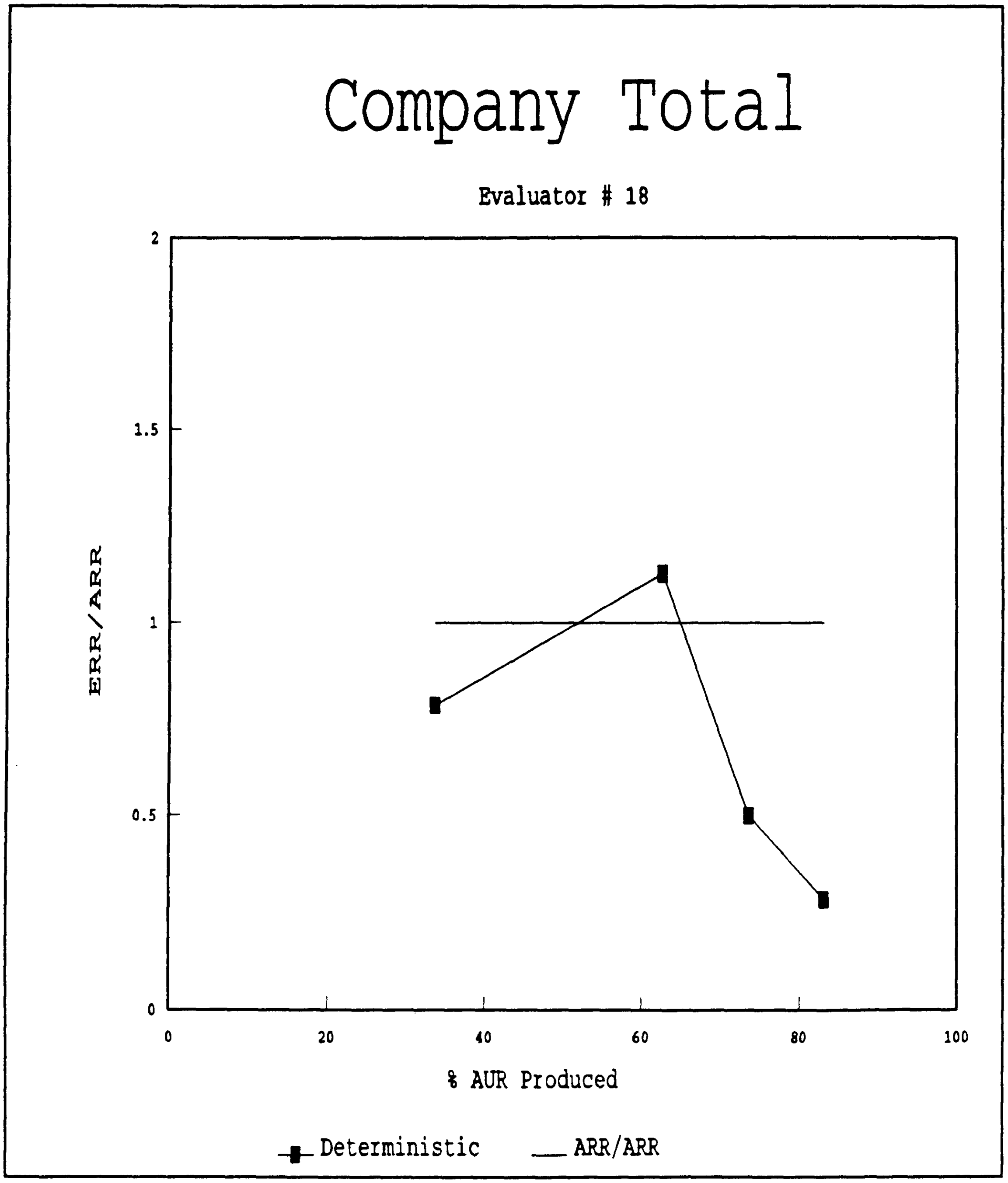

Figure H-6 Evaluator # 18, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total

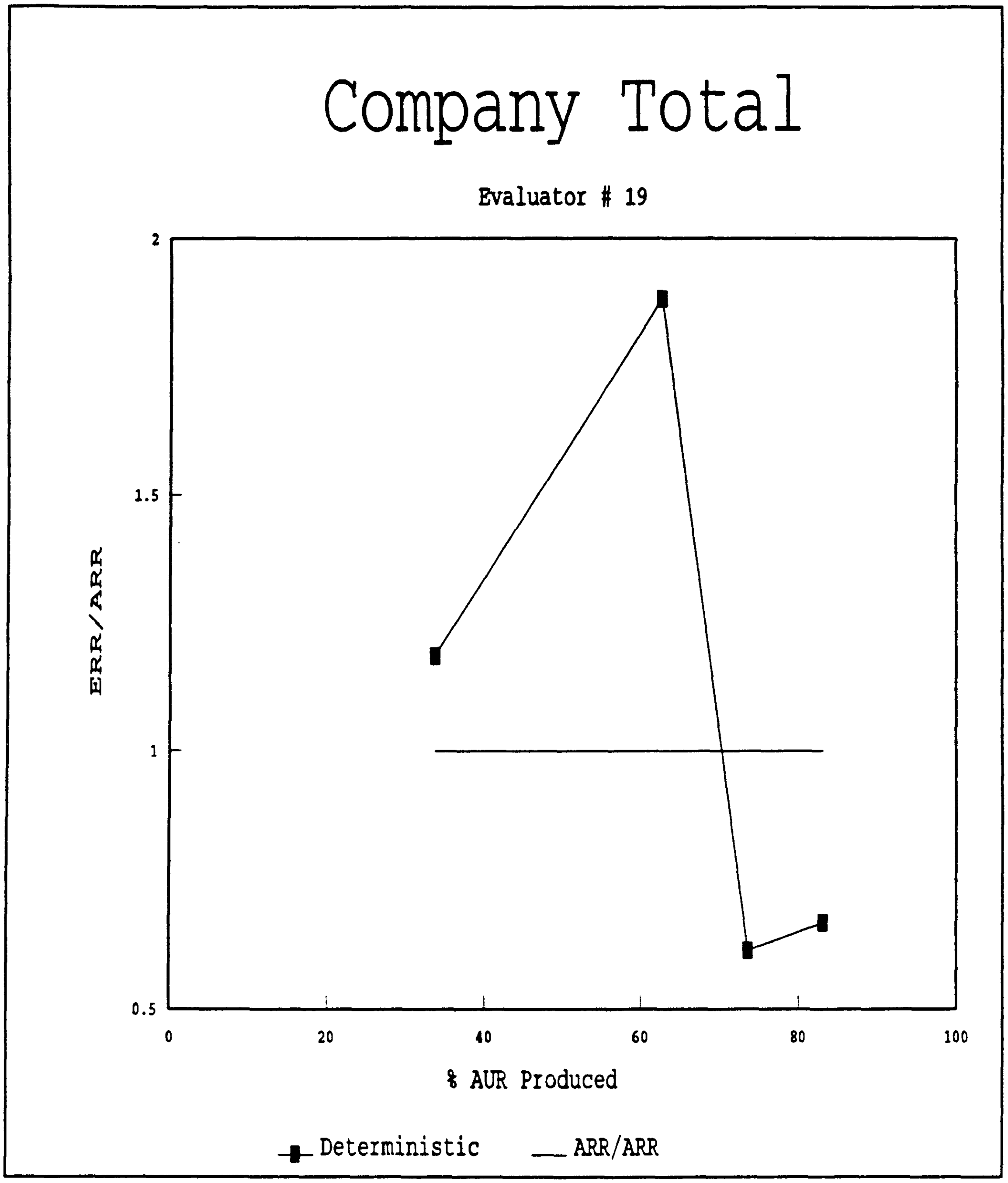

Figure H-7 Evaluator # 19, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total

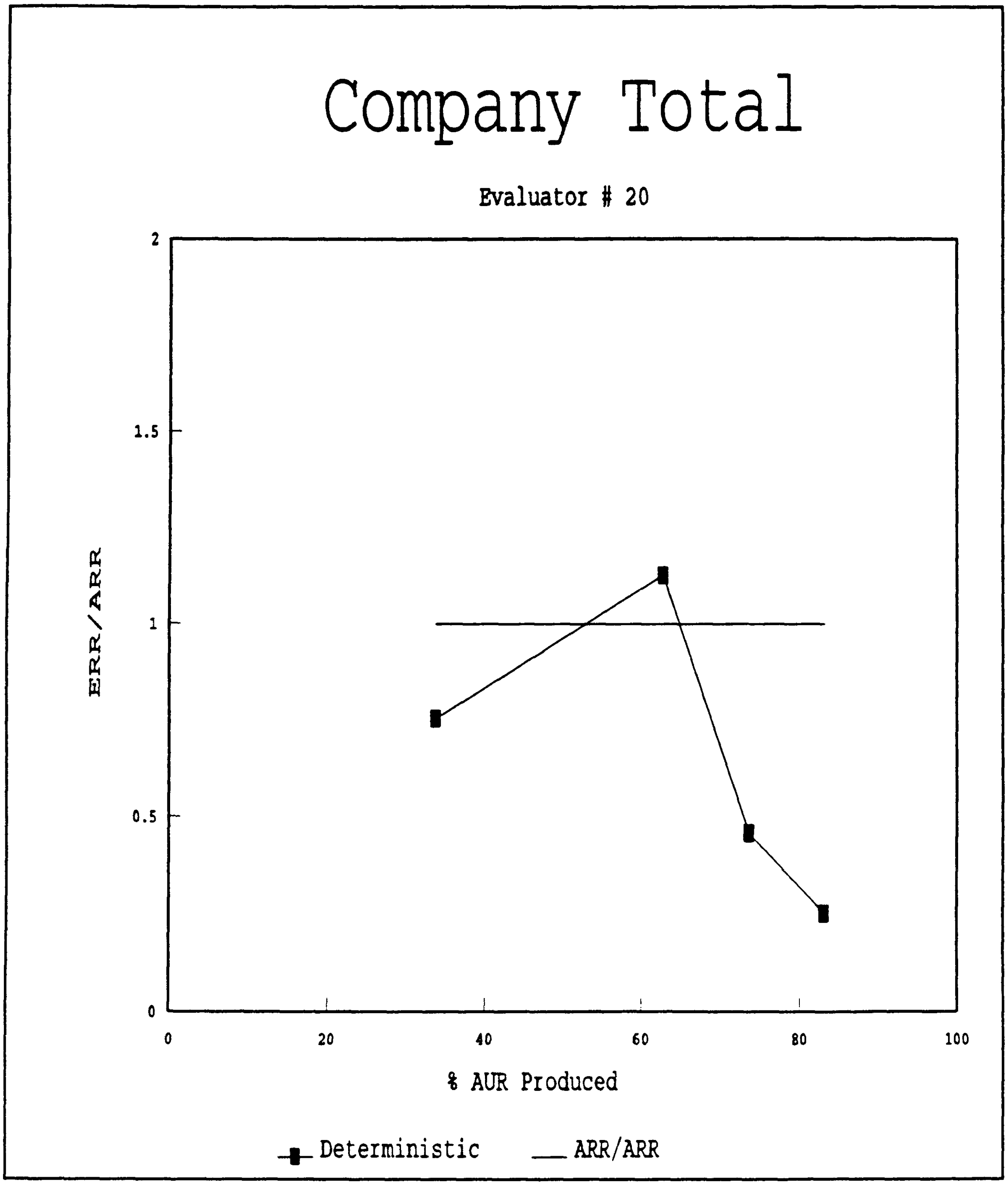

Figure H-8 Evaluator # 20, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total

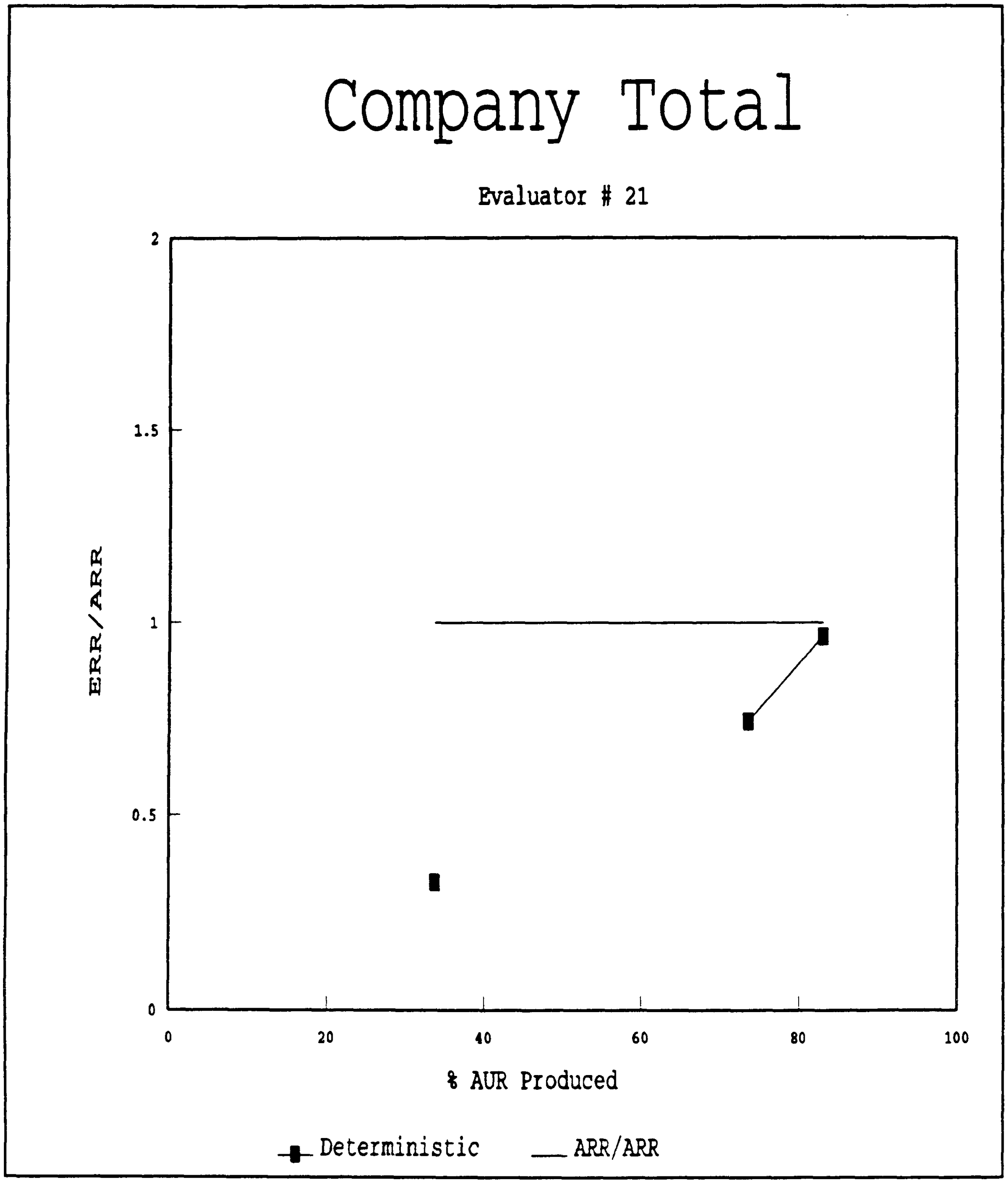

Figure H-9 Evaluator # 21, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total

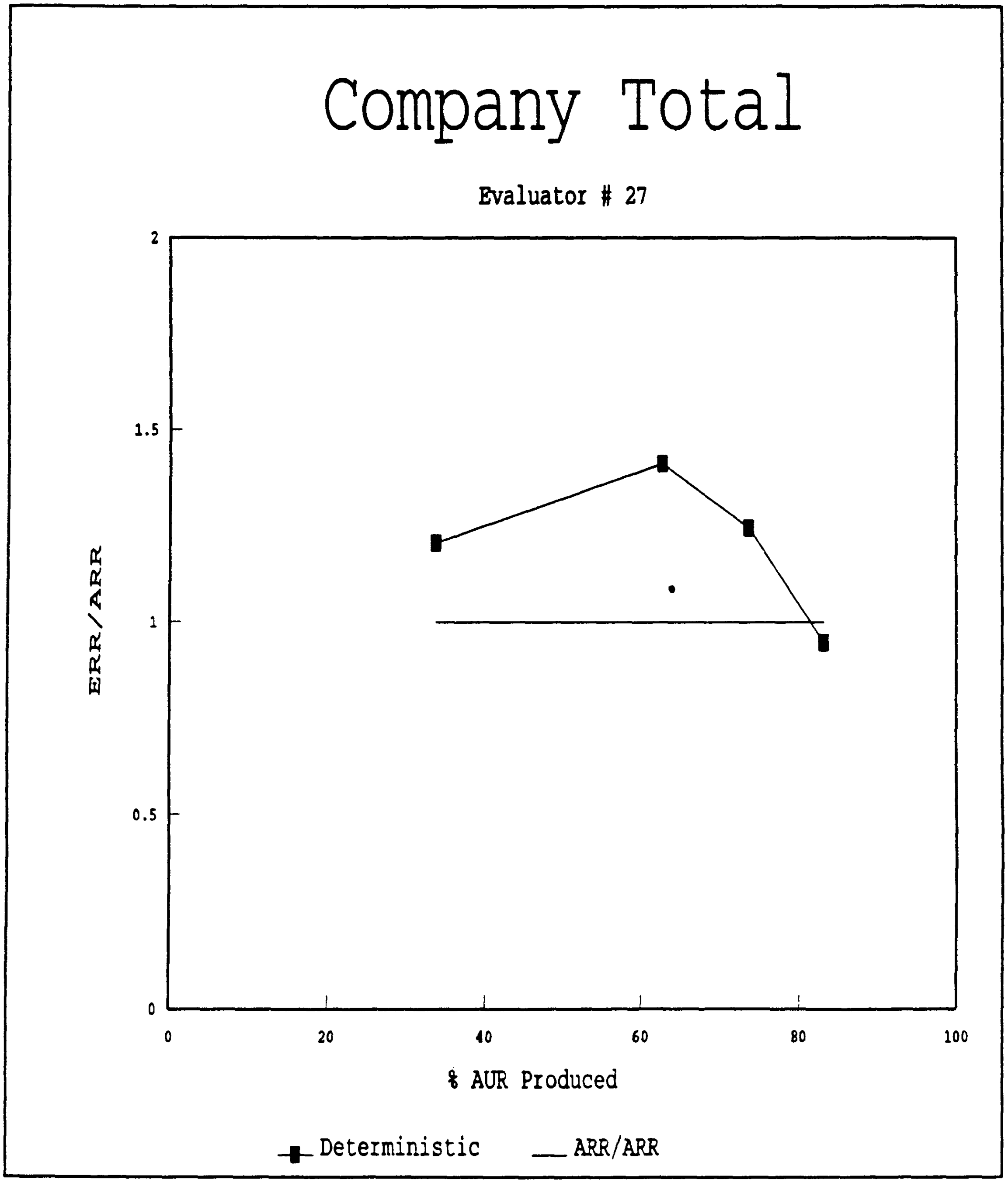

Figure H-10 Evaluator # 27, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total

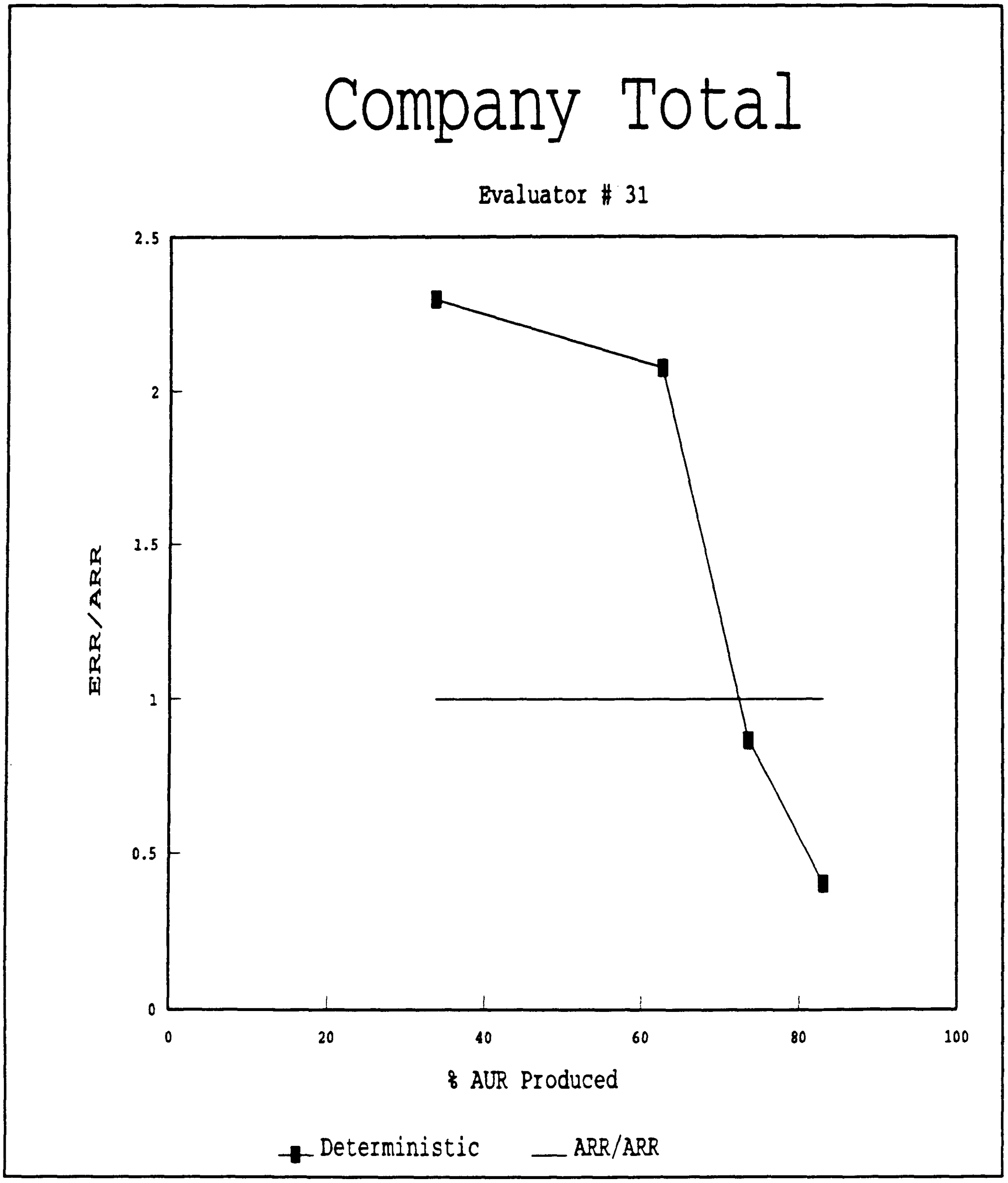

Figure H-11 Evaluator # 31, Estimates of Deterministic, P_{90}, P_{50}, P_{10} values for the Company Total