Aug. 5, 1969 W. W. DOLLISON 3,459,260

WELL TOOLS

Filed March 27, 1967 4 Sheets-Sheet 1

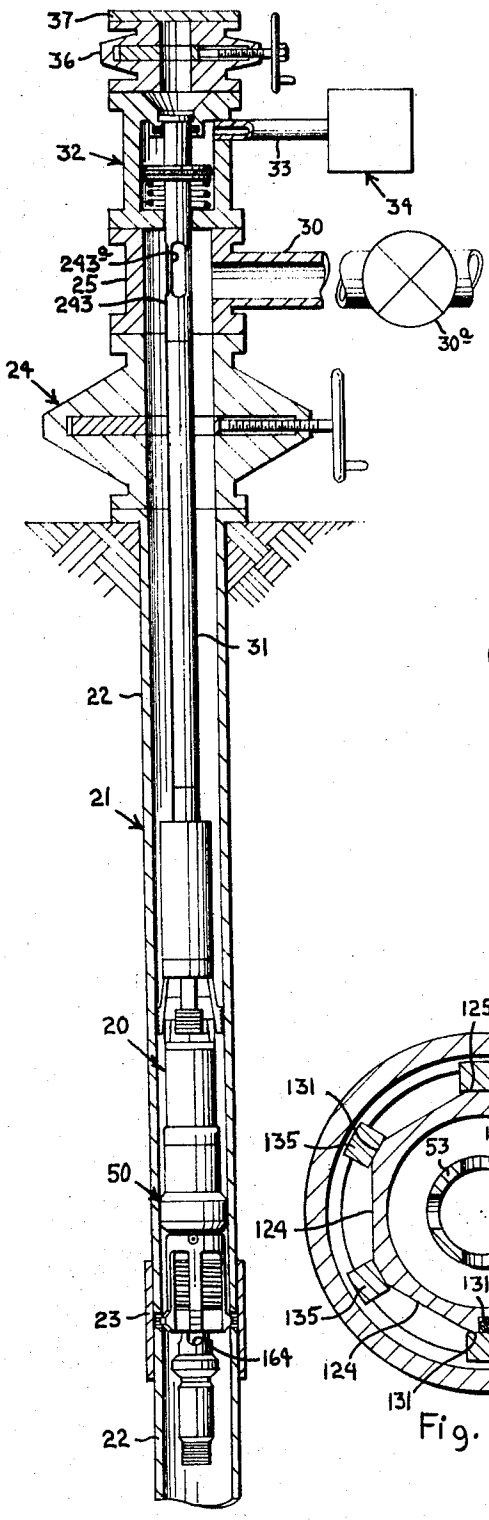


Fig. 1

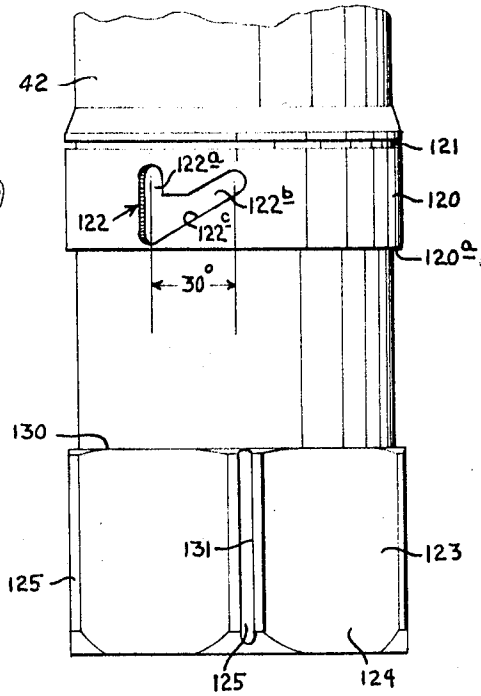


Fig. 3B

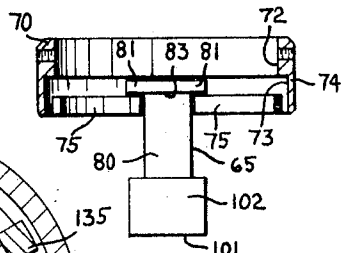


Fig. 3A

Fig. 8

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WELL TOOLS

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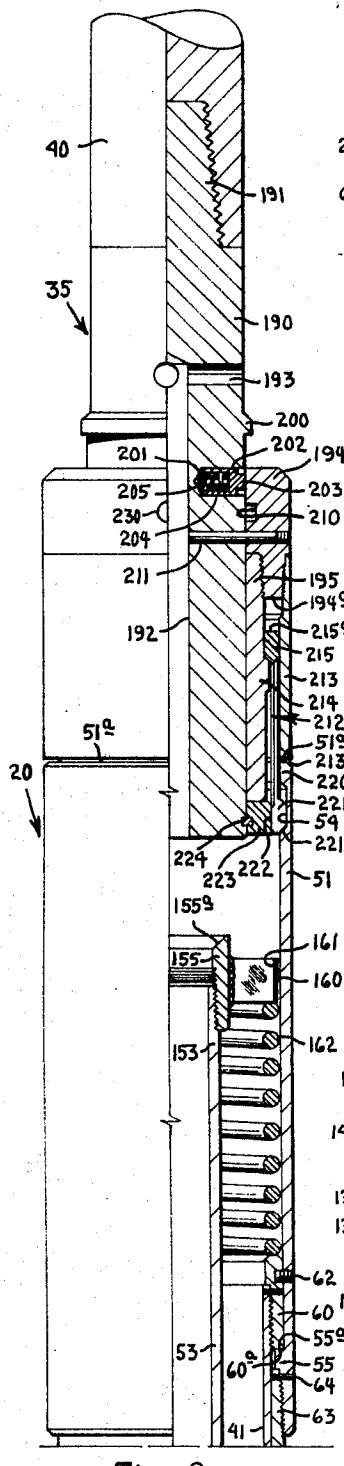


Fig. 2

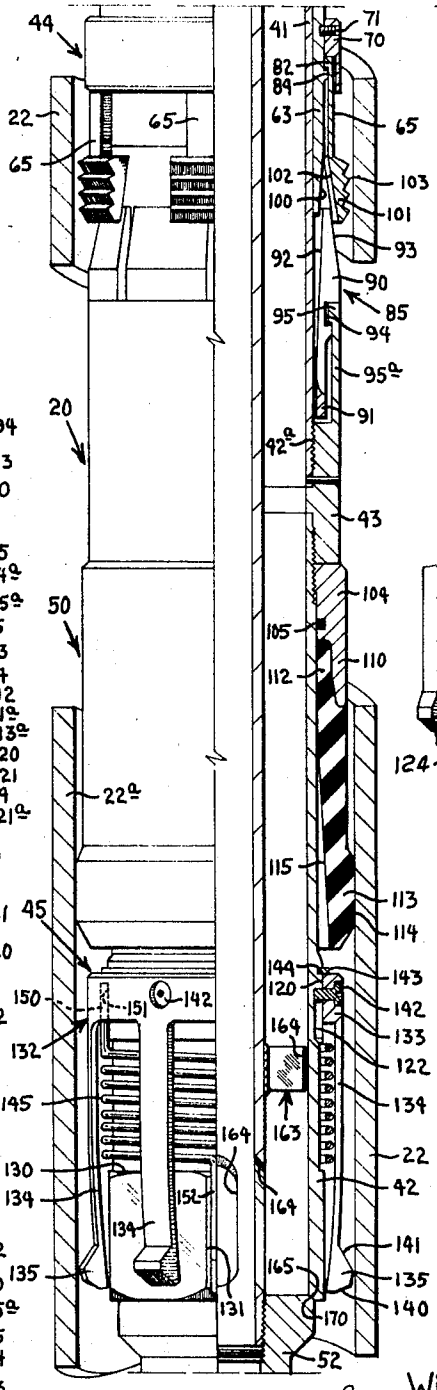


Fig. 3

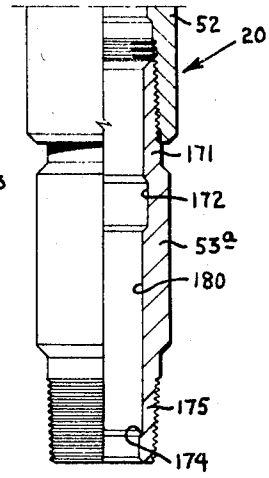


Fig. 4

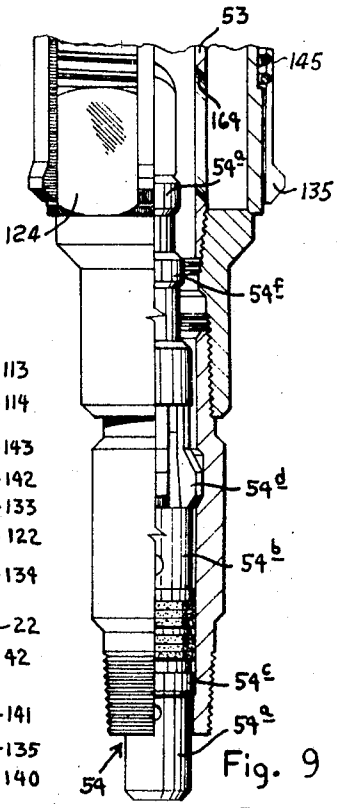


Fig. 9

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WELL TOOLS

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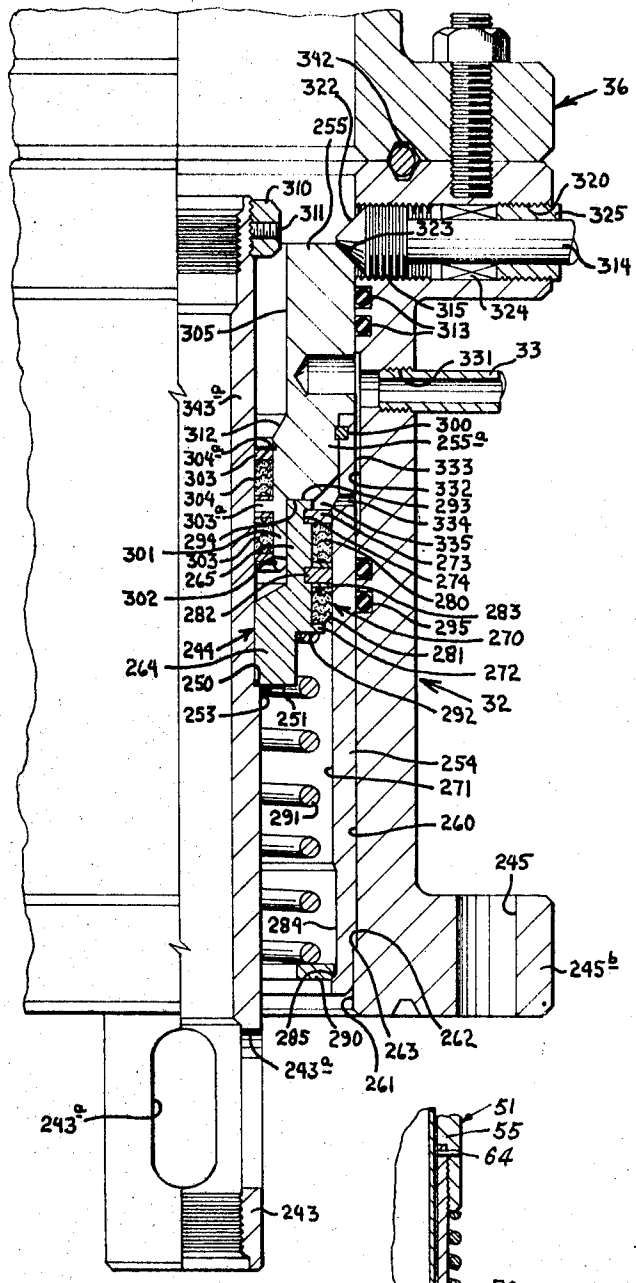


Fig. 5

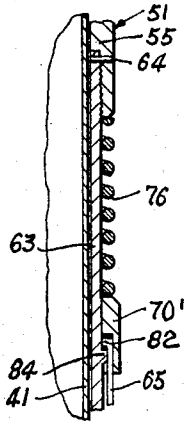


Fig. 11

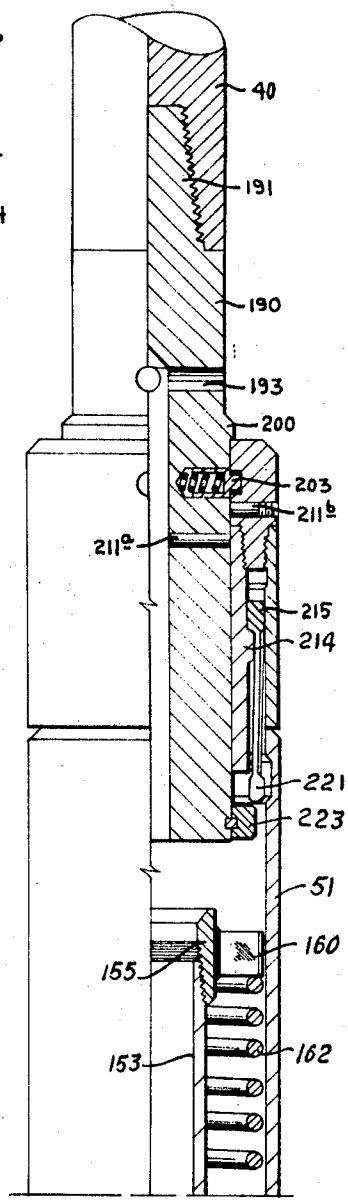


Fig. 10

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WELL TOOLS

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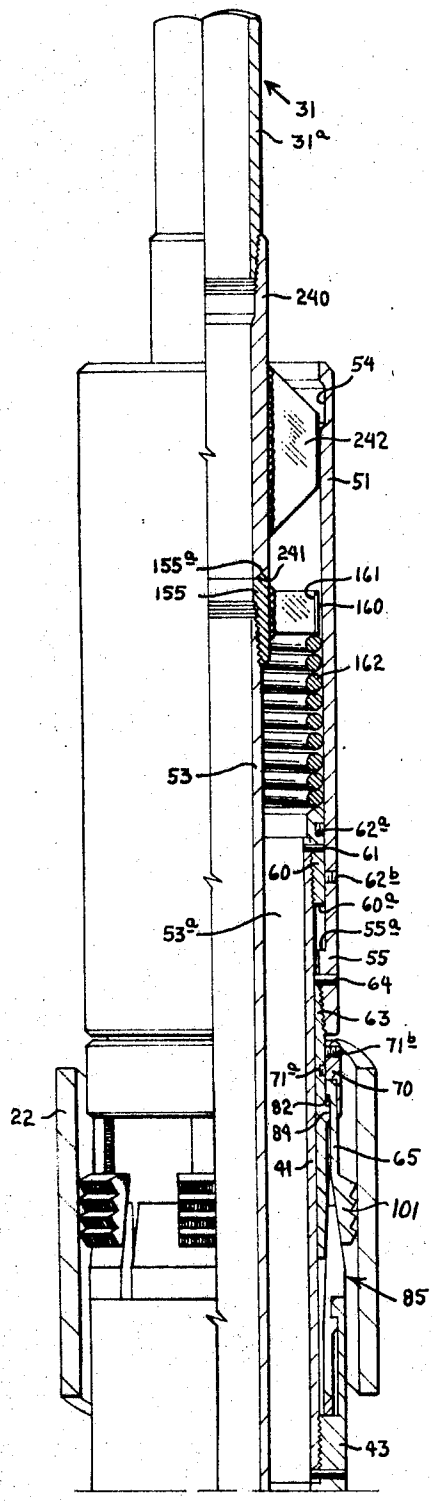


Fig. 6

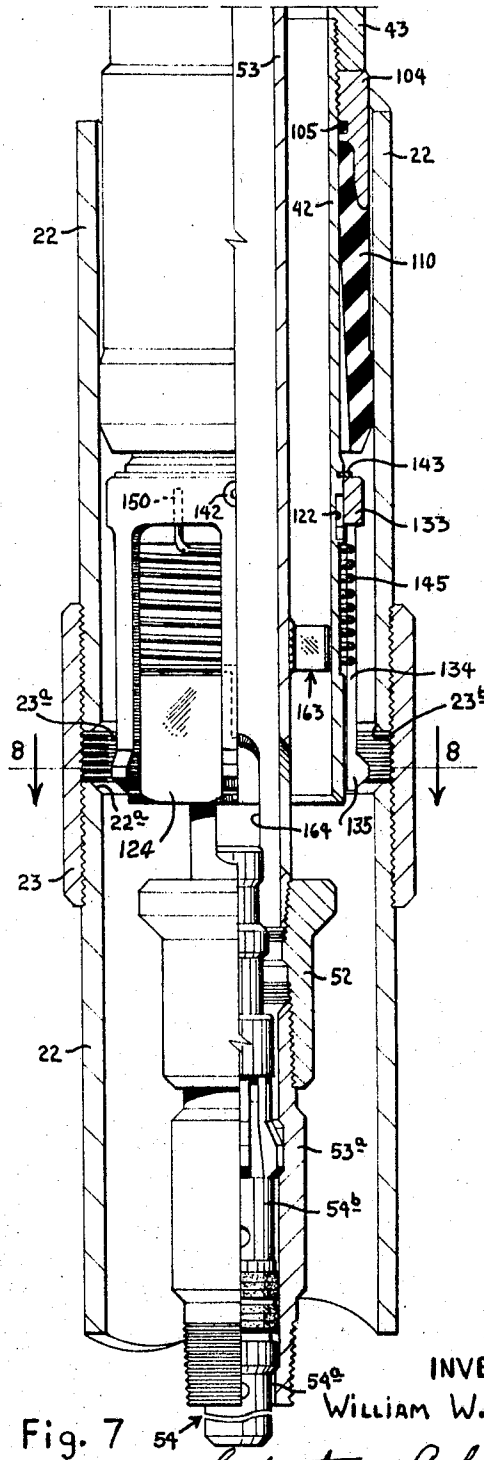


Fig. 7

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United States Patent Office 3,459,260 Patented Aug. 5, 1969

3,459,260

WELL TOOLS

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Int. Cl. E21b 33/03, 33/128, 23/00
U.S. Cl. 166—73 24 Claims

ABSTRACT OF THE DISCLOSURE

A surface controlled subsurface valve for controlling fluid flow through a conductor. A longitudinally movable valve in a body supporting an annular external seal for sealing around the body within a flow conductor. The valve has a spring biasing it toward closed position. A tubular member extends in the flow conductor to the valve to hold the valve at open position against the force of the valve spring. A surface positioned fluid controlled piston unit is secured to the tubular member for holding the valve at open position.

This invention relates to well tools and more particularly relates to a remotely controlled valve device.

It is an object of the present invention to provide a device for controlling flow through a flow conductor.

It is another object of the invention to provide a subsurface flow control device controlled from the surface.

It is another object of the invention to provide a subsurface safety valve through which well surveys may be run when desired.

It is another object of the invention to provide a safety valve including a tubular mandrel, an annular seal on the mandrel, upper and lower locking means on the mandrel, a valve member in the mandrel biased toward closed position by a spring, an operating tube extending from the surface to the valve member for holding it at open position, and means at the surface for actuating the operating tube.

It is another object of the invention to provide means for locking a body in a passage comprising a collet type slip expander secured around the body, a wedge and slip release sleeve movable on the body toward the expander and releasably secured to the body, and slips secured on the wedge and release sleeve for expansion by the expander, the slips sliding along outside expander surfaces as the wedge and release sleeve slides into the expander, and the wedge and release sleeve being released for movement along the body prior to being released from the slips for movement thereto.

It is still another object of the invention to provide a subsurface safety valve having a lower locking assembly comprising an inner locking mandrel concentrically positioned within a locking collet rotatably supported on the mandrel and biased for rotation by spring means from unlocked to locked position and an upper locking assembly including a plurality of circumferentially spaced slips supported on a tubular wedge member movable toward a collet type expander having fingers insertable between the wedge member and slips upon relative longitudinal movement of the wedge member and slips toward the expander.

It is another object of the invention to provide a safety valve system for a well which includes a subsurface safety valve, an operating tube extending between the surface and the safety valve for moving the safety valve from a closed to an open position from the surface, and fluid pressure means at the surface for moving the operating tube to open and hold open the safety valve.

Additional objects and advantages of the invention will be readily apparent from the reading of the following description of a device constructed in accordance with the invention, and reference to the accompanying drawings thereof, wherein:

FIGURE 1 is a schematic view partially in section showing a subsurface safety valve system embodying the invention, illustrating the valve at its open position;

FIGURE 2 is a vertical view partly in section of an upper end portion of a safety valve embodying the invention coupled with a handling tool for installing and removing the safety valve;

FIGURE 3 is a vertical view partly in section and showing an intermediate portion of the safety valve with its upper and lower locking assemblies at their retracted unlocked positions;

FIGURE 3A is a view in section of the slip carrier and one slip of the safety valve;

FIGURE 3B is a fragmentary view in elevation of a lower end portion of the lower mandrel of the safety valve showing one of the J-slots;

FIGURE 4 is a vertical view partly in section of a lower end portion of the valve;

FIGURE 5 is a vertical view partly in section of the surface piston unit for moving the safety valve to and holding it at open position;

FIGURE 6 is a vertical view partly in section of the upper end portion of the safety valve shown locked in operating position within a well casing and held open by an operating tube assembly;

FIGURE 7 is a view similar to FIGURE 6 showing the lower portion of the safety valve locked in the well casing and held open;

FIGURE 8 is a view in section along the line 8—8 of FIGURE 7;

FIGURE 9 is a vertical view partly in section showing the lower portion of the valve closed;

FIGURE 10 is a vertical view partly in section of the upper portion of the safety valve and the handling tool in position for release from the valve; and

FIGURE 11 is a fragmentary sectional view of an alternate form of the upper slip assembly of the safety valve.

Referring to the drawings, particularly FIGURE 1, a subsurface safety valve **20** is releasably locked within a well casing **21** including casing sections **22** connected together by couplings **23**. At the surface a suitable master valve **24** is secured on the upper end of the casing. A flow T **25** is secured on the master valve. A flow line **30** having a wing valve **30***a* is connected into the flow T. The safety valve is controlled from the surface by an operator tube assembly **31** supported from an operator piston assembly **32** supplied with fluid under pressure through a line **33** from a suitable fluid pressure source **34**. The safety valve is held downwardly at its open position by fluid pressure in the piston assembly which holds the operator tube assembly at a lower position. Reduction of fluid pressure in the piston assembly permits the valve to move upwardly to a closed position shown in FIGURE 9. A valve **36** with a blind flange **37** are secured on the piston assembly.

The safety valve **20** is shown in detail in FIGURES 2–4 during installation in the casing with a handling tool **35** supported on a wire line tool string **40**. The safety valve includes an upper mandrel **41** and a lower mandrel **42** which are connected by a coupling and expander collet retainer **43**. A slip assembly **44** is supported on the upper mandrel while a collet lock assembly **45** is secured on the lower mandrel. An external annular seal assembly **50** is supported on the lower mandrel between the collet assembly and coupling **43** for sealing between the safety valve and the inner wall surface **22***a* of the casing. A setting sleeve **51** is releasably secured for telescopic movement downwardly on the upper mandrel for actuating

the slip assembly **44**. A valve member **52** is supported on the lower end portion of a tubular valve stem **53** for controlling fluid flow into the lower end of the lower mandrel. A landing nipple **53***a* is threaded into the valve member, FIGURE 4, for supporting a releasable plug assembly **54** to provide a closure for the bore through the safety valve which is removable for performing servicing functions in the well below the safety valve without removing the valve from the casing.

Referring to FIGURE 2 the setting sleeve **51** has internal annular locking recess **54** for receiving locking collet bosses on the handling tool **35** during both installation and removal of the safety valve. The setting sleeve is held on the upper mandrel by its internal annular flange **55** which has an upper shoulder surface **55***a* engageable with a lower end surface **60***a* on a nut **60** threaded on an upper end portion of the upper mandrel **41**. The nut **60** is held against rotation on the mandrel by a lock pin **61**. A sliding fit is provided between the nut **60** and the setting sleeve while the nut and setting sleeve are releasably secured together by one or more shear pins **62** threaded through the sleeve into the nut. A wedge and slip release sleeve **63** is disposed on the mandrel **41** threaded along an upper end portion into the setting sleeve and secured by a lock pin **64** extending through the setting sleeve below the flange **55** into the sleeve **63**.

Referring to FIGURES 3 and 3A, a plurality of locking slips **65** are supported in circumferentially spaced relationship around the wedge and slip release sleeve by ring shaped slip carrier **70** which is slidably disposed on the wedge and slip release sleeve and before setting the slips is secured against movement on the sleeve by one or more shear pins **71**. Referring to FIGURE 3A, the slip carrier has an upper bore portion **72** which fits in sliding relationship around the wedge and slip release sleeve and a lower larger bore portion **73** defining a skirt portion **74** which encloses head portions of the slips **65**. Internal annular circumferentially spaced flange portions **75** are formed within the slip carrier for holding the slip head portions within the carrier around the wedge and slip release sleeve. Each pair of adjacent flange portions **75** of the slip carrier are spaced to receive a portion of a central body section **80** of a slip **65**. Adjacent flange portions **75** within the slip carrier are engaged by laterally extending head portion tabs **81** of the slips loosely coupling the slips with the slip carrier. Each of the slips has an internal flange portion **82** within its head end defining a downwardly facing shoulder surface **83** which is engageable by an external annular flange **84** on the wedge and slip release sleeve **63** for releasing the slips and lifting them with the slip carrier during removal of the safety valve from the casing.

The slip expander **85** is disposed on the upper mandrel **42** and loosely held by the retainer **43** for expanding the slips **65** when they are moved downwardly on the expander. The slip expander is a collet type member having a plurality of circumferentially spaced expander fingers **90** formed on and extending upwardly from a base ring portion **91**. Each of the fingers has an internal upwardly and outwardly extending wedge receiving surface **92** and an external upwardly and inwardly sloping slip expander surface **93**. Each expander finger also has a centrally positioned external recess portion **94** for receiving an internal annular upper end flange **95** on the coupling **43** which holds the slip expander in a retainer sleeve portion **95***a* of the coupling **43** around the mandrel. The expander fingers **90** are sufficiently resilient that they bend inwardly to the extent necessary for inserting the expander into the carrier **43** until the flange **95** of the retainer moves upwardly over the ring **91** and the expander fingers into the recess **94**. The wedge surface **92** on each of the expander fingers is engageable by a downwardly and inwardly sloping external surface **100** on the wedge and slip release sleeve **63** for camming the expander fingers radially outwardly as the sleeve **63** moves downwardly into the expander. Each of the slips **65** has a lower locking portion **101** provided with an internal downwardly and outwardly sloping wedge surface **102** engageable by the slip expander surface **93** on an expander finger **90** within the slip for camming the slip outwardly toward the casing wall **220**. Each of the slip locking portions has upwardly facing external teeth **103** for gripping the internal wall surface of the casing to hold the safety valve against upward movement in the casing when the valve is at its locked position. The slope and spacing of the sleeve surface **100** and the internal slip surfaces **102** are related so that an expander finger **90** is received between the surface **100** and each of the inner slip surfaces **102** as the slips are forced downwardly on the slip expander **85**.

The seal assembly **50** includes a ring shaped head member **104** threaded on the upper end portion **42***a* of the mandrel **42** below the coupling **43** so that the assembly is held at a fixed position on the mandrel. An O-ring seal **105** is disposed within an internal recess in the head member around the mandrel. The head member has a downwardly extending lip or flange portion **110**. A seal element **111** formed of rubber or similar flexible material has an upper reduced portion **112** molded within the lip portion **110** of the head member. The seal element has a lower outer boss portion **113** having an external cylindrical surface **114** of a diameter sufficient to form a tight or "interference fit" with the inner surface of the casing **22** so that under static conditions a seal is effected between the seal element and the internal surface of the casing. The seal element has a downwardly and outwardly flaring internal surface **115** exposed to well pressure from below the seal element so that when a pressure differential is applied across the seal element with the higher pressures being below the element the element is biased outwardly to effect a tighter sealed relationship with the casing wall proportional to the pressure differential applied across the member. The seal assembly **50** is thus designed to hold pressure from below its seal element **110**.

Referring particularly to FIGURES 3 and 3B, the mandrel **42** is enlarged along a lower intermediate portion **120** which is provided with an external annular locking ring recess **121** and a plurality of outwardly opening circumferentially spaced J-slots **122**. Each of the J-slots **122** includes a vertical portion **122***a* and a connecting slanting portion **122***b*. The vertical and slanting portions communicate at their lower ends while the upper ends of both portions are substantially aligned longitudinally. The J-slots each extend circumferentially such a distance that the upper ends of the vertical and slanting portions of each J-slot are spaced apart about 30 degrees around the mandrel. The lower mandrel **42** is further provided with a lower enlarged portion **123** which has a plurality of circumferentially spaced collet finger release surface **124** evenly separated by an equal number of narrower longitudinally extending collet finger locking surfaces **125**. The enlarged mandrel portion **123** also provides an upwardly facing shoulder **130**. A longitudinal external slot **131** extends in the enalrged mandrel portion **123** substantially along the center line of one of the locking surfaces **125**. The surfaces **124** and **131** on the mandrel are circumferentially related such that the center lines of adjacent surfaces **131** and **124** are spaced substantially 30 degrees apart around the mandrel so that rotational movement of each collet finger of the assmbly **45** substantially 30 degrees around the mandrel moves the finger between approximately the centers of adjacent locking and releasing surfaces **131** and **124**.

A locking collet **132** is rotatably disposed on the mandrel **42** for movement between release and locking positions relative to the mandrel. The collet comprises a ring **133** supporting a plurality of circumferentially spaced dependent collet fingers **134** each of which has an external locking boss **135** providing a lower cam surface **140** and an upper cam surface **141**. The collet is movably secured on the mandrel by a plurality of circumferentially spaced

guidepins **142** each of which extends through the ring **133** into a J-slot **122** so that the collet is movable longitudinally and rotatable on the mandrel along paths defined by the configuration of the J-slots which guide the pins **142** as the collet is moved longitudinally and rotated on the mandrel. A split retainer ring **143** is disposed in an external annular recess **144** at the upper end of the collet ring **133**. A spring **145** is disposed within the collet around the lower mandrel **42** between the shoulder surface **120***a* on the flange **120** and the upwardly facing shoulder surface **130**. A bent longitudinally oriented upper end portion **150** of the spring is received within a downwardly opening blind hole **151** in the collet ring **133** while a bent longitudinally oriented lower end portion **152** of the spring is received within the longitudinal slot **131** on the enlarged lower mandrel portion **123**. The spring **145** is a left hand spring which is wound or tightened by clockwise rotation of the collet **132** on the mandrel as viewed from above the collet. So long as the collet is positioned on the mandrel with the guide pins in the J-slot vertical portions the collet is locked against rotation with its fingers along the release surfaces **124** and thus free to flex inwardly. When the collet is moved downwardly on the mandrel positioning the guide pins at the lower ends of the J-slot vertical portions, the pins are free to move into the sloped portions **122***b* of the J-slot and the collet is free to turn. If the collet fingers are not being held inwardly the spring **145** will revolve the collet until the fingers are aligned with the surfaces **131** holding the collet fingers against inward flexing. Also the guide pins follow the sloping J-slot portion lifting the collet as the guide pins move to the upper ends of the J-slots. The spring when installed on the mandrel between the mandrel and collet is wound sufficiently tightly that irrespective of the position of the collet on the mandrel, it is constantly biased in a counterclockwise direction as vewed from above. The positions of the J-slots **122** relative to the mandrel release and locking surfaces **124** and **131** and the positions of the guide pins **142** in the collet rings **133** are all correlated to position the collet fingers **134** each substantially along the center line of a mandrel release surface **124** when the guide pins are in the vertical portions **122***a* of the J-slots and substantially along the center line of a locking surface **131** when the guide pins of the collet are at the upper ends of the slanted J-slot portions **122***b*.

The valve stem **53** is threaded along an upper end portion **153** into a spring retaining guide member **154** comprising a central tubular member **155** supporting a spring retainer guide ring **160** having a plurality of longitudinal, circumferentially spaced, ports **161** to allow fluid flow past the ring between the valve stem and the setting sleeve **51**. A coil spring **162** is disposed around the valve stem confinded between the guide ring **160** and the nut **60** on the upper mandrel **41**. The spring **162** biases the valve stem upwardly toward the closed position of the valve. As shown in FIGURE 3, a lower guide ring **163** having circumferentially spaced longitudinal ports **164***a* is secured, as by welding on the valve stem **53** to guide the stem as it moves longitudinally within the lower mandrel while permitting fluid flow around the stem within the mandrel.

The valve stem **53** is provided with slots or ports **164** between the guide ring **163** and the valve member **52** allowing fluid communication between the interior and exterior of the valve stem above the valve member. The valve member **52** has an upper annular seat surface **165** which engages a similar seat surface **170** on the lower end of mandrel **42** to prevent fluid flow around the valve member **52** into the mandrel when the valve stem and valve member are held at their upper end position by the spring **162**, FIGURES 2 and 3, while the valve stem and member are movable against the spring to a lower open position at which the surfaces **165** and **170** are longitudinally spaced as shown in FIGURE 7.

The landing nipple **53***a*, which is threaded along its upper end portion **171** into a lower end portion of the valve member, has an upper internal locking recess **172** and an internal annular stop shoulder **174** at its bottom end. The landing nipple has a lower threaded end section **175** to provide for the connection of a tubing string below the safety valve if desired.

The bore **180** through the landing nipple **53** is closed, FIGURES 7 and 9, during certain stages in the operation of the safety valve by a suitable plug assembly **54** which may include a type C or D Otis Bean **54***a* illustrated at page 3913 supported on a type N Otis Mandrel **54***b* illustrated at page 3893 of the 1962–63 edition of the Composite Catalogue of Oil Field Equipment and Services, published by World Oil, Houston, Tex. The mandrel **54***b* has a "no-go" ring **54***c* which engages the shoulder **174** in the landing nipple limiting the downward movement of the mandrel which is releasably locked against upward movement by locking dogs **54***d* which are received in the locking recess **172** of the landing nipple. The mandrel **54***b* has a running neck **54***e* and a pulling neck **54***f* for engagement of the tools employed in installing and removing the plug assembly. The plug assembly is inserted into and removed from the landing nipple by suitable conventional wire line operated handling tools.

The safety valve **20** is installed in and removed from the casing **22** by means of the handling tool **35** illustrated in FIGURE 2 coupled with the safety valve for installing the valve and in FIGURE 10 at an intermediate stage in the uncoupling of the handling tool from the landed and locked safety valve. The handling tool includes a mandrel **190** having a threaded upper end section **191** for connection with the wire line tool string **40** and a blind bore **192** opening downwardly and communicating at its upper end with lateral ports **193** for fluid bypass through the tool during installation and removal procedures. The mandrel extends slidably through an annular head **94** and a collet retainer sleeve **195** threaded along an upper end portion into the head member. The mandrel **190** has an external annular flange **200** which engages the head **194** limiting the downward movement of the mandrel through the head. The mandrel **190** also is provided with an outwardly opening blind hole **201**. A lock pin **202** is slidably disposed in the hole **201** and has a reduced head **203** and a tubular skirt portion **204** enclosing a spring **205** confined between the lock pin and the bottom of the hole for biasing the lock pin radially outwardly. The head **194** has an internal annular locking recess **210** for receiving the lock pin head **203** when the mandrel **190** is positioned as shown in FIGURE 10 for removing the handling tool from the safety valve. The mandrel **190** is releasably secured against longitudinal movement in the head member and sleeve **195** by shear pins **211**.

A locking collet **212** is disposed around the sleeve **195** within an external sleeve **213** threaded along its upper end portion on the head **194** in concentric spaced relationship around the sleeve **195**. The sleeve **195** has an external annular flange **214** which supports an upper base ring **215** of the collet **212** from which a plurality of circumferentially spaced collet fingers **220** are dependent. Each of the collet fingers has an external locking boss **221** receivable within the locking recess **54** of the sleeve **51** of the safety valve. Each of the collet fingers also has an internal locking boss **222** engageable with the outer surface of a lock ring **223** secured on the mandrel **190** below the sleeve **214** by an annular lock wire **224** disposed within aligned external and internal recesses in the mandrel **190** and lock ring **223**, respectively. The lock wire **224** is installed in the aligned recesses between the mandrel and lock ring through an outwardly opening slot, not shown, in the lock ring which permits the lock wire to be fed through the slot in the lock ring into the aligned recesses and pushed in until it is disposed within the recesses with its free ends tucked into the insertion slot. The lock ring **223** holds the collet fingers outwardly in

the locking recess 54 of the safety valve and is movable with the mandrel 190 out of alignment with the collet finger inner bosses to release the fingers for inward movement. The sleeves 194 and 213 are spaced apart sufficiently to allow the collet fingers to be cammed inwardly for coupling and uncoupling the handling tool and safety valve. The mandrel 190 has at least one radial hole 230 opening into the internal locking recess 210 for insertion of a punch or other suitable tool to engage the lock pin 202 for forcing the pin inwardly out of the locking recess 210 for resetting the tool from its release position after removal from the safety valve subsequent to pulling the safety valve from the casing.

Substantial space is provided between the upper end surface 215*a* of the collet ring 215 and the lower end surface 194*a* of the head 194 for the collet to move upwardly relative to the retainer 214 and sleeve 213 to position the inner collet bosses 222 above the lock ring 223 without shearing the pins 211 to release the mandrel so that the handling tool is inserted into the safety valve setting sleeve without removing or shearing the pins 211 in coupling the valve and handling tool for installation and in latching the handling tool into the valve when removing the valve from the casing.

When the safety valve 20 is locked at its operating position within the well casing, FIGURES 6 and 7, it is held at the open position by the operating tube assembly 31 extending from the surface piston unit 32. As shown in FIGURE 6, the operator tube assembly 31 includes a tube 31*a* threaded along a lower end portion into a tubular member 240 having a downwardly and inwardly convergent seat surface 241 which engages an upwardly facing downwardly and inwardly convergent seat surface 155*a* on the ring 155 connected on the valve stem 53 for forcing the valve stem downwardly against the spring 162 and holding it at its open position, FIGURE 7. The member 240 has a plurality of radial guide vanes 242 which serve as a centralizer to guide the assembly 31 through the casing into the safety valve sleeve 51.

At its surface end the operator tube assembly 31 is connected to a tubular head 243 of the piston unit 32. The head 243 has a plurality of ports 243*a* communicating its interior with the interior of the flow T 25 so fluid flowing upwardly from the safety valve through the operator tube assembly flows outwardly from the head 243 joining fluid flowing in the casing around the operator tube assembly as they flow outwardly in the conduit 30.

Referring to FIGURE 5, the head 243 is secured to an annular piston 244 slidably disposed in a spool shaped body 245. The head 243 is slightly reduced in diameter along a substantial upper portion 243*a* providing an external upwardly facing annular shoulder surface 250 supporting the annular piston by engaging its lower end face 251. The annular piston is secured to the head member 243 by welding at 253. The piston 244 slides within a liner sleeve 254 secured within the body 245 by an annular cylinder head or retainer 255. The bore 260 of the body 245 is slightly reduced in diameter along a short lower end portion 261 providing an upwardly facing internal annular shoulder 262 which is engaged by an external annular downwardly facing shoulder 263 on the sleeve 254 to support the sleeve in the body. An upper end portion of the sleeve 254 telescopes upwardly on a reduced lower end portion 255*a* of the retainer 255.

The annular piston 244 is a graduated or stepped member having a lower portion 264 of reduced diameter and an enlarged upper portion 265 on which supports an external annular seal assembly 270 for sealing with the internal wall surface of the bore 271 of the liner sleeve 254. The packing 270 is held on the annular cylinder between an external annular flange 272 on the cylinder and an upper split lock ring 273 disposed in an external annular recess 274 in the upper portion of the piston. The packing has upper and lower resilient seal elements 280 and 281, respectively, disposed on opposite sides of a split lock ring 282 confined between split back up rings 283.

The bore of the liner sleeve 254 is enlarged along a lower portion 284 providing an upwardly facing internal shoulder 285 which supports a split spring retainer ring 290. A piston spring 291 disposed around the head 243 within the liner sleeve is confined between the retainer ring 290 and a downwardly facing annular shoulder surface 292 on the piston 244. The spring biases the piston upwardly toward the retainer 255. Upward movement of the piston is limited by engagement of the upper end surface 293 of the piston with a lower end surface 294 on the retainer.

Ring seals 295 disposed in internal annular recesses within the body 245 seal between the inner surface of the body and the external surface of the liner sleeve 254. A lock wire 300 disposed in aligned recesses within the sleeve 254 and on the retainer 255 interlock the sleeve and retainer.

The retainer 255 has a reduced lower end portion forming a downwardly extending flange or lip 301 which is telescopically received within the upper piston portion 265 when the piston is at an upper position within the cylinder.

The retainer 255 has a lower bore portion 303 which is larger than the head 243 and is divided in each of which is disposed an annular packing assembly by an internal flange 303*a*. Identical upper and lower annular packings 304 are supported in the bore 303 above and below the flange 303*a*. Each packing 304 is retained between the flange 303*a* and a split lock ring having an outer peripheral portion in an internal recess in the retainer 255 around its bore portion 303. The retainer has an enlarged upper bore portion 305 for receiving a stop nut 310 threaded on the upper end portion of the head 243 and secured thereto by a set screw 311. The stop nut engages an internal downwardly sloping shoulder 312 at the lower end of the retainer bore portion 305 limiting the downward stroke of the piston 244 and head 243. Ring seals 313 disposed in internal annular recesses within the body 245 seal between the retainer 255 and the body. The retainer is held within the body against the liner sleeve 254 by a plurality of radial lock bolts 314 threaded along an inward head portion 315 into a radial bore 320 in an upper flange 321 of the body 245. The lock bolts each have conical inward end surfaces 322 each of which engages an upper outer beveled surface 323 on the retainer 255. A packing 324 around each of the lock nuts 314 is held in position by a nut 325 threaded into the bore 320.

The fluid conduit 33 is connected into a threaded port 331 in the body 245. The port 331 communicates with an enlarged bore portion 332 of the body 245 defining an annular chamber 333 around a portion of the retainer 255 and an upper end portion of the liner sleeve 254. The chamber 333 communicates with a plurality of fluid ports 334 through the liner sleeve into an annular cylinder chamber 335 defined between the head 243 on the inside, the liner sleeve 254 on the outside, the piston assembly 244 at the lower end and the retainer 255 at the upper end. The cylinder chamber receives fluid under pressure introduced through the line 33 to force the piston assembly downwardly for opening the subsurface safety valve with its operator tube assembly 31. Control fluid pressure within the chamber 335 applies a downward force to the piston over an effective annular area defined between the line of sealing engagement of the seal assemblies 304 with the outer surface of the head 243 and the line of sealing engagement of the seal assembly 270 on the piston with the liner sleeve bore surface 271. The pressure of well fluids in the flow T 25 is transmitted upwardly into the sleeve 254 applying an effective upward force on the annular piston over the downwardly facing surfaces of the piston whose area is equal to that of its upwardly facing surfaces exposed to the pressure

within the chamber 335. The piston is also biased upwardly by the spring 291 and the spring 162 in the safety valve.

The upper flange 321 of the body 245 supports the valve 36 which is secured to the body by a plurality of bolts, not shown. A recess 342 in the flange 321 receives a ring seal, not shown, to seal between the body 245 and the valve 36. The blind flange 37 is secured as by bolts, not shown, to the valve 36. Various suitable well servicing equipment may be supported on the valve 36, such as a stuffing box and wire line servicing equipment employed in installing and removing the landing nipple plug 54 and in conducting certain well servicing operations through the piston and operator tube assemblies. Also, a lubricator, not shown, is supportable on the valve 36 for installing and removing the safety valve while the well is under pressure. Such equipment is well known and generally includes spaced valves in a conductor for providing a pressure holding chamber through which the safety valve is loaded into the casing.

The control fluid introduced into the piston assembly through the line 33 may be supplied from the fluid pressure unit 34 which may comprise an Otis Surface Control Manifold illustrated and described at page 3845 of the 1966–67 edition of the Composite Catalogue of Oil Field Equipment and Services, published by World Oil, Houston, Tex. The manifold unit supplies hydraulic fluid to the piston assembly at a predetermined pressure level. The manifold unit may be coupled with other suitable components, not shown, for manitoring any one or several physical conditions responsive to which closure of the safety valve is desired. For example, if stoppage of flow from the well is desired responsive to a surface fire in the vicinity of the well head equipment the manifold unit is coupled with a suitable temperature sensing means adapted to actuate the manifold unit to reduce the hydraulic pressure supplied by it to the piston assembly so that when a fire occurs the pressure within the piston assembly is reduced to allow it the safety valve to move upwardly to its closed position. Another condition which may be sensed is rate of increase of flow through the conduit 30. Any suitable means for measuring flow rate may be included in the conduit and connected with the unit 34 to release or reduce the control fluid pressure allowing the safety valve to close when a predetermined flow rate increase is reached. Such a rate increase is generally determined as representing quantitatively a value indicating a leak in the conduit 30 or related flow systems.

If desired, depending upon the conditions to which the control fluid pressure is to be reacted, the control fluid may be sealed in the piston assembly under adequate pressure to hold the safety valve open as by substitution of a suitable plug on the conduit 33 for the unit 34. Such a modified system may respond to a physical blow rupturing the conduit 33 releasing the control fluid pressure allowing the safety valve to move to closed position.

A well in which the subsurface safety valve 20 is to be installed is first equipped by suitable conventional procedures with a well casing comprising casing sections 22 interconnected by couplings 23 as illustrated in FIGURE 1. At the surface a master valve 24 is secured on the casing for closing off flow in the casing at desired times during the servicing of the well. After installation of the master valve a suitable lubricator is installed on the master valve for use during the installation of the subsurface safety valve in the casing and are subsequently removed, as discussed hereinafter, after the valve installation is completed.

The handling tool 35 is coupled to the setting sleeve 51 of the safety valve in the relationship shown in FIGURE 2 with the mandrel 190 and the head member 194 of the handling tool secured together by the shear pins 211. The handling tool is inserted into the sleeve 51 until the collet finger bosses 221 moves into the locking recess 54 and are aligned with the locking ring 223. In introducing the handling tool into the sleeve 51 of the lower outer cam surfaces 221*a* on the outer bosses of the collet fingers engage the inner edge of the upper end surface of the sleeve 51 holding the collet 212 against movement as the collet retainer 195 and the sleeve 213 are pushed toward the sleeve 51. The upper end surface 215*a* of the ring 215 of the collet engages the lower end surface 194*a* of the head 194 at which position the inner bosses 222 of the collet fingers are out of alignment with the lock ring 223 so that the collet fingers are cammed inwardly by the sleeve 51. The handling tool is telescoped into the sleeve until the lower end edge 213*a* of the sleeve 213 engages the upper end surface 51*a* of the sleeve 51. The collet finger heads are forced into the sleeve 51 and are aligned with the locking recess 54. The collet fingers expand outwardly into the recess 54 to their normal position so allowing the collet to return to a position aligning its finger heads with the lock ring 223, FIGURE 2, at which position the outer surface of the lock ring engages the inner surfaces of the inner collet finger bosses 222 holding the collet finger heads in the locking recess 54. The handling tool is not removable from the sleeve 51 of the safety valve without shearing the pins 211, as explained hereinafter. The lock pin 203 is held at its inward position by the inner surface of the bore of the head member 194, FIGURE 2.

The collet 132 is manually rotated on the mandrel 42 in a clockwise direction as viewed from above until the guide pins 142 projecting into the J-slots 122 are moved to the vertical portions 122*a* of the J-slots. The collet is pushed toward the seal assembly 50 until the guide pins are at the upper ends of the vertical portions of the J-slots. The rotation of the collet to position the guide pins in the vertical portions of the J-slots further tightens the spring 145 so that with the guide pins at the upper ends of the vertical portions of the J-slots the counterclockwise biasing force of the spring holds the collet at such position on the mandrel so long as the collet is not forced on the mandrel away from the seal assembly to the position at which its guide pins are at the juncture of the J-slot vertical and sloping portions. The collet fingers 134 are each aligned substantially with the center line of a release surface 124 of the mandrel 42 so that the collet fingers may flex inwardly when the safety valve is inserted into the casing and pushed downwardly to its operating position. The slips 65 are held at their retracted positions, FIGURE 3, with the shear pins 62 connected between the setting sleeve 51 and nut 60 and the shear pins 71 interconnecting the slip carrier 70 with the wedge and slip release sleeve 63.

The handling tool 35 is coupled with the wire line tool string 40 and inserted through the lubricator and open master valve 24 into the casing 22. The safety valve landing nipple 53 is left empty with its bore open while the valve stem 53 is biased upwardly by the spring 162 until the seat surface 165 on the valve member 52 engages the lower end seat surface 170 on the mandrel 42 as shown in FIGURE 3. The normal positions of the collet fingers 134 is slightly outward of their positions as shown in FIGURE 3 so that when the valve 20 enters the upper end of the casing the outer bosses of the collet finger heads 135 engage the inner wall surface of the casing forcing the collet fingers radially inwardly so that the collet fingers drag along the inner wall surface of the casing positioned as shown in FIGURE 3. The dragging force of the collet fingers against the casing wall as the safety valve is lowered on the handling string in the casing holds the collet at its upper end position on the mandrel 42 so that the inward ends of the guide pins 142 on the collet remain in the upper ends of the vertical portions 122*a* of the J-slots 122 holding the collet in the released position with its fingers along the release surfaces 124 so that the collet fingers may remain cammed inwardly as the safety valve is lowered in the casing. Also, as the safety valve is lowered in the casing

the outer surface 114 of the packer element 110 drags the inner casing wall due to the interference fit relationship between the packer element and the bore of the casing.

As the safety valve is lowered in the casing the collet fingers 134 spring outwardly to their normal positions each time the collet finger heads are aligned with a tool joint recess, such as the recess 23*a* between adjacent ends of casing sections 22 within the coupling 23. As the collet 132 passes through each tool joint recess the collet remains at locked position so long as it is not pulled downwardly on the mandrel 42 sufficiently for its guide pins to enter the lower ends of the J-slot sloping portions 22*b*. As the collet heads pass downwardly in each tool joint recess they are cammed back inwardly by the upper end surface of the next string of casing into which the collets are entering.

When the safety valve has been lowered to the desired depth in the casing of the well, which may be only about 30 to 70 feet below the surface, the valve is manipulated until its collet fingers 134 expand into the nearest tool joint recess 23a. As a practical matter, with a knowledge of the lengths of the casing joints, the joints of the handling string, and the length of the safety valve, the position of the valve relative to a particular casing joint recess is easily determined. The valve is lowered beyond the desired casing joint recess and is lifted upwardly until the collet finger heads expand outwardly into the recess 23*a* so that further lifting of the valve casing causes the upper cam surfaces 141 on the collet finger heads to engage the lower end surface 23*b* of the casing section defining the upper end of the casing recess. As the safety valve is lifted toward the desired recess the dragging effect of the outer bosses of the collet fingers with the casing wall holds the collet as its mandrel 42 moves upwardly until the guide pins 142 are moved to the lower ends of the vertical portions 122*a* of the J-slots 122. When the pins 42 enter the slanting ports 122*b* of the J-slots the collet is free to move to its locked position responsive to the biasing force of the spring 145. So long as the casing wall prevents expansion of the collet fingers to their normal positions the heads 135 each remain wedged between the casing wall and a release surface 124 preventing rotation of the collet to its locked position. When sufficient space exits around the collet 132 for its fingers to flex outwardly to their normal positions, as by entry of the collet finger heads into a recess 23*a*, the spring 145 rotates the collet on the mandrel in a counterclockwise direction and upwardly until the upper end surface of the collet engages the snap ring 143. The guide pins 142 move upwardly in the slanted portions 122*b* of the J-slots rotating the collet substantially 30 degrees and raising it back to substantially its same longitudinal position as when its guide pins occupied the upper end portions of the vertical portions of the J-slots. At its moved position the collet fingers are each aligned with a mandrel locking surface 131 thereby holding the collet finger heads within the recess 23*a* as illustrated in FIGURES 7 and 8. At their positions as shown in FIGURES 7 and 8 the collet finger heads lock the safety valve against downward movement within the casing.

After locking the collet fingers 134 the safety valve is lowered until the lower outer surfaces 140 of the collet finger heads rest against the upper end surface 22*a* of the lowermost casing section 22, FIGURE 7. The camming action of the casing surface 22*a* on the collet finger heads applies an inward and upward force to the collet finger heads which cannot move inwardly as they are positioned along the mandrel locking surfaces 131 which extend along the back face of the collet finger heads preventing inward movement of the collet fingers. The upward force on the collet finger heads tends to lift the collet relative to the mandrel 42 while the collet is held against upward movement by the snap ring 143.

The slope of the J-slot portions 122*b* cams the collet counterclockwise as viewed from above so that it remains immovable on the safety valve mandrel so long as a downward force is applied to the safety valve mandrel.

The next step in the installation of the valve is the expansion of the slips 65 to lock the safety valve against upward movement in the casing. A downward jarring force is applied by the wire line tool string to the handling tool 35 engaging the lower end surface 213*a* on the outer sleeve 213 of the tool with the upper end surface 51*a* of the setting sleeve 51. The heads of the collet fingers 220 are held within the locking recess 54 of the setting sleeve by the lock ring 223. The downward force on the setting sleeve is opposed by the shear pins 62 connected into the nut 60 on the upper mandrel 41 which is supported against downward movement along with the coupling 43 and lower mandrel 42 by the collets 134. The pins 62 are sheared releasing the setting sleeve 51 which is forced downwardly over the nut 60 on the mandrel 41 moving the wedge and slip release sleeve 63 downwardly on the mandrel 41 toward the expander 85. The slips 65 supported by the slip carrier 70 held on the sleeve 63 by the shear pin 71 also are forced downwardly so that the lower end portion of the sleeve including the tapered expander surface 100 moves into the expander 85 while the surfaces 102 of the slips 65 slide along the outer surfaces 3 of the expander. The slips are expanded until their portions 101 are wedged sufficiently tightly between the expander fingers 90 and the inner wall surface of the casing to resist further downward movement. It will be recognized that since the sleeve 63 moves into the expander simultaneously with the downward movement of the slips on the expander the expander fingers 90 are held against inward movement as the slips are wedged between them and the casing wall surface. When the wedging action of the slips provides sufficient resistance to the downward movement of the sleeve 63 through the shear pins 71 that the shear pins are severed releasing the sleeve so that it continues downward movement relative to the slip carrier, the slips, and the expander 85. The further movement of the wedge sleeve behind the expander fingers 90 forces the fingers radially outwardly due to the camming action of the coengaging wedge sleeve surface 100 and inner expander finger surfaces 92. This additional downward movement of the sleeve 63 expands the expander fingers 90 forcing the slips 65 into tighter engagement with the inner casing wall. The additional downward movement of the wedge sleeve after severance of the shear pin 71 is evident in FIGURE 6 from the relationship shown between the downwardly spaced release flange 84 on the sleeve 63 from the inner flanges 82 of the heads of the slips 65. It will also be noted that the shear pin 71 is now severed into an inner pin segment 71*a* which moves downwardly with the sleeve 65 and an outer pin segment 71*b* which remains in the slip carrier 70. Similarly, the downward movement of the setting sleeve 51 relative to the upper mandrel and the nut 60 is evident from the longitudinal spacing inner shear pin segments 62*a* and the outer shear pin segments 62*b* of the shear pins 62 which were initially severed to release the setting sleeve from the nut 60.

The downward jarring of the safety valve and the handling tool by the wire line tool string is continued until the slips 65 are so tightly wedged outwardly into the inner casing wall surface by the expanded fingers 90 and the expander sleeve 63 that the downward jarring force is opposed by the sleeve 63 holding the setting sleeve 51, the outer sleeve 213, and head member 194 of the setting tool until the pin 211 is sheared freeing the mandrel 190 to move downwardly relative to the head member 194 of the handling tool. After the shear pin 211 is severed, the mandrel 190 is jarred downwardly until the flange 200 engages the upper end surface of the head member 194 aligning the lock pin 203 with the internal annular recess 210. The spring 204 forces the lock pin outwardly into the recess 210 until its flange 202 engages the inner surface of the bore of the head member 194. The collet lock ring 223 is moved downwardly with the

mandrel 190 from the collet retainer 214 and the heads of the collet fingers 220 to a position spaced sufficiently below the collet finger heads that the heads are no longer locked within the locking recess 54 of the setting sleeve of the safety valve, FIGURE 10.

The handling tool is lifted by an upward force on its mandrel 190 which is transmitted through the head member 194 to the sleeves 213 and 214. The sleeve 214 lifts the collet 212 until the outer upper end surfaces of the collet finger heads engage the upper end surface of the locking recess 54. The collet finger heads are cammed inwardly around the sleeve 214 above the lock ring 223 out of the locking recess 54 releasing the handling tool from the setting sleeve of the safety valve. The handling tool and tool string are withdrawn from the casing through the master valve and the lubricator by conventional procedure.

The plug assembly 54 is installed in the safety valve nipple 53*a* so that flow may not occur through the valve when it is at its closed position. The plug assembly 54 is inserted through the well head lubricator equipment as discussed above and lowered through the casing and the safety valve into the landing nipple 53*a*. For example, a string of Otis Wire Line Tools as illustrated at page 3929 and a type T Otis Running Tool illustrated at page 3931 of the 1962–63 edition, Composite Catalogue of Oil Field Equipment and Services, supra, may be utilized to lower the plug assembly through the lubricator and master valve 24 into the casing to the landing nipple. The plug assembly is lowered downwardly through the tubular valve stem 53 into the landing nipple 53*a* where the plug assembly is seated on the "no-go" shoulder 174. The locking dogs 54*d* of the mandrel of the plug assembly are expanded into the locking recess 172 of the landing nipple. The plug assembly blocks the bore 180 of the landing nipple to fluid flow therethrough.

After the installation of the plug assembly 54 in the landing nipple, the wire line tool string with its running tool are released from the plug assembly and withdrawn to the surface. As previously explained, after the initial phases of the installation of the safety valve 20 in the casing, the valve stem 53 and its valve member 52 are at the upper position at which the seat surface 165 on the valve member is engaged with the seat surface 170 at the lower end of the valve mandrel 42. Also, the interference fit of the seal assembly member 110 with the inner wall surface of the casing effects an initial seal by the seal assembly with the casing wall surface. Thus, upon completion of the installation of the plug assembly 54 in its landing nipple, the safety valve is in the fully closed position.

With the subsurface safety valve 20 locked in the casing at its closed position, the wing valve 30*a* is opened to bleed off pressure within the casing 22 above the closed safety valve. The distance is then determined between the seat surface 155*a* at the upper end of the valve stem 53 and the required location of the upper end of the head member 243 of the piston assembly 32 when the assembly is set in place on the well head. This distance is best determined by assembly of the guide member 240 on the lower end of the operating tube 31, lowering the tube through the flow master valve into the casing until the lower end surface 241 of the operating assembly is seated on the surface 155*a* of the valve stem. The tube 31 is marked out, and threaded for connection of the head 243. Consideration is given to the fact that the subsurface safety valve is at its closed position and the piston assembly 32 when initially installed on the well head with no control fluid pressure within its piston chamber has its head member 243 at its upper end position. Also, preferably the tube 31*a* is cut slightly short so that upon initial installation the end surface 241 of the operating assembly is spaced above the valve stem surface 155*a* so that the safety valve is not inadvertently opened upon initial installation of the operator assembly 31. The full stroke of the piston assembly 244 is greater than the distance between the open and closed portions of the safety valve assembly 31.

The operating tube assembly 31 is lowered through the flow T and master valve into the casing and supported with a small portion of the tube 31*a* extending above the flow T 25 to permit connection thereto of the head member 243 of the piston assembly 32. The piston assembly 32 is then supported above the flow T while the connection is made between the upper end of the tube and the lower threaded end portion of the head member 243. The piston assembly is then lowered and positioned on the flow T to which it is secured by bolts, not shown, through bolt holes 245*a* in the lower spool flange 245*b* of the body of the piston assembly. The lowering and securing of the piston assembly on the valve 25 is carefully done to insure that the guide member 240 is directed into the sleeve 51 of the safety valve with the lower end surface 241 of the guide member being seated on or near the end surface 155*a* of the safety valve stem. While the guide member 240 need not upon initial installation of the operator tube assembly and piston actually engage the end surface 155*a* of the valve stem it must be sufficiently close to the seat surface that when the piston assembly is actuated moving the operator tube 31*a* downwardly the valve stem 53 and valve member 52 of the subsurface safety valve will be shifted downwardly to its open position as illustrated in FIGURE 7. When the piston assembly is positioned and secured on the flow T the valve 36 and its blind flange 37 are installed on the flange 321 of the piston assembly body. The required connections are made with the control fluid line 33 and the pressure source unit 34. If desired the unit 34 is interconnected with such detector systems as desired which monitor one or more physical conditions responsive to changes in which it is desired that the safety valve close. For example, if it is desired that the safety valve close responsive to a temperature in excess of a predetermined value, temperature sensing means, not shown, are interconnected with the unit 34 for actuating the unit to relieve the fluid pressure transmitted from the unit through the line 33 to the piston assembly 32 to permit the safety valve to close in the event of such surface occurrences as fires.

With the surface connections completed for supplying control fluid pressure to the piston assembly, the unit 34 is actuated supplying fluid under pressure through the line 33 into the piston assembly. The pressure is transmitted into the body 245, downwardly within the body in the annular flow passage 332 around the liner sleeve 254 to the ports 334. The fluid flows inwardly through the ports 334 into the annular cylinder chamber 335 acting on upwardly facing surfaces of the piston assembly 244 over an effective area defined between the line of sealing of the seal assemblies 303 and 304 with the outer surface of the head member 243 on the inside and the line of sealing of the seal assembly 270 with the inner wall surface of the liner sleeve 254 on the outside. The force of the control fluid pressure on the piston assembly biases the head member 243 and the operator tube assembly 31 downwardly. When the downward force of the control fluid pressure on the piston 244 exceeds the resistances of the spring 291 on the piston assembly and the spring 162 on the valve stem 53 with the upward force of the well pressure on the valve member 52 over an effective area defined within the line of sealing of the mandrel seal surface 170 and valve member seat surface 165 the valve stem is forced downwardly to open the safety valve. The valve stem tube 53 is forced downwardly by the operator tube assembly 31 by virtue of the engagement of the operator tube assembly seat surface 241 with the valve stem assembly seat surface 155*a*. The valve is moved to its lower open position by what may be referred to as "snap action" since the force of the well pressure on the plug valve member and landing nipple rapidly diminishes when the seal is

broken between the seat surfaces **165** and **170** so that the control fluid pressure necessary to break the seal against the well pressure ceases to be opposed by the well pressure momentarily after the seal between the seat surfaces is broken and thus the substantial control fluid pressure acting against the springs **162** and **291** rapidly moves the valve downwardly to its open position.

Well fluids flow upwardly between the spaced seat surfaces **165** and **170** into the ports **164** in the valve stem and also into the annular space **53***a* around the valve stem within the mandrels of the safety valve. The fluids flow through the valve in both the valve stem and the annular space **53***a*. Those fluids in the annular space flow through the longitudinal flow passages in the guide rings **163** and **160**, past the vanes **242**, and into the casing **22** above the valve around the operator tube **31***a*. The fluids then flow upwardly within the casing around the operator tube into the flow T **25** where they again mix with well fluids flowing upwardly from the valve in the operator tube **31** and head member **243**. The fluids in the member **243** enter the flow T through the ports **243***a*. The mixed fluids flow from the flow T through the conduit **30**. So long as the control fluid pressure is maintained at a sufficient level to overcome the upward force of the springs **291** and **162** together with the upward force effect of the well fluids flowing through the safety valve and the well fluid pressure on the piston assembly **244** below its seals the safety valve is held at its open position.

When the control fluid pressure applied from the unit **34** through the conduit **33** into the piston assembly is reduced below the value required to hold the safety valve open the forces of the springs **291** the well pressure below the piston **244** lift the operator tube assembly **31** upwardly relieving the downward force holding the valve open. The valve is then lifted to its closed position by the spring **162** raising the valve stem **53** and the effect of the pressure drop in the well fluids flowing through the safety valve. If the spring force and fluid flow conditions are such that the valve stem and member tend to move upwardly more rapidly than the operator tube assembly and piston, the valve stem may contribute somewhat to lifting the operator tube assembly and piston. In any event, however, the valve stem along with the valve member **52** and plug landing nipple **52***a* are lifted solely by the force of the spring **162** and the well fluids flowing through the safety valve. As soon as the valve stem lifts the valve member sufficiently to move the seat surfaces **165** and **170** close enough together to effect an appreciable pressure differential across the valve member due to the pressure reduction of the well fluids flowing between the seat surfaces, the upward force of the well pressure drop in the well fluids exerts a substantial upward force upon the valve member to aid the spring **162** in moving it to the fully closed position illustrated in FIGURE 9.

The valve is held closed by the upward force of the spring **162** on the guide ring and spring retainer **160** along with the upward force of the well pressure on the valve member over the effective area defined by within the line of sealing of the seat surfaces **165** and **170**. The valve will remain so closed until the control fluid pressure within the piston assembly is again raised to a sufficient level, as explained above, to reopen the valve against the force of the pressure of the well fluids and the springs **162** and **291**.

Well surveys are conducted through the safety valve **20** without removing the safety valve from its locked position within the well bore. In order to run a well survey through the safety valve it is necessary that the plug assembly **54** be removed from the landing nipple **53** of the safety valve to allow well survey tools to pass through the safety valve. The valve **36** is closed, the blind flange **37** is removed, and suitable wire line equipment, as previously referred to, is installed on the valve **36** for removing the plug assembly **54** and introducing the particular well surveying tools to be employed. The valve **36** is then opened again for access into the well. The pressure is equalized across the plug assembly either by opening the safety valve with control fluid pressure in the piston assembly or by opening the plug unit **54***a* with an equalizing prong in the pulling tool used to remove the plug assembly as shown at page 3938, 1962–63 edition, Composite Catalogue of Oil Field Equipment and Services, supra. A suitable pulling tool, such as the previously referred to Type T Otis Running Tool, is utilized for withdrawing the plug assembly **54**. The pulling tool is lowered from the wire line equipment on the well head, which includes a unit such as a lubricator, through the open valve **36** into the open upper end of the head member **243** in the piston assembly **245**. The running tool is lowered through the head member **243**, the operator tube assembly **31**, and the valve stem tube **53** and coupled with the pulling head **54***e* of the mandrel of the plug assembly **54**. The plug assembly is pulled from the landing nipple **53** with the running tool and withdrawn through the valve stem tube **53**, the operator tube assembly **31**, and the head member **243** to the surface. The removal of the plug assembly from the landing nipple provides access to the well bore below the safety valve and thus well surveys in the well bore below the safety valve are carried out through the safety valve stem tube **53** and the operator tube **31** utilizing the wire line equipment to introduce and remove the well survey instruments. When such well surveys are completed, the plug assembly **54** is reinstalled in the landing nipple **53** in the manner previously described, and the wire line equipment is removed from the well head with, of course, the valve **36** being closed and preferably after permitting the safety valve **20** to return to its closed position to provide an added degree of safety while removing the wire line equipment and reinstalling the blind flange **37**.

The safety valve **20** is removable from the well casing utilizing the same well head equipment as employed for the installation of the valve. The first phase of the removal of the safety valve comprises withdrawing the operator tube assembly **31**. The control fluid pressure is reduced to allow the safety valve to move to its closed position subsequent to which the pressure within the casing above the safety valve is bled down to atmospheric through the conduit **30**. The blind flange **37** is removed. The screws **314** are retracted releasing the piston assembly **244** from the body **245**. A suitable pulling tool is threaded into the upper end of the member **243** and the piston assembly **244** along with the operating tube assembly is lifted from the well. The piston assembly **244** is welded to the member **243** and is lifted with the member **243**. The piston assembly raises the retainer **255** and the liner sleeve **254** is lifted due to the lock wire **300** so that the entire assemblage in the spool body is removed. A wire line tool string lubricator is installed on the valve **36** for removing the plug assembly **54** from the safety valve.

The pressure is equalized in the well across the plug assembly **54** either by use of an equalizing prong on a pulling tool, as described above, or by pumping fluid into the well casing above the safety valve through the conduit **30**. The plug assembly **54** is then removed from the safety valve and the master valve **24** is closed while a large lubricator capable of accommodating the safety valve is installed on the well head on the valve **36**.

The handling tool **35** is then employed for releasing and lifting the safety valve from the casing. The handling tool is lowered from the lubricator downwardly through the spool **245** of the piston assembly and the master valve and the casing to the sleeve **51** of the safety valve. The handling tool is lowered into the sleeve with the lower outer boss surfaces **221***a* of the handling tool collet fingers engaging the upper end surface of the sleeve **51** holding the collet against downward movement while the remainder of the handling tool moves downwardly

relative to its collet. The mandrel **190** and the sleeve **214** along with the lock ring **223** move downwardly within the collet so that the lock ring moves below the collet finger heads. The collet fingers are cammed inwardly by the upper end surface of the sleeve **51** allowing the handling tool to move downwardly into the sleeve **51** until the lower end surface **213***a* of the sleeve **213** engages the upper end sleeve surface **51***a* of the setting sleeve. When the collet finger heads **221** are aligned with the locking recess **54** of the sleeve the collets move back outwardly into the recess. The handling tool is then lifted with the collet being held against upward movement by engagement of its outer bosses **221** in the locking recess while the other components of the handling tool move upwardly lifting the lock ring **223** to a position within the collet heads, FIGURE 2, holding the collet heads at their normal position and preventing their being cammed inwardly out of the locking recess **54** of the sleeve **51** of the safety valve.

With the handling tool coupled with the safety valve the tool is lifted. The sleeve **51** moves upwardly lifting the wedge and slip release sleeve **63** thereby withdrawing the wedge surface **100** from within the expander fingers **90**. As the sleeve **63** moves upwardly the flange **84** on the sleeve engages the internal shoulder surface **83** at the head end of each of the slips **65** pulling the slips upwardly along the upwardly and inwardly tapered expander finger surfaces **93** withdrawing the slip heads from their wedged position at the inner wall of the casing around the expander **85**. Subsequent to the release of the slips **65** the sleeve **51** is lifted farther upwardly by the handling tool with the upper end surface **55***a* of the inner flange **55** engaging the lower end surface **60***a* of the nut **60**. The nut **60** lifts the remainder of the packer including its upper mandrel **41**, the coupling member **43**, and the lower mandrel **42** along with the seal assembly **50**. The upward movement of the mandrel **42** moves the J-slots **122** upwardly relative to the collet **132**. The collet finger heads **135** are in the coupling recess **23***a* being held outwardly by the mandrel locking surfaces **125**. The collet is lifted until its finger head surfaces **141** engage the lower end surface **23***b* on the upper casing section defining the upper end of the recess **23***a*.

With the collet **132** held against upward movement and locked against radial compression by the mandrel locking surfaces **131** the upward movement of the mandrel relative to the collet engages the lower surfaces **122***c* of the slanting portions of the J-slots with the guide pins **142** of the collet camming the guide pins laterally toward the left as viewed in FIGURE 3B rotating the collet in a clockwise direction as viewed from above until the cam surfaces **122***c* of the J-slots force the guide pins to the bottom ends of the J-slots. The collet is rotated about 30 degrees back to its unlocked position at which the collet fingers are aligned with the release surfaces **124** on the lower mandrel **42** whereby the collet fingers may be cammed inwardly out of the recess **23***a*. Further upward force on the safety valve forces the collet fingers inwardly against the release surfaces **124** out of the coupling recess **23***a* releasing the safety valve to be lifted from the casing. After moving out of the recess **23***a* the collet finger heads drag along the inner wall surface of the casing as illustrated in FIGURE 3 imparting sufficient downward force to the collet relative to the mandrel to hold the collet downwardly at its unlocked position due to the camming action of the J-slot surfaces **122***c* on the collet guide pins. As the safety valve is lifted in the casing the outer surface **114** of the seal member **110** also drags along the inner wall surface of the casing. After initial release, if the safety valve is lifted through another tool joint having an internal annular recess such as the recess **23***a* the spring **145** of the locking collet momentarily rotates the collet on the mandrel toward locked position and it is cammed back to its unlocked position as soon as the upper end surfaces of the collet finger heads engage the upper end of the tool joint recess, as previously described. The safety valve is lifted into the lubricator and removed in a conventional manner. The master valve **24** is closed shutting in the well until reinstallation of the safety valve is desired.

It will now be seen that a new and improved valve device has been described and illustrated.

It will be further seen that a new and improved surface controlled subsurface safety valve has been described and illustrated.

It will be further seen that the safety valve includes features which permit well surveys to be run through the valve without removing the valve from its operating position within a well bore.

It will also be seen that the valve includes a tubular mandrel, an annular seal on the mandrel for sealing with the inner wall surface of a well casing, upper and lower locking means on the mandrel, valve means in the mandrel biased toward closed position, operator means extending from the surface to the valve means for holding the valve at open position, and means at the surface for actuating the operator means.

It will also be seen that a new and improved locking device has been described for locking a body in a passage including a collet type slip expander secured around the body, a wedge and slip release sleeve movable on the body toward the expander and releasably secured to the body, and slips secured on the release sleeve for expansion by the expander, the slips sliding along an outside surface of the expander as the wedge and release sleeve slides into the expander, and the wedge release sleeve being released for movement along the body prior to release of the slips for initially setting the slips and subsequently being disengaged from the slips for movement relative to the slips for expanding the expander to further wedge the slips in locking engagement with an inner wall surface of a casing.

It will be further seen that the safety valve includes a lower locking assembly having an inner locking mandrel concentrically positioned within a rotatable locking collet biased by a spring means toward a locked position and an upper locking assembly including circumferentially spaced slips supported on a tubular wedge member movable toward a collet type expander having fingers insertable between the wedge member and the slips upon relative movement of the wedge member and slips toward the expander.

It will also be seen that a new and improved safety valve system has been described and illustrated including a subsurface safety valve, an operating tube assembly extending between the valve and the surface for moving the valve from a closed to an open position from the surface, and actuating means at the surface for moving the operating tube assembly for opening the safety valve and holding it at an open position.

The upper slip assembly **44** of the safety valve as shown in FIGURES 3 and 6 is not reengaged with the casing after it is released until the valve is removed from the well and the shear pin **71** replaced. The valve is thus not relocatable in a well without removal to the surface. The setting of the slips **65** requires a downward force from the sleeve **63** which is applied in the form of locking assembly of FIGURE 3 only so long as the shear pin **71** is intact. An alternate form of slip assembly which requires no shear pin and is resettable as shown in FIGURE 11. The assembly of FIGURE 11 is identical to that of FIGURES 3 and 4 in all respects except that the assembly employs a slip carrier **70'** without a shear pin slidably disposed on the sleeve **63**. A spring **76** is disposed around the sleeve **63** confined between the upper end surface of the slip carrier **70'** and the lower end surface of the setting sleeve **51** so that the slip carrier and slips are biased downwardly by the spring to the lower end position at which the slip flanges **82** engage the sleeve flange **84**. The spring **76** applies force from the setting sleeve **51**

to the slip carrier and slips when the sleeves **51** and **63** are forced downwardly toward the slip carrier and slips. The spring compresses under substantially the same force as required to shear the pin **71** so that as the setting sleeve and the sleeve **63** are moved downwardly the slips are forced along the expander surfaces **93**. When the slips have been expanded into the inner wall surface of the casing **22** and resist further downward movement with sufficient force the spring **76** is compressed allowing the sleeve **63** to continue downward movement for wedging the expander fingers **90** outwardly.

The slip assembly of FIGURE 11 is released in the same manner as the slip assembly shown in FIGURE 3. The sleeve **63** is lifted by the sleeve **51** engaging the internal flanges **82** of the slips by the external flange **84** on the sleeve **63** to pull the slips along the expander surface **93** retracting them from the inner wall surface of the casing. As the sleeve **63** is lifted the spring **76** expands holding the slip carrier **70'** and the slips **65** at the positions on the sleeve **63** shown in FIGURE 11 until the assembly is reset in the casing. Thus, the spring **76** holds the slips and slip carrier against upward movement on the sleeve **63** until a force is applied to the sleeve **63** which initially sets the slips and then exceeds the resistance of the spring to allow the sleeve to move downwardly relative to the slips to wedge the slips farther outwardly.

It will thus be seen that an alternate form of locking assembly for locking a body within a well casing is provided which includes a slip expanding and release sleeve supporting slip and a slip carrier in sliding relationship thereon and held against movement thereon by compressible means until a force tending to move the sleeve relative to the slips and slip carrier exceeds a predetermined value to compress such means and allow the sleeve to wedge the slip outwardly, the compressible means returning the slips and slip carrier to a position permitting resetting of the slip assembly after removal of the slip assembly to an unlocked relationship.

The foregoing description of the invention is explanatory only, and changes in the details of the construction illustrated may be made by those skilled in the art, within the scope of the appended claims, without departing from the spirit of the invention.

I claim:

1. A valve device comprising: a body having a flow passage; valve means on said body movable between a first closed position and a second open position; means biasing said valve means toward said first closed position; said valve means being adapted to be moved to and held at said open position by a force applied to said valve means opposing said biasing means; annular seal means supported on said body; and means for locking said body in a flow passage comprising first means for locking said body against movement in one direction and second means including slip means for locking said body against movement in an opposite direction; said second means including expansible slip expander means secured on said body against movement relative thereto, said expander means having surface portions for expanding slips responsive to movement of such slips along said expander means; slip wedge and release means for moving said slips along said expander means for expanding said slips and coacting with said expander means to wedge said slips tightly outwardly when moved in a direction toward said expander means, said wedge and release means releasing said slips and retracting said slips along said expander means responsive to movment of said wedge and release means in a direction away from said expander; gripping slips supported on said wedge and release means, said slips having inner surface portions adapted to engaged said expander means for expansion of said slips; and means for applying force from said wedge and release means to said slips whereby said slips are moved relative to said expander means to initially expand said slips into gripping position, said wedge and release means being further movable relative to said slips for wedging and expansible expander means and said slips further outwardly.

2. A valve device as defined in claim **1** wherein said expansible slip expander means comprises an annular expander collet secured on said body including flexible fingers having end portions spaced from said body; said slip wedge and release means comprises a sleeve slidably supported on said body for longitudinal movement relative to said expander collet, said sleeve having an end portion insertable between said body and said expander collet fingers for wedging said fingers outwardly; said gripping slips are supported on said slip wedge and release sleeve and movable with said sleeve toward and away from said expander collet, said slips having free end portions adapted to move along the outer surfaces of said expander collet fingers for expanding and retracting said slips responsive to movement relative to said expander collet; and slip retainer means supporting said slips on said slip wedge and release sleeve, said slip retainer means being movable on said sleeve to allow said sleeve to slide relative to said slips after said slips are set in expanded position for wedging said expander collet fingers radially outwardly toward said slips.

3. A valve device as defined in claim **1** wherein said first means for locking said body comprises an annular collet having flexible fingers provided with external lug means adapted to be received in a locking recess, said collet being supported on said body for limited rotation and longitudinal movement on said body between locked and unlocked positions; means biasing said collet toward a locked position on said mandrel; and circumferentially spaced release and locking surfaces on said body to hold and collet fingers against compression at said locked position of said collet on said body and to permit compression of said collet fingers at said unlocked position of said collet on said body.

4. A valve device in accordance with claim **3** wherein said valve means is longitudinally slidable within said body between said first and said second positions and includes a valve member having a seat surface engageable with a seat surface on said body at said first closed position and spaced from said body seat surface at said second open position and a valve stem supporting said valve member extending longitudinally in said flow passage of said body, said valve stem being biased in one direction for moving said valve member to said first closed position and being engageable by operator means for movement in the other direction for moving said valve member to said second open position.

5. A valve device as defined in claim **4** wherein said valve stem and said valve member are provided with a longitudinal flow passage extending therethrough adapted to receive releasable plug means for closing said flow passage, said plug means being remotely insertable and removable.

6. A valve device as defined in claim **5** including an operator assembly supported in spaced relation to said valve device when said device is locked in a flow conductor and extending to said device for moving said valve stem and valve member from said first closed position to and holding said stem and member at said second open position and means associated with said operator assembly for actuating said assembly responsive to a predetermined condition.

7. The apparatus of claim **6** wherein said actuating means comprises a fluid pressure responsive piston assembly secured to and supporting said operator assembly for operating said operator assembly responsive to fluid pressure transmitted into said piston assembly.

8. An apparatus as defined in claim **7** wherein said annular seal means comprises an annular flexible seal member adapted to effect an interference fit with an inner wall surface of a flow conductor providing an initial seal with said surface upon insertion of said valve device into said conductor and said seal means is biased toward

said conductor surface by the force of fluid pressure proportional to the fluid pressure differential across said seal member.

9. An apparatus as defined in claim 8 including spring means between said valve stem and said body for biasing said valve stem and said valve member toward said first closed position.

10. A valve device comprising: a body having a flow passage therethrough; means associated with said body for locking said body in a flow conductor; seal means on said body for sealing around said body within said flow conductor; a valve assembly supported in said body for longitudinal axial movement between open and closed position; said valve assembly having a tubular body and a removable closure in the bore of said body closing the same, and means engageable by an operator assembly extending through said flow conductor to said valve device for holding said valve assembly at an open position; and means associated with said valve assembly biasing said valve assembly toward closed position.

11. A valve device comprising: a body having a flow passage and a seat surface at one end; a valve assembly supported in said body for movement between open and closed positions including a longitudinally oriented tubular valve stem and a valve member having a valve seat surface engageable with said seat surface on said body; said valve assembly having a flow passage therethrough including recess means for receiving locking means on a plug assembly in said flow passage; biasing means between said valve stem and said body biasing said valve assembly toward said closed position; said valve assembly having upper surface portions engageable by an operator assembly extending through said flow conductor from above said valve device for holding said valve assembly at said open position; an external annular seal assembly supported on said body intermediate the ends thereof for sealing around said body within an inner wall surface of a flow conductor; a lock assembly above said seal assembly for engaging said inner casing wall to hold said body against upward movement within said flow conductor; and a locking assembly below said seal assembly for locking said body against downward movement within said flow conductor.

12. In combination with the valve device of claim 11 an operator tube assembly movably supported in said flow conductor and engageable with said valve assembly to move said valve assembly to said open position from a location spaced along said flow conductor from said valve device.

13. In combination with the apparatus of claim 12 a piston assembly supported on said flow conductor interconnected with and supporting said operator tube assembly for moving said valve device to said open position and holding said device at said position responsive to fluid pressure in said piston assembly controlled by predetermined operating conditions.

14. A valve device comprising: a body having a flow passage extending longitudinally therethrough; an annular seal assembly secured on said body intermediate the ends thereof, said seal assembly having a flexible seal member having an outer surface portion adapted to effect an interference fit with the inner wall surface of a flow conductor in which said valve device is positioned; an upper locking assembly on said body for locking said body in said flow conductor against upward movement, said upper locking assembly including an annular expander collet having flexible fingers secured on said body above said seal assembly, said fingers having upper end portions spaced from the outer surface of said body, a wedge and slip release sleeve slidably positioned on said body above said expander collet, said sleeve having a lower end portion insertable into said expander collet for expanding said fingers outwardly, a plurality of slips supported around said wedge sleeve, a slip retainer releasably secured on said wedge sleeve for supporting said slips, said slips having lower inner surfaces for engaging the outer surfaces of said expander collet fingers so that when said wedge and slip release sleeve moves toward said expander collet said sleeve is inserted into said collet as said slips slide along and are expanded by outer surface portions of said expander collet fingers, said slip retainer being movably secured on said wedge sleeve whereby said sleeve is movable farther into said expander collet after said slips are set, said wedge sleeve having an external flange engageable with internal flanges on said slips for retracting said slips from said collet expander; a setting sleeve secured to the upper end of said wedge and slip release sleeve and releasably secured with said body for moving said wedge and slip release sleeve and said slips toward said collet expander after release on said body, said setting sleeve forming an upper end portion of said valve device; lower locking means on said body below said annular seal assembly for locking said body against downward movement within a flow conductor including a locking collet having downwardly extending flexible fingers provided with outer locking bosses supported on said body for limited rotational and longitudinal movement thereto, said body having a plurality of J-slots in the outer surface thereof circumferentially spaced about said body, guide pins extending through an upper ring portion of said locking collet into said J-slots, said J-slots having vertical portions communicating at the lower ends thereof with upwardly slanting portions, said body having circumferentially spaced external release and locking surfaces within the free end portions of said locking collet fingers, said locking collet fingers being aligned over said release surfaces when said guide pins are positioned in said vertical portions of said J-slots and said locking collet fingers being aligned over said locking surfaces when said guide pins are positioned in upper end portions of the slanted portions of said J-slots, said J-slots and said guide pins coacting to cam said locking collet toward said release surfaces responsive to upward movement of said body relative to said collet and toward said locking surfaces responsive to downward movement of said body relative to said collet, a spring disposed around said body within said locking collet, one end of said spring being secured with said collet and the other end of said spring being secured with said body for biasing said collet toward locked position on said body; and a valve assembly supported in said body for movement between an upper closed position and a lower open position, said valve assembly including a tubular valve stem concentrically spaced within said body, a valve member secured on the lower end of said valve stem having a seat surface engageable with a seat surface on the lower end of said body for preventing fluid flow into the lower end of said body when said valve member is at an upper closed position and for permitting fluid flow into the lower end of said body when said valve member is at a spaced position below said body, said valve stem having ports therein above said valve member to permit fluid entry into said valve stem at the lower end thereof, said valve stem having a fluid flow passage extending therethrough and being adapted to receive a removable plug assembly for closing said flow passage, upper and lower guide ring members on said valve stem within said body for guiding said valve stem as said stem moves between upper and lower positions, and a spring disposed within said body around said valve stem engaged at an upper end thereof with said upper guide ring and at a lower end thereof with said body for biasing said valve assembly toward said upper closed position.

15. In combination with the valve device of claim 14 an operating tube assembly for actuating said valve device from a location along said flow conductor spaced from said valve device including a tubular guide member engageable at a lower end thereof with an upper end of said valve stem for applying a downward force to said valve stem to move said valve stem from said upper

closed to said lower open position and means thereon for guiding said guide member into said setting sleeve of said valve device, an operator tube connected with said guide member and extending through said flow conductor to said spaced location, and means at said spaced location for moving said operator tube to open said valve device.

16. The apparatus of claim 15 wherein said means for actuating said operator tube comprises a piston assembly including a cylinder body, an annular piston movable in said body responsive to fluid pressure transmitted into said body, a head member secured through said annular piston and connected with said operator tube, said head member having ports therein below said piston assembly to provide fluid communication through said head member for fluid flowing upwardly through said valve stem and said operator tube assembly.

17. A locking assembly for releasably engaging a wall surface around a body comprising: an expander collet secured on said body having flexible collet fingers; a wedge and slip release sleeve releasably secured on said body for movement toward said expander collet, said sleeve having an end portion insertable into said expander collet to expand the fingers of said expander collet radially outwardly; a plurality of slips supported on said wedge and slip release sleeve and having portions adapted to slide along the outer surfaces of said expander collet fingers as said wedge and slip release sleeve slides into said expander collet fingers, said slips being supported on said wedge and slip release sleeve whereby when said slips are wedged between said expander collet fingers and said wall surface said wedge sleeve is movable farther into said expander collet for wedging said slips outwardly, said wedge and slip release sleeve having an outer flange engageable with a shoulder surface of said slips when said wedge and slip release sleeve is retracted from said expander collet for withdrawing said slips from said outer surfaces of said expander collet; and a setting sleeve releasably secured on said body and connected with said wedge and slip release sleeve for moving said sleeve on said body for setting and releasing said slips.

18. A locking assembly as defined in claim 17 including a slip retainer ring having an internal annular recess and circumferentially spaced downwardly opening slots communicating therewith for receiving head portions of said slips for holding said slips on said wedge and slip release sleeve.

19. A locking assembly as defined in claim 18 including shearable means releasably supporting said slip retainer ring on said wedge and slip release sleeve whereby said slip retainer ring and said slips are moved by said wedge and slip release sleeve toward said expander collet for initially expanding said slips and when the force urging said slips outwardly exceeds a predetermined value said shearable means shears releasing said wedge and slip release sleeve from said slip retainer ring whereby said wedge and slip release sleeve is movable farther toward said expander collet for wedging said slips outwardly more tightly.

20. A locking assembly as defined in claim 18 including spring means between said setting sleeve and said slip retainer ring biasing said slip retainer ring toward said expander collet on said wedge and slip release sleeve whereby said slips are moved along said expander collet responsive to movement of said wedge and slip release sleeve for initially expanding said slips until said slips engage said wall surface and resist further movement sufficiently for said spring to compress allowing said wedge and slip release sleeve to move relative to said slip retainer ring for wedging said expander collet outwardly more tightly against said slips and said spring returning said slip retainer ring to its initial position on said slip and wedge release sleeve when said locking assembly is released from engagement with said wall surface.

21. A body provided with first locking means for locking said body against movement in one direction comprising radially movable lug means and second locking means locking said body against movement in a second direction comprising slip means; said first locking means including an annular collet having flexible fingers provided with external lug means adapted to be received in a locking recess, said collet being supported on said body for limited rotation and longitudinal movement between locked and unlocked positions; means biasing said collet toward a locked position on said mandrel.

22. The apparatus of claim 21 wherein said first locking means comprises release and locking surface portions provided on said body for holding the fingers of said collet at a locked position and for permitting radial compression of said fingers at said unlocked position, and biasing means coupled between said body and said collet biasing said collet toward said locked position, and said second locking means comprises slip expander means fixed on said body, slip means slidably supported on said body for movement along said slip expander means to expander means to expand said slips, and means movable within said slip means for further expanding said slip expander means after initial expansion of said slips.

23. A locking assembly for releasably securing a body against movement within a surrounding surface comprising: expansible slip expander means supported on said body; slip means supported on said body for movement along said slip expander means into locking engagement with said surrounding surface; and slip wedge and release means supported on said body for engaging said expansible slip expander means to expand said expander means and further expand said slip means after initial engagement of said slip means with said surrounding surface.

24. A locking assembly for releasably locking a body with respect to a surrounding surface comprising: a body: expander means secured on said body and held against movement relative thereto; slip wedging and releasing means slidably supported on said body for expanding slip means and wedging said slip means outwardly responsive to movement along said body toward said expander means and for releasing said slip means responsive to movement in a direction along said body away from said expander means; slip means supported on said wedge and slip release means and adapted to slide thereon; and means coupling said slip means with said wedge and slip release means whereby said slip means is moved along said expander means for initially expanding said slips and said wedge and slip release means is subsequently movable relative to said slip means for coacting with said expander means to wedge said slip means farther outwardly without moving said slip means longitudinally along said expander means.

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